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## Mineral resources of Asia continent: Resource endowment, mining industry pattern, and contributions to the world economy

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### ABSTRACT

Mineral resources in Asia continent and its mining industry play a significant role in the economic growth and industrialization of both Asia and the world. Asia continent boasts the most comprehensive kinds of minerals, with reserves of at least 38 of over 80 widely used minerals worldwide accounting for more than 30% of the global total reserves. Asia continent experienced three main tectonic evolution and mineralization stages: The Precambrian, the Paleozoic, and the Mesozoic to Cenozoic. The abundant mineral resources in this continent can be divided into seven first-order metallogenic belts (metallogenic domains), 18 second-order metallogenic belts (metallogenic provinces), 61 third-order metallogenic belts (metallogenic zones), and nine main minerogenetic series. Asia continent exhibits the most significant metallogenic specialization among all continents. Specifically, granite belts of Asia continent manifest pronounced metallogenic specialization of tin, rare metals, and porphyry Cu-Au-Mo deposits. Its mafic-ultramafic rock belts and ophiolite belts display notable metallogenic specialization of lateritic nickel deposits and magmatic type chromite deposits, while its Mesozoic to Cenozoic basalt belts show remarkable metallogenic specialization of lateritic bauxite deposits. Consequently, many giant metallogenic belts were formed, including the Southeast Asian tin belt, the Qinghai-Xizang Plateau rare metal metallogenic belt, the Tethyan porphyry Cu-Au-Mo metallogenic belt, the circum-Pacific porphyry Cu-Au-Mo metallogenic belt, the Southeast Asian lateritic bauxite metallogenic belt, the Deccan Plateau lateritic bauxite metallogenic belt in India, the Southeast Asian lateritic nickel metallogenic belt, and the Tethyan magmatic type chromite metallogenic belt—all of which are significant metallogenic belts in Asia continent. Future mineral exploration in Asia should focus primarily on the Precambrian mineralization of ancient cratons, the Paleozoic mineralization of the Central Asian-Mongolian orogenic belt, and the Mesozoic to Cenozoic mineralization of the Tethyan and circum-Pacific mobile belts. Asia's mining industry not only underpins its own economic growth but also propels global economic development and industrialization, contributing significantly to the world economy. Asia boasts the highest production value of minerals, the largest annual production of minerals, and the greatest trade value of mineral products among all the continents, having emerged as the trade center of global mineral products and the center of the mining industry economy. China is identified as one of the few countries that possess the most comprehensive kinds of minerals, and its mining industry has supported and driven the economic development and industrialization of Asia and even the world. Standing as the largest mineral producer worldwide, China ranked first in the production of 28 mineral commodities in the world in 2022. Besides, China exhibits the highest annual production value of minerals and the largest trade value of mineral products among all countries. Therefore, China's demand for global mineral products influences the global supply and demand patterns of minerals and the world economic situation.

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## 1. Introduction

Mineral resources, known as the “food” and “blood” of

industries, as well as the “food” of people's well-being, play an irreplaceable role in supporting global economic development and people's production and lives. Especially in the present and future when strategic emerging and high-tech industries experience rapid growth and wide application, the high-quality, sustainable, and green production and utilization of mineral resources hold great significance for the world economy and people's well-being. With the development of the world economy, population growth, and the constant

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improvement in people's requirements for living standards, all continents have paid increasing attention to the development of the mining industry. Against the backdrop of achieving carbon neutrality and sustainable development in the new era, geologists worldwide are required to explore more mineral resources more effectively and achieve their sustainable exploitation and utilization.

Among all continents, Asia holds the most extensive area and the largest population and is at the forefront of economic development in the world. This continent, featuring the most prolonged, complex, and active geological tectonic evolution worldwide, boasts favorable ore-forming geological conditions and abundant mineral resources (Shi JF et al., 2006; Writing group of world mineral fact of Asia, 2023; Chen XF et al., 2024a, 2024b). Currently, Asia has emerged as the largest producer and trade center of mineral products in the world, as well as the economic center of the global mining industry. The exploitation and utilization of mineral resources in Asia have supported its own economic growth and people's work and lives while contributing significantly to global economic development and industrialization, as well as the fulfillment of people's material needs worldwide. Asia will play a more significant role in advancing carbon neutrality and sustainable development required by the new era and in supporting the development of the world economy.

However, there is a lack of comprehensive studies of Asia that integrate mineral resource types, the global position of mineral reserves, geological tectonic evolution and ore-forming geological conditions, metallogenic specialization, the division of metallogenic belts, the minerogenetic series of major minerals, the deposit types and their metallogenic epochs for major minerals, the geological and mineral characteristics of significant metallogenic belts, mineral resources exploration and exploitation, mineral products trade, mining industry economy, the environmental protection of mines, development trends in the mining industry, and contributions to the world economy. Consequently, it is challenging to gain a systematic, comprehensive, and multidimensional understanding of the mineral resources in Asia, including resource endowment, mining industry development patterns, and contributions to the world economy. Therefore, this study presents a holistic view of Asia's mineral resource endowment and mining industry development patterns, aiming to provide a basis for the high-quality, sustainable, and green exploitation and utilization of mineral resources in Asia.

## 2. Mineral resource endowment and significant metallogenic belts in Asia continent

### 2.1. Mineral resource endowment of Asia continent

#### 2.1.1. Asia standing as a continent with the most comprehensive kinds of minerals

Asia, with the most extensive land area among the world's seven continents, boasts extremely abundant mineral

resources due to its broad land areas. This continent hosts almost all known minerals of the world. Most especially, Asia is rich in mineral resources closely related to strategic emerging and high-tech industries (Fig. 1). China is identified as one of the few countries with the most comprehensive kinds of minerals, with 173 kinds minerals having been discovered by 2023 (Ministry of Natural Resources, PRC, 2023). Besides, Russia<sup>①</sup> also ranks among the few countries with the most comprehensive kinds of minerals. From the perspective of the mineral resources demands of primary countries and regions, Asia hosts all kinds of minerals in the latest critical mineral lists released by Japan, Canada, the UK, the U.S., Australia, and the European Union.

#### 2.1.2. Asia's global positions in mineral reserves

Besides a comprehensive kinds of minerals, Asia exhibits substantial reserves of some minerals. Incomplete statistics reveal that Asia holds over 30% of the global reserves of at least 38 of more than 80 widely used minerals worldwide (USGS, 2024). Specifically, Asia's reserves of boron and gallium in Asia represent over 90% globally, those of chromite, natural gas, tin, barite, tungsten, rare earths, and antimony account for more than 70%, and those of minerals like oil, tantalum, vanadium, and manganese account for more than 50%. Regarding new energy minerals, Asia holds more than 30% of global reserves of nickel, graphite, and fluorite. Furthermore, Asia has emerged as the continent with the highest nickel and bauxite reserves, surpassing Oceania and Africa, respectively. The global share of Asia's gold reserves has increased by 5%. Besides these minerals, Asia has strong global positions in the reserves of many other minerals (Table 1). Notably, Afghanistan has achieved significant breakthroughs in lithium exploration over recent years (USGS, 2024).

### 2.2. Metallogenic characteristics of mineral resources in Asia continent

#### 2.2.1. Geological tectonic evolution and ore-forming geological conditions of Asia continent

As one of the most ancient continents in the world, Asia continent has a geological evolution history of at least 3.8 Ga (Wan YS et al., 2001), having experienced virtually all the geologic historical periods and processes in the Earth's evolution. Its prolonged and complex geological tectonic evolution exhibits multistage characteristics, involving the formation and breakup of paleocontinents such as the Columbia, Rodinia, and Pangea supercontinents and the Gondwana and Laurasia continents, as well as complex ocean-continent transitional processes like the opening and closure of Paleo-Asian and Tethys oceans and the opening of the India Ocean. After undergoing a series of tectonic movements including the convergence and intracontinental tectonic evolution of numerous plates/blocks from the Mesozoic to the Cenozoic, the present-day geotectonic features of Asia continent were formed (Sone M and Metcalfe I, 2008; Metcalfe I, 2011, 2013; Ren JS et al., 2013; Pan GT

<sup>①</sup>Russia, a European country geographically, is involved in this study since the third-fourth of its territorial area falls in Asia.

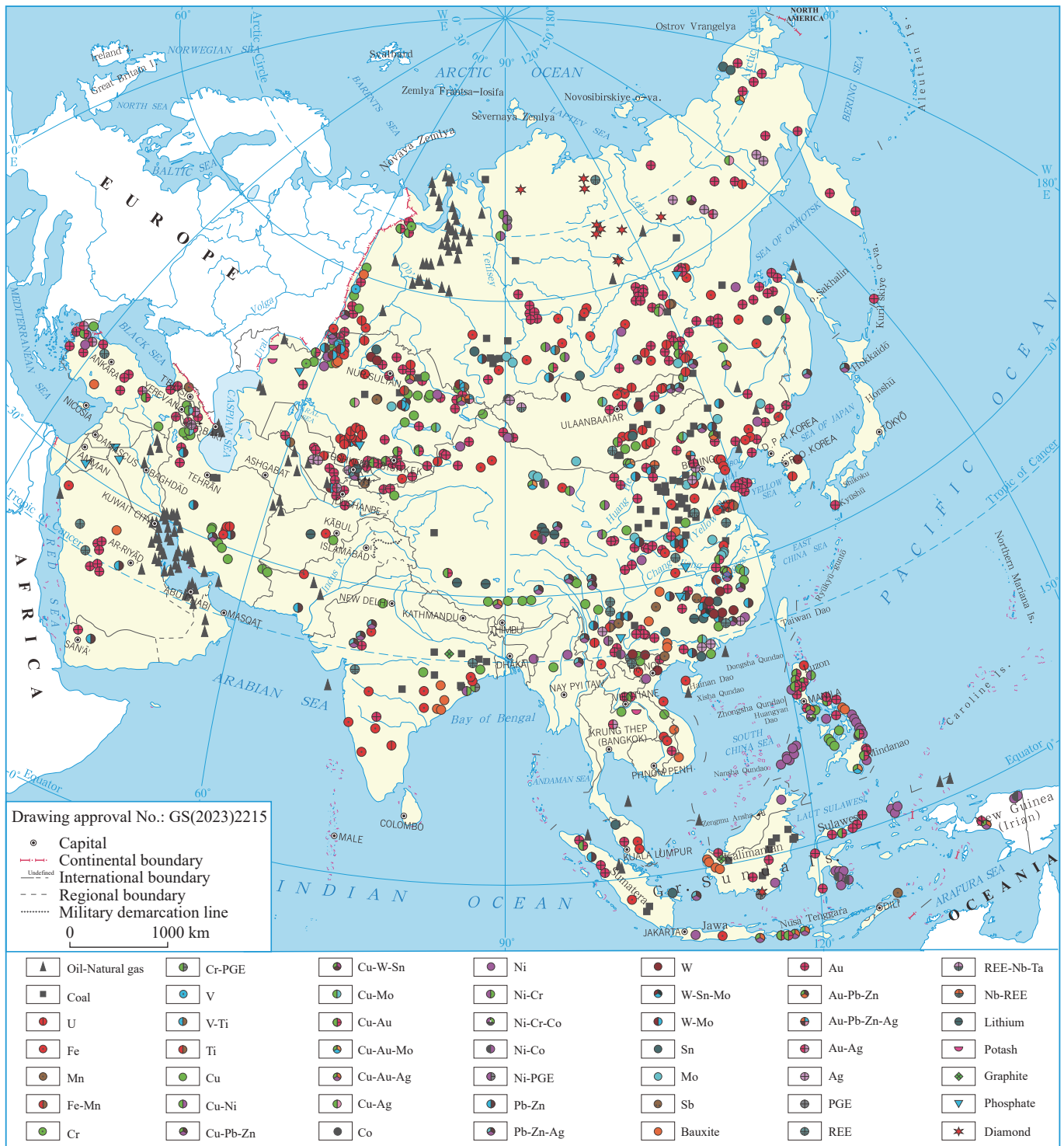


Fig. 1. Distribution map of mineral resources in Asia.

et al., 2009, 2016; Wan TF, 2013, 2018; Xiao WJ et al., 2017; Zhao GC et al., 2018; Şengör AMC et al., 1993, 2022). Generally, Asia continent has undergone all tectonic cycles from the Archean to the Cenozoic, including the Qianxian, Fupingian, Lvlngian, Jinningian, Salair, Caledonian, Hercynian, Indosinian, Yanshanian, and Himalayan cycles, during which multistage large-scale magmatic activity occurred. The tectonic evolution of Asia continent can be broadly divided into three main stages: The formation of its continental basement (approximately 830 Ma), the formation

of its main body (830 Ma to 210 Ma), and the formation of its present-day tectonic framework and the intracontinental evolution (210 Ma to modern). The abovementioned lengthy and complex tectonic movements and magmatic activity, as well as the evolutionary processes of metamorphism and sedimentation, have created favorable ore-forming geological conditions, establishing Asia as a continent with the most complex ore-forming geological conditions and mineralization. This complexity is primarily manifested in two aspects. First, Asia is the continent with the largest

**Table 1. Asia's global positions in the reserves and resources of major mineral resources.**

| Commodities          | Unit                                  | Reserves  | Global share of reserves/% | Resources | Global share of resources/% |
|----------------------|---------------------------------------|-----------|----------------------------|-----------|-----------------------------|
| Oil                  | 10 <sup>8</sup> t                     | 1386      | 56.71                      |           | >50% <sup>e</sup>           |
| Natural gas          | 10 <sup>12</sup> m <sup>3</sup>       | 146.20    | 77.72                      |           | >50% <sup>e</sup>           |
| Coal                 | 10 <sup>8</sup> t                     | 4990.23   | 46.46                      | 6638.42   | 38.04                       |
| Uranium              | 10 <sup>4</sup> t (U)                 | 204.84    | 33.70                      | 164.52    | 22.23                       |
| Iron                 | 10 <sup>8</sup> t (ore)               | 746.24    | 41.46                      | 2078.02   | 34.05                       |
| Manganese            | 10 <sup>8</sup> t (ore)               | 8.69      | 51.12                      | 10.42     | 17.96                       |
| Chromite             | 10 <sup>8</sup> t (ore)               | 4.41      | 78.75                      | 9.84      | 22.88                       |
| Magnesite            | 10 <sup>4</sup> t                     | 3364      | 49.47                      |           |                             |
| Copper               | 10 <sup>4</sup> t                     | 20506.62  | 23.04                      | 46618.66  | 22.24                       |
| Lead                 | 10 <sup>4</sup> t                     | 3533.43   | 41.57                      | 18985.54  | 69.12                       |
| Zinc                 | 10 <sup>4</sup> t                     | 9452.30   | 45.01                      | 40807.07  | 64.18                       |
| Tungsten             | 10 <sup>4</sup> t                     | 274.85    | 72.33                      | 521.76    | 62.43                       |
| Tin                  | 10 <sup>4</sup> t                     | 341.24    | 74.18                      | 859.50    | 85.78                       |
| Molybdenum           | 10 <sup>4</sup> t                     | 524.42    | 43.20                      | 1151.56   | 23.85                       |
| Antimony             | 10 <sup>4</sup> t                     | 128       | 71.11                      | 146.34    | 64.33                       |
| Cobalt               | 10 <sup>4</sup> t                     | 110.01    | 13.25                      | 599.53    | 21.57                       |
| Nickel               | 10 <sup>4</sup> t                     | 4397.44   | 43.97                      | 9594.04   | 35.34                       |
| Bauxite              | 10 <sup>8</sup> t (ore)               | 123.11    | 39.71                      | 174.73    | 31.77                       |
| Gold                 | t                                     | 20523.31  | 39.47                      | 39646.51  | 24.60                       |
| Silver               | t                                     | 154970.17 | 28.18                      | 332703.23 | 19.58                       |
| Platinum group metal | t                                     | 5610.24   | 8.01                       | 8668.86   | 11.19                       |
| Rare earths          | 10 <sup>4</sup> t (REO)               | 9393      | 72.25                      | 4333.43   | 35.67                       |
| Titanium             | 10 <sup>8</sup> t (TiO <sub>2</sub> ) | 2.84      | 40.57                      |           |                             |
| Graphite             | 10 <sup>4</sup> t                     | 18210     | 55.18                      |           | >40% <sup>e</sup>           |
| Fluorite             | 10 <sup>4</sup> t                     | 7940      | 30.54                      |           | >20% <sup>e</sup>           |
| Diamond              | 10 <sup>4</sup> ct (Industrial grade) | 60118.37  | 46.24                      | 38728.88  | 18.68                       |
| Potash               | 10 <sup>8</sup> t (K <sub>2</sub> O)  | 54.28     | 69.74                      | 32.60     | 12.81                       |
| Phosphate            | 10 <sup>8</sup> t (ore)               | 80.44     | 11.17                      | 456.08    | 38.68                       |

Note: Data sources, [Energy Institute, 2024](#); [IEA/NEA, 2023](#); [USGS, 2024](#), and [S&P Global Market Intelligence, 2024](#). “e” denotes estimates; resources exclude reserves.

number of Precambrian cratons, including the renowned, giant Siberian, Indian, Sino-Korean, Arabian, Tarim, and Yangtze cratons. These cratons have undergone prolonged and complex evolutionary processes, from the initial paleocontinental nuclei to accretion, followed by multiple convergence and breakup, leading to the formation of abundant mineral resources. Second, Asia continent is home to the largest number of giant mobile belts among all continents. During the Phanerozoic, the Paleo-Asian Ocean, Tethyan, and circum-Pacific mobile belts emerged as the three largest mobile belts worldwide under the action of three main global dynamic systems: The Paleo-Asian Ocean, the Tethys-Paleo-Pacific oceans, and the Indian-Pacific oceans. From the Mesozoic to the Cenozoic, the Tethyan and circum-Pacific mobile belts were superimposed on the Paleo-Asia Ocean mobile belt, establishing Asia as the continent with the most complex geological structures and the most active neotectonic movements, as exemplified by the present-day uplift of the Qinghai-Xizang Plateau ([Ren JS et al., 2013](#)). The three giant mobile belts experienced active tectonic movements, frequent and intense magmatic activity, and multistage extensive mineralization, leading to the formation of extremely abundant mineral resources.

### 2.2.2. Primary mineralization stages in Asia continent

Asia continent experienced mineralization across all geological periods from the Archean to the Cenozoic. Based on the geological tectonic evolution and magmatic activity, the mineralization of this continent can be divided into three stages: Precambrian, Paleozoic, and Mesozoic to Cenozoic ([Table 2](#)). Mineral resources formed during the Precambrian are primarily distributed in Precambrian cratons, with typical metal mineral resources including banded iron formation (BIF) type iron deposits and greenstone type gold deposits. Mineral resources formed during the Paleozoic are principally distributed in the Central Asian-Mongolian orogenic belt, typified by porphyry Cu-Au-Mo deposits. The Mesozoic to Cenozoic is identified as an important mineralization stage of metal minerals in Asia continent. The metal mineral resources formed in this stage exhibit an extensive distribution, concentrated in the Tethyan and circum-Pacific mobile belts. These resources include world-renowned lateritic nickel/bauxite deposits, porphyry Cu-Au-Mo deposits, epithermal type gold deposits, placer type deposits of various minerals, oil, natural gas, and potash ([Hu P et al., 2006](#); [Kuşcu İ et al., 2013](#)).

**Table 2. Primary tectonic evolution-metallogenic stage and related tectonic movements, tectonic environments, and magmatic activity in Asia continent.**

| Primary tectonic evolution-metallogenic stage          | Precambrian                                                                                                                                      | Paleozoic                                                                                                          | Mesozoic to Cenozoic                                                                                                                                                                                                                                     |
|--------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Tectonic movement                                      | Qianxiian movement (2800 Ma), Lüliangian movement (1850 Ma), and Jinningian movement (830 Ma)                                                    | Caledonian movement (510–408 Ma), Hercynian movement (408–251 Ma)                                                  | Indosinian movement (210 Ma), Yanshan movement (100–40 Ma), and Himalayan movement (40–20 Ma)                                                                                                                                                            |
| Regional strata                                        | Precambrian                                                                                                                                      | Precambrian                                                                                                        | Mesozoic to Cenozoic                                                                                                                                                                                                                                     |
| Primary geotectonic environment for mineral occurrence | Precambrian cratons                                                                                                                              | Central Asian-Mongolia orogenic belt                                                                               | Tethys and circum-Pacific mobile belts                                                                                                                                                                                                                   |
| Mineralization-related magmatic rocks                  | Granitoids, greenstone belts, mafic-ultramafic rocks, intermediate-basic volcanic rocks                                                          | Intermediate-acid intrusions, intermediate-basic volcanic rocks, mafic-ultramafic rocks, and ophiolite             | Volcanic rocks, intermediate-acid intrusions, mafic-ultramafic rocks, ophiolite, and basalt                                                                                                                                                              |
| Major mineral resources                                | Iron, manganese, gold, copper, iron, uranium, lead, zinc, etc., typified by BIF type iron (manganese) deposits and greenstone type gold deposits | Oil, natural gas, coal, uranium, iron, gold, copper, molybdenum, silver, nickel, tungsten, phosphate, potash, etc. | Oil, natural gas, potash, tungsten, tin, nickel, copper, gold, molybdenum, bauxite, lead, zinc, silver, antimony, etc., typified by lateritic nickel deposits, lateritic bauxite deposits, porphyry Cu-Au-Mo deposits, and epithermal type gold deposits |

### 2.2.3. Primary minerogenetic series in Asia continent

Asia continent is characterized by multiple commodities and complex mineralization. Major mineral resources in this continent can be categorized into nine minerogenetic series based on the minerogenetic series theory (Cheng YQ et al., 1983; Zhai YS et al., 1999; Chen YC et al., 2016), as well as a comprehensive analysis of the metallogenic environments, mineralization, deposit types, the tectonic environments for deposit occurrence, dominant ore-controlling factors, the types and assemblages of magmatic rocks, facies conditions for mineral occurrence (marine, continental, extrusive, and intrusive facies), the combinations of primary and secondary ore-forming elements, and metallogenic epochs (Table 3).

I. The Precambrian craton-related minerogenetic series of iron, manganese, and gold—an important minerogenetic series in Asia continent. The deposits derived from this minerogenetic series are primarily distributed within Precambrian cratons, with deposit types dominated by BIF type iron (manganese) deposits and greenstone type gold deposits. For this minerogenetic series, the iron and gold mineralization is associated with BIFs and greenstone belts, and the metallogenic epochs typically range from the Archean to the Proterozoic.

II. The intermediate-acid intrusive related minerogenetic series of tungsten, tin, molybdenum, bismuth, antimony, mercury, uranium, copper, gold, silver, lead, zinc, rare earths, rare metals, and fluorite—also an important minerogenetic series in Asia continent. The deposits derived from this minerogenetic series occur primarily in orogenic belts and island arc belts, exhibiting extensive distributions, with primary deposit types including porphyry, orogenic, pegmatite, intrusive related, skarn, alkaline granite, granite, greisen, and hydrothermal types. For this minerogenetic series, the mineralization is principally associated with intermediate-acid intrusions, and the metallogenic epochs exhibit a lengthy time span.

III. The volcanism-related minerogenetic series of copper, gold, molybdenum, lead, zinc, silver, iron, and rare metals.

The deposits stemming from this minerogenetic series are primarily associated with volcanic and subvolcanic rocks in different tectonic environments, with primary deposit types including volcanic-hosted massive sulfide (VHMS), hydrothermal, and volcanic types. The metallogenic epochs exhibit a lengthy time span.

IV. The mafic-ultramafic rock and ophiolite-related minerogenetic series of chromium, nickel, copper, gold, platinum-group elements (PGEs), and diamond. The deposits originate from this minerogenetic series occur primarily in tectonic environments such as deep-seated fault zones, island arcs, rifts, suture zones, and plate or block margins, with primary deposit types including magmatic type chromite deposits, kimberlite type diamond deposits, magmatic type PGE deposits, hydrothermal type nickel deposits, and magmatic type Cu-Ni sulfide deposits. For this minerogenetic series, the mineralization is principally associated with mafic-ultramafic rocks and ophiolites, and the metallogenic epochs span from the Late Paleozoic to the Cenozoic, dominated by Mesozoic to Cenozoic, with a minority of deposits formed during the Precambrian.

V. The intermediate-mafic, alkaline, and carbonate rock-related minerogenetic series of iron, vanadium, titanium, rare earths, niobium, tantalum, and phosphate. The deposits derived from this minerogenetic series are primarily distributed along paleocontinental margins and deep-seated fault zones, with primary deposit types including magmatic type V-Ti-magnetite deposits, alkaline rock-related Nb-Ta deposits, carbonate type rare earth-Nb-Ta-phosphate deposits, alkaline rock-related rare metal-rare earth deposits, and magmatic type phosphate deposits, occasionally associated with elements such as cobalt, nickel, and chromium. For this minerogenetic series, the mineralization is principally associated with intermediate-mafic, alkaline, and carbonate rocks, and the metallogenic epochs range from the Paleozoic (dominant) to the Cenozoic.

VI. The sedimentation-related minerogenetic series of oil, natural gas, coal, uranium, vanadium, iron, manganese,

**Table 3. Minerogenetic series, Ore-controlling factors, deposit types, and typical deposits of Asia continent.**

| Metallogenic series                                                                                                                                                                                     | Primary ore-controlling factors                                                    | Primary deposit types                                                                                                                                                                                                                                                                                                                                                                                             | Primary metallogenic epochs                                                                                                                                                                                                      | Typical deposits                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| I. Precambrian craton-related metallogenic series of iron, manganese, and gold                                                                                                                          | Precambrian cratons, Precambrian silicon and iron formations, and greenstone belts | BIF type iron deposits<br>BIF type manganese deposits<br>Greenstone type gold deposits                                                                                                                                                                                                                                                                                                                            | Precambrian<br>Precambrian<br>Precambrian                                                                                                                                                                                        | Bailadila iron deposit in India<br>Balaghat manganese deposit in India<br>Kolar gold deposit in India                                                                                                                                                                                                                                                                                                                                                                        |
| II. Intermediate-acid intrusive related metallogenic series of tungsten, tin, molybdenum, bismuth, antimony, mercury, uranium, copper, gold, silver, lead, zinc, rare earths, rare metals, and fluorite | Intermediate-acid intrusions, orogenic belts, and island arc belts                 | Quartz vein type tin deposits<br>Pegmatite type tin deposits<br>Greisen type W-Sn deposits<br>Pegmatite type lithium deposits<br>Intrusive related uranium deposits<br>Pegmatite type Nb-Ta deposits<br>Porphyry type Cu-Au-Mo deposits<br>Skarn type U-Sn deposits<br>Hydrothermal type fluorite deposits<br>Iron Oxide Copper Gold (IOCG) type deposits<br>Skarn type Fe-Cu deposits<br>Skarn type gold deposit | Proterozoic<br>Proterozoic<br>Mesozoic to Cenozoic<br>Mesozoic to Cenozoic<br>Jurassic<br>Paleozoic to Cenozoic<br>Mesozoic to Cenozoic<br>Mesozoic<br>Paleozoic to Cenozoic<br>Precambrian<br>Paleozoic to Cenozoic<br>Mesozoic | Mawchi W-Sn deposit in Myanmar<br>Takua Pa tin deposit in Thailand<br>Pilok U-Sn in Thailand<br>Jiajika lithium deposit in China<br>Taoshan uranium deposit in China<br>Medvedka Nb-Ta deposit in Kazakhstan<br>Grasberg Cu-Au deposits in Indonesia<br>Shizhuyuan W-Sn deposit in China<br>Dongqiyishan fluorite deposit in China<br>Sin Quyen Cu-Au-rare earth deposit in Vietnam<br>Ertsberg Fe-Cu (Au, Ag) deposit in Indonesia<br>Phu Thap Fah gold deposit in Thailand |
| III. Volcanism-related metallogenic series of copper, gold, molybdenum, lead, zinc, silver, iron, and rare metals                                                                                       | Volcanic and subvolcanic rocks                                                     | VHMS type Cu-Pb-Zn polymetallic deposits<br>Post-magmatic hydrothermal type Au-Ag deposits<br>Volcanic type iron deposits<br>Volcanic type Cu deposits<br>Hydrothermal type manganese deposits<br>Volcanic-sedimentary type manganese deposits<br>Volcanic type uranium deposit<br>Volcanic-hydrothermal type copper deposits<br>Epithermal gold deposits                                                         | Paleozoic to Cenozoic<br>Paleozoic<br>Paleozoic<br>Mesozoic to Cenozoic<br>Paleozoic to Mesozoic<br>Precambrian, Carboniferous, and Paleogene<br>Paleozoic to Cenozoic<br>Cenozoic<br>Cenozoic                                   | Sulat Cu-Au-Ag deposit in Philippines<br>Chatree Au-Ag deposit in Thailand<br>Sokolov-Sarbai iron deposit in Kazakhstan<br>Bagacay Cu deposit in Philippines<br>Lang Bai manganese deposit in Vietnam<br>Magnitogorsk manganese deposit in Russia<br>Dornod uranium deposit in Mongolia<br>Monywa copper deposit in Myanmar<br>Gunung Pongkor gold deposit in Indonesia                                                                                                      |
| IV. The mafic-ultramafic rock and ophiolite-related minerogenetic series of chromium, nickel, copper, gold, PGEs, and diamond                                                                           | Mafic-ultramafic rocks and ophiolite suites                                        | Magmatic type Cu-Ni sulfide deposits<br>Magmatic type chromite deposits<br>Magmatic type platinum group metallic deposits<br>Kimberlite type diamond deposits                                                                                                                                                                                                                                                     | Proterozoic-Cenozoic<br>Paleozoic to Cenozoic<br>Paleozoic to Cenozoic<br>Paleozoic to Cenozoic                                                                                                                                  | Norilsk Cu-Ni deposit in Russia<br>Kempirsai chromite deposit in Kazakhstan<br>Maslovsky Kempirsai platinum group mineral deposit in Russia<br>Lomonosov diamond deposit in Russia                                                                                                                                                                                                                                                                                           |
| V. The intermediate-mafic, alkaline, and carbonate rock-related minerogenetic series of iron, vanadium, titanium, rare earths, niobium, tantalum, and phosphate                                         | Intermediate-basic rocks, carbonatites, and alkaline rocks                         | Magmatic type iron deposits<br>Alkaline rock-related rare earth-rare metal deposits<br>Alkaline rock-related Nb-Ta deposits<br>Carbonatite type rare earth-Nb-phosphate deposits                                                                                                                                                                                                                                  | Paleozoic<br>Neoproterozoic<br>Neoproterozoic<br>Proterozoic to Mesozoic                                                                                                                                                         | Panzhihua V-Ti-magnetite deposit in China<br>Jabal Hamra Rare earth deposit in Saudi Arabia<br>Ghurayyah Nb-Ta deposit in Saudi Arabia<br>Tomtorskoye rare earths deposit in Russia                                                                                                                                                                                                                                                                                          |

**Table 3. (Continued)**

| Metallogenic series                                                                                                                                                                                  | Primary ore-controlling factors                                                    | Primary deposit types                        | Primary metallogenic epochs | Typical deposits                                                  |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------|----------------------------------------------|-----------------------------|-------------------------------------------------------------------|
| VI. (Hydrothermal) sedimentation-related metallogenic series of oil, natural gas, coal, uranium, vanadium, iron, manganese, copper, gold, cobalt, lead, zinc, phosphate, lithium, gypsum, and halite | Sedimentary basins and sedimentary rocks                                           | Sandstone-shale type Cu-Co deposits          | Proterozoic-Paleozoic       | Udokan copper deposit in Russia                                   |
|                                                                                                                                                                                                      |                                                                                    | MVT type Pb-Zn deposits                      | Paleozoic to Cenozoic       | Fankou Pb-Zn deposit in China                                     |
|                                                                                                                                                                                                      |                                                                                    | SEDEX type Pb-Zn deposits                    | Proterozoic-Paleozoic       | Tekeli Pb-Zn deposit in Kazakhstan                                |
|                                                                                                                                                                                                      |                                                                                    | Sedimentary type phosphate deposits          | Proterozoic-Cenozoic        | Partomchorr phosphate deposit in Russia                           |
|                                                                                                                                                                                                      |                                                                                    | Sedimentary type coalfields                  | Paleozoic to Cenozoic       | Tunguska coal deposit in Russia                                   |
|                                                                                                                                                                                                      |                                                                                    | Marine sedimentary type manganese deposits   | Paleozoic to Cenozoic       | Chiatura manganese deposit in Georgia                             |
|                                                                                                                                                                                                      |                                                                                    | Sedimentary type iron deposits               | Paleozoic to Cenozoic       | Ayat iron ore deposit in Kazakhstan                               |
|                                                                                                                                                                                                      |                                                                                    | Sedimentary type gold deposits               | Paleozoic                   | Sepon Au-Cu polymetallic deposit in Laos                          |
|                                                                                                                                                                                                      |                                                                                    | Black rock series type gold deposits         | Proterozoic-Paleozoic       | Murantau gold deposit in Uzbekistan                               |
|                                                                                                                                                                                                      |                                                                                    | Sandstone type uranium deposits              | Mesozoic                    | Strel'tsovskoye uranium deposit in Russia                         |
|                                                                                                                                                                                                      |                                                                                    | Karst type bauxite deposits                  | Paleozoic to Cenozoic       | Alkarec bauxite deposit in Kazakhstan                             |
|                                                                                                                                                                                                      |                                                                                    | Sedimentary type oil and natural gas fields  | Mesozoic to Cenozoic        | Ghawer oil field in Saudi Arabia                                  |
|                                                                                                                                                                                                      |                                                                                    | Evaporative sedimentary type potash deposits | Mesozoic to Cenozoic        | potash deposits in Khorat basin, Thailand                         |
|                                                                                                                                                                                                      |                                                                                    | Metamorphic type phosphate deposits          | Proterozoic                 | Lao Cai sedimentary metamorphic type phosphate deposit in Vietnam |
|                                                                                                                                                                                                      |                                                                                    | Metamorphic type gold deposits               | Precambrian                 | Gold deposit in Dongfengshan of Heilongjiang Province, China      |
|                                                                                                                                                                                                      |                                                                                    | Sedimentary metamorphic type Pb-Zn deposits  | Proterozoic                 | Komdok Pb-Zn deposit in North Korea                               |
| VII. Metamorphism-related metallogenic series of uranium, lead, zinc, graphite, and phosphate                                                                                                        | Metamorphic rocks                                                                  | Metamorphic type graphite deposits           | Proterozoic                 | Graphite deposit in Lao Cai, Vietnam                              |
|                                                                                                                                                                                                      |                                                                                    | Metamorphic type uranium deposits            | Proterozoic                 | Narwapahar uranium deposit in India                               |
|                                                                                                                                                                                                      |                                                                                    | Metamorphic type gemstone deposits           | Paleozoic-Mesozoic          | Tawmaw jadeite deposit in Myanmar                                 |
|                                                                                                                                                                                                      |                                                                                    | Lateritic type Co-Ni deposits                | Cenozoic                    | Surigao Co-Ni deposit in Philippines                              |
|                                                                                                                                                                                                      |                                                                                    | Lateritic type bauxite deposits              | Cenozoic                    | Dak Nong bauxite deposit in Vietnam                               |
| VIII. Supergene mineralization-related metallogenic series of iron, manganese, nickel, chromium, tin, bauxite, gold, diamond, kaolin, and gemstone                                                   | Lateritic weathering crusts, proluvium, and the alluvium and diluvium in riverbeds | Lateritic type chromite deposits             | Cenozoic                    | Huiyang Cr-Co-Ni deposit in Philippines                           |
|                                                                                                                                                                                                      |                                                                                    | Lateritic type Fe deposits                   | Cenozoic                    | Twinnge Fe deposit in Myanmar                                     |
|                                                                                                                                                                                                      |                                                                                    | Weathering leaching type Fe deposits         | Cenozoic                    | Bailadila Fe deposit in India                                     |
|                                                                                                                                                                                                      |                                                                                    | Weathered leaching type manganese deposits   | Mesozoic to Cenozoic        | Kyaukpadaung manganese deposit in Myanmar                         |
|                                                                                                                                                                                                      |                                                                                    | Placer type gold deposits                    | Mesozoic to Cenozoic        | Bocu gold deposit in Vietnam                                      |
|                                                                                                                                                                                                      |                                                                                    | Placer type chromite deposits                | Cenozoic                    | Co Dinh chromite deposit in Vietnam                               |
|                                                                                                                                                                                                      |                                                                                    | Placer type diamond deposits                 | Cenozoic                    | Diamond placer deposit in Urals district, Russia                  |
|                                                                                                                                                                                                      |                                                                                    | Placer type Sn deposits                      | Mesozoic to Cenozoic        | Sn deposit in Kinta Valley, Malaysia                              |
|                                                                                                                                                                                                      |                                                                                    | Placer type gemstone deposits                | Mesozoic to Cenozoic        | Jade deposit in Mogok, Myanmar                                    |
|                                                                                                                                                                                                      |                                                                                    | Placer type iron deposits                    | Mesozoic to Cenozoic        | Jogjakarta iron deposit in Indonesia                              |

Table 3. (Continued)

| Metallogenic series                                                   | Primary ore-controlling factors | Primary deposit types                | Primary metallogenic epochs | Typical deposits                            |
|-----------------------------------------------------------------------|---------------------------------|--------------------------------------|-----------------------------|---------------------------------------------|
| IX. Salt lake brine-related metallogenic series of lithium and potash | Salt lake brine                 | Placer type antimony deposits        | Cenozoic                    | Klong kra Sae antimony deposit in Thailand  |
|                                                                       |                                 | Gossan type manganese deposits       | Mesozoic to Cenozoic        | Ban Maejoug manganese deposit in Thailand   |
|                                                                       |                                 | Gossan type gold deposits            | Mesozoic to Cenozoic        | Canatuan gold deposit in Philippines        |
|                                                                       |                                 | Salt lake brine type potash deposits | Paleozoic-Modern            | Qarhan Salt Lake potash deposit in China    |
|                                                                       |                                 | Salt lake brine type lithium deposit | Mesozoic to Cenozoic        | Taijinar Salt Lake lithium deposit in China |

copper, gold, cobalt, lead, zinc, phosphate, potash, lithium, gypsum, and halite. The deposits derived from this minerogenetic series occur primarily in sedimentary basins, with primary deposit types including sedimentary, sandstone-shale, Mississippi valley-type (MVT), and sedimentary exhalative (SEDEX) types. For this minerogenetic series, the mineralization is predominantly associated with sedimentary rocks, the metallogenic epochs exhibit a prolonged time span, and oil and natural gas are primarily distributed within Mesozoic to Cenozoic sedimentary basins.

VII. The metamorphism-related minerogenetic series of uranium, lead, zinc, graphite, and phosphate. The deposits originating from this minerogenetic series are primarily associated with metamorphism, with primary deposit types including metamorphic and hydrothermal types. For this minerogenetic series, the ore bodies are distributed within metamorphic rocks, and the metallogenic epochs exhibit a prolonged time span.

VIII. The supergene mineralization-related minerogenetic series of manganese, nickel, chromium, tin, bauxite, gold, iron, diamond, kaolin, and gemstone —also an important minerogenetic series in Asia continent. The deposits stemming from this minerogenetic series have undergone weathering, erosion, transport, accumulation, and deposition, exhibiting an extremely extensive distribution and primary deposit types including placer, lateritic, gossan, and weathering leaching eluvial-deluvial types, which are typified by placer type gold/diamond deposits and lateritic bauxite/nickel deposits. For this minerogenetic series, primary ore-bearing layers include lateritic weathering crusts, and Cenozoic eluvium, proluvium, and the alluvium and diluvium in riverbeds, and the metallogenic epochs are dominated by Mesozoic to Cenozoic.

IX. The salt lake brine-related minerogenetic series of lithium and potash. The deposits originating from this series are primarily associated with salt lake brine, with ore-forming elements distributed primarily in salt lakes and deposit types dominated by the salt lake brine type. The metallogenic epochs of this minerogenetic series are dominated by Mesozoic to Cenozoic.

#### 2.2.4. Deposit types and metallogenic epochs of major mineral resources in Asia continent

The mineralization of major minerals in Asia continent is

closely related to magmatic activity, tectonic movements, sedimentation, and metamorphism, corresponding to complex metallogenic geological settings (He CS et al., 2018). The mineralization occurred throughout all metallogenic epochs from the Archean to the Cenozoic. Consequently, comprehensive and complex mineral deposits were formed, with almost all globally known deposit types found in Asia continent. Regarding commodities, energy minerals like oil, natural gas, and coal were formed primarily from the Paleozoic to the Cenozoic. Metal minerals in Asia continent have experienced mineralization throughout the whole geologic history. Mesozoic and Cenozoic identified as the periods of their extensive mineralization, witnessing the formation of world-renowned mineral deposits such as tin deposits, rare metal deposits, rare earths deposits, lateritic nickel deposits, lateritic bauxite deposits, porphyry Cu-Au-Mo deposits, and epithermal type gold deposits (Table 4; Li JJ et al., 2016; Khalil YS et al., 2022).

#### 2.2.5. Metallogenic specialization in Asia continent

##### (i) Metallogenic specialization of granitoids

Granite belts are widely distributed across the Paleo-Asia Ocean, Tethys, and circum-Pacific mobile belts in Asia continent, leading to the formation of abundant minerals closely associated with these mobile belts, including tin, tungsten, copper, gold, molybdenum, and rare metals (Wang T et al., 2023). These mobile belts are typified by those in Southeast Asia, which exhibit significant metallogenic specialization of tin and host the world-renowned giant Southeast Asian tin belt. This tin belt extends from northern Myanmar to Billiton of Indonesia after passing through Thailand and Malaysia, measuring over 2000 km in total length. It holds abundant tin polymetallic deposits closely associated with granitoids, with over 500 tin deposits (occurrences) having been identified. The tin-rich granite belts in Southeast Asia can be divided into the western, main, and eastern ones. The magmatic activity in these belts occurred from the Permian to the Triassic (dominant) and from the Cretaceous to the Cenozoic, peaking during the Late Triassic (220 Ma). S- and I-type granites are found in these tin-rich granite belts, with the granites associated with tin mineralization dominated by S-type granites in the western and main granite belts and by I-type granites in the eastern granite belt (Chen XF et al., 2020; Fig. 2). Additionally, giant

**Table 4. Deposit types and metallogenic epochs of major mineral resources in Asia continent.**

| Commodities         | Major deposit types                                                                                                           | Major metallogenic epochs                                                                                         |
|---------------------|-------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------|
| Oil and natural gas | Sedimentary type                                                                                                              | Mesozoic and Cenozoic primarily, followed by Paleozoic                                                            |
| Coal                | Sedimentary type                                                                                                              | Paleozoic primarily, followed by Mesozoic and Cenozoic                                                            |
| Uranium             | Sandstone, metamorphic rock, intrusive related, mudstone, lignite, and volcanic types, dominated by the sandstone type        | Mesozoic primarily, followed by Paleozoic and Cenozoic, with a minority formed during the Archean and Proterozoic |
| Iron                | BIF, magmatic, skarn, volcanic, lateritic and placer, and weathering leaching types                                           | Archean and Paleozoic primarily, followed by Proterozoic, Mesozoic, and Cenozoic                                  |
| Manganese           | BIF, sedimentary, hydrothermal, and weathering leaching types                                                                 | Proterozoic and Paleozoic primarily, followed by Mesozoic and Cenozoic                                            |
| Chromite            | Magmatic, placer, and lateritic types, dominated by the magmatic type                                                         | Cenozoic primarily, followed by Archean, Paleozoic, and Mesozoic                                                  |
| Vanadium            | Magmatic, sedimentary, and placer types, dominated by magmatic types                                                          | From Archean to Cenozoic, with a dominance of Paleozoic and Cenozoic                                              |
| Titanium            | Placer and magmatic types                                                                                                     | Magmatic deposits formed from Archean to Cenozoic, and placer deposits formed primarily during the Cenozoic       |
| Copper              | Porphyry, Cu-Ni sulfide, sandstone shale, skarn, VMS, and IOCG types, dominated by the porphyry type                          | Cenozoic primarily, followed by Paleozoic and Mesozoic, with a minority of Proterozoic                            |
| Lead-zinc           | MVT, SEDEX, VMS, skarn, porphyry, and sandstone types                                                                         | Paleozoic and Mesozoic primarily, followed by Proterozoic and Cenozoic                                            |
| Nickel              | Lateritic, Cu-Ni sulfide, and hydrothermal types, dominated by the lateritic type                                             | Cenozoic primarily, followed by Paleozoic and Mesozoic with a minority of Proterozoic                             |
| Cobalt              | Sedimentary, magmatic, lateritic, and hydrothermal types, dominated by magmatic and lateritic types                           | A dominant period from Paleozoic to Cenozoic, with a minority of Archean                                          |
| Bauxite             | Lateritic and karst types, dominated by the lateritic type                                                                    | Cenozoic primarily, followed by Paleozoic                                                                         |
| Tungsten-tin        | Skarn, cassiterite wolframite quartz vein, greisen, pegmatite, and placer types                                               | Mesozoic and Cenozoic primarily, followed by Paleozoic                                                            |
| Antimony            | Hydrothermal type                                                                                                             | Mesozoic primarily, followed by Paleozoic and Cenozoic                                                            |
| Gold                | Porphyry, skarn, epithermal, black rock series, orogenic, sedimentary, gossan, and altered rock types                         | From Archean to Cenozoic, with a dominance of Mesozoic and Cenozoic                                               |
| Silver              | Porphyry, hydrothermal, SEDEX, skarn, and VMS types                                                                           | Mesozoic and Cenozoic primarily, followed by Proterozoic and Paleozoic                                            |
| Rare earths         | Magmatic, sedimentary, weathering crust ion absorption, and hydrothermal types                                                | Cenozoic primarily, followed by Paleozoic, Proterozoic, and Mesozoic                                              |
| Lithium             | Salt lake brine, pegmatite, clay, and oil-natural gas field brine types, dominated by the pegmatite and salt lake brine types | Cenozoic                                                                                                          |
| Phosphate           | Magmatic, metamorphic, sedimentary, and guano types                                                                           | From Proterozoic to Cenozoic, dominated by Proterozoic and Paleozoic primarily, followed by Mesozoic and Archean  |
| Potash              | Salt lake brine and evaporative sedimentary types                                                                             | a period from Paleozoic to Cenozoic                                                                               |
| Diamond             | Kimberlite and placer types                                                                                                   | Mesozoic primarily, followed by Paleozoic and Cenozoic, with a minority of Proterozoic                            |
| Graphite            | Metamorphic type primarily                                                                                                    | A predominance of Precambrian primarily, followed by Paleozoic and Mesozoic                                       |
| Fluorite            | Hydrothermal type primarily                                                                                                   | From Archean to Cenozoic                                                                                          |
| Niobium-tantalum    | Alkaline rock-related, pegmatite, carbonatite, granite, and placer types                                                      | Predominately in Paleozoic primarily, followed by Mesozoic, Neoproterozoic, and Cenozoic                          |

rare metal metallogenic belts related to granitoids have been discovered on the Qinghai-Xizang Plateau in recent years (Qin KZ et al., 2021).

(ii) Metallogenic specialization of Mesozoic to Cenozoic basalts

From the Mesozoic to the Cenozoic, partial regions of Asia continent experienced significant eruptions of basaltic magmas, leading to the formation of extensive basalts and other associated and paragenetic rocks on the Deccan Plateau, India, and in areas within the Indo-China Peninsula, Southwest Asia, with the latter including the Tay Nguyen Highlands in Vietnam, the Boloven Plateau in Laos, and the Mondulkiri Plateau in Cambodia, as well as their surrounding areas. The basalts in the Indo-China Peninsula were primarily

formed during the Cenozoic and those on the Deccan Plateau were principally formed from the Late Cretaceous to the Paleogene. These widespread basalts include tholeiitic, alkaline, and strongly alkaline basalts, providing abundant ore-forming materials for the formation of lateritic bauxite deposits. Consequently, world-renowned lateritic bauxite metallogenic belts have been formed in the Indo-China Peninsula and on the Deccan Plateau, with over 100 lateritic bauxite deposits (occurrences) having been identified in the Indo-China Peninsula (Fig. 3). The ore bodies of these bauxite deposits are primarily distributed in lateritic weathering crusts, characterized by high quality, high alumina-silica ratios, shallow burial depths, and low exploitation costs (Chen XF et al., 2020).

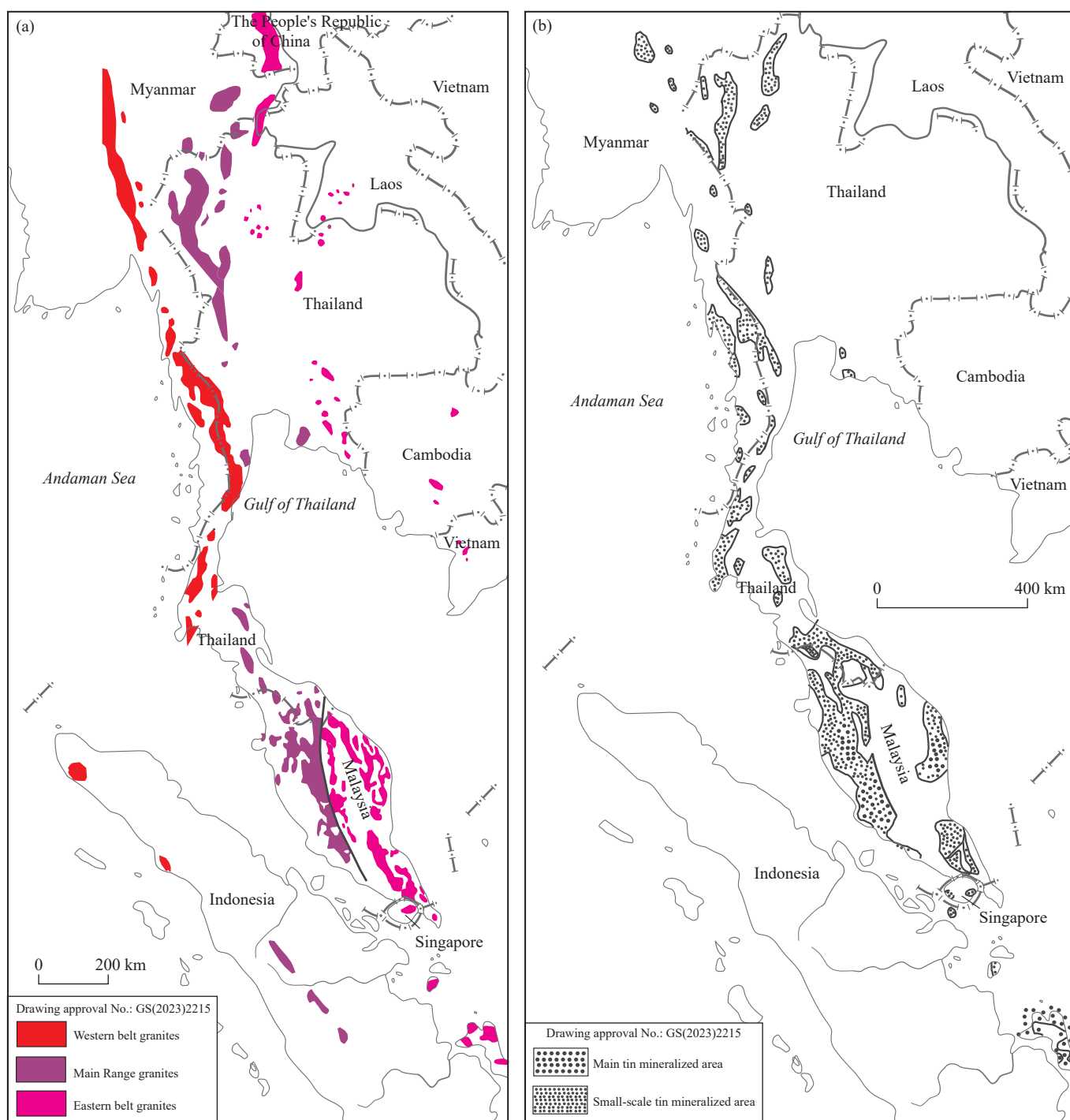


**Fig. 2.** Sketch maps of main granite belts and tin deposits in Southeast Asia (modified from [Chen XF et al., 2015](#)).

(iii) Metallogenic specialization of mafic-ultramafic rocks and ophiolites

Asia continent exhibits widely distributed ophiolites and mafic-ultramafic rocks, with large-scale ophiolite belts and mafic-ultramafic rock belts principally distributed in the Tethys mobile belt, the circum-Pacific mobile belt, and the Central Asian-Mongolian orogenic belt ([Ren JS et al., 2013](#)).

The ophiolite and mafic-ultramafic rock belts in the Tethys mobile belt extend from Turkey in the west to Xizang and southern Yunnan of China after passing through Iran, Afghanistan, India, and Pakistan. Then, these belts turn southward to Myanmar and Indonesia and finally turn

eastward to connect to the giant circum-Pacific ophiolite and mafic-ultramafic rock belts. These belts were primarily formed from the Late Paleozoic to the Paleogene, dominated by the Carboniferous-Permian, Triassic, and Jurassic-Cretaceous ophiolite and mafic-ultramafic rock belts, holding significant potential for chromite prospecting. Among them, the Carboniferous-Permian belts are principally distributed along the southern Kunlun Mountains and the Jinsha River and then extend westward into the southern margin of the Elburz Mountains in northern Iran after passing through the Pamirs. The Triassic belts are located along the Yarlung Zangbo River and the Bangonghu-Nujiang area. The giant

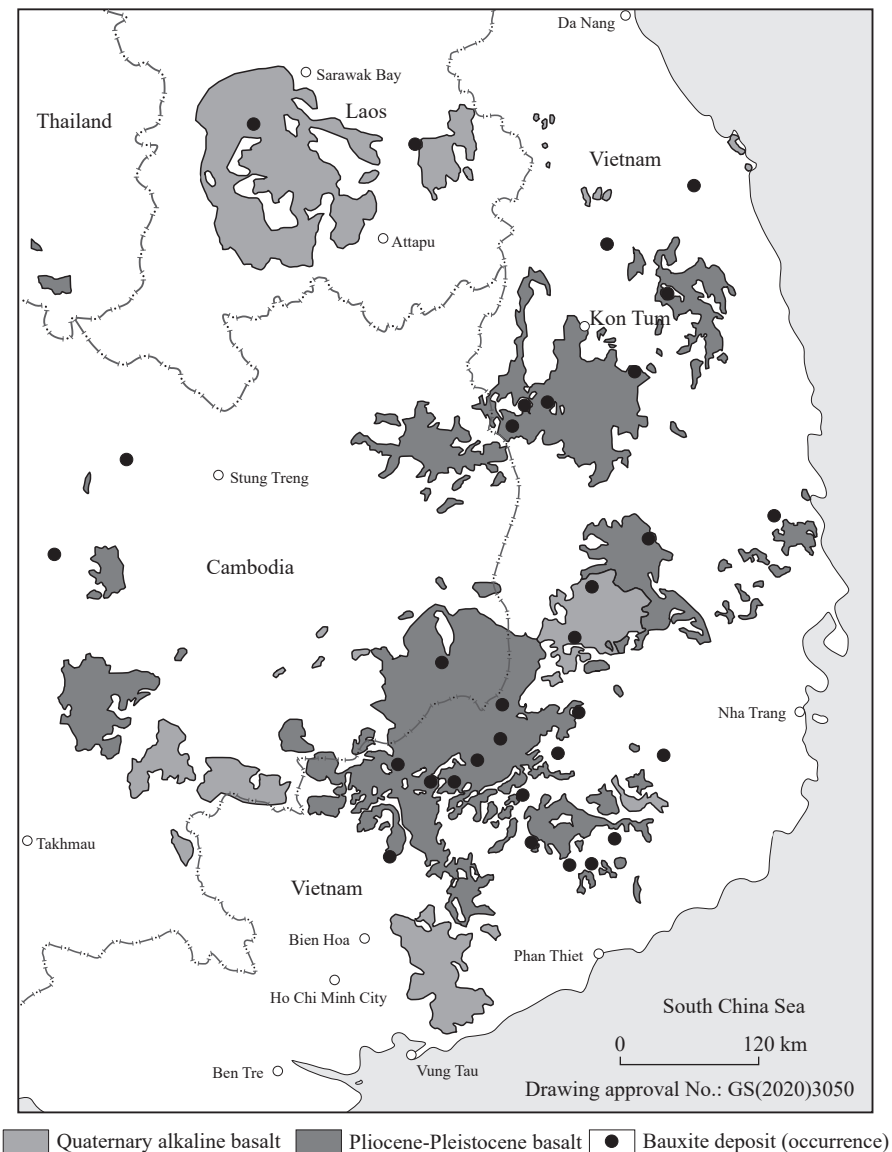


**Fig. 3.** Map showing the distribution of Mesozoic to Cenozoic basalts and lateritic bauxite deposits in the Indo-China Peninsula, Southeast Asia (modified from [Chen XF et al., 2020](#)).

ophiolite and mafic-ultramafic rock belts in the Tethys mobile belt consist of the Archean ophiolite belt in southeastern India, the Mesozoic Guleman ophiolite belt in Turkey, the eastern Zagros ophiolite belt in Iran, and secondary ophiolite belts located in the northern mountains, Baluchistan, and Chagai of Pakistan.

The ophiolite and mafic-ultramafic rock belts in the circum-Pacific mobile belt stretch from northern Kalimantan in the south to the Kamchatka Peninsula in Russia after passing through the Philippines, eastern Taiwan Province of China, and Japan. These belts were primarily formed in four stages: The Early Paleozoic, the Late Paleozoic, the Mesozoic, and the Cenozoic.

The ophiolite and mafic-ultramafic rock belts in the Central Asian-Mongolian orogenic belt run through north-central Asia, exhibiting an arc-shaped distribution from the Ertix River to the east side of the Da Hinggan Mountains. These belts consist of the southern and northern branches. The southern branch is the Hercynian south-central Ural - southern

Tianshan ophiolite and mafic-ultramafic rock belts. The northern branch refers to the West Sayan-Okhotsk ophiolite and mafic-ultramafic rock belts, principally comprising the early-middle Neoproterozoic, late Neoproterozoic-early Cambrian, Cambrian-Ordovician, and Carboniferous-Permian belts, with the late Neoproterozoic and Cambrian-Ordovician belts proving the most developed.

The above mentioned ophiolite and mafic-ultramafic rock belts, especially in Southeast Asia, exhibit significant metallogenic specialization of minerals including chromite, nickel, PGEs, cobalt, gold, and copper. Southeast Asia experienced repeated ocean-continent and intra-oceanic subductions throughout its geologic history, leading to the formation of multiple ophiolite belts and abundant metal mineral resources closely related to ophiolites and mafic-ultramafic rocks, including chromium, PGEs, gold, copper, nickel, and cobalt. These mineral resources are typified by lateritic nickel deposits, with nickel reserves ranking top in the world and establishing Southeast Asia as a significant

nickel producer in the world.

### 2.3. Significant metallogenic belts in Asia continent

#### 2.3.1. Division of metallogenic belts in Asia continent

Asia continent underwent multistage tectonic movements, magmatic activity, metamorphism, and sedimentation, which created favorable ore-forming geological conditions for mineralization in Asia continent. The multistage regional mineralization in Asia continent formed substantial mineral resources in this continent.

The metallogenic belts in Asia continent can be determined based on the theories of plate tectonics and regional mineralization, as well as factors including regional evolutionary history of geological structures, regional geotectonic units, regional lithospheric structures, metallogenic environments, regional metallization regularity, metallization, metallogenic epochs, dominant ore-forming factors, minerogenetic series, and deposit types. As a result, Asia continent can be divided into seven first-order metallogenic belts (metallogenic domains): The Siberian Craton metallogenic domain, the Paleo-Asian metallogenic domain, the Tarim - Sino-Korean - Yangtze metallogenic domain, the Tethyan metallogenic domain, the Arabian Craton metallogenic domain, the Indian Craton metallogenic domain, and the circum-Pacific metallogenic domain. These first-order metallogenic belts can be further divided into 18 second-order metallogenic belts (metallogenic provinces) and 61 third-order metallogenic belts (Fig. 4; Table 5).

#### 2.3.2. Geological and mineral characteristics of significant metallogenic belts in Asia continent

##### (i) Siberian Craton metallogenic domain (I)

The Siberian Craton metallogenic domain is located in the Siberian Craton geotectonically, with primary outcrops including Precambrian metamorphic basement and cap rocks consisting of significantly thick carbonate - terrigenous formations and volcanic rock formations formed since the Neoproterozoic. This metallogenic domain hosts dark rock series ejected from the Late Devonian to the Early Carboniferous and from the Permian to the Triassic, dominated by basalts (Donskaya TV et al., 2021). The mineral resources in this metallogenic domain include oil, natural gas, coal, uranium, copper, gold, nickel, lead, zinc, PGEs, silver, phosphate, diamond, and potash. The mineral deposits identified in this metallogenic domain comprise sedimentary type deposits primarily, followed by magmatic, placer, and epithermal type deposits, with a minor presence of Cu-Ni sulfide deposits, black rock series type gold deposits, sandstone-shale type copper deposits, volcanic type uranium deposits, and kimberlite type diamond deposits (Zorin YA et al., 2001). The metallogenic epochs of the Siberian Craton metallogenic domain are dominated by the Precambrian, Mesozoic, and Cenozoic, followed by the Paleozoic (Gibsher NA et al., 2017). Oil & natural gas and coal within this metallogenic domain principally occur in the East Siberian Basin, with the former formed primarily from the Paleozoic to

the Mesozoic and the latter during the Paleozoic. Notably, the world-known Lena-Tunguska oil and natural gas field and the Tunguska coal deposit occur in this metallogenic domain. The Cu-Ni sulfide deposits in this metallogenic domain are primarily distributed in the Norilsk area, formed primarily during the Mesozoic and typified by the Norilsk and the Talnakh Cu-Ni deposits. The gold and PGEs in this metallogenic domain are primarily found in Irkutsk Oblast, Russia. The deposits of these minerals are primarily of the black-rock-series type (Yudovskaya MA et al., 2016), with typical deposits including the Sukhoi Log Au-PGE deposit and dominant metallogenic epoch proving to be the Proterozoic. Copper and uranium in this metallogenic domain are principally distributed in the Chita Oblast. The copper deposits are primarily of the sandstone-shale type, formed principally during the Proterozoic and typified by the Udokan sandstone-shale type copper deposit. The uranium deposits consist primarily of volcanic type ones, formed principally during the Mesozoic and typified by the Streltsovskaya volcanic type uranium deposit. Diamond in the Siberian Craton metallogenic domain is primarily found in the Yakutia region, formed primarily during the Paleozoic and the Mesozoic. A large number of diamond deposits are found in this metallogenic domain, dominated by the kimberlite type. Potash in this metallogenic domain is predominantly distributed in the Nepa Basin, with metallogenic epochs dominated by the Paleozoic and large potash deposits occurring in Nepa.

##### (ii) Paleo-Asian metallogenic domain (II)

The Paleo-Asian metallogenic domain appears as an arc shape that extends in the nearly east-west direction and protrudes southward overall. It stretches from the Ural Mountains in the west to Mongolia, Xinjiang of China (Altai and Tianshan mountains), Yinshan Mountains within Inner Mongolia, Liaoning, Yanshan Mountains within Hebei, and Da Hinggan Mountains after passing through Central Asia. This metallogenic domain boasts very abundant mineral resources, being superimposed by the Mesozoic mineralization of the circum-Pacific metallogenic domain (Zhao GC et al., 2018). Within this metallogenic domain, the Ural-Mongolia metallogenic province, situated in the Central Asian-Mongolian orogenic belt geotectonically, is recognized as the most significant secondary metallogenic belt. Formed after the closure of the Paleo-Asian Ocean, the Ural-Mongolia metallogenic province has experienced multistage orogeny. This metallogenic province extends over 3000 km in the east-west direction and consists of the Altai-Sayan, Tianshan, Da Hinggan Mountains, South Mongolia, and Baikal orogenic belts, as well as blocks sandwiched by them (Liu HC et al., 2021). Geologically, the Ural-Mongolia metallogenic province spans various countries including China, Mongolia, Russia, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan. Within this metallogenic province, major mineral resources include oil, natural gas, coal, uranium, iron, gold, lead, zinc, copper, molybdenum, silver, nickel, tungsten, phosphate, and potash. The metallogenic epochs of this



Fig. 4. Map of metallogenic belts in Asia continent.

metallogenic province are dominated by the Mesozoic and the Paleozoic, followed by the Cenozoic, with a few deposits formed during the Proterozoic and the Archean (Wei SN et al., 2020; Zu B et al., 2018; Davaasuren OE et al., 2021; Petrov OV et al., 2021). The oil and natural gas resources in this metallogenic province occur principally in the West Siberian Basin—a cratonic depression formed during the

Hercynian, where Mesozoic and Cenozoic hydrocarbon reservoirs with thicknesses ranging from 2000 m to 10000 m are developed. Specifically, oil and natural gas are primarily distributed in the basin's southern and northern portions, respectively, with typical oil and natural gas fields including the Samotlor oilfield and the Urengoy natural gas field. Both coal and potash in the Ural-Mongolia metallogenic province

**Table 5. Metallogenic belts in Asia continent.**

| First-order metallogenic belts                          | Second-order metallogenic belts                                                     | Third-order metallogenic belts                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|---------------------------------------------------------|-------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Siberian Craton metallogenic domain (I)                 | Tunguska metallogenic province (I-1)                                                | Tunguska coal-Cu-Ni-diamond metallogenic zone (I-1-1)<br>Taseev Au-Cu-Ni-Pb-Zn polymetallic metallogenic belt (I-1-2)<br>Angara-Lena coal-Fe-Cu-Au-Ni-potash metallogenic belt (I-1-3)                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|                                                         | Anabar metallogenic province (I-2)                                                  | Magan oil-natural gas-Fe-diamond metallogenic belt (I-2-1)<br>Daldyn rare earth polymetallic metallogenic zone (I-2-2)<br>Marha oil-natural gas-coal-Au-Fe-Ni metallogenic zone (I-2-3)                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Paleo-Asian metallogenic domain (II)                    | Aldan-Stanovoy metallogenic province (I-3)                                          | Aldan coal-U-Fe-Ti-Cu-Ni-Ag-Phosphate metallogenic belt (I-3-1)<br>Stanovoy Fe-Au-U metallogenic belt (I-3-2)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|                                                         | Ural-Mongolia metallogenic province (II-1)                                          | Ural Fe-V-Cr-Ni-Cu-Au-Pb-Zn-bauxite metallogenic belt (II-1-1)<br>West Siberia oil-natural gas-coal-U-Fe-Mn-V-Ti-potash metallogenic belt (II-1-2)<br>Altai-Central Mongolia-Baikar-Hailar Fe-Ni-Cr-Mo-W-Pb-Zn-Au-Hg-Sb-rare earth-potash metallogenic belt (II-1-3)<br>Karaganda-Balkhash-Tianshan Mountains-Hinggan Mountains oil-natural gas-coal-Fe-Mn-Cr-Cu-Au-Pb-Zn-Ag-Mo-bauxite metallogenic belt (II-1-4)                                                                                                                                                                                                                           |
|                                                         | Turan-Karakum metallogenic province (II-2)                                          | Krakum basin oil-natural gas-Au polymetallic metallogenic zone (II-2-1)<br>Turan platform oil-natural gas-U-Fe-V-Ti-Cu-Au-Pb-Zn-Ag metallogenic zone (II-2-2)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|                                                         | Tarim Craton - Sino-Korean Craton Metallogenic province (III-1)                     | Tarim Craton oil-natural gas-Fe-V-Ti-Cr-Cu-Au-Mo-Pb-Zn-phosphate-diamond-asbestos-gemstone metallogenic zone (III-1-1)<br>Sino-Korean Craton coal-Au-Cu-Pb-Zn-W-Sb-bauxite-Ag-Hg- Phosphate metallogenic zone (III-1-2)                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Tarim - Sino-Korean - Yangtze metallogenic domain (III) | Yangtze Craton metallogenic province (III-2)                                        | Upper Yangtze Block Fe-Mn-V-Ti-Cu-Pb-Zn-W-Sn-Au-Ag-Sb-Hg-phosphate-rare earth metallogenic zone(III-2-1)<br>Lower Yangtze Block Au-W-Cu-Pb-Zn-Mo-Sb-Ag metallogenic belt (III-2-2)                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|                                                         | West Asian metallogenic province (IV-1)                                             | Caucasus-Elburz Mn-Cu-Pb-Zn-W-Mo metallogenic belt (IV-1-1)<br>Turkey-Iran-eastern Afghanistan-Pakistan Cu-Cr-Mo metallogenic belt (IV-1-2)<br>Zagros-Kabul oil-natural gas-Pb-Zn metallogenic belt (IV-1-3)                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| Tethyan metallogenic domain (IV)                        | Gangdese-Sanjiang metallogenic province (IV-2)                                      | Songpan-Ganzi Au-Cu-U-Co-Ni-rare metal metallogenic belt (IV-2-1)<br>Sanjiang Cu-Pb-Zn-Sn-Mo-Au-Ag-Ni-Co metallogenic belt (IV-2-2)<br>Central Pamir-South Qiangtang shale oil-coal-Fe-Cu-Au-Pb-Zn-Ag metallogenic belt (IV-2-3)<br>South Pamir-Gangdese Cu-Cr-Ni-Co-Au-W-Mo-Fe-Pb-Zn-Ag polymetallic metallogenic belt (IV-2-4)<br>Yarlung Zangbo chromite metallogenic belt (IV-2-5)                                                                                                                                                                                                                                                       |
|                                                         | Indo-China Peninsula-Sumatra-Jawa-Banda metallogenic province in (IV-3)             | Indo-Burman Ranges junction zone Cr-Ni-Cu-Au metallogenic belt (IV-3-1)<br>Sumatra-Jawa-Banda-Timor -Leste oil-natural gas-Fe-Mn-Cu-Au-Mo-Ni-Pb-Zn-Ag metallogenic belt (IV-3-2)<br>West Myanmar-West Sumatra oil-natural gas-coal-Cu-Au-Cr-Ni-Pb-Zn-platinum group metals-Sb-W-Sn-jadeite metallogenic belt (IV-3-3)<br>Sibumasu Block oil-natural gas-Fe-Mn-W-Sn-Sb-Au-Cu-Pb-Zn-Ag-rare earth-bauxite-gemstone metallogenic belt (IV-3-4)<br>Indo-China Block Fe-Mn-Cr-W-Sn-Cu-Pb-Zn-Au-Mo-Sb-bauxite-rare earth-potash-gemstone metallogenic zone (IV-3-5)<br>Eastern Malay Peninsula W-Sn-Au-bauxite-Cu-Fe-Mn metallogenic belt (IV-3-6) |
|                                                         | Metallogenic province in Qinling Mountains-Qilian Mountains-Kunlun Mountains (IV-4) | Northern Qinling Mountains Ag-Au-Cu-Fe-Pb-Zn metallogenic belt (IV-4-1)<br>Southern Qinling Mountains Pb-Zn-Ag-Au-Hg-Cu metallogenic belt (IV-4-2)<br>Qilian Mountains Cu-Fe-Pb-Zn-Cr-Ni-W-Mo metallogenic belt (IV-4-3)<br>Pb-Zn-Cr-potash metallogenic belt of the Qaidam basin and its surrounding areas (IV-4-4)<br>Eastern Kunlun - Altun Fe-Cr-Ni-Pb-Zn-Cu metallogenic belt (IV-4-5)<br>Western Kunlun Fe-Cr-Cu metallogenic belt (IV-4-6)                                                                                                                                                                                            |
|                                                         | Arabian Shield metallogenic province (V-1)                                          | Damascus - western Saudi Arabia phosphate-potash-Fe-Au-Pb-Zn-bauxite-rare earth metallogenic belt (V-1-1)<br>Sana'a Au-Pb-Zn metallogenic zone (V-1-2)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| Arabian Craton metallogenic domain (V)                  | Persian Gulf metallogenic province (V-2)                                            | Zagros oil - natural gas enrichment zone (V-2-1)<br>Arabian Basin oil and natural gas enrichment zone (V-2-2)<br>Persian Gulf oil - natural gas enrichment zone (V-2-3)                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|                                                         | Himalayan metallogenic province (VI-1)                                              | Northern Himalayan Au-Cu-Ag-rare metal belt (VI-1-1)<br>Southern Himalayan Cu-Au metallogenic belt (VI-1-2)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Indian Craton metallogenic domain(VI)                   |                                                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |

**Table 5. (Continued)**

| First-order metallogenic belts           | Second-order metallogenic belts                                          | Third-order metallogenic belts                                                                                       |
|------------------------------------------|--------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------|
| Circum-Pacific metallogenic domain (VII) | Indian Peninsula metallogenic province (VI-2)                            | Aravalli Cu-Fe-Pb-Zn-Ag metallogenic belt (VI-2-1)                                                                   |
|                                          |                                                                          | Singhbhum coal-Fe-Cr-Mn-rare earth-mica-asbestos-graphite metallogenic belt (VI-2-2)                                 |
|                                          |                                                                          | Deccan - eastern Ghats coal-U-Mn-Fe-bauxite-rare earth-mica-gemstone-graphite metallogenic belt (VI-2-3)             |
|                                          |                                                                          | Western Talwar Fe-Au metallogenic belt (VI-2-4)                                                                      |
|                                          |                                                                          | Southern granulite block Fe-Mn-Cr-bauxite metallogenic belt (VI-2-5)                                                 |
|                                          |                                                                          | Sri Lanka Fe-Cu-graphite-gemstone metallogenic zone (VI-2-6)                                                         |
|                                          | East Siberian metallogenic province (VII-1)                              | Okhotsk-Chukchi Cu-Au-W-Sn-Mo-Ag metallogenic belt (VII-1-1)                                                         |
|                                          |                                                                          | Kolyma Cu-Au-Ag metallogenic zone (VII-1-2)                                                                          |
|                                          | East Asian continental margin metallogenic province (VII-2)              | Koryakskiy-Kamchatka-Sakhalin-Japan oil-natural gas-Fe-Cu-Au-Ag-W-Sn-Mo-Sb-Pb-Zn metallogenic belt (VII-2-1)         |
|                                          |                                                                          | Sikhote-Aline Cu-Au-W-Sn-Ag-Pb-Zn metallogenic belt (VII-2-2)                                                        |
|                                          |                                                                          | Cathaysia block Nb-Ta-rare earth-W-Sn-Pb-Zn-Cu-Mo-Fe-Au-U metallogenic zone (VII-2-3)                                |
|                                          |                                                                          | Kalimantan Fe-Cu-Cr-Au-bauxite-Pb-Zn-Ni-Sn-Ag metallogenic belt (VII-3-1)                                            |
|                                          | Philippines-Kalimantan-Sulawesi-New Guinea metallogenic province (VII-3) | Palawan Cu-Au-Ni-Cr-Fe-Pb-Zn metallogenic belt (VII-3-2)                                                             |
|                                          |                                                                          | Mindoro-West Mindanao island-Sulawesi Cu-Au-Ni-Cr-Co-Pb-Zn-Ag-Fe metallogenic belt (VII-3-3)                         |
|                                          |                                                                          | Luzon island - eastern Mindanao island - Moluccas island Cu-Au-Ni-Cr-Pb-Zn-Ag-Fe-bauxite metallogenic belt (VII-3-4) |
|                                          |                                                                          | Au-Cu-Ni-Pb-Zn-Ag polymetallic metallogenic zone in New Guinea (VII-3-5)                                             |

were formed primarily during the Paleozoic. Coals in this metallogenic province are principally found in the Kuznetsk Basin, exemplified by the large-scale Kuznetsk coal deposit. In contrast, potash in this metallogenic province are primarily distributed in the Upper Kama Basin, with typical deposits including the large-scale Upper Kama potash deposit. Crucially, the Paleo-Asian metallogenic domain hosts the world-known “Central Asian Gold Belt”, which contains numerous world-renowned gold deposits such as the Kumtor gold deposit in Kyrgyzstan and the Muruntau gold deposit in Uzbekistan.

### (iii) Tarim - Sino-Korean - Yangtze metallogenic domain (III)

The Tarim - Sino-Korean - Yangtze metallogenic domain consists roughly of the Tarim, Sino-Korean, and Yangtze cratons. Geologically, the Tarim Craton comprises the Tarim Basin and its surrounding areas, with basement and cap rocks having developed. The basement comprises Neoarchean and Paleoproterozoic mesometamorphic rock series, while the cap rocks consist primarily of Mesoproterozoic and Neoproterozoic epimetamorphic rock series, Paleozoic clastic-carbonate formations, and significantly thick Cenozoic strata. In the Tarim Craton, major mineral resources include oil, natural gas, iron, vanadium, titanium, chromium, copper, gold, molybdenum, lead, zinc, phosphate, diamond, asbestos, and gemstone. The deposits in this craton include magmatic type V-Ti-magnetite deposits, kimberlite type diamond deposits, magmatic type Cu-Ni sulfide deposits, greenstone type gold deposits, magmatic type chromite deposits, metamorphic volcanic-sedimentary type iron deposits, and sedimentary type phosphate deposits. These deposits were formed primarily during the Proterozoic and the Paleozoic, followed by the Cenozoic, and they are typified by the

Puchang V-Ti-magnetite deposit and the Kalama copper deposit.

The Sino-Korean Craton spans northern China, North Korea, and South Korea geologically. The outcrops in this craton consist primarily of basement composed of Archean-Paleoproterozoic mesometamorphic rock series and nonmetamorphic cap rocks formed since the Mesoproterozoic. The Sino-Korean Craton experienced roughly four stages of tectonic evolution and mineralization: The basement formation and mineralization from the Archean to the Paleoproterozoic, the tectonic evolution and mineralization from the Mesoproterozoic to the Neoproterozoic and during the Paleozoic, and the tectonic-magmatic mineralization from the Mesozoic to the Cenozoic (Zhai YS et al., 1999). In the Sino-Korean Craton, the mineral resources include coal, gold, copper, lead, zinc, tungsten, antimony, bauxite, silver, mercury, and phosphate, and the metallogenic epochs are dominated by the Mesozoic and the Paleozoic, followed by the Proterozoic, the Cenozoic, and the Archean. Primary deposits in this craton include BIF type iron deposits, SEDEX type Cu-Pb-Zn polymetallic deposits, porphyry Cu-Mo deposits, karst type bauxite deposits, sedimentary metamorphic type Pb-Zn deposits, hydrothermal type Pb-Zn deposits, orogenic type gold deposits, and skarn type molybdenum deposits (Chen C et al., 2016).

The Yangtze Craton experienced complex and multistage tectonic evolution, exhibiting a series of rift basins and large numbers of NE-directed granite belts formed during the middle-late Neoproterozoic. The basement rock series exposed in this craton are dominated by Proterozoic epimetamorphic rocks, with more ancient rock series possibly underlying. The Yangtze Craton exhibits Neoproterozoic marine sedimentary cap rocks and extensive Middle Permian

basalts. In this craton, major minerals include iron, manganese, chromium, vanadium, titanium, copper, lead, zinc, tungsten, tin, gold, silver, antimony, mercury, phosphate, rare earths, oil, and natural gas. Primary deposits in this craton include volcanic type Fe deposits, volcanogenic massive sulfide (VMS) copper polymetallic deposits, MVT type Pb-Zn deposits, tectonic altered rock type gold deposits, hydrothermal type Hg-Sb deposits, magmatic type V-Ti-magnetite deposits, porphyry Cu-Mo deposits, porphyry tungsten deposits, skarn type Pb-Zn deposits, skarn type scheelite deposits, and epithermal type gold deposits. These deposits were primarily formed during the Precambrian, the Paleozoic, and the Mesozoic, followed by the Cenozoic. Within the Yangtze Craton, oil and natural gas resources occur principally in the Sichuan Basin, and metal minerals are extensively distributed in the middle and lower reaches of the Yangtze River, and Jiangxi, Yunnan, Guizhou, and Guangxi provinces.

#### (iv) Tethyan metallogenic domain (IV)

The Tethyan metallogenic domain, also known as the Tethyan-Himalayan metallogenic domain, stretches from West Asia in the west. After passing through the Qinghai-Xizang Plateau, the Himalayas, and China's Sanjiang area in the east, as well as the Indo-China Peninsula in Southeast Asia, this metallogenic domain extends into a vast region from the Sumatra and Java islands of Indonesia to East Timor. The mineralization in this metallogenic domain is principally related to the tectonic movements and magmatic activity from the Mesozoic to the Cenozoic. Major mineral resources in the Tethyan metallogenic domain include oil, natural gas, coal, uranium, iron, manganese, chromium, copper, cobalt, nickel, lead, zinc, antimony, tungsten, tin, bauxite, gold, silver, PGEs, rare earths, rare metals, scattered metals, phosphate, graphite, potash, and mercury. The metallogenic epochs of this metallogenic domain widely span the Proterozoic, the Paleozoic, the Mesozoic, and the Cenozoic, dominated by the Mesozoic to Cenozoic. This metallogenic domain exhibits a complete range of complex deposit types, hosting porphyry Cu-Au-Mo deposits, orogenic type gold deposits, epithermal type gold deposits, Carlin type gold deposits, ophiolite type chromite deposits, sedimentary type phosphate deposits, skarn type W-Mo deposits, sandstone-shale type copper deposits, and VMS type Cu-Pb-Zn polymetallic deposits (Carlile JC et al., 1998; Çolakoglu AR et al., 2011; Braxton DP et al., 2018). Notably, this metallogenic domain is home to various world-renowned giant mineral concentration zones, including the giant Southeast Asian tin belt, the giant Tethyan porphyry Cu-Au belt, the giant Qinghai-Xizang Plateau rare metal belt, and the Southeast Asia lateritic bauxite belt, and the Southeast Asia lateritic nickel belt (Yigit O, 2006, 2012; Wang R et al., 2017; Zhu XP et al., 2017; Hosseini ST et al., 2020; İsmayıl C et al., 2020).

#### (v) Arabian Craton metallogenic domain (V)

The Arabian Craton metallogenic domain largely resides within the Arabian Craton geotectonically. In terms of geographical location, this metallogenic spans across Saudi Arabia, Jordan, Israel, Yemen, Oman, Bahrain, Qatar, Kuwait,

United Arab Emirates, Iran, and Iraq, as well as their surrounding areas, facing Africa across the Red Sea. The strata in this metallogenic domain consist of Precambrian basement and later sedimentary cap rocks. The Precambrian basement comprises intensely metamorphosed magmatic rocks and metamorphic rock series, while the cap rocks consist of Paleozoic, Mesozoic, and Cenozoic strata (Stewart SA et al., 2023; Mansouri SM et al., 2023). The Arabian Craton metallogenic domain is known for its rich oil and natural gas resources, with other major minerals including iron, vanadium, titanium, copper, nickel, lead, zinc, tungsten, tin, bauxite, gold, silver, phosphate, and potash. Deposits in this metallogenic domain are primarily of the sedimentary type, including lateritic bauxite deposits, VMS type Cu-Pb-Zn deposits, MVT type Pb-Zn deposits, and sedimentary type phosphate deposits. These deposits were formed primarily during the Mesozoic, followed by the Cenozoic, with a few formed during the Paleozoic and Proterozoic. Oil & natural gas resources in this metallogenic domain, accumulating predominantly from the Mesozoic to the Cenozoic, are primarily distributed in its eastern portion, which is home to the renowned giant petroliferous Persian Gulf basin, the giant petroliferous Arabian Basin, and the Zagros oil and natural gas enrichment zone. Notably, the Arabian Basin oil and natural gas enrichment zone, primarily located within the Arabian Basin, is recognized as the area with the richest oil and natural gas resources worldwide, hosting several world-class oil and natural gas fields, such as the South Pars oil and natural gas field in Iran, the Burgan oilfield in Kuwait, and the Ghawar oilfield in Saudi Arabia. Metal minerals in the Arabian Craton metallogenic domain are primarily distributed in its platform area. Among them, iron ore minerals are primarily distributed along the northeastern coast of the Red Sea. The iron deposits are primarily of the sedimentary-metamorphic type, with typical deposits including the Wadi Sawawin iron deposit.

#### (vi) Indian Craton metallogenic domain (VI)

The Indian Craton metallogenic domain, geotectonically nestling in the Indian Craton, consists of India and its environs geologically. Outcrops in this metallogenic domain include the metamorphic rock series of the Precambrian basement, deposited Paleozoic marine carbonate rocks and sandstones-shales, and Mesozoic to Cenozoic fluvial and lacustrine sedimentary layers. The Indian Craton metallogenic domain exhibits a complete range and extensive distribution of magmatic rocks, among which the Deccan melanocratic rocks are the most renowned. The Deccan melanocratic rocks, distributed in the central and western Indian Peninsula, started to erupt from the Late Cretaceous, peaking during the Eocene. After experiencing weathering, these rock series formed lateritic bauxite deposits with high reserves (Manikyamba C et al., 2022). Major mineral resources in the Indian Craton metallogenic domain include iron, manganese, chromium, bauxite, copper, lead, zinc, mica, phosphate, oil, and natural gas. Primary deposits in this metallogenic domain include BIF type Fe-Mn deposits, lateritic bauxite deposits, magmatic

stratiform chromite deposits, greenstone type gold deposits, porphyry copper deposits, hydrothermal type copper deposits, and sandstone type uranium deposits. These deposits were formed primarily during the Precambrian and the Mesozoic, followed by the Cenozoic and the Paleozoic (Singh S et al., 2018). Oil and natural gas resources in the Indian Craton metallogenic domain are largely distributed in the continental shelf areas along the western coast of India, with oil and natural gas fields found in the Mumbai Basin. Iron and manganese deposits in this metallogenic domain are primarily distributed in its southern, central, and eastern portions. These deposits are primarily of the BIF type, with metallogenic epochs dominated by the Precambrian and important deposits including the Kudremukh and Bailadila iron deposits. Gold deposits in this metallogenic domain, typified by the Kolar gold deposit, are distributed in the greenstone belt within its southern portion. These deposits, primarily of the greenstone type, were principally formed during the Archean. Copper deposits in the Indian Craton metallogenic domain are concentrated in its central, eastern, and northern parts. These deposits are of the porphyry and hydrothermal types, with typical deposits including the Singhbhum, Malanjkhand, and Rampura-Agucha copper deposits. They were primarily formed during the Proterozoic. Lateritic type bauxite deposits in this metallogenic domain are principally discovered in Bihar and Odisha in eastern India, with the Cenozoic identified as their dominant metallogenic epoch. Uranium deposits in this metallogenic domain, principally found in Bihar and Meghalaya in eastern India, are of the sandstone and vein types. Chromite deposits in this metallogenic domain, concentrated in Bihar and Odisha in eastern India, are primarily of magmatic stratiform chromite type, with typical deposits including the Sukinda-Nausash chromite deposit. These deposits were principally formed during the Archean.

(vii) Circum-Pacific metallogenic domain (VII)

The circum-Pacific metallogenic domain is largely located within the circum-Pacific mobile belt geotectonically. In terms of geographical position, this metallogenic domain stretches from Russia's Chukchi Peninsula in the north. After passing through the Okhotsk Sea and the Sikhote-Alin Mountains of Russia, as well as Japan and the Philippine Islands in the east, this metallogenic domain extends into the Kalimantan, Sulawesi, and New Guinea islands of Indonesia. Its mineralization is primarily related to the tectonic movements and magmatic activity triggered by the Pacific Plate subduction from the Mesozoic to the Cenozoic, leading to the formation of Mesozoic to Cenozoic volcanic-plutonic and mafic-ultramafic rock belts. The circum-Pacific metallogenic domain enjoys extremely abundant mineral resources, hosting the world-known circum-Pacific porphyry Cu-Au-Mo metallogenic belt. Major minerals in this metallogenic domain include oil, natural gas, coal, uranium, iron, chromium, copper, gold, nickel, cobalt, lead, zinc, tungsten, tin, molybdenum, silver, antimony, and bauxite. Notably, this metallogenic domain exhibits abundant porphyry Cu-Au deposits, lateritic nickel/bauxite deposits,

and epithermal type gold deposits. These deposits were primarily formed from the Mesozoic to the Cenozoic, with typical deposits including the Grasberg skarn porphyry Cu-Au-Ag deposit, the Rio Tuba lateritic nickel (cobalt) deposit, and the Batu Hijau porphyry Cu-Au deposit in Indonesia.

### 3. Mining industry development patterns in Asia

#### 3.1. Asia's mining industry serving as a significant driving force and major contributor to the economic development of Asia and even the world

Asia's mining industry plays a pivotal role in driving the economic development of Asia and even the world. In 2018, the production value of minerals in Asia reached \$2.51 trillion, accounting for 7.55% of Asia's GDP and 2.90% of global GDP. By 2022, this value had surged to \$4.38 trillion, with its share of GDP rising to 11.11% in Asia and 4.34% globally, with an increase of 3.56% and 1.44%, respectively, compared to 2018 (Federal Ministry of Finance of Austria, 2024). These findings demonstrate that Asia's mining industry has emerged as an increasingly important pillar of economic development within the region and has become a significant driving force for the world economy. The mining sector is playing an increasingly significant role in GDP growth, export earnings, and employment in some countries. For instance, in several Asian countries, the mining sector contributes to more than 20% of annual GDP, over 70% of export earnings, and more than 70% of annual GDP growth. Besides, the mining sector contributes significantly to employment in Asian countries, particularly in Indonesia, where approximately 150000 individuals are employed in the mining industry (Table 6).

#### 3.2. Asia leading in global mineral exploration investment, with China ranking first in Asia

From 2014 to 2023, Asia emerged as a primary investor in global mineral exploration across various continents, with annual investments ranging from \$1.35 billion to 2.06 billion, accounting for 10.55% to 19.14% of the world's total.

In terms of commodities, gold ranks first in Asia's mineral exploration investment, with annual allocations to gold exploration representing 40.41% to 50.21% of Asia's total. Copper ranks second in Asia's mineral exploration investment, with annual investments accounting for 18.78% to 23.47% of Asia's total. Thus, the annual gold and copper exploration investments constitute 62.34% to 72.85% of Asia's annual mineral exploration investment. Additionally, minerals like uranium, molybdenum, zinc, lithium, cobalt, nickel, rare earths, and fluorite are also key targets for mineral exploration investment in Asia (S&P Global Market Intelligence, 2024).

Among countries worldwide, China is recognized as a primary investor in mineral exploration, consistently ranking among the top 10 globally from 2014 to 2023. In 2023, China ranked ninth worldwide in mineral exploration investment, contributing 3.0% of the global total. Additionally, China led

Table 6. Role of mining industry in the economic and social development of Asia.

| Category                                                                                   | Countries                                                                                                                                                |
|--------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------|
| Countries with production value of minerals exceeding 20% of their GDP                     | Mongolia, Russia, Kazakhstan, Kuwait, Iraq, Iran, Azerbaijan, Qatar, Oman, Saudi Arabia, Brunei, Kyrgyzstan Uzbekistan United Arab Emirates, and Bahrain |
| Countries with export value of mineral products exceeding 70% of their total export values | Kuwait, Iraq, Azerbaijan, Qatar, Brunei, Oman, Kazakhstan, United Arab Emirates, Saudi Arabia, and Iran                                                  |
| Countries with over 70% annual GDP growth originating from the mining sector               | Iraq, Bahrain, Kazakhstan, Oman, Saudi Arabia, Brunei, Kuwait, Azerbaijan, Qatar, Tajikistan, Mongolia, and United Arab Emirates                         |

in investment in the exploration of molybdenum, zinc, cobalt, gold, rare earths, nickel, silver, lithium, uranium, and copper (Table 7). Within Asia, China has long been recognized as the largest investor in mineral exploration, with its annual investment accounting for 29.75% of Asia’s total mineral exploration investment in 2023 (S&P Global Market Intelligence, 2024).

3.3. Asia recognized as the world’s largest mineral-producing continent, with China ranking first globally

Since the 1980s, Asia has always been the world’s largest mineral producer, with both annual mineral production and its proportion in the world steadily trending upward. Notably, over the last decade, Asia’s annual mineral production has grown rapidly, accounting for more than 55% of the world’s total. In 2022, this proportion reached up to 61.7%, increasing by 1.30% from 60.4% in 2021 (Federal Ministry of Finance of Austria, 2024).

In terms of commodities, Asia exhibits a high share of global production for many minerals. For instance, the annual production of minerals such as gallium, germanium, mercury, bismuth, tungsten, antimony, indium, vanadium, graphite, magnesite, coal, fluorite, and rare earths accounts for over 70% of the global totals. Similarly, the annual production of minerals like oil, natural gas, nickel, cadmium, asbestos, barite, tin, selenium, phosphate, lead, and bentonite represents more than 50% of the global totals. Besides, the annual production of over ten minerals, including copper, chromite, titanium, bauxite, iron ore, and gold, accounts for 20% to 50% of the global totals. The annual production of minerals such as lithium, cobalt, rhenium, zirconium, and uranium also represents significant proportions of the global production (Table 8). Asia’s abundant mineral resources and high

production levels not only support the continent’s rapid economic development but also supply large quantities of mineral resources to major economic and industrial powers such as the U.S., Canada, France, the UK, and Germany (USGS, 2024). Therefore, Asia’s mineral resources provide a solid material foundation for global economic and industrial development, making significant contributions to the world economy.

Among all countries, China stands as the world’s largest mineral producer. In 2021 and 2022, China’s mineral production reached  $4.64 \times 10^9$  t and  $5.04 \times 10^9$  t, respectively, accounting for 25.38% and 26.43% of the global production and 42.94% and 43.75% of Asia’s production, respectively. These results indicate China’s position as the largest mineral-producing country and a mineral production center in Asia. In 2022, China ranked first in the production of 28 minerals, including molybdenum, titanium, tungsten, vanadium, antimony, bismuth, rare earths, lead, and zinc. In the same year, several other Asian countries such as India, Indonesia, Saudi Arabia, and Iran also ranked among the top 10 countries in mineral production in the world (Federal Ministry of Finance of Austria, 2024).

3.4. Asia recognized as the continent with world’s largest mineral product trade value, with China ranking first globally

Regarding its position and role in global mineral product trade, Asia ranks first among all continents worldwide. In 2022, Asia’s import and export values for mineral products accounted for 47.82% and 38.7% of the global totals, respectively, both ranking first among continents. Specifically, the import and export values for mineral fuels accounted for 47.21% and 41.70%, respectively; those for metal minerals represented 49.64% and 32.34%, respectively, and those for gemstones accounted for 51.26% and 49.28%, respectively (Table 9). These figures collectively demonstrate that Asia has emerged as the world’s mineral trade center (UN Comtrade, 2024).

In terms of the types and global standing of exported mineral products, Asia primarily exports over 20 commodities, including oil, natural gas, coal, iron, manganese, copper, cobalt, nickel, gold, and diamond. Notably, the export values for rare earths account for more than 70% of the global total; those of mineral products including Sb ores and concentrates, thorium ores and concentrates, and oil represent 60% to 70%; those of diamond, gold (nonmonetary), nickel ores and concentrates, natural gas, tungsten ores and concentrates, and coal occupy

Table 7. World positions of China in mineral exploration investment.

| Commodities | China’s investments in mineral exploration |                |                |
|-------------|--------------------------------------------|----------------|----------------|
|             | Exploration investments/million dollars    | Global share/% | World rankings |
| Molybdenum  | 4.70                                       | 28.48          | 1              |
| Zinc        | 38.90                                      | 9.44           | 4              |
| Cobalt      | 3.90                                       | 5.26           | 5              |
| Gold        | 188.80                                     | 3.19           | 5              |
| Rare earths | 5.20                                       | 3.72           | 5              |
| Nickel      | 17.50                                      | 2.39           | 6              |
| Silver      | 17.0                                       | 3.06           | 8              |
| Lithium     | 16.60                                      | 2.0            | 9              |
| Uranium     | 3.90                                       | 1.57           | 11             |

40% to 50%; those of silver, palladium in unwrought and powder forms, platinum in unwrought and powder forms, and osmium-iridium-ruthenium in unwrought and powder forms represent 20% to 30%, and those of the ores and concentrates

**Table 8. Proportions of Asia's major mineral resources production.**

| Commodities                | Unit                                                | Production |         |              | Global share of mineral production/% |       |       |
|----------------------------|-----------------------------------------------------|------------|---------|--------------|--------------------------------------|-------|-------|
|                            |                                                     | 2021       | 2022    | 2023         | 2021                                 | 2022  | 2023  |
| Gallium                    | t                                                   | 430        | 616     | 610          | 99.77                                | 100   | 100   |
| Germanium                  | t                                                   | 139        | 137     |              | 97.89                                | 98.56 |       |
| Mercury                    | t                                                   | 1753       | 978     | 1106         | 96.85                                | 96.35 | 92.17 |
| Bismuth                    | 10 <sup>4</sup> t                                   | 1.06       | 0.99    | 0.95         | 95.28                                | 96.55 | 94.65 |
| Tungsten                   | 10 <sup>4</sup> t (W)                               | 8.28       | 8.03    | 7.02         | 93.28                                | 93.47 | 90    |
| Antimony                   | 10 <sup>4</sup> t                                   | 8.49       | 7.62    | 7.73         | 92.39                                | 91.74 | 93.12 |
| Tellurium                  | t                                                   | 663        | 611     | 583          | 89.35                                | 89.72 | 91.09 |
| Indium                     | t                                                   | 807        | 924     | 920          | 88.10                                | 91.67 | 92.93 |
| Vanadium                   | 10 <sup>4</sup> t (V)                               | 9.43       | 9.92    | 8.80         | 85.48                                | 86.01 | 88    |
| Graphite                   | 10 <sup>4</sup> t                                   | 134.48     | 133.76  | 129.73       | 80.87                                | 77.43 | 81.08 |
| Magnesite                  | 10 <sup>4</sup> t                                   | 2174.30    | 2072.71 | 1647         | 77.50                                | 77.64 | 74.86 |
| Coal                       | 10 <sup>4</sup> t                                   | 630570     | 693790  | 7365.90      | 77.28                                | 78.81 | 81.0  |
| Fluorite                   | 10 <sup>4</sup> t                                   | 645.55     | 656.61  | 697.20       | 76.44                                | 71.09 | 79.23 |
| Rare earths                | 10 <sup>4</sup> t (REO)                             | 20.0       | 23.25   | 29.13        | 74.35                                | 78.33 | 83.22 |
| Cadmium                    | 10 <sup>4</sup> t                                   | 1.75       | 1.62    | 1.70         | 68.63                                | 70.21 | 74    |
| Asbestos                   | 10 <sup>4</sup> t                                   | 88.0       | 82.50   | 109          | 67.57                                | 65.58 | 83.85 |
| Barite                     | 10 <sup>4</sup> t                                   | 564.53     | 534.43  | 660          | 67.54                                | 64.56 | 77.65 |
| Selenium                   | t                                                   | 2460       | 2365    | 2704         | 65.90                                | 63.32 | 75.41 |
| Tin                        | 10 <sup>4</sup> t                                   | 16.67      | 18.04   | 19.04        | 63.24                                | 61.71 | 65.66 |
| Phosphate                  | 10 <sup>4</sup> t (P <sub>2</sub> O <sub>5</sub> )  | 4521.32    | 4646.96 | 13651 (ore)  | 62.41                                | 65.65 | 62.05 |
| Lead                       | 10 <sup>4</sup> t                                   | 272.42     | 272.97  | 249          | 59.22                                | 58.15 | 55.33 |
| Boron                      | 10 <sup>4</sup> t                                   | 288.16     | 298.15  | 248          | 58.54                                | 55.77 |       |
| Bentonite                  | 10 <sup>4</sup> t                                   | 1032.77    | 1040.32 |              | 54.84                                | 55.80 |       |
| Oil                        | 10 <sup>4</sup> t                                   | 231180     | 244180  | 241920       | 54.66                                | 55.41 | 53.60 |
| Nickel                     | 10 <sup>4</sup> t                                   | 150.97     | 194.69  | 251          | 52.93                                | 59.93 | 69.72 |
| Natural gas                | 10 <sup>8</sup> m <sup>3</sup>                      | 21225      | 20555   | 20264        | 52.36                                | 50.83 | 50.0  |
| Zinc                       | 10 <sup>4</sup> t                                   | 588.79     | 590.38  | 550          | 45.84                                | 46.26 | 45.83 |
| Molybdenum                 | 10 <sup>4</sup> t                                   | 12.38      | 13.12   | 12.91        | 45.67                                | 49.41 | 49.65 |
| Arsenic                    | 10 <sup>4</sup> t                                   | 2.48       | 2.45    | 2.42         | 45.42                                | 43.51 | 40.40 |
| Potassium                  | 10 <sup>4</sup> t (K <sub>2</sub> O)                | 1941.12    | 1811.85 | 1810         | 41.89                                | 43.18 | 46.41 |
| Titanium                   | 10 <sup>4</sup> t (TiO <sub>2</sub> )               | 342.52     | 369.15  | 346.30       | 39.99                                | 41.28 | 37.64 |
| Diamond (industrial grade) | 10 <sup>4</sup> ct                                  | 1564.71    | 1676.99 | 1800         | 36.25                                | 38.51 | 40    |
| Bauxite                    | 10 <sup>8</sup> t (ore)                             | 1.37       | 1.47    | 1.56         | 36.05                                | 37.00 | 39.10 |
| Diamond (gemstone quality) | 10 <sup>4</sup> ct                                  | 2347.02    | 2515.44 |              | 31.47                                | 31.68 |       |
| Iron ore                   | 10 <sup>8</sup> t (Fe content)                      | 4.94       | 4.91    | 4.67         | 31.04                                | 31.75 | 31.12 |
| Gold                       | t                                                   | 96.82      | 104.64  | 102          | 30.12                                | 31.49 | 34    |
| Beryllium                  | t (concentrate)                                     | 1750       | 1850    | 74 (metal)   | 26.67                                | 27.19 | 22.42 |
| Diatomite                  | 10 <sup>4</sup> t                                   | 63.97      | 73.64   | 58           | 25.63                                | 29.50 | 22.31 |
| Silver                     | t                                                   | 6635.37    | 6620.50 | 6280         | 24.94                                | 24.90 | 24.15 |
| Chromite                   | 10 <sup>4</sup> t (Cr <sub>2</sub> O <sub>3</sub> ) | 352.22     | 373.55  | 1620 (ore)   | 23.93                                | 24.48 | 39.51 |
| Copper                     | 10 <sup>4</sup> t                                   | 490.37     | 496.81  | 405          | 22.86                                | 22.35 | 18.40 |
| Uranium                    | t (U <sub>3</sub> O <sub>8</sub> )                  | 9917       | 9921    |              | 17.71                                | 17.72 |       |
| Zirconium                  | 10 <sup>4</sup> t                                   | 24.96      | 27.88   | 23           | 17.12                                | 20.11 | 14.38 |
| Rhenium                    | Kg                                                  | 7040       | 7640    | 10980        | 16.54                                | 14.15 | 19.61 |
| Manganese                  | 10 <sup>4</sup> t (Mn content)                      | 277.08     | 264.91  | 237          | 13.51                                | 13.06 | 11.85 |
| Lithium                    | 10 <sup>4</sup> t (Li <sub>2</sub> O)               | 3.05       | 5.79    | 3.30 (metal) | 13.13                                | 16.76 | 18.33 |
| Tantalum                   | T (Ta <sub>2</sub> O <sub>5</sub> )                 | 220        | 120     | 109          | 12.50                                | 6.95  | 4.54  |
| Cobalt                     | 10 <sup>4</sup> t                                   | 1.45       | 2.25    | 3.24         | 10.77                                | 13.52 | 14.09 |

Notes: Data sources: data on oil, natural gas, and coal originate from the Energy Institute, 2024. For other minerals, the production from 2021 to 2022 originates from the Federal Ministry of Finance of Austria, 2024 and the production in 2023 from USGS, 2024.

Table 9. Proportions of Asia’s mineral product trade values.

| Mineral product category | Import value/billion dollars | Global share of import value/% | Export value/ billion dollars | Global share of export value/% |
|--------------------------|------------------------------|--------------------------------|-------------------------------|--------------------------------|
| Energy                   | 2126.06                      | 47.21                          | 18827                         | 41.70                          |
| Metal minerals           | 1067.37                      | 49.64                          | 691.27                        | 32.34                          |
| Gemstones                | 80.93                        | 51.26                          | 76.33                         | 49.28                          |
| Asian total trade values | 3274.36                      | 47.82                          | 2650.31                       | 38.70                          |

Note: Data source: UN Comtrade, 2024

of copper, lead, zirconium, bauxite, tin, zinc, chromium, molybdenum, titanium, niobium, tantalum, and vanadium contribute to 10% to 20% (UN Comtrade, 2024).

Among all Asian countries, the United Arab Emirates, Saudi Arabia, China, India, Iraq, and Indonesia are primary traders of mineral products, with their combined trade values accounting for over 50% of Asia’s total (UN Comtrade, 2024). China stands as the largest mineral product trader in the world and the mineral product trade center of Asia, with the import values for many mineral products representing high proportions in the world. Specifically, the import values for energy minerals, metal minerals, and gemstones account for 12%, 23%, and 21% of the world’s totals, respectively. The import values for the ores and concentrates of copper, nickel, chromium, bauxite, iron, and manganese exceed 50%, while those of oil, natural gas, and coal account for over 10%. Additionally, several Southeast Asian countries have emerged as vital supply bases of mineral resources in the world. For instance, the Philippines and Indonesia have become primary global producers of nickel.

3.5. Asia recognized as the continent hosting the world’s largest mining economy, while China ranks first globally

From the perspective of the mining economy, Asia stands as the continent with the largest production value of minerals. In 2021 and 2022, its production values of minerals reached \$2.80 trillion and \$4.37 trillion, respectively (excluding diamonds; same hereafter), representing 54.55% and 58.17% of the world’s totals. In other words, Asia contributes more than half of the world’s production value of minerals, ranking first among continents. Notably, the production values of energy minerals, including coal, oil, and natural gas, account for over 60% (Federal Ministry of Finance of Austria, 2024). As the continent with the largest production value of minerals and the largest trade value of mineral products, Asia has become the economic center of the global mining industry. Its mining economy has emerged as an integral part of the global economy, making considerable contributions to the economic development of the world.

In recent years, China has become the country with the largest production value of minerals worldwide. In 2021 and 2022, its production values of minerals were \$879.46 billion and \$1437.94 billion, respectively, accounting for 17.13% and 19.15% of the world’s totals and 31.43% and 32.94% of Asia’s totals. Besides China, countries including Russia, Saudi Arabia, India, Iran, Indonesia, Iraq, Kazakhstan, and the United Arab Emirates are also leading countries in the world in terms of the production values of minerals, ranking at the

forefront globally (Federal Ministry of Finance of Austria, 2024).

3.6. Role of China in the mining development of Asia and the world

With the sustained socio-economic development and industrialization process, China, an economic and manufacturing powerhouse with a vast population, stands as the largest producer, trader, and economy in the global mining sector. Within the framework of Asia’s mining industry, China functions as the production and trade center of mineral products, as well as the mining economy center, providing a solid material foundation for population growth and socio-economic development worldwide. China’s demand for mineral resources influences the global supply-demand patterns and fluctuations in mineral product price, serving as a weathervane and barometer for the mining industry in Asia and even the world. It plays a significant role in driving the economic development of both Asia and the world.

4. Environmental protection and governance of mines in Asia

Asian countries have always attached importance to the environmental conservation of mines, boasting a prolonged history of the environmental protection of mines. For instance, China has highlighted the environmental protection of the Daye Iron Mine since the Qing Dynasty. With the continuous improvement in Asia’s mineral exploitation and utilization, along with the constant increase in its population density, Asian countries attach growing importance to environmental protection and governance of mines following the concept of sustainable development. Asian countries, typified by China, the Philippines, Indonesia, Mongolia, Korea, Vietnam, Laos, Myanmar, Malaysia, India, Pakistan, and Kyrgyzstan, have taken a series of measures to reinforce the environmental protection of mines. These countries have ceaselessly revised and established relevant legal and regulatory systems (Writing group of world mineral fact of Asia, 2023). For instance, they have developed a series of systems for mine environments, including the environmental impact assessment system for mines, the permit system for mine environment, and the supervision, inspection, and enforcement system for the mine environment. Furthermore, they implemented plans for mine environment reclamation and governance and prepared standards for the mine environment (Aung TR et al., 2024). Asian countries have innovated technical approaches for the environmental protection of mines in the fields of hyperspectral remote

sensing, 3D visualization, phytoremediation, surveying and mapping geographic information, and smart mines (Xing ST and Zhou LC, 2024). Specifically, to strengthen ecological civilization construction in the mining industry, China has put forward the development philosophy of green mines, set a specialized deposit system, established improved legal and regulatory systems for the environmental protection of mines, and constructed mine buildings and parks. For example, China has built the world-known eco-friendly hotel, InterContinental Shanghai Wonderland, in a huge abandoned pit. As early as the 1960s and 1970s, the Philippines formulated regulations on the environmental protection of mines and introduced a series of legal provisions. Indonesia has entrusted the management of the environmental reclamation and governance of mines to the mining management department closely related to mineral resource development and protection, thus rationalizing the management system of the mine environment. Laos emphasizes that the development of the mining industry should follow a sustainable and green path and stipulates that the government must assess and review the environmental impacts of mines (Writing group of world mineral fact of Asia, 2023). As a typical case of environmental protection of mines in China, the Daye Iron Mine has experienced more than 1780 years of mining since 226 AD. Over recent years, Asia's largest ecological forest on reclaimed mine degraded land has been built at the Daye Iron Mine during the "green mines" initiative, creating a miracle of planting trees on hard rocks. Furthermore, the mining canyon at the Daye Iron Mine, known as "the first pit in Asia" and hosting millennia of mining civilization, along with relics and sites with great scientific research value, has been developed into a national mine park. Presently, China has built over 20 open national mine parks. Notably, Asian countries have attracted increasing importance to concepts including sustainable development, green mines, and smart mines in recent years.

## 5. Development trends in Asia's mining industry

### 5.1. Great potential for mineral exploration and exploitation in Asia

The global energy transformation and the pursuit of "carbon neutrality" have led to a surge in the demand for minerals. The world is predicted to face a huge demand for energy transformation-related minerals, such as high-purity quartz, rare earths, uranium, copper, bauxite, lithium, nickel, cobalt, manganese, vanadium, titanium, platinum group metals, chromium, zirconium, and graphite. However, given that the supply of these minerals can hardly meet the current demand, the supply-demand contradiction will intensify in the short to medium term (Pricewaterhouse Coopers, 2022). Asia is rich in these mineral resources, especially in rare earths, uranium, bauxite, nickel, copper, chromium, and graphite, which represent high proportions to the world's totals. This, combined with the low exploration and exploitation level, indicates Asia's great potential for the exploration and exploitation these mineral resources (Li N et al., 2018; Chen XF et al., 2024a, 2024b).

### 5.2. Asia's mining industry remaining as a major contributor and driving force for Asia's and global economic development

Asia's mining industry has underpinned the economic development within the region, emerging as a pillar and crucial driving force for the economic and social progress of some Asian countries. Furthermore, it plays an increasingly significant role in global economic development. In the future, there will be a sustained strong demand for mineral raw materials as critical material support in the short and medium term against the background of the economic recovery, population growth, people's requirements for living standards, and constant advancements in industrialization of both Asia and the world. Asia will remain as the largest supplier of mineral products in the framework of the global mining industry, as well as the trade center of global mineral products and the center of the mining industry economy. Moreover, this country will remain as a major contributor and driving force for the economic development of both Asia and the world. In the framework of the global mining industry, China will remain as the largest producer of global mineral products in the short and medium term. In the framework of Asia's mining industry, this country will still serve as the production and trade center of mineral products, as well as the center of the mining industry economy. The rapid development of China's economy will provide robust momentum and potential for the development of the mining industry of Asia and the world, while the development of China's mining industry will continuously serve as a vital supporter and driver in the development of the world economy.

### 5.3. Minerals closely related to the new energy industry, emerging strategic industry, and high-tech industry will guide the direction of Asia's mining industry

The mining industry has been an integral part of all fields of global economy, society, industry, and science and technology, with its development involved throughout their whole processes. Notably, the mining industry provides unnegligible support for strategic emerging and high-tech industries. In recent years, these industries have been increasingly valued by various countries, especially by major economies worldwide. As a result, the demand for specific mineral resources has become a crucial factor guiding the direction of the global mining industry. The World Bank Group has predicted that the demand for minerals closely related to strategic emerging and high-tech industries, such as lithium, cobalt, and nickel, will increase by 500% by 2050 (World Bank Group, 2024). Therefore, the exploitation and utilization of these minerals will become a crucial direction for Asia's mining industry. For instance, the exploration and exploitation of minerals that are crucial to the development of new energy industries, digital economy, low-carbon economy, and military sectors, including copper, chromium, lithium, nickel, cobalt, graphite, rare earths, and rare metals, will set the development trend in the mining industry.

#### 5.4. Development pattern and philosophies of Asia's mining industry will undergo significant transformation

The development pattern of the mining industry stays up-to-date, evolving with and adapting to economic and social development. Currently, the previous development pattern characterized by extraction, primary processing (or not), and export in sequence is unsustainable and cannot meet the needs of present-day socio-economic development. Instead, the future development pattern consisting of successive extraction, deep processing, manufacturing, infrastructure construction, and equipment will become the mainstream pattern of the mining industry. The development concepts of green transition, sustainable development, and the application of intelligent technologies in the mining industry are increasingly valued by some Asian countries. For instance, the application of smart mine technology has changed the development pattern of the mining industry, potentially leading to revolutionary change. Notably, some Asian countries have rolled out or improved policies and regulations on the environmental protection of mines, strengthened research and management for the sustainable development and utilization of mineral resources, and enhanced the research and development of intelligent mining technologies, aiming to achieve modernized, sustainable development of the mining industry (Writing group of world mineral fact of Asia, 2023).

## 6. Conclusions

(i) Asia continent, the largest continent by land area in the world and one of the most ancient continents, experienced prolonged, complex, and multistage geological tectonic evolution and magmatic activity. The tectonic evolution of this continent can be roughly divided into three stages: The formation of its continental basement (about 830 Ma), the formation of its main body (830–210 Ma), and the formation of its present-day tectonic framework and the intracontinental evolution (210 Ma–Modern).

(ii) Asia continent boasts superior ore-forming geological conditions and abundant mineral resources. It is recognized as the continent with the most comprehensive kinds of mineral resources and also the continent with the greatest concentration of globally significant metallogenic belts. Notably, it is the only continent that hosts the world's top four metallogenic domains: The circum-Pacific, Tethyan, Laurasian, and Gondwana giant metallogenic domains.

(iii) Asia continent experienced three major tectonic evolution and mineralization stages: The Precambrian, the Paleozoic, and the Mesozoic to Cenozoic. The abundant mineral resources in this continent can be divided into seven first-order metallogenic belts (metallogenic domains), 18 second-order metallogenic belts (metallogenic provinces), 61 third-order metallogenic belts (metallogenic zones), and nine major minerogenetic series. Primary deposit types in this continent include sedimentary, magmatic, lateritic, porphyry, epithermal, skarn type, pegmatite, BIF, black rock series, and placer types. Therefore, the mineralization theory for Asia continent can be summarized into seven metallogenic

domains, 18 metallogenic provinces, 61 metallogenic belts, nine major metallogenic series, and 10 primary deposit types.

(iv) Future mineral exploration and prospecting in Asia should focus primarily on the Precambrian mineralization of ancient cratons, the Paleozoic mineralization of the Central Asian-Mongolian orogenic belt, and the Mesozoic to Cenozoic mineralization of the Tethyan and circum-Pacific mobile belts.

(v) Asia continent manifests the most significant metallogenic specialization worldwide, especially the pronounced metallogenic specialization of granitoids, Mesozoic to Cenozoic basalts, mafic-ultramafic rocks, and ophiolites. Specifically, the granitoids show significant metallogenic specialization of tin, rare metal, and porphyry Cu-Au-Mo deposits, leading to the formation the giant Southeast Asian tin belt with a south-north length of over 2000 km, the giant Tethyan porphyry Cu-Au-Mo metallogenic belt, the giant Qinghai-Xizang Plateau rare metal metallogenic belt, and the giant circum-Pacific porphyry Cu-Au-Mo metallogenic belt. The Mesozoic to Cenozoic basaltic rocks display distinct metallogenic specialization of lateritic bauxite deposits, resulting in the formation of the giant Southeast Asian lateritic bauxite metallogenic belt and the Deccan Plateau lateritic bauxite metallogenic belt in India. The mafic-ultramafic rocks and ophiolites exhibit notable metallogenic specialization of lateritic nickel deposits and magmatic type chromite deposits, leading to the formation of the giant Southeast Asian lateritic nickel metallogenic belt and several large magmatic type chromite metallogenic belts within the Tethys mobile belt. These giant metallogenic belts prove significant in Asia continent.

(vi) Asia's mining industry not only underpins its own rapid economic development but also provides a solid material foundation for global economic development, contributing significantly to the world economy. Asia boasts the highest production value of minerals, the largest annual production of minerals, and the greatest trade value of mineral products among all the continents, having emerged as the trade center of global mineral products and the center of the mining industry economy.

(vii) China is one of the few countries with the most comprehensive kinds of minerals, and its mining industry has supported and driven the economic development and industrialization of Asia and the world. China is the world's largest mineral producer, ranking first in the production of 28 minerals in the world. Besides, it boasts the highest annual mineral production value and mineral product trade value among all countries. There, China's demand for global mineral products influences the global supply and demand patterns of minerals and the world economic situation, having emerged as a vital driving force for the economic development of Asia and the world.

## CRedit authorship contribution statement

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and Yan-yun Ma conceived of the presented idea. Xi-feng Chen wrote and revised the paper with support from all authors and drew all the figures.

## Declaration of competing interest

The authors declare no conflicts of interest.

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## References

- Aung TR, Choi D, Jung J. 2024. Adapting an environmental impact assessment method for open pit mines in Myanmar: A modified semi-mathematical Folchi approach. *Environmental Impact Assessment Review*, 108, 107599–107599. doi: [10.1016/J.EIAR.2020.107599](https://doi.org/10.1016/J.EIAR.2020.107599).
- Braxton DP, Cooke DR, Ignacio AM, Waters PJ. 2018. Geology of the Boyongan and Bayugo porphyry Cu-Au deposits: an emerging porphyry district in northeast Mindanao, Philippines. *Economic Geology*, 113(1), 83–131. doi: [10.5382/econgeo.2018.4545](https://doi.org/10.5382/econgeo.2018.4545).
- Carlile JC, Davey GR, Kadir I, Langmead RP, Rafferty WJ. 1998. Discovery and exploration of the Gosowong epithermal gold deposit, Halmahera, Indonesia. *Journal of Geochemical Exploration*, 60, 207–227. doi: [10.1016/S0375-6742\(97\)00048-4](https://doi.org/10.1016/S0375-6742(97)00048-4).
- Chen C, Niu SY, Zhang JZ, MA BG, Zhang FX, Sun AQ, Wang BD, Zhang X, Zhang HL, Ma GX, Chen ZK. 2016. A quantitative discussion on element mass migration during alteration processes in the Mujicun Cu (Mo) deposit, Hebei Province. *Geology in China*, 43(6), 2118–2130 (in Chinese with English abstract). doi: [10.12029/gc20160621](https://doi.org/10.12029/gc20160621).
- Chen XF, Xiang YC, Ye JH, Cai G, Chen XF, Zhang ZF, Li N, Zhang XY. 2015. Metallogenic characteristics of the Central South Peninsula tin ore belt in Southeast Asia. *Geological Bulletin of China*, 34(4), 734–745 (in Chinese with English abstract). doi: [10.12097/gbc.20150413](https://doi.org/10.12097/gbc.20150413).
- Chen XF, Chen XF, Ye JH, Lin FC, Shi MF, Yu R. 2020. The mineral resources of Southeast Asia. Beijing: Geological Publishing House, 1–496 (in Chinese).
- Chen XF, Zhang C, Zhang ZF, Wang QS, Chen XF, Zhang FL, Huang X, Zhang WB, Zhao DJ, Li YL, Yu R, Wang LL, He XZ, Wang YG, Hao LR, Wang XN. 2024a. Geological characteristics of the newly discovered copper deposits by exploration in Asia continent since the 21st century. *Geology in China*, 51(2), 710–718 (in Chinese with English abstract). doi: [10.12029/gc20240314001](https://doi.org/10.12029/gc20240314001).
- Chen XF, Zhang FL, Chen XF, Wang QS, Zhang C, Han JX, Li YC, Hao LR. 2024b. Geological characteristics of 44 newly discovered copper deposits and nickel (cobalt) deposits by exploration in Asia continent since the 21st century. *Geology in China*, 51(3), 1080–1090 (in Chinese with English abstract). doi: [10.12029/gc20240507001](https://doi.org/10.12029/gc20240507001).
- Chen YC, Pei RF, Wang DH, Huang F. 2016. Minerogenetic series for mineral deposits: discussion on minerogenetic Series(V). *Acta Geoscientia Sinica*, 37(5), 519–527 (in Chinese with English abstract). doi: [10.3975/cagsb.2016.05.02](https://doi.org/10.3975/cagsb.2016.05.02).
- Cheng YQ, Chen YC, Zhao YM, Song TR. 1983. Further discussion on the problems of minerogenetic series of mineral deposits. *Bulletin Chinese Academy of Geological Sciences*, 5(6), 1–64 (in Chinese).
- Çolakoglu AR, Oruç M, Arehart GB, Poulson S. 2011. Geology and isotope geochemistry (C–O–S) of the Diyadin gold deposit, Eastern Turkey: a newly-discovered Carlin-like deposit. *Ore Geology Reviews*, 40, 27–40. doi: [10.1016/j.oregeorev.2011.04.002](https://doi.org/10.1016/j.oregeorev.2011.04.002).
- Davaasuren OE, Koh SM, Kim N, Lee BH. 2021. Late Paleozoic adakitic magmatism in the Zogdor Cu occurrences, southern Mongolia, and their tectonic implications: New SHRIMP zircon age dating, Lu–Hf isotope systematics and geochemical constraints. *Ore Geology Reviews*, 138, 104356. doi: [10.1016/j.oregeorev.2021.104356](https://doi.org/10.1016/j.oregeorev.2021.104356).
- Donskaya TV, Gladkochub DP. 2021. Post-collisional magmatism of 1.88–1.84Ga in the southern Siberian Craton: An overview. *Precambrian Research*, 367, 1–19. doi: [10.1016/J.PRECAMRES.2021.106447](https://doi.org/10.1016/J.PRECAMRES.2021.106447).
- Energy Institute. 2024. Statistical Review of World Energy 2024. London, Energy Institute, 1–76.
- Federal Ministry of Finance of Austria. 2024. World Mining Data 2024. Vienna: Austrian Federal Ministry of Finance, 1–266.
- Gibsher NA, Ryabukha MA, Tomilenko AA, Sazonov AM, Khomenko MO, Bul'bak TA, Nekrasova NA. 2017. Metal-bearing fluids and the age of the Panimba gold deposit (Yenisei Ridge, Russia). *Russian Geology and Geophysics*, 58, 1366–1383. doi: [10.1016/j.rgg.2017.11.004](https://doi.org/10.1016/j.rgg.2017.11.004).
- He CS, Zheng YF. 2018. Seismic evidence for the absence of deeply subducted continental slabs in the lower lithosphere beneath the Central Orogenic Belt of China. *Tectonophysics*, 723, 178–189. doi: [10.1016/j.tecto.2017.12.018](https://doi.org/10.1016/j.tecto.2017.12.018).
- Hu P, Nie FJ, Jiang SH, Zhang WY. 2006. Geological features of typical ore deposits in southern Mongolia and their implications for mineral exploration of adjacent areas. *Mineral Deposits*, 25(S1), 123–126 (in Chinese with English abstract). doi: [10.1177/146642406008000453](https://doi.org/10.1177/146642406008000453).
- Hosseini ST, Asghari O, Haroni HA. 2020. Multivariate anomaly modeling of primary geochemical halos by U-spatialstatistic algorithm development: A case study from the Sari Gunayepithermal gold deposit, Iran. *Ore Geology Reviews*, 127, 10384. doi: [10.1016/j.oregeorev.2020.103845](https://doi.org/10.1016/j.oregeorev.2020.103845).
- IEA/NEA. 2023. Uranium 2022: Resources, production and demand. Paris, NEA, 1–561.
- İsmayıl C, Özen Y, Arık F, Veliyev A. 2020. Genesis of the Gedabek Au–Ag–Cu deposit (Azerbaijan) in the Lesser Caucasus: Insights from geochemistry, fluid inclusion and sulfur isotope. *Journal of Asian Earth Sciences*, 206, 104627. doi: [10.1016/J.JSEAES.2020.104627](https://doi.org/10.1016/J.JSEAES.2020.104627).
- Kuşçu İ, Tosdal RM, Gençlioğlu-Kuşçu G, Friedman R, Ullrich TD. 2013. Late Cretaceous to middle Eocene magmatism and metallogeny of a portion of the Southeastern Anatolian Orogenic Belt, east central Turkey. *Economic Geology*, 108, 641–666. doi: [10.2113/econgeo.108.4.641](https://doi.org/10.2113/econgeo.108.4.641).
- Khalil YS, Li WY, Huang JK. 2022. Geophysical exploration and geological appraisal of the Siah Diq porphyry Cu–Au prospect: A recent discovery in the Chagai volcano magmatic arc, SW Pakistan. *Open Geosciences*, 14, 1250–1267. doi: [10.1515/geo-2022-0429](https://doi.org/10.1515/geo-2022-0429).
- Li JJ, Tang WL, Fu C, Li C, Qu WJ, Zhang T, Wang SG, Dang ZC, Zhou Y, Zhao LJ. 2016. Re–Os isotopic dating of molybdenites from the Bilugangan porphyry Mo deposit in Abag Banner, Inner Mongolia, and its geological significance. *Geological Bulletin of China*, 35(4), 519–523 (in Chinese with English abstract). doi: [10.12097/gbc.dztb-35-4-519](https://doi.org/10.12097/gbc.dztb-35-4-519).
- Li N, Chen XF, Chang XG. 2018. “The belt and road” industrial civilization resource integration. Beijing: Publishing House of Electronics Industry, 1–158 (in Chinese).
- Liu HC, Shao J, Zhu GY, Li YL. 2021. Neoproterozoic basement, mantle enrichment and crustal extraction in central Asia: petrogenesis of 2.5Ga amphibolite and metadiorite in the China. *American Journal of Science*, 321, 1350–1379. doi: [10.2475/09.2021.03](https://doi.org/10.2475/09.2021.03).
- Metcalf I. 2011. Tectonic framework and Phanerozoic evolution of Sundaland. *Gondwana Research*, 19, 3–21. doi: [10.1016/j.gr.2010.02.016](https://doi.org/10.1016/j.gr.2010.02.016).
- Metcalf I. 2013. Gondwana dispersion and Asian accretion: Tectonic and palaeogeographic evolution of eastern Tethys. *Journal of Asian Earth*

- Sciences, 66, 1–33. doi: [10.1016/j.jseaes.2012.12.020](https://doi.org/10.1016/j.jseaes.2012.12.020).
- Manikyamba C, Harshitha RG. 2022. Paleo-subduction Zones in the Indian Cratons. *Journal of the Geological Society of India*, 98(4), 447–450. doi: <https://doi.org/10.1007/s12594-022-2000-7>.
- Mansouri SM, Keshavarz S, Shahpasandzadeh M, Faghih A. 2023. Kinematics of the Tanbour Metamorphic Complex (SE Iran): Implications for Cenozoic Metamorphism and Deformation in the Northeastern Margin of the Afro-Arabian Plate. *Geotectonics*, 57(2), 213–229. doi: [10.1134/S001685212302005X](https://doi.org/10.1134/S001685212302005X).
- Ministry of Natural Resources, PRC. 2023. China mineral resources 2023. Beijing, Geological Publishing House, 1–51.
- Pan GT, Xiao QH, Lu SN, Den JF, Feng YM, Zhang KX, Zhang ZY, Wang FG, Ring GF, Hao GJ, Feng YF. 2009. Subdivision of tectonic units in China. *Geology in China*, 30(1), 1–28 (in Chinese with English abstract). doi: [10.12029/gc20090101](https://doi.org/10.12029/gc20090101).
- Pan GT, Lu SN, Xiao QH, Zhang KX, Yin FG, Hao GJ, Luo MS, Ren F, Yuan SH. 2016. Division of tectonic stages and tectonic evolution in China. *Earth Science Frontiers*, 23(6), 1–23 (in Chinese with English abstract). doi: [10.13745/j.esf.2016.06.001](https://doi.org/10.13745/j.esf.2016.06.001).
- Petrov OV, Khanchuk AI, Ivanov VV, Shatov VV, Selmann R, Dolgoplova AV, Alenicheva AA, Molchanov AV, Terekhov A V, Leontev VI, Belyatsky BV. 2021. Porphyry indicator zircons (PIZ) and geochronology of magmatic rocks from the Malmyzh and Pony Cu-Au porphyry ore fields (Russian Far East). *Ore Geology Reviews*, 139(A), 1–22. doi: [10.1016/j.oregeorev.2021.104491](https://doi.org/10.1016/j.oregeorev.2021.104491).
- Pricewaterhouse Coopers. 2022. Mine 2022: A Critical Transition. London, Pricewaterhouse Coopers, 1–35.
- Qin KZ, Zhao JX, He CT, Shi RZ. 2021. Discovery of the Qongjiagang giant lithium pegmatite deposit in Himalaya, Tibet, China. *Acta Petrologica Sinica*, 37(11), 3277–3286 (in Chinese with English abstract). doi: [10.18654/1000-0569/2021.11.02](https://doi.org/10.18654/1000-0569/2021.11.02).
- Ren JS, Niu BG, Wang J, Jin XC. 2013. International geological map of Asia 1 : 5000000. Beijing, Geological Publishing House.
- Sengör AMC, Natapin B A, Burtman VS. 1993. Evolution of the Altaid tectonic collage and Palaeozoic crustal growth in Eurasia. *Nature*, 364(22), 299–307. doi: [10.1038/364299a0](https://doi.org/10.1038/364299a0).
- Sengör AMC, Sunal G, Natal'in BA, Voo RVD. 2022. The Altai: A review of twenty-five years of knowledge accumulation. *Earth Science Reviews*, 228, 262–286. doi: [10.1016/j.earscirev.2022.104013](https://doi.org/10.1016/j.earscirev.2022.104013).
- Shi JF, Li YZ, Jin QH, Tang JR, Yao HJ. 2006. World mineral fact, Asia. Beijing, Geological Publishing House, 1–514 (in Chinese).
- Singh S, Maurya VP, Singh RK, Srivastava S, Tripathi A, Adhikari PK. 2018. Audio-magnetotelluric investigation of sulfide mineralization in Proterozoic–Archean greenstone belts of Eastern Indian Craton. *Journal of Earth System Science*, 127(3), 1–18. doi: [10.1007/s12040-018-0938-z](https://doi.org/10.1007/s12040-018-0938-z).
- Sone M, Metcalfe I. 2008. Parallel Tethyan sutures in mainland Southeast Asia: new insights for Palaeo-Tethys closure and implications for the Indosinian orogeny. *Comptes Rendus Geoscience*, 340(2–3), 166–179. doi: [10.1016/j.crte.2007.09.008](https://doi.org/10.1016/j.crte.2007.09.008).
- Stewart SA, Salem AS. 2023. Proterozoic fold and thrust belt imaged on reflection seismic in Arabian plate basement. *Tectonophysics*, 856, 229847. doi: [10.1016/j.tecto.2023.229847](https://doi.org/10.1016/j.tecto.2023.229847).
- S&P Global Market Intelligence. 2024. Commodities, Screener. <https://www.capitaliq.spglobal.com/web/client?auth=inherent&OktaLogin=true#dashboard/metalsAndMining>.
- UN Comtrade. 2024. Trade Data. <https://comtradeplus.un.org/TradeFlow>. <https://resourcetrade.earth/>.
- USGS. 2024. Minerals commodity summaries 2024. <https://pubs.usgs.gov/periodicals/mcs2024/mcs2024.pdf>.
- Wan YS, Song B, Liu DY, Li HM, Yang C, Zhang QD, Yang CH, Geng YS, Shen QH. 2001. Geochronology and geochemistry of 3.8–2.5 Ga Ancient Rock Belt in the Dongshan Scenic Park, Anshan Area. *Acta Geologica Sinica*, 75(3), 363–370 (in Chinese with English abstract).
- Wan TF. 2013. A new Asian tectonic unit map. *Geology in China*, 40(5), 1351–1365 (in Chinese with English abstract). doi: [10.12029/gc20130502](https://doi.org/10.12029/gc20130502).
- Wan TF. 2018. Tectonic unit and large-deposits in Asia. Beijing: Higher Education Press, 1–150 (in Chinese).
- Wang R, Tafti R, Hou ZQ, Shen ZC, Guo N, Evans NJ, Jeon H, Li QY, Li WK. 2017. Across-arc geochemical variation in the Jurassic magmatic zone, Southern Tibet: Implication for continental arc-related porphyry Cu-Au mineralization. *Chemical Geology*, 451, 116–134. doi: [10.1016/j.chemgeo.2017.01.010](https://doi.org/10.1016/j.chemgeo.2017.01.010).
- Wang T, Tong Y, Huang H, Zhang HR, Guo L, Li ZX, Wang XX, Eglington B, Li Sn, Zhang JJ, Donskaya TV, Petrov O, Zhang L, Song P, Zhang XW, Wang CY. 2023. Granitic record of the assembly of the Asian continent. *Earth-Science Reviews*, 237, 104298. doi: [10.1016/j.earscirev.2022.104298](https://doi.org/10.1016/j.earscirev.2022.104298).
- Wei SN, Zhu YF, An F. 2020. Oxygen fugacity of the intrusion III-2 in the Baogutu porphyry copper deposit, Xinjiang: evidence from mineral compositions. *Acta Geologica Sinica*, 94(8), 2367–2383 (in Chinese with English abstract). doi: [10.19762/j.cnki.dizhixuebao.2020042](https://doi.org/10.19762/j.cnki.dizhixuebao.2020042).
- World Bank Group. 2024. Climate-smart mining: minerals for climate action. <https://www.worldbank.org/en/topic/extractiveindustries/brief/climate-smart-mining-minerals-for-climate-action>.
- Writing group of world mineral fact of Asia. 2023. World mineral fact, Asia (second edition). Beijing, Geological Publishing House, 1–719 (in Chinese).
- Xiao WJ, Shen P, Chen XH. 2017. Tectonics, magmatism and mineralization of Circum-Balkash–Junggar area in the Central Asian Orogenic Belt. *International Geology Review*, 59(9), 1047–1052. doi: [10.1080/00206814.2017.1326181](https://doi.org/10.1080/00206814.2017.1326181).
- Xing ST and Zhou LC. 2024. Application of new wireless sensor network technology in mine environmental monitoring. *Surveying & Mapping and Geology*, 6(3), 106–108 (in Chinese with English abstract). doi: [10.12345/smg.v6i3.17722](https://doi.org/10.12345/smg.v6i3.17722).
- Yigit O. 2006. Gold in Turkey—a missing link in Tethyan metallogeny. *Ore Geology Reviews*, 28, 147–179. doi: [10.1016/j.oregeorev.2005.04.003](https://doi.org/10.1016/j.oregeorev.2005.04.003).
- Yigit O. 2012. A prospective sector in the Tethyan Metallogenic Belt: Geology and geochronology of mineral deposits in the Biga Peninsula, NW Turkey. *Ore Geology Reviews*, 46, 118–148. doi: [10.1016/j.oregeorev.2011.09.015](https://doi.org/10.1016/j.oregeorev.2011.09.015).
- Yudovskaya MA, Distler VV, Prokofiev VY, Akinfiyev NN. 2016. Gold mineralisation and orogenic metamorphism in the Lena province of Siberia as assessed from Chertovo Koryto and Sukhoi Log deposits. *Geoscience Frontiers*, 7, 453–481. doi: [10.1016/j.gsf.2015.07.010](https://doi.org/10.1016/j.gsf.2015.07.010).
- Zhao GC, Wang YJ, Huang BC, Deng YP, Li SZ, Zhang GW, Yu S. 2018. Geological reconstructions of the East Asian blocks: From the breakup of Rodinia to the assembly of Pangea. *Earth Science Reviews*, 186, 262–286. doi: [10.1016/j.earscirev.2018.10.003](https://doi.org/10.1016/j.earscirev.2018.10.003).
- Zhai YS, Deng J, Che XB. 1999. Regional metallogeny. Beijing: Geological Publishing House, 1–256 (in Chinese).
- Zhu XP, Li GM, Chen HA, Ma DF, Zhang H, Zhang H, Liu CQ, We LJ. 2017. Petrogenesis and metallogenic setting of porphyries of the Duobuza porphyry Cu–Au deposit, central Tibet, China. *Ore Geology Reviews*, 89, 858–875. doi: [10.1016/j.oregeorev.2017.07.013](https://doi.org/10.1016/j.oregeorev.2017.07.013).
- Zu B, Xue CJ, Chi GX, Nikolay P, Zhao XB, Wang XL. 2018. Age and petrogenesis of the Andagul granodiorite and its implications on gold mineralization of the Kassan region, western Kyrgyzstan Tian Shan. *Ore Geology Reviews*, 101, 54–73. doi: [10.1016/j.oregeorev.2018.07.007](https://doi.org/10.1016/j.oregeorev.2018.07.007).
- Zorin YA, Zorina LD, Spiridonov AM, Rutshtein IG. 2001. Geodynamic setting of gold deposits in Eastern and Central Trans-Baikal (Chita Region, Russia). *Ore Geology Reviews*, 17, 215–232. doi: [10.1016/S0169-1368\(00\)00015-9](https://doi.org/10.1016/S0169-1368(00)00015-9).