

# Fluorspar in Mongolia

**Geology, Mineralogy, Processing Technologies  
and Market Analysis**

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Stilleweg 2  
30655 Hannover  
Germany

### **Authors:**

Dr. Tumenbayar Baatar, senior consultant geologist, *tumenbayarbaatar@gmail.com*  
Mr. Nasanbileg Batbayar, geological consultant, *Naska89@gmail.com*  
Dr. Khulan Berkh, BGR, *mineralische-rohstoffe@bgr.de*  
Dr. Purev-Ochir Togtokhbaatar, German-Mongolian Institute for Resources and Technology (GMIT),  
*purevochir@gmit.edu.mn*  
Dr. Manlaibaatar Zagdbazar, *manlaibaatar@eri.mn*, Ms. Nomun Enkhbold, Researcher  
and Ms. Nomunaa Ganbold, Researcher, Economic Research Institute (ERI)

### **Editors:**

Ms. Kerstin Kuhn, Mr. Jaime Fernández, project manager, Dr. Martin Erdmann, BGR

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### **Contact:**

Dr. Thekla Abel, Ms. Kerstin Kuhn  
Bundesanstalt für Geowissenschaften und Rohstoffe  
Stilleweg 2  
30655 Hannover  
E-Mail: *mineralische-rohstoffe@bgr.de*

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## Foreword

Fluorspar is an important industrial mineral and is categorized as a strategic and/or critical mineral in several states and associations of states, such as the EU, USA, China, due to its economic importance for certain industrial sectors and its globally concentrated supply. Its global demand – particularly for acidspar – is expected to continue rising. Mongolia, the world's third- largest supplier of fluorspar, plays a key role in ensuring a stable and sustainable supply. Despite this significance, no comprehensive and up-to-date study has been available on Mongolia's fluorspar deposits, mineralogical characteristics, and market potential.

The present study, Fluorspar in Mongolia: Geology, Mineralogy, Processing Technologies, and Market Analysis, aims to help fill this gap. It has been conducted as part of the German-Mongolian technical cooperation project Advisory Services for Sustainable Mineral Resources Management, which is implemented by the Federal Institute for Geosciences and Natural Resources (BGR) and funded by the German Federal Ministry for Economic Cooperation and Development (BMZ). Developed in close collaboration with the Ministry of Industry and Mineral Resources (MIMR), the Mineral Resources and Petroleum Authority of Mongolia (MRPAM), and the National Geological Survey (NGS) the study is a first step toward a better understanding of the Mongolian Fluorspar Market, including its geological and mineralogical characteristics, existing processing technologies, and current and potential market trends. Additionally, it provides an initial assessment of Mongolia's fluorspar resources, offering insights into their economic significance and potential for sustainable development.

This publication is compiled by expert geologists who have been working on fluorspar for many years, as well as researchers from the German-Mongolian Institute for Resources and Technology (GMIT), the Economic Research Institute (ERI), and the Federal Institute for Geosciences and Natural Resources (BGR).

At the same time, it is important to clarify that this study is an initial characterization and does not constitute a comprehensive resource evaluation, feasibility study, or reserve classification in accordance with international reporting standards. Rather, it provides a geological and market-oriented overview that can serve as a basis for further research and investment considerations.

By analyzing the geological, mineralogical, and geochemical characteristics of known deposits and occurrences, as well as evaluating processing technologies and market trends, this study offers valuable insights for policymakers, industry stakeholders, and researchers. A key component of the research involved sample collection from selected ore districts, and advanced analytical techniques – including energy-dispersive X-ray fluorescence spectrometry and mineral liberation analysis – used to enhance the understanding of the ore composition, contributing to a more detailed assessment of Mongolia's fluorspar deposits.

Through the compilation and analysis of extensive geological and economic data, this study contributes to strengthening Mongolia's capacity for sustainable mineral resource management. We hope its findings will serve as a valuable resource for decision-makers, industry leaders, and the mining and processing industry, supporting responsible mining practices, enhancing investment opportunities, and ensuring the long-term competitiveness of Mongolia's fluorspar sector.

## Glossary

**Acid-grade fluorspar / Acidspar:** Fluorspar containing more than 97% calcium fluoride.

**Calcium fluoride:** inorganic compound of the elements calcium and fluorine with the formula  $\text{CaF}_2$ . In nature, it occurs in the form of the mineral fluorite.

**Ceramic-grade fluorspar / Ceramic spar:** Fluorspar concentrate containing 85-96% calcium fluoride and special requirements for the maximum content of certain impurities, which is mainly used in the glass and ceramics industry as well as for the production of welding materials.

**Concentrate:** A processing product containing the valuable ore mineral from which most of the waste material (e.g. host rock, gangue material) has been eliminated.

**Deposit:** Deposits are natural accumulations of usable minerals and rocks whose extent, quality, extraction and economic viability have been sufficiently clarified by exploration. As the economic viability of the raw material is strongly influenced by demand and supply (availability due to natural and political conditions), the assessment of a mineral deposit's economic viability can change over time.

**According to the Mongolian Minerals Law, clause 4.1.9:** Mineral deposit means mineral concentration that has been formed on the surface or in the subsoil as a result of geological evolutionary processes, where the quality and proven reserve makes it feasible to economically mine the natural resource.

**Fluorine:** Chemical element F

**Fluorite:** Mineral consisting of calcium fluoride ( $\text{CaF}_2$ ).

**Fluorspar:** Trade name and frequently used term in mining for the mineral fluorite.

**Grade:** The average concentration of the target mineral or element in each tonne of ore given as weight percent. If concentrations are extremely low, as with Au, Ag, Pt and others, the concentration may be given in grams per tonne (g/t).

**Metallurgical-grade fluorspar / Metspar:** Fluorspar concentrate containing 60-97% calcium fluoride. Coarse metspar concentrates that have only been slightly processed (e.g. sieving, handpicking) are often referred to as fluorspar/metspar lumps.

**Mineral reserve:** The economically mineable part of a Measured or Indicated Mineral Resource demonstrated by at least a pre-feasibility study. This study must include adequate information on mining, processing metallurgical, economic and other relevant factors that demonstrate, at the time of reporting, that economic extraction can be justified. A mineral reserve includes allowances for dilution and losses that may occur when the material is mined.

**Mineral resource:** A concentration or occurrence of natural, solid, inorganic or fossilized organic material in or on the earth's crust in such form and quantity, and of such a grade or quality, that it has reasonable prospects for economic extraction. The location, quantity, grade, geological characteristics and continuity of a mineral resource are known, estimated or interpreted from specific geological evidence and knowledge.

**Ore (raw ore):** Metal or mineral, or a combination of these, of sufficient value in terms of quality and quantity to enable it to be mined and processed at a profit. The material has not yet been processed to enrich the target metals or minerals.

**Ore body:** An ore body may correspond to an ore deposit, but more often the deposit includes several ore bodies.

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# 1

## **Introduction: Technical background**

*Dr. Khulan Berkh, BGR*

# Introduction

Fluorspar is an essential raw material in various industrial processes, playing a critical role in the global economy. With applications ranging from hydrofluoric acid production to metallurgy and ceramics, fluorspar has gained strategic importance due to its limited supply and increasing demand.

This chapter provides an overview of fluorspar as a critical raw material, its mineral properties, geological setting, and industrial applications in various sectors.

## 1.1 Fluorspar: a critical mineral

Fluorspar is classified as a critical mineral in certain countries due to its essential role in various industries. A critical mineral is generally defined as any mineral, element, or material vital to a nation's economy and technological development but vulnerable to supply disruptions due to factors such as scarcity, geopolitical influences, or limited availability. The lack of substitutes for its key applications further contributes to its critical status, as disruptions in supply could significantly affect industries and national security.

In the European Union (EU), critical raw materials (CRMs) are considered to be those that have high economic importance for the EU based on the value added of corresponding EU manufacturing sectors, corrected by a substitution index and a high supply risk based on supply concentration at global and EU levels weighted by a governance performance index, corrected by recycling and substitution parameters.

Fluorspar is one such mineral, being irreplaceable in key industrial processes and highly concentrated in a few countries, with three-quarters of the world's fluorspar reserves located in just four countries. Recognizing its strategic importance, the EU designated fluorspar as a critical raw material in 2011, and the United States included it in its critical minerals list in 2022.

Global fluorspar production has been steadily increasing, reaching approximately 8.8 million tonnes in 2022. China remains the world's largest supplier, accounting for 70% of global demand, followed by Mexico (11%) and Mongolia (5%). Other significant producers include South Africa (5%), Vietnam (3%), and Spain (2%). Global fluorspar imports totaled 2.8 million tonnes in 2023 with China being the largest importer accounting for 35% of the total volume, followed by the United States (13%) and India (10%). More details are provided in chapter 4.

Demand for fluorspar is, in general, expected to rise. Growth is attributed to higher demand for acidspar, particularly for the production of hydrofluoric acid and the fluorocarbons and numerous other chemicals obtained from it. Therefore, there may be a market shortage of acidspar. In turn, demand for metspar is likely to decline over the next ten years, as metspar consumption in the steel industry is generally decreasing owing to improvements in steelmaking technology, even though the sector itself will probably grow slightly (Roskill, 2020).

China is the world's largest supplier of fluorspar, but its export has declined in recent years. The reasons for the decline are the growing domestic demand and the depletion of resources at many mid- and large-scale mines as well as increasingly strict environmental regulations on the mining



industry (McRae, 2023). Thus, there is a risk of a market tightness for acidspar in the next ten years if not enough new fluorspar deposits are discovered and brought into operation (Roskill, 2020).

A shortage will lead to a price increase, which will provide an economic motivation for mining in currently unprofitable deposits and the further exploration of new fluorspar deposits. In the long term, this should also allow the situation to ease again. However, several uncertainties remain, including:

- Lack of knowledge about available resources in Chinese deposits and their quality.
- Potential upgrading of Mongolian metspar to higher-quality acidspar in China.
- Possible start-up of large new fluorspar mines in the next few years
- Increasing production of fluorosilicic acid (FSA) as a byproduct of phosphoric acid production as an alternative fluorine source (SCREEN2, 2023)
- Development of battery technologies
- Possible restrictions on the use of persistent per- and polyfluoroalkyl substances (PFAS) in the EU (PFAS REACH restriction).

In Mongolia, fluorspar is one of the major economic minerals, along with copper, gold, coal, and iron and its production has been steadily increasing, reaching 1 million tonnes in 2023. The country hosts over 600 fluorspar deposits and occurrences, mostly concentrated in the eastern and southeastern regions, forming mineralized zones extending up to 300 km wide and over 1000 km long. More details are provided in chapter 2.

Due to the lack of domestic consumption, Mongolia exports its entire fluorspar production. Most of these exports consist of metallurgical-grade fluorspar as lumps ore or lower-grade flotation concentrates. A comprehensive analysis of the global and Mongolian fluorspar markets, including demand and supply dynamics as well as international and domestic processing technologies, with an emphasis on future potentials is presented in Chapter 4 and 5 respectively.

## 1.2 Mineral characteristics

Fluorspar is the trade name and a frequently used term in mining for the mineral fluorite that is the most common and most important fluorine-containing mineral for direct applications or the production of fluorine compounds. It has the chemical formula  $\text{CaF}_2$ . Pure fluorite theoretically consists of 51.3 wt.% calcium and 48.7 wt.% fluorine. In nature, fluorite often contains impurities like silicon, aluminum and magnesium as well as inclusions of fluids and gases, such as water and petroleum. Additionally, inclusions of solid minerals such as pyrite, marcasite, and other sulfides, are common. Yttrium, as well as rare earth elements, can also be present as a substitution for calcium.

Fluorite is known for its wide range of colors, earning it the title of “the most colorful mineral in the world”. Pure fluorite is colorless and transparent, but its color can vary significantly due to trace amounts of chemical impurities or exposure to natural radiation. The most common color is purple, followed by golden yellow, green, blue, pink, brown, white, gray and black. The cause of the widespread purple coloration of natural fluorites has not been conclusively clarified. Currently, electron defects in the crystal lattice are considered the most likely cause of the purple color of fluorite (Kempe, 2006). The yellow coloration is due to the incorporation of oxygen in the crystal, while the greenish color is caused by joint incorporation of cerium and yttrium. Fluorites containing

only yttrium are colored light blue (Bill and Calas, 1978). Fluorite frequently exhibits multiple colors arranged in zones or in alternating bands parallel to crystal faces. Prolonged exposure to sunlight, such as in mine dumps, often leads to the fading of the original coloration. Fluorite is well known for its blue or violet fluorescence under ultraviolet light.

Fluorspar occurs in various crystal forms, with the most recognizable being well-formed isometric cubic and octahedral crystals. It can also appear in massive and earthy forms, occasionally exhibiting columnar crystal structures. Additionally, fluorite can be found as crusts and, though rare, in globular aggregates characterized by a radial fibrous texture. Additional properties of fluorite are detailed in Table 1.1.

*Table 1.1: Selected properties of fluorite*

| Chemical formula        | CaF <sub>2</sub>                                                                                              | Unit              |
|-------------------------|---------------------------------------------------------------------------------------------------------------|-------------------|
| Color                   | Colorless, often deeply colored due to impurities; purple, green, blue, golden-yellow, pink, champagne, brown |                   |
| Streak                  | White                                                                                                         |                   |
| Crystal system          | Isometric                                                                                                     |                   |
| Crystal habit           | Well-formed coarse sized crystals; also nodular, botryoidal, rarely columnar or fibrous; granular, massive    |                   |
| Cleavage                | perfect on {111}                                                                                              |                   |
| Hardness                | 4                                                                                                             | Mohs scale        |
| Refraction index        | 1.433–1.448                                                                                                   |                   |
| Specific gravity        | 3.2 or higher if rich in rare earth elements                                                                  | g/cm <sup>3</sup> |
| Melting point           | 1360                                                                                                          | °C                |
| Boiling point           | 2500                                                                                                          | °C                |
| Solubility              | Soluble in hot hydrochloric acid and slightly soluble in water                                                |                   |
| Special characteristics | Blue to blue-green fluorescence, phosphorescence, triboluminescence                                           |                   |

For industrial applications, fluorspar concentrates (including lumps) are classified into three main quality grades including acid-grade, metallurgical-grade, and ceramic-grade, based on purity, particle size distribution, and other parameters. Additionally, there is optical-grade fluorspar, which represents a distinct and rare quality category.

Acid-grade fluorspar (acidspars) is the high purity grade, primarily used in chemical production, particularly for manufacturing hydrofluoric acid. Achieving its high purity requires a combination of wet milling and multi-stage flotation, processes that produce a fine particle size, typically ranging from 0.01 to 0.15 mm. To meet quality standards, no more than 5% of the particles may exceed 150 µm, while at least 60% must be smaller than 45 µm. In addition to a calcium fluoride (CaF<sub>2</sub>) content exceeding 97%, strict limits on impurities are essential for its industrial use.

Specifically, the concentrations of silica ( $<1\%$   $\text{SiO}_2$ ), iron oxide ( $<0.5\%$   $\text{Fe}_2\text{O}_3$ ), calcium carbonate ( $<1\%$   $\text{CaCO}_3$ ), sulfur ( $<0.1\%$  S), and phosphorus ( $<0.05\%$   $\text{P}_2\text{O}_5$ ) must remain low. Furthermore, lead, arsenic, cadmium, and beryllium must be present only in trace amounts to meet stringent chemical industry requirements.

Metallurgical-grade fluorspar (metspar) is defined by a calcium fluoride content of  $\leq 97\%$ . However, 80%–95% calcium fluoride is usually sufficient for its primary use in steel and cast iron production, where it functions as a flux, reducing slag viscosity and melting temperature. High iron content is not a concern, but impurity limits include silica ( $<15\%$   $\text{SiO}_2$ ), calcium carbonate ( $<3\%$   $\text{CaCO}_3$ ), magnesium carbonate ( $<1\%$   $\text{MgCO}_3$ ), sulfur ( $<1\%$ ), and lead ( $<0.5\%$  Pb). These thresholds are higher than those for acidspar. Metallurgical-grade fluorspar is typically coarse-grained, with particle sizes usually ranging from 5 to 80 mm, and is sometimes available in briquetted form. It must not be fine, as finer material would fail to sink into the iron or steel melt. The ore processing is relatively simple, involving crushing, washing, and screening, potentially followed by density separation using heavy media. Fine material ( $<5$  mm) generated during processing can be repurposed for other fluorspar grades. Metspar with lower calcium fluoride contents between 60–85% is often used in the cement industry for clinker production and is therefore also referred to as cement-grade fluorspar.

Ceramic-grade fluorspar (ceramic spar) is used as a flux, refining agent, and opacifier in applications such as the production of enamel, glazes, glass, abrasives, and welding electrodes. In addition to the purity of the concentrate, color is a critical factor for many applications. In such cases, the final concentrate must be pure white to avoid altering the end product's color. To prevent discoloration, the iron content must not exceed 0.12%  $\text{Fe}_2\text{O}_3$ . The  $\text{CaF}_2$  content of ceramic-grade fluorspar varies between 85% and 96%, depending on its intended application. High-purity grades are typically produced through flotation. Additionally, silica ( $\text{SiO}_2$ ) and calcium carbonate ( $\text{CaCO}_3$ ) contents must remain below 3% and 1%, respectively, with only minimal metal sulfide impurities. For ceramic spar used in enamel production, the total content of these three impurities must be kept below 2.5%. Other crucial factors include particle size distribution and the resulting bulk density of the concentrate, as different applications require varying levels of fineness. The pH value of the concentrate in an aqueous suspension is also important for specific applications, for example when fluorspar is used as an abrasive-active filler in grinding materials.

For the production of fluorine and fluorophosphate glasses used in optical applications such as spectroscopy, microscopy, and laser systems, optical-grade fluorspar with a  $\text{CaF}_2$  content of over 99% is required. Optical fluorspar consists of colorless, highly transparent crystals that must be chemically pure and crystallographically flawless. Additionally, they should have a diameter ranging from 12 mm to over 50 mm. Since naturally occurring fluorite with these properties is rare and costly due to its complex extraction process, it is typically produced synthetically (Kuhn, 2017).

## 1.3 Geological settings and occurrences

Fluorite forms under a wide range of physical and chemical conditions, leading to its occurrence in diverse geological settings and a variety of fluorspar deposit types. It is found as an accessory mineral in igneous rocks and as a precipitate from hydrothermal processes, where rocks are either replaced or cut by discrete veins. It can also form a stockwork of veinlets and lenticular bodies or occur as cavity fillings.

Fluorspar deposits are frequently associated with igneous rocks including carbonatites, alkaline intrusions, and strongly differentiated granites. Deposits related to carbonatites occur on every continent and examples are the deposits Amba Dongar (India), Okurusu (Namibia), Mato Preto (Brazil), Karasug (Russia) and Speewah (Australia). Examples for alkaline intrusion-related fluorspar deposits are Yermakovskoye (Russia) and St. Lawrence (Canada; Hayes et al., 2017). Deposits associated with strongly differentiated granites (e.g. tin granites) include fluorite-rich tin and tungsten skarns, fluorite-rich veins with tin, tungsten or antimony, fluorite-rich greisen deposits (partly lithium- and fluorine-rich mica), pegmatites, and disseminated or stockwork fluorspar deposits. Molybdenum and bismuth can also be enriched in these deposits. Examples include the Voznesenka and Pogranichny deposits (Russia), Lost River deposit (USA), and presumably the Vergenoeg (South Africa) and El Hammam (Morocco) deposits (Hayes et al., 2017).

Other deposits associated with igneous rocks are alkaline- and subalkaline volcanic-related epithermal fluorspar deposits. Although volcanic and intrusive rocks (including carbonatites) serve as a source of fluorine that is leached by meteoric water and heated by magmatic activity (sometimes also contributing late-stage, water-rich magmatic fluids), the fluorspar deposits themselves may occur in igneous, metamorphic, or sedimentary rocks. Epithermal fluorspar deposits associated with subalkaline volcanic rocks are the most common in China, with many located in Zhejiang Province along the country's southeastern coast. Other examples include the Kalangui deposit (Russia) and presumably the Las Cuevas deposit (Mexico; Hayes et al., 2017).

Notable alkaline-related epithermal fluorspar deposits include the Aguachile deposit (Mexico) and the Kimwarer deposit (Kenya; Hayes et al., 2017). Volcanic-related epithermal fluorspar deposits are also among the most economically viable fluorspar resources in Mongolia. A comprehensive analysis of the geology, mineralogy, and geochemistry of Mongolia's fluorspar deposits is presented in Chapters 2 and 3.

Fluorite is also commonly associated with sedimentary rocks and form Mississippi Valley-Type (MVT) fluorspar deposits (e.g. Northern and Southern Pennine Orefield/U.K., Illinois-Kentucky fluorspar district/USA, Marico district/South Africa), salt-related carbonate-hosted fluorspar deposits (e.g. deposits in Asturias/Spain and Rossignol/France), and tuffaceous limy lacustrine sediment-related fluorspar deposits (e.g. Castel Giuliano-Pianciano and Santo Mariadi Sala deposits/Italy; Hayes et al., 2017). Additionally, fluorite is found as residual material from the weathering of primary deposits (e.g. in the Illinois-Kentucky fluorspar district/USA, Marico district/South Africa).

Structure-bound (large faults and subordinate fissures) hydrothermal vein deposits can also be rich in fluorite and found in igneous (Plateau Central/France), metamorphic (Clara and Niederschlag/Germany) and sedimentary rocks (Rosiclaire/USA; Rottleberode/Germany). The fluids originate for example from basement brines and fluorite is often associated with sulfides and sulfosalts (usually containing Pb, Zn, Cu, Sb or Ag), quartz, barite or calcite.

## 1.4 Uses

The global fluorspar market is segmented into four key applications: hydrofluoric acid production, steel production, aluminum production, and other industrial uses. The hydrofluoric acid production relies on acidspar and accounts for approximately 47% of global fluorspar consumption. The hydrofluoric acid is the primary source of fluorine for industrial applications and serves as a precursor for most fluorine-containing chemicals. Steel production represents around 26% of global fluorspar consumption, where metspar is used as a flux in steelmaking processes.

Aluminum production accounts for approximately 20% of global fluorspar consumption, where acidspar is used in the manufacture of aluminum fluoride ( $\text{AlF}_3$ ) and cryolite ( $\text{Na}_3\text{AlF}_6$ ), both essential for primary aluminum smelting. Other industrial applications include cement, ceramics, enamel, glass, and welding rod coatings (McRae, 2023).

### ***Hydrofluoric acid production***

Hydrofluoric acid is produced from acid-grade fluorspar concentrates by reacting them with sulfuric acid at high temperatures. It plays a crucial role in semiconductor manufacturing, uranium enrichment, petroleum alkylation, and metal processing. However, its primary use (half of global acidspar consumption) is in fluorocarbon production, which accounts for one-third of global fluorspar consumption (Roskill, 2020). Fluorocarbons are divided into feedstock uses (used in fluoropolymers) and non-feedstock uses (e.g. aerosols, refrigerants, foam-blowing agents). Due to high global warming potential, the non-feedstock fluorocarbon gases including chlorofluorocarbon (CFC) and hydrochlorofluorocarbon (HCFC) were phased out under the Montreal Protocol, replaced by hydrofluorocarbon (HFC), which are now being phased down under the Kigali Amendment due to their high global warming potential.

Fluoropolymers and fluoroelastomers, essential for high-performance plastics and rubbers, remain unrestricted under these regulations. These materials are used in electronics, transportation, and chemical processing, along with applications in construction, consumer products (e.g. nonstick cookware, waterproof textiles), lithium-ion batteries, solar panels, and medical implants (McRae, 2023).

### ***Steel and iron production***

Metallurgical-grade fluorspar is a crucial flux in steel production, facilitating impurity removal and improving process efficiency. The fluoride ions in fluorspar help break down compounds with a high melting point such as silica, forming volatile or liquid compounds like  $\text{SiF}_4$ . Additionally, fluorspar reduces the viscosity of slag and supports the efficient separation of impurities from molten iron. In basic oxygen furnaces, it enhances both the dephosphorization and desulfurization processes, resulting in a higher steel purity (Fulton and Miller, 2006).

Fluorspar consumption in the steel industry varies significantly depending on the process and region. Since the 1990s, technological advancements, the partial substitution of fluorspar with alternative fluxes, increased recycling efforts, and initiatives to reduce fluoride emissions have led to a drastic decline in fluorspar usage in Europe and North America. Some steel plants have even completely phased out fluorspar as a fluxing agent. When fluorspar is used, typical consumption rates are approximately 5–6 kg per tonne of steel in the basic oxygen process, 0.3–3 kg per tonne in the Siemens-Martin process, and 3–10 kg per tonne in the electroslag remelting (ESR) process.

In the ESR process, fluorspar is used in combination with calcium oxide (CaO) and aluminum oxide (Al<sub>2</sub>O<sub>3</sub>) to create synthetic remelting slags. These slags help to remove impurities from the metal melt, improving the overall steel quality.

Additionally, in continuous casting operations, fluorspar is also used as a flux in casting powders. These casting powders are added to the molten steel, which prevents oxidation of the steel surface, absorbs impurities, and facilitates the smooth transport of partially solidified steel strands along the mold walls, ensuring an efficient casting process (Kuhn, 2017).

### ***Aluminum production***

Acid-grade fluorspar is used to make hydrofluoric acid, which is an intermediate for the production of aluminum fluoride (AlF<sub>3</sub>) and cryolite (Na<sub>3</sub>AlF<sub>6</sub>), both essential for primary aluminum smelting.

In the Hall-Héroult process, a method used for the production of pure aluminum, the addition of cryolite significantly lowers the high melting point of aluminum oxide from 2,045°C to approximately 950°C, resulting in substantial energy savings. The molten mixture used in this process typically consists of 80–90% cryolite, 2–6% aluminum oxide, and additional compounds such as 10–13% aluminum fluoride and 2–6% calcium fluoride (CaF<sub>2</sub>), which increase the electrolyte's conductivity. Through subsequent molten salt electrolysis, the process yields liquid aluminum with a purity ranging between 99.0% and 99.9%.

During smelting process, external cryolite input is minimal, as it is regenerated during the process from aluminum fluoride and sodium oxide. The sodium oxide originates from sodium hydroxide, which is used in the Bayer process for alumina extraction from bauxite and is continuously reintroduced into the system along with the aluminum oxide (Kuhn, 2017).

Recent advances in the aluminum industry is a reduced fluorspar consumption. To minimize emissions of hydrogen fluoride, fume treatment plants are used to capture the hydrogen fluoride from the cells and recycle it as AlF<sub>3</sub> for reuse in the smelting process (Tercero Espinoza et al., 2015).

### ***Other applications***

Fluorspar enhances opalescence of glass and is used in ceramic industry to produce flint glass, white or colored opal glasses, and enamels. This effect is based on a similar size of fluorine and oxygen ions enabling a substitution of oxygen in the glass by fluorine, which interrupts the glass network. However, the use of fluorine-containing materials in the glass, fiberglass, and ceramic industries may pose environmental concerns, as it can lead to kiln corrosion and the emission of hydrogen fluoride. Thus, the glass and ceramic industry is increasingly shifting towards reducing the use of fluorine compounds (García-Ten et al., 2024).

In welding applications, fluorspar is used in the coating of welding electrodes and in welding powders. Fluorspar is also used as a flux in the molten salt electrolysis process for extracting metallic calcium and magnesium. Additionally, in magnesium production, sulfur hexafluoride (SF<sub>6</sub>) gas is used as a protective atmosphere to prevent the hot metal melt from coming into contact with ambient air (Kuhn, 2017).

Fluorspar producers have increasingly been developing products for the cement industry. These products typically contain 40% to 50% fluorite, which is significantly lower than the fluorite content of metallurgical-grade fluorspar used as a steelmaking flux (McRae, 2023). It is added to the raw material mix before entering the rotary kiln. Its addition lowers the kiln operating temperature,

reducing fuel consumption. It also helps produce a softer clinker product that is easier to grind, thus saving electrical energy.

Crystalline fluorite is isotropic and has a very low refraction index ( $n = 1.43$ ), low dispersion, and high transparency to ultraviolet light. These characteristics make it useful as prisms in optical systems and as components of high quality specialized lenses. However, due to the rarity and high cost of high-purity natural fluorspar crystals, synthetic fluorite has largely replaced the natural mineral for optical applications (Fulton & Miller, 2006).

Furthermore, fluorspar, hydrofluoric acid and fluorine compounds are utilized across various industries, including cleaning and etching processes, lithium-ion batteries, lithium-graphite fluoride batteries, sodium-nickel chloride batteries, abrasives, aluminum component soldering, lubricants, pesticides, pharmaceuticals, and many more (Kuhn, 2017).

### ***Substitutes***

(Hexa)fluorosilicic acid (FSA), also known as fluosilicic acid, is a byproduct of phosphoric acid production from phosphate rock and is increasingly replacing a small portion of fluorspar as a fluorine source in the production of fluorochemicals. These include hexafluorosilicate salts, aluminum fluoride, cryolite, hydrofluoric acid, and silicon tetrafluoride. One of the major applications of FSA is the production of aluminum fluoride for the aluminum industry (Drevet, 2012).

By neutralizing FSA with alkali metal bases (e.g., NaOH), a variety of useful hexafluorosilicate salts, such as sodium hexafluorosilicate ( $\text{Na}_2\text{SiF}_6$ ), are produced. These salts are primarily used for drinking water fluoridation and, to a lesser extent, in the production of porcelain, hardened concrete, insecticides, leather processing, wood preservation, and glass etching (Samrane & Al-Hjouj, 2011).

Another significant application of FSA is the production of silicon tetrafluoride ( $\text{SiF}_4$ ), which serves as a raw material for polysilicon production – an intermediate product in the manufacturing of high-purity silicon for solar panels and semiconductor chips.

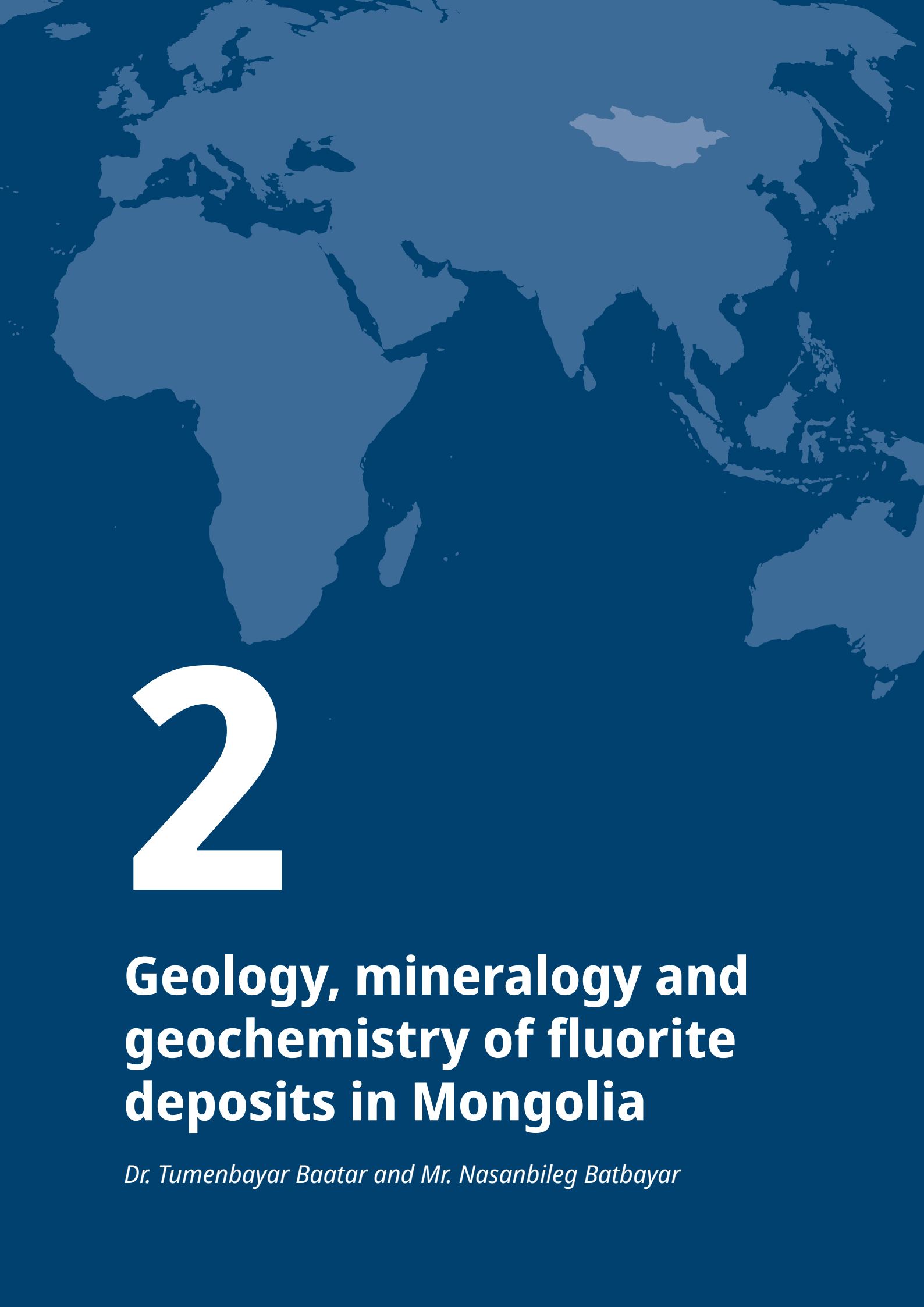


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# 2

## **Geology, mineralogy and geochemistry of fluorite deposits in Mongolia**

*Dr. Tumenbayar Baatar and Mr. Nasanbileg Batbayar*

### Introduction

The studies of fluorite deposits have been conducted by N. Marinov, A. Kalenov, R. Khasin, A. Bobrov, A. Khrapov, N. Zimina, I. Khrt, J. Bouska, J. P. Kotov, N. Zarembo, J. Banzragch, D. Enkhbaatar, M. Chuluundorj, N. Enkhbaatar, J. Badamgarav, J. Batjargal, J. Lkhamsuren, B. Sambalkhunde, B. Tumenbayar, D. Erdene, B. Shiiter, D. Tsetsenpil, D. Batbold, Khashbat, G. Ukhnaa and G. Dejidmaa and others.

Over 90% of Mongolia's epithermal fluorite deposits and occurrences are located in the eastern part of the country. This region represents the southwestern extension of the major fluorite province of Central Asia, which spans the borders of three countries (Mongolia, Russia and China). Within Mongolia, this province branches into two zones of large and small extensions through the eastern and southern parts of the country (Figure 2.1).

Fluorite deposits and occurrences beyond Mongolia's borders are classified by Chinese and Russian researchers as part of large metallogenic zones containing fluorite associated with base and rare metals. This metallogenic zone (Zn, Pb, Cu, Mo, Ag, U, Fe, Sn, W, Au, Cr) extends into Mongolia, covered by late Mesozoic and Cenozoic sediments containing oil, coal and uranium. The fluorite deposits of Eastern Mongolia, Transbaikalian fluorite occurrences and the East Uzumuchin group of deposits in China were formed under similar geological-structural conditions.

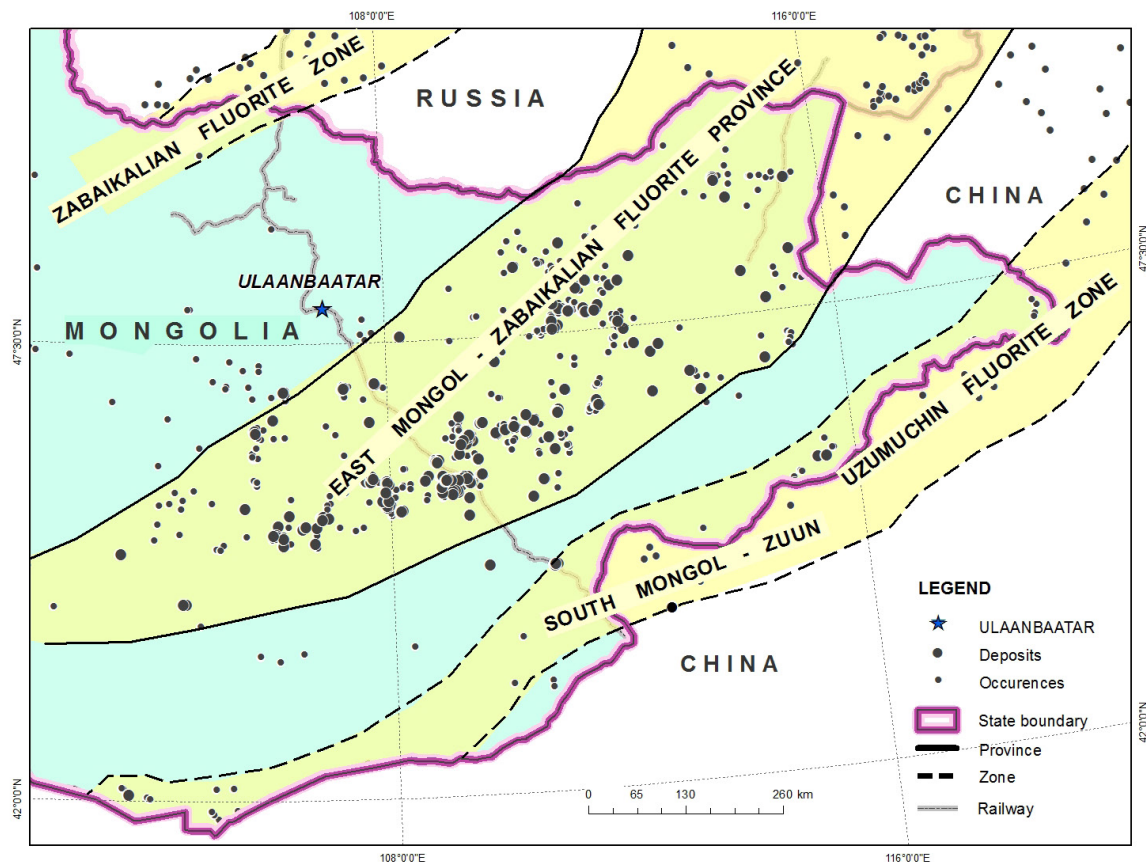


Figure 2.1: Distribution of fluorite deposits in Central Asia (Tumenbayar and Banzragch, based on Ivanova (1974), Koshelev (1984), Xu (2008), and Distribution map (2007)).

Another potential fluorite province that could extend into the northern part of Mongolia is the Western Transbaikalian fluorite province in Russia. This fluorite province may continue southwestward along the direction of the Buteel Range in Mongolia. However, no promising fluorite deposits have yet been identified along with its continuation (Figure 2.1).

Mongolia's fluorite deposits are mineralogically classified into 5 to 6 distinct types (Jamsran, 1986). Notably, approximately 97–98% of all industrially significant deposits fall exclusively into two categories: quartz-fluorite and carbonate-quartz-fluorite. Consequently, this report presents a detailed analysis of these two deposit types (see Chapter 2.2.3), while brief descriptions of the remaining types are provided in Chapters 2.2.2 and 2.1.3.

For prospective areas suitable for exploration and evaluation, details are given in Chapter 2.2.4 and Figures 2.2 and 2.9, with detailed explanations for each region. However, for Western Mongolia, due to the available information and the characteristics of the deposits, the information provided is relatively limited (Chapter 2.1.3). Nevertheless, information about the Jandai deposit and potential areas in Northern Mongolia is included in Figure 9 and Chapter 2.2.4.

Additionally, new ideas have been proposed regarding the high fluorite content in the ores of rare earth and rare metal deposits and the possibility of extracting and utilizing it as a byproduct, as well as the possibility of detecting high fluorite content in the Tsagaan Tsav and Shine Khudgiin formations (Chapters 2.1.3 and 2.2.1.6).

## 2.1 Metallogenic provinces of fluorite deposits in Mongolia

### 2.1.1 Eastern Mongolian fluorite metallogenic province (I)

The Eastern Mongolian fluorite province (I) is the largest province, extending 1,200 km from northeast to southwest with a width of 250 km (Figure 2.2). The Eastern Mongolian fluorite metallogenic province is defined by the distribution of late Mesozoic (Upper Jurassic-Lower Cretaceous) volcanic effusive rocks, covering central and northeastern Mongolia.

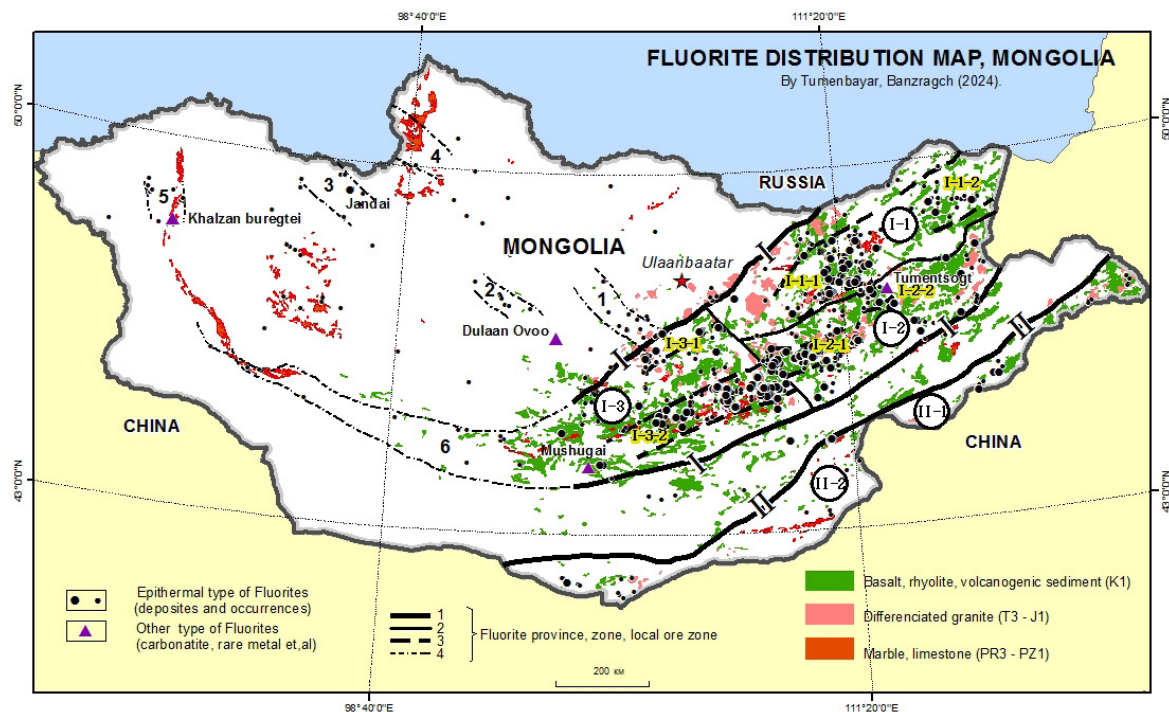
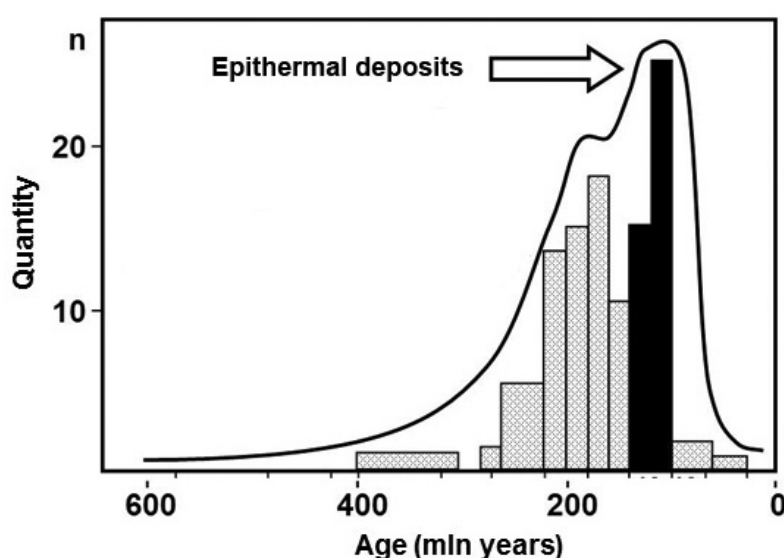


Figure 2.2: Map of fluorite metallogenic provinces in Mongolia.

I Eastern Mongolian fluorite metallogenic province, I-1 Northern Kherlen fluorite sub-province, I-1-1 Delgerkhaan (Berkh) ore district, I-1-2 Baruun Suuj ore district, I-2 Southern Kherlen fluorite sub-province, I-2-1 Bor Undur-Galshar ore district, I-2-2 Tumentsogt ore district, I-3 Central-Dundgobi fluorite sub-province, I-3-1 Adaatsag-Maanit Uul ore district, I-3-2 Khar Airag-Bilkh Uul ore district, II Southern Mongolian fluorite metallogenic province, II-1 Khalkh Gol-Nukhet Davaa, II-2 Urgan-Kharmorit (B. Tumenbayar, J. Banzragch, modified after Distribution map 2007 (2021)).

The Lower Cretaceous effusive rocks mainly consist of bimodal magmatic compositions, such as basalt, liparite and trachyliparite, unconformably overlaying pre-Mesozoic rocks (Badamgarav, 2010). The basic effusive rocks are distributed over large areas along the regional fault structures (Jamsran, 1986 and Lkahmsuren, 1998).

Acidic effusive rocks occur in the form of paleovolcanic features such as tuffogenic-sedimentary deposits, subvolcanic domes, stocks and lava flows. It has been demonstrated that acidic effusive rocks can be classified under the subvolcanic facies of intrusive rocks, as evidenced by the discovery of ongonite (albite-topaz keratophyre) in Mongolia (Kovalenko, 1976). Most epithermal fluorite deposits have been dated to the Late Cretaceous (Figure 2.3).



*Figure 2.3: Ages of fluorite deposits in Mongolia: Fluorite in hydrothermal rare metal deposits marked in gray and fluorite in epithermal deposits in bold black (Tumenbayar, 1984).*

### Structure

The Eastern Mongolia epithermal fluorite province is interpreted as being associated with continental rifting activity that was active in the eastern part of Central Asia during the Early Cretaceous.

During the Late Mesozoic, the continental rift structure formed as grabens bordered by linear and domal uplifts. These grabens were filled with volcanogenic, volcanogenic-sedimentary and coal-bearing terrigenous sediments. The volcanogenic assemblages primarily consist of bimodal basalt-trachyrhyolite compositions (Graham et.al., 2012).

The Eastern Mongolian fluorite metallogenic province is subdivided into three independent sub-provinces based on geological structure: Northern Kherlen (I-1), Southern Kherlen (I-2) and Central-Dundgobi (I-3) (Banzragch, 1979 and Khrapov, 1977). In addition to the Eastern Mongolia fluorite metallogenic province, there is a separate Southern Mongolia fluorite metallogenic province located along Mongolia's southern border (Figure 2.2). The metallogenic provinces of fluorite in Mongolia are summarized in the following Table 2.1, categorizing them into sub-provinces, fluorite districts, major deposits and occurrences within these provinces. A brief explanation is provided for each sub-province thereafter.



## 2. Geology, mineralogy and geochemistry of fluorite deposits in Mongolia

Table 2.1: Zoning of fluorite deposits and occurrences

| Sub province, province        | Ore districts                  | Major deposit names                                                                                                                                                                                                                        | Number of occurrences |
|-------------------------------|--------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|
| Northern Kherlen (I-1)        | Delgerkhaan (Berkh) (I-1-1)    | Delgerkhaan, Tavyt, Ovoo Sum (Dojir), Mali, Khuliin Khol-boo, Khutag, Chimidiin, Khavtgai I, II, Yamaat, Bulgan Uul, Idermeg, Shuvuut, Serven, Bayankhaan, Khai- Delgerkhaan, Shar Undur, Dund Bulag, Tsagaanchuluut Uul, Bayanovoo, Shalz | 91                    |
|                               | Baruun Suuj (I-1-2)            | Baruun Suuj, Khuv Bulag, Murgutsug                                                                                                                                                                                                         | 20                    |
| Southern Kherlen (I-2)        | Bor Undur, Galshar (I-2-1)     | Bor Undur, Adag, Undur Ovoo, Zuun Tsagaan Del, Khamar Us, Khajuu Ulaan, Tsagaan Elgen, Galshar, Dai Uul, Tsagaan Undur, Khutul                                                                                                             | 67                    |
|                               | Tumentsogt (I-2-2)             | Jonshit, Anas, Basalt (deposit)                                                                                                                                                                                                            | 7                     |
| Central-Dundgobi (I-3)        | Khar Airag-Bilkh Uul (I-3-1)   | Khar Airag, Khongor, Bujgar, Bor Tolgoi, Omnod Khar Airag, Khoid Khar Airag, Baruun Tsagaan Del, Maikhan I, II, Tsagaan Takhilch, Suul Undur, Bilkh Uul, Khutul, Ikh Nartiin Khiid, Bumbat, Khetsuu Tsav, Tsogzol Uul, Ulziit, Khuh Del    | 90                    |
|                               | Adaatsag-Maanit (I-3-2)        | Chuluut Tsagaan Del, Ukhaa Ovoo, Baruun Zuund Khad, Tsagaan Del, Takhilga Uul, Jonshit Uul                                                                                                                                                 | 19                    |
| South Mongolian Province (II) | Khalkh Gol-Nukhet Davaa (II-1) | Bulgiin, Bayan-Urgun                                                                                                                                                                                                                       | 19                    |
|                               | Urgun-Kharmorit (II-2)         | Urgun, Kharmorit (group of deposits), Bargilt Ovoo                                                                                                                                                                                         | 30                    |

### 2.1.1.1 Northern Kherlen fluorite sub-province (I-1)

This sub-province is bounded to the northwest by the Southern Khentii and Onon faults and to the southeast by the Kherlen deep faults. It extends northeastward, covering an area 710 km long and 150 km wide (Figure 2.2).

In the central part of the area, metamorphic and intrusive rocks of Upper Proterozoic age are widely distributed. This area is composed of complexly structured blocks, dissected by northwest- and northeast-trending faults. During the Late Mesozoic, continental rifting activity intensified, leading to active tectonic-magmatic processes. Significant amounts of andesite, basalt, liparite and trachyliparite erupted widely. In the central part of the region, a large volcanic-tectonic plateau structure formed, primarily composed of Late Mesozoic basaltic andesite (Banzragch and Chuluundorj, 1986).

The northeast- and northwest-trending faults that dissect these structures provided favorable conditions for the formation of fluorite deposits during the Late Cretaceous. The Northern Kherlen fluorite deposits are mostly spatially associated with volcanic rocks and occur as quartz-fluorite veins within Mesozoic and Late Paleozoic granites. In this area, deposits and occurrences of rare metals associated with intrusive rocks of Upper Triassic-Lower Jurassic age, as well as low-temperature vein-type gold, zinc, lead and uranium deposits, have been identified. Among these, fluorite mineralization is the most widely distributed

and significant resource in the region (Koshelev, 1984). The Northern Kherlen fluorite province consists of two ore districts: Delgerkhaan (Berkh) (I-1-1) and Baruun Suuj (I-1-2).

### 2.1.1.2 Southern Kherlen fluorite sub-province (I-2)

This sub-province is bounded to the north by the Kherlen deep fault and to the southeast by the Undurshil-Delgerekh deep faults, extending northeastward. The sub-province has a length of 600 km and an average width of 150 km.

Within the sub-province, the key indicators of Late Mesozoic tectonic-magmatic activity such as basalt, andesite and liparite are widely distributed. Basaltic andesite-rhyolites are primarily found along orthogonal faults trending northwest and northeast. These rocks are widely distributed where these fault systems intersect, creating favorable conditions for the formation of fluorite deposits.

In this area, deposits and occurrences of rare metals (e.g., W, Mo, Pb, Sn, Nb, Ta) associated with intrusive rocks of Upper Triassic-Lower Jurassic age are widely distributed. Structurally, the area belongs to the Dundgobi-Kherlen continental rift zone.

In the southern Kherlen sub-province, Proterozoic limestone is more prevalent and a deep fault known as the Khalzan-Galshar fault has been identified in the central part of the sub-province. Along with this fault, Late Mesozoic volcanic rocks erupted and were deposited.

The fluorite deposits in this sub-province are predominantly formed as quartz-fluorite veins within volcanic rocks, Early Mesozoic and Late Paleozoic granites and occasionally within Late Proterozoic limestone as veins or, less commonly, as mineralized zones. This sub-province is divided from west to east into the Bor Undur-Galshar (I-2-1) and Tumentsogt (I-2-2) fluorite ore districts (Figure 2.2).

### 2.1.1.3 Central-Dundgobi fluorite sub-province (I-3)

This sub-province is located within a geo-anticlinal uplift, bounded by the northern Gobi, Undurshil, Choir and Ongiin Gol deep faults. The northeastern boundary of the sub-province is defined by the Choir-Khar Airag deep fault, while the southwestern section narrows along latitudinal deep faults and their intersections, following the attenuation of Late Mesozoic magmatic activity. Overall, the sub-province extends 650 km in length and 220 km in width, trending east to northeast along the Central Mongolian regional deep fault system.

In this sub-province, quartz-fluorite and carbonate-quartz-fluorite epithermal deposits are distributed, with carbonate-quartz-fluorite type deposits tending to dominate in terms of resource volume.

In this sub-province, Upper Riphean-Vendian-aged Oortsog Formation rocks, including limestone, mica and graphite schists, as well as aleurolites (consolidated sediment with more than 50% of alevrite), are widely distributed. However, the basaltic andesite and other effusive rocks, products of Mesozoic tectonic-magmatic activity, are relatively limited in extent (Koshelev, 1984).

This sub-province consists of two ore districts: the Khar Airag-Bilkh Uul (I-3-2) in the southern part and the Adaatsag-Maanit Uul (I-3-1) in the northern part (Figure 2.2).

### 2.1.2 Southern Mongolian fluorite metallogenic province (II)

This province is an extension of the rare and polymetal-fluorite ore province in the East Uzunuchin Banner of China, located along the southeastern and southern borders of Mongolia. The province spans approximately 1,000 km in length and 100 km in width. It contains scattered and underexplored fluorite deposits and occurrences, the most significant and industrially valuable of which is the Urgun deposit. The deposits and occurrences in this province can be grouped into the Khalkh Gol-Nukhet Davaa (II-1) and Urgun-Kharmorit (II-2) areas. The Khalkh Gol-Nukhet Davaa occurrences are vein-type fluorite deposits formed along the edges of Late Permian granites intruding Lower-Middle Devonian carbonate sediments.

In addition, the Nukhet Davaa rare metal zone hosts 6 fluorite deposits and occurrences. Among these, the recently discovered Bayan-Urgun fluorite deposit, formed in association with rare metal mineralization, highlights the promising potential of this province. The Urgun fluorite deposit, part of the Urgun-Kharmorit group, is capable of becoming a significant deposit for future mining due to its ore reserves and deposit type. The geological conditions of the Urgun deposit suggest a high likelihood of discovering similar deposits within the province, making this area of special interest.

### 2.1.3 Other types of fluorite-bearing deposits in central and eastern Mongolia

The fluorite occurrences in western and eastern Mongolia differ significantly in their geological characteristics (Table 2.2). In the western and northern parts of the country, the deposits and occurrences belong to pre-Mesozoic formations. Most of these are associated with Paleozoic alkaline rocks. These include the Dulaan Uul (fluorite and rare metals such as Be, W, Ta, Nb, Hf, Zr, REE), the Jandai fluorite group occurrences, the Khalzan Buregtei (rare earth element deposit), Sudal Uul, the Shivert and the Ar Gol group occurrences (Figure 2.2).

Among the deposits in western Mongolia, particular attention should be given to the Dulaan Uul deposit, which contains beryllium; the Khalzan Buregtei deposit, associated with alkaline rocks and rare earth elements; and the Mushgai Khudag deposit, associated with carbonatites (Lkhamsuren et al., 2021). These three deposits will be discussed in detail in the following chapter.

The Jandai fluorite deposit is considered one of the most promising. It is a stratiform-type deposit formed within Lower Permian granite and Lower Cambrian limestone (Figure 2.2). The deposit has confirmed reserves of 500,000 tonnes, with the potential for further resource expansion (Enkhbat, 1998).

Large fluorite-bearing deposits and occurrences are primarily located in the western part of Mongolia and are often rare metal deposits containing rare earth elements, Nb, Ta, Zr, Hf and Be. The comparison of Mongolian deposits with the general classification of global fluorite-bearing deposits is presented in the table below (Table 2.3).

*Table 2.2: Comparison of fluorite mineralization in western and eastern Mongolia.*

| Feature                 | Western Mongolia                                             | Eastern Mongolia                                                                         |
|-------------------------|--------------------------------------------------------------|------------------------------------------------------------------------------------------|
| Geology-Tectonics       | Major Faults and Uplifted Blocks                             | Continental Rift Zones, Mesozoic Basin Marginal Uplifts, Orthogonal Faults and Limestone |
| Magmatism               | Paleozoic Alkaline Rocks                                     | Mesozoic Magmatism and Late Mesozoic Bimodal Volcanic Rocks                              |
| Mineralogy              | REE (Rare Earth Elements), Rare Metals, Phosphorus, Fluorite | Quartz-Fluorite<br>Calcite-Quartz-Fluorite                                               |
| Age                     | Paleozoic                                                    | Late Mesozoic                                                                            |
| Number of Active Mines  | None                                                         | Over 60                                                                                  |
| Types of Mineralization | Accessory and Hydrothermal Mineralization                    | Epithermal                                                                               |
| Example Deposits        | Dulaan Uul, Khalzan Buregtei                                 | Over 200 deposits such as Bor Undur, Chuluut Tsagaan Del, Zuun Tsagaan Del               |
| Practical Significance  | Currently None                                               | High Significance                                                                        |

*Table 2.3: Types of fluorite deposits in Mongolia (Based on the classification by Hayes, 2017).*

| Related rock type                                                      | Deposit type                                            | Foreign deposits                                   | National deposits                 |
|------------------------------------------------------------------------|---------------------------------------------------------|----------------------------------------------------|-----------------------------------|
| Carbonatite related                                                    | Carbonatite                                             | Mato Preto (Brazil), Okorusu (Namibia)             | Mushgai khudag                    |
| Alkaline-intrusion related                                             | Accessore                                               | Lawrence district (Canada), Yermakovskoye (Russia) | Khalzan buregtei (Figure 2.4)     |
| Alkaline-volcanic related                                              | Epithermal (fluorite occurring in veins), breccia-fills | Aguachile (Mexico), Kimwarer (Kenya)               | Naran                             |
| Mississippi Valley type (incl. salt-related carbonate hosted deposits) | Carbonate hosted                                        | Marico District (South Africa), Asturias (Spain)   | Not known                         |
| Strongly differentiated granites related                               | Greisen, Skarns, hydrothermal vein-type                 | Voznesenka (Russia)                                | Tumentsogt, Dulaan ovoo           |
| Subalkaline volcanic related                                           | Epithermal veins<br>Carbonate replacement               | Kalangui (Russia), Yangia-Wuyi (China)             | Epithermal more than 200 deposits |
| Tuffaceous related                                                     | Lacustrine sediments                                    | Santo Maria (Italy)                                | Toost                             |

### ***Carbonatite (REE) deposits***

This type of deposit includes Mushgai Khudag, Lugiin Gol and Khotgor deposits. Among these, the most thoroughly studied is the Mushgai Khudag deposit. It contains rare earth minerals such as bastnäsite, synchysite and monazite, along with associated minerals like fluorite, apatite and phosphorite. Fluorite occurs as an associated mineral in the ore, comprising 2-5% of the total composition (Samoilov and Kovalenko, 1983).

Based on this, it has been concluded that the Mushgai Khudag rare earth element deposit could become a new source of fluorite for Mongolia. The possibility of such a deposit is demonstrated by the Bayan Ovoo rare earth element deposit in China, located just 200 km south from Mongolian border (Fan et al., 2016).

### ***Rare metal (W, Pb, Mo, Sn, Be, etc.) deposits***

These deposits are primarily associated with lithium-fluorine enriched alaskite granite, formed during the final stages of granite differentiation. Such granites typically form hypabyssal bodies. In Mongolia, there are about 10 deposits of this type, which are further divided into hydrothermal, greisen and combined types. The fluorite content in the ores of these deposits ranges from 1.0-10.0% (Kovalenko, 1971).

In rare metal deposits fluorite forms in two stages. It first forms in hydrothermal veins or greisen with rare metal ores (between 305-260°C) and later forms quartz-fluorite veins during the final stage (between 100-163°C). The fluorite content in the ore is directly related to the presence of other minerals such as fluorine-bearing topaz, apatite and biotite (Ivanova, 1976). Deposits such as Tumentsogt, Shar Khad (Western part), Yugzer (Chono Gol), Baga Gazar, Buren Tsogt and Chuluun Khoroot are examples of such ore bodies. These deposits have been mined and fluorite remains in the tailings from the extraction process.

Among the unexplored deposits, the Dulaan Uul Be-bearing fluorite-bertrandite deposit, located in the central part of Mongolia, is particularly noteworthy. This deposit consists of carbonate-fluorite, siliceous, muscovite-phenakite-fluorite (with tourmaline and tin) and muscovite-chrysoberyl-fluorite (with tungsten and molybdenum) ore bodies. The independent carbonate-fluorite ore contains up to 30% fluorite, while the carbonate-siliceous ore contains higher than 30% fluorite. Associated minerals include quartz, tourmaline, wolframite, molybdenite, sellaite, sphalerite, galena, arsenopyrite and barite. The ore bodies take the form of lens-like, layered and tubular metasomatic strata. The length and extension of the ore bodies exceed 100 meters, with a thickness of 25-30 meters and in expanded sections, up to 80-100 meters. Currently, detailed exploration work has not been conducted on this deposit.

### ***Alkaline granite-associated (REE, Nb, Ta, Zr, Hf) deposits***

Currently, the main representative of this type of deposit is the Khalzan Buregtei deposit. This deposit is located in the Altai Mountain range of Western Mongolia. It is situated in one of the southern branches of the Mongol Altai, located to the west-northwest of Khovd city (40 km) on the Khalzan Buregtei mountain. The mineralization extends along a northward-trending ridge.

The Khalzan Buregtei deposit is located in the southeastern part of the Khalzan Buregtei massif, which has an elliptical shape, measuring 5x3 km. The massif is composed of various rocks, including nordmarkite, alkaline granite-alkaline pegmatite, fine-grained microcline-albite granite,



arfvedsonite-pantellerite and alkaline microcline-albitic granite with rare metals, as well as dykes of alkaline granite, rare metal-enriched alkaline granite, and syenite (Kovalenko and Samoylov, 1979).

The main rare metal mineralization in this deposit is associated with the final stage of rock formation, concentrated in a stock-like body that outcrops and covers an area of 0.86 km<sup>2</sup>. The ore contains minerals such as pyrochlore (Ca, Ce, Pb), columbite, zircon, elpidite-armstrongite, xenotime, monazite, bastnäsite, fluorite, polycrystalline and apatite (Figure 2.4). The average content of valuable minerals in the ore body is as follows:

$$\text{Ta}_2\text{O}_5 = 0.011\%, \text{Nb}_2\text{O}_5 = 0.2\%, \text{ZrO}_2 = 1.46\%, \text{Y}_2\text{O}_3 = 0.112\% \text{ and } \Sigma\text{TR}_2\text{O}_3 = 0.3\%$$

Fluorite content is present at levels of 2-8% (with an average of 3.8%) in granite as one of rock forming minerals, as confirmed through electron microscope analysis (Baasandorj, 2022).

Currently, Khalzan Buregtei mine is being studied at the exploration stage and further research is needed to determine the feasibility of utilizing fluorite as a by-product when progressing to the stages of extraction and processing.

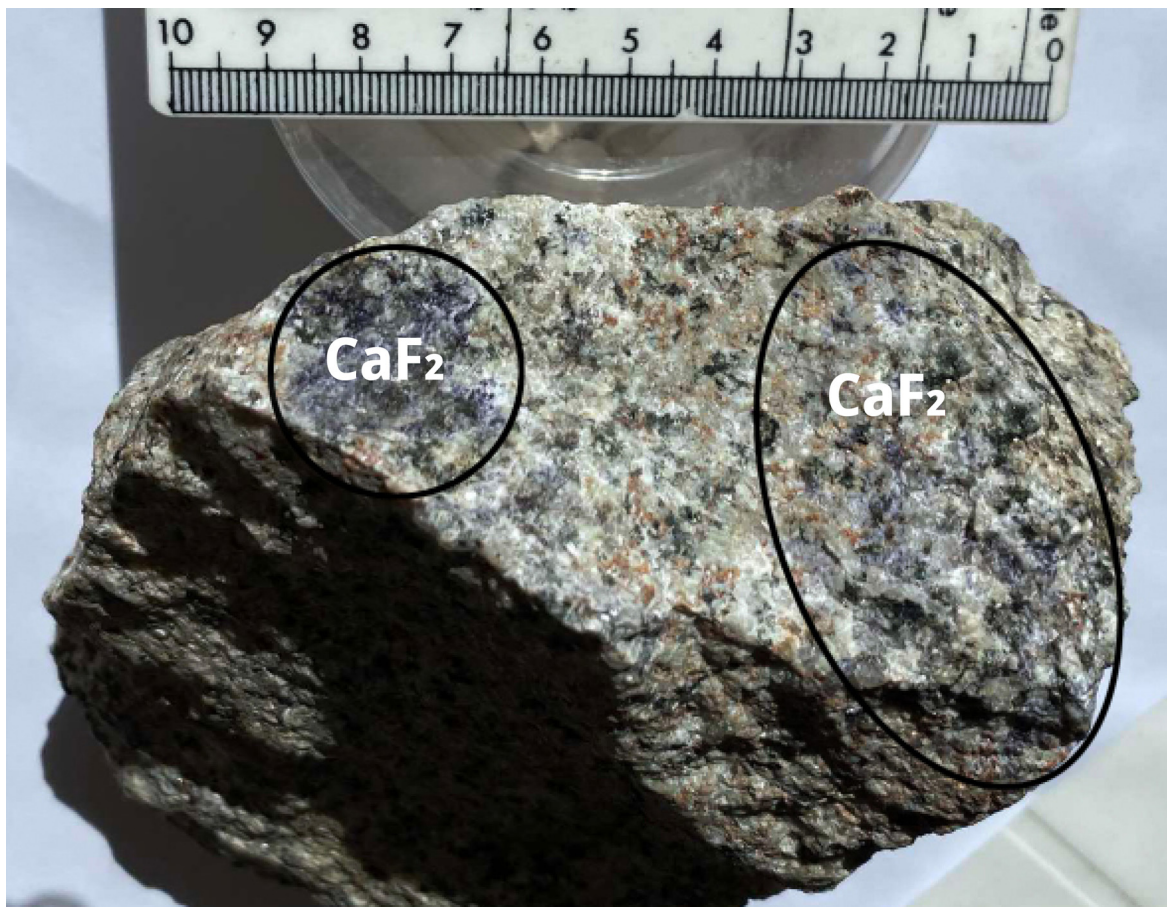


Figure 2.4: Rare metal and rare earth element ore of Khalzan Buregtei (fluorite content 2-8%, Photo by B. Tumenbayar).

### ***Sedimentary-origin fluorine deposits***

Another promising source of fluorine is the extensive volcanic activity during the Late Mesozoic, which produced fluorine-rich volcanic magma, lava and hydrothermal solutions. Through diagenetic processes, these rocks transformed into fluorine-enriched tuffs and sedimentary deposits. These sediments can contain up to 3% fluorine, which accumulates in macro and micro forms (embedded in the crystal structure) within clay minerals and mica flakes. From this perspective, the Late Mesozoic volcanic-sedimentary and sedimentary rocks (such as the Tsagaan Tsav and Shine Khudag formations) that cover over 20% of the territory of Eastern Mongolia hold significant potential for fluorine resources.

In addition, accumulations of proluvial deposits often form near fluorite deposits that have undergone intense weathering. For example, such deposits are found extending up to 3-4 kilometers from deposits like Jonshit Tolgoi and Khutul Us. Similar deposits are likely to have formed along an approximately 80-kilometer zone from the Bilkh Uul deposit to the Sant Uul and Tsogzol Uul deposits.

During the International Fluorine Forum held in October 2024 in Mongolia, the National Geological Survey (Ministry of Industry and Mineral Resources) officially reported that there are 549 fluorite occurrences and 157 deposits recorded across the entire territory of Mongolia, with total reserves amounting to 35.9 million tonnes (<https://imformed.com/get-imformed/forums/fluorine-forum-2024/>).



## 2.2 Fluorite ore districts, geology, mineralogy and geochemistry

### 2.2.1 Ore districts (infrastructure, geological structure, deposit types, mineralization)

This section provides a brief overview of the geological structure, deposit types and mineralization of the major fluorite ore districts included in the fluorite sub-provinces, as outlined in Chapter 2.1.

#### 2.2.1.1 Delgerkhaan (Berkh) ore district (I-1-1)

In this region, Upper Jurassic–Lower Cretaceous volcanic rocks dominated by basalt and andesite, formed during tectonic-magmatic activity, are widely distributed. A large volcanic structure known as the Batnorov Basalt Plateau is identified in the central part of the area. Surrounding this structure are several fluorite deposits, including Berkh, Delgerkhaan, Ovoo Sum (Dojir), Yamaat, Khavtgai-1,2, Bayankhaan, Bulgan Uul, Mali, Chimed, Bayan Ovoo, Saikhan Uul and Shuvuut. To the northeast of Berkh, deposits such as Khai-Delgerkhaan, Shalz and Shar Undur, along with numerous occurrences, have been identified. Overall, the fluorite deposits are situated along northwest-trending fault zones that intersect the northeast-trending structures (Figure 2.2). Mineralogically, the deposits primarily belong to the quartz-fluorite type. The Delgerkhaan deposit, a key representative of this district, will be discussed in detail in Chapter 2.3.

#### 2.2.1.2 Baruun Suuj ore district (I-1-2)

The Baruun Suuj ore district is located at the northeastern end of the Berkh District and shares similar magmatic characteristics with it. Structurally, it lies in the southern part of the Mongol–Okhotsk orogenic belt. Geologically, the Baruun Suuj fluorite ore district is situated in the central part of the Baruun Suuj granite massif, a Permian-aged granite formation covering a large area of 200 km<sup>2</sup>, with the ore district itself extending over 60 km<sup>2</sup>. This area features widespread occurrences of shallow-depth volcanic and alkaline intrusive rocks from the Early Cretaceous. Notably, porphyritic granodiorite, silicified granite bodies and extensive breccia zones draw significant attention. The main representatives of this district include fluorite deposits such as Baruun Suuj, Murgutsug and Khov Bulag, along with a few additional occurrences. The district also hosts deposits such as the Mardai uranium deposit, the Ulaan polymetallic deposit and the Tsav zinc deposit. Consequently, it is reasonable to consider that some fluorite mineralization in this district formed during the late stages of rare metal and zinc-lead ore deposit development (Figure 2.2).

#### 2.2.1.3 Bor Undur-Galshar ore district (I-2-1)

In this district, intrusive and volcanic rocks from the Late Paleozoic and Late Mesozoic are widely distributed. In the northwestern part of the ore district lies the Alag Tsav volcanic plateau, which borders the western edge of the Bor Undur fluorite group. This group includes deposits such as Bor Undur, Adag, Undur Ovoo and Saikhan Gashuun. Further east-northeast, the deposits extend along the edge of the Cretaceous basin, encompassing deposits such as Khajuu Ulaan, Zuun Tsagaan Del, Khamar Us, Tsagaan Elgen, Baruun Barga Ovoo, Galshar, Bambar and Khavtsal Shand Bulag.

The ore bodies in this district are primarily elongated in a northward direction. The deposits mainly belong to the quartz-fluorite and carbonate-quartz-fluorite mineral types. However, the mineralization in Galshar and Saikhan Gashuun is classified as the chalcedony-barite-fluorite mineral type. The ore bodies in this district vary in width from several centimeters to several meters and can extend for several hundred meters. Larger vein bodies continue at depth, as evidenced by

deposits such as Bor Undur and Zuun Tsagaan Del, which have been confirmed to extend to depths of 300 meters or more.

### 2.2.1.4 Tumentsogt ore district (I-2-2)

The Tumentsogt ore district includes deposits such as Jonsh Tolgoi, Anas, Bazalt and in the southern part, Buduun Ukhaa, Jonshit Ukhaa and Bayan Ulziit. The Jonsh Tolgoi deposit is geologically associated with the Sharkhad granite, the final phase of Late Triassic–Early Jurassic rare-metal granites. Its fluorine-enriched hydrothermal fluids infiltrated Late Proterozoic limestone, forming the deposit under favorable lithological conditions. The mineralization primarily consists of north-south trending quartz-fluorite veins, as well as lenticular, horizontally layered deposits along fractures in marbleized limestone. Surrounding this district are deposits such as Tumentsogt, Buren Tsogt (Figure 2.5), Zaan Shiree, which are associated with Triassic and Jurassic granites and host rare, nonferrous and polymetallic elements (e.g., W, Mo, Sn, Nb, Ta, Zn, Cd, Cu, Pb). While many of these deposits feature fluorite mineralization, they lack immediate industrial significance for direct extraction of fluorite. Additionally, some deposits, such as Tumentsogt and Buren Tsogt, have already been mined out. However, the discovery of new epithermal fluorite occurrences in the eastern extension of this area remains intriguing.

### 2.2.1.5 Adaatsag-Maanit Uul ore district (I-3-1)

The Adaatsag-Maanit Uul ore district was identified by researcher J. Banzragch. It encompasses a more than 200-kilometer-long, northeast-east trending area along the Northern Gobi deep fault. This area includes the Adaatsag-Takhilga Uul deposit group, Tsagaan Tolgoi occurrence group, Ukhaa Ovoo, Chuluut Tsagaan Del deposit and extends to Baganuur's Jonshit Tolgoi. The district also incorporates the Maanit Uul fluorite occurrence group. This area is located at the northwestern edge of the Dornod Mongolian continental rift and overlaps with the Northern Gobi deep fault zone. Within this district, Mesozoic rare-metal-bearing granite bodies are widespread. Associated with these granites are rare-metal deposits (e.g., Ongon Khaikhan, Ikh Khaikhan) and small fluorite occurrences formed during the later stages of granite emplacement. A major representative deposit in this district is the Chuluut Tsagaan Del group of deposits.

### 2.2.1.6 Khar Airag-Bilkh Uul ore district (I-3-2)

This region encompasses the Dundgobi uplift, bounded to the north by the Northern Gobi regional fault and to the south by the Saikhandulaan deep fault. The Khar Airag-Bilkh Uul ore district primarily consists of two main groups of deposits: the Khar Airag-Khukh Del group and the Bilkh Uul group.

In the Khar Airag-Khukh Del area, intrusive, extrusive and metamorphic rocks of various ages are widely distributed, with Late Mesozoic magmatism being confined to limited areas. Most fluorite deposits in this region are uniquely formed within Neoproterozoic marbleized limestones of the Oortsog formation, which is representative of the Dundgobi Uplift. The ore bodies typically form as horizontal layers or lenticular shapes. In the Khar Airag area, deposits such as Khongor, Khutul Ulaan, the Khar Airag group, Khar Yamaat and the Maikhan group are included. In the Khukh Del area, deposits include Khukh Del, Bumbat, Tsagaan Undur, Manuultai, Ikh Nartyn Khiid, Log Fluorite, Khukh Teeg and Tsagaan Takhilch, among others (Samballkhundev, 1979). In the Narangiin deposit, located in Saikhandulaan soum of Dornogobi province, fluorite has formed as an ore cementing material within a volcanic breccia pipe hosted by Permian-aged volcanic rocks. The average fluorite content ranges from 10% to 20%.

In the Bilkh Uul ore field, deposits such as Bilkh Uul, Tsant Uul, Ulziit, Khuld, Khutul Us, Tal and Tsogtsol Uul are included. These deposits are primarily located along the edges of Cretaceous

basins, in areas dominated by northeast-southwest trending Upper Riphean-Vendian Oortsog formation rocks.

These formations consist of limestone, mica schist, graphite schist and aleurolite, which are widely distributed. The carbonate rocks are predominantly marbleized, providing favorable lithological conditions for the formation of fluorite ores (Figure 2.6). The morphology of the ore bodies includes cavity-filling and horizontal-layered forms (stratiform).

Along the western end of the region, deposits and occurrences of interest extend along the Main Mongolian Lineament (Central Regional Fault of Mongolia), associated with Late Jurassic alkaline rocks. These include the Mushgai Khudag rare earth element deposit, Olon Ovoot gold deposit, Avdrant fluorite deposit and further to the northwest, the Hetsuu Tsav gold-mineralized fluorite occurrences.

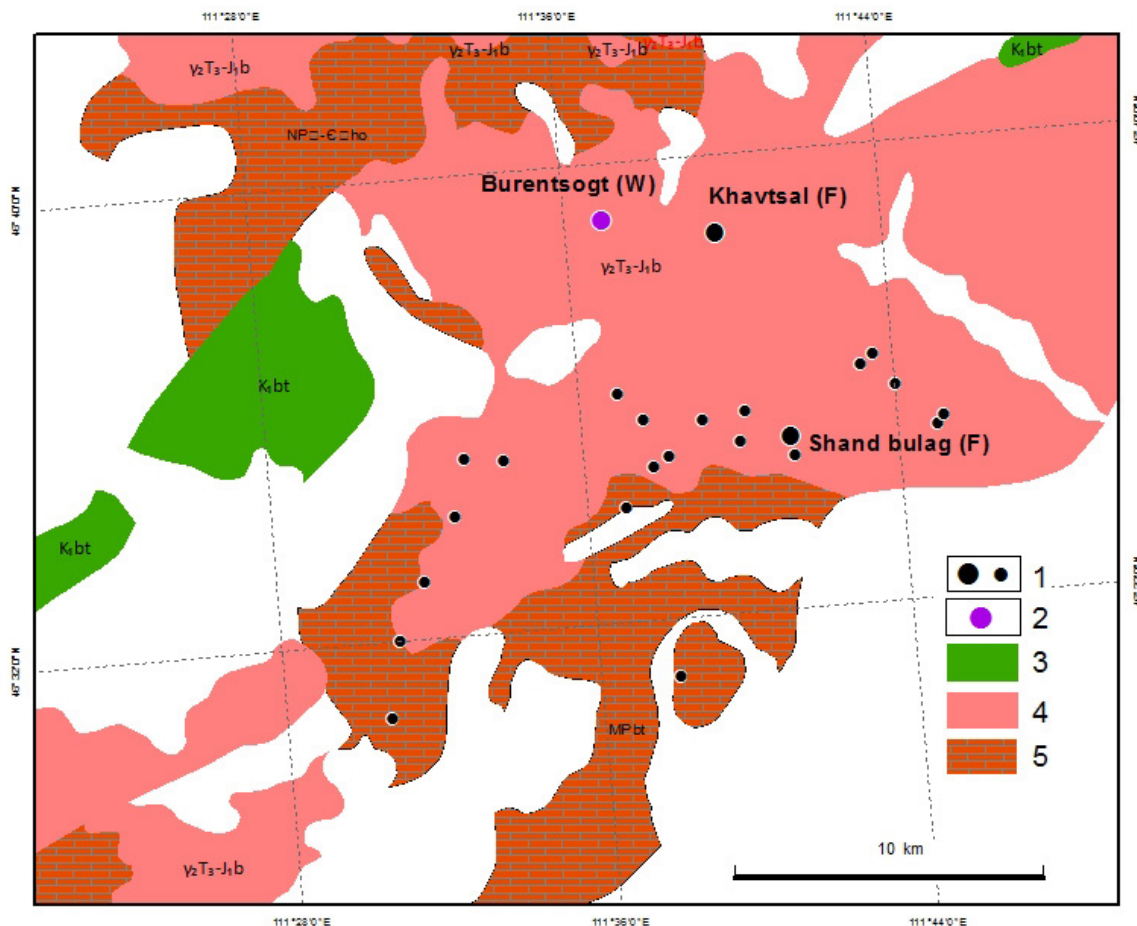


Figure 2.5: Fluorite deposits commonly occurring as veins in Late Mesozoic granites (B. Tumenbayar, J. Banzragch, modified after Distribution map 2007 (2021)).

1- $\text{CaF}_2$  deposits and occurrences, 2-Rare metal deposits, 3-Late Cretaceous volcanites and sediments (Tsagaan Tsav formation), 4-Mesozoic granites, 5-Proterozoic limestone.

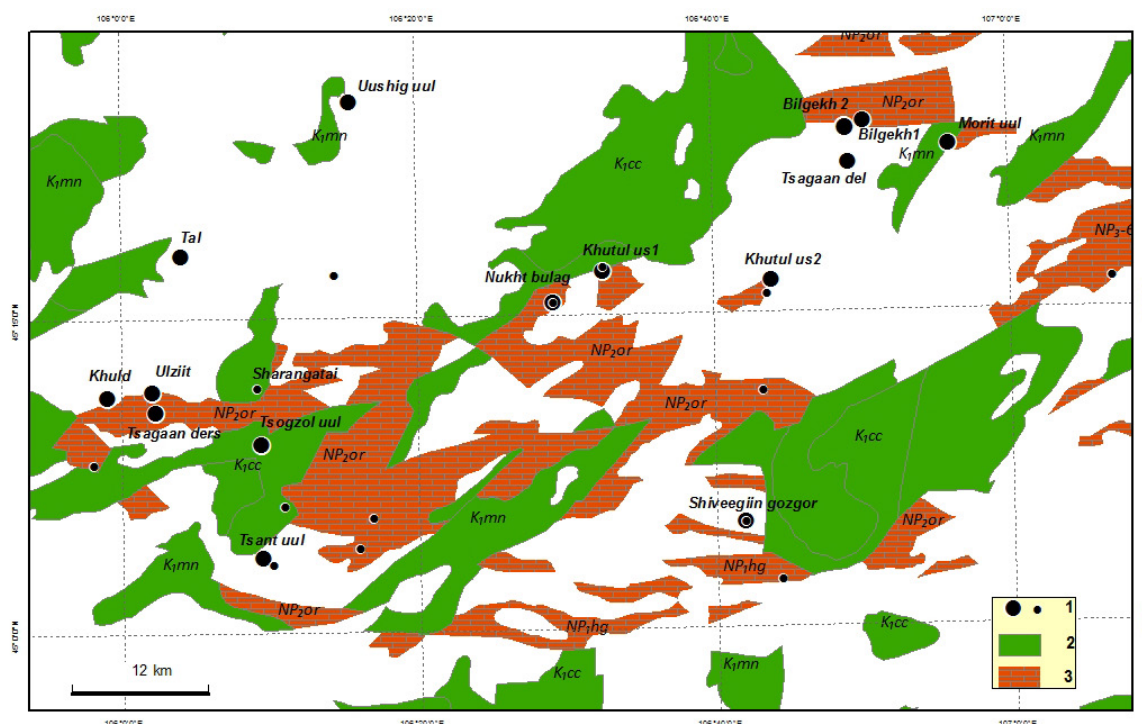


Figure 2.6: Fluorite deposits forming carbonate replacement and vein-type ores associated with Proterozoic limestone (B. Tumenbayar, J. Banzragch, modified after Distribution map 2007 (2021)).

1-Deposits and occurrences, 2-Late Cretaceous volcanites and sediments (Tsagaan Tsav formation), 3- Proterozoic limestone.

### 2.2.1.7 Khalkh Gol-Nukhet Davaa occurrence group (II-1)

Fluorite deposits and occurrences in this district are notable for being closely associated with rare metal and tungsten-quartz veins. Almost all these occurrences are genetically linked to the final stages of differentiation of Mesozoic rare-metal-bearing granites (analogous to the Yan Shan granite on the Chinese side).

Rare-metal granites are widely distributed in this region, with associated deposits and occurrences formed during their late stages, such as the Bayan Urgun and Batguai groups, as well as Uushig, Modot Uul and others. The Bayan Urgun deposit is a vein-type deposit located west of Nukhet Davaa. It consists of nearly pure chalcedony-fluorite ore and is situated parallel to production-grade silica-tungsten veins, making it industrially important. Additionally, higher-temperature fluorite mineralization is commonly found alongside rare and base metal deposits in this district. However, the industrial potential of these occurrences has not yet been determined.

### 2.2.1.8 Urgun-Kharmorit occurrence group (II-2)

This area is located along the southern border of Mongolia, within the Hercynian folded belt and includes the Kharmorit and Urgun deposit groups. The largest among these is the Urgun deposit group. The Urgun fluorite deposit, situated in the Bargiin Ovoo uplift, is a stratiform and vein-type deposit formed at the contact zone between limestone and ultrabasic rocks. The deposit comprises 14 ore bodies, with the largest central body being stratiform and vein-like in nature, developed within limestone and shale layers. Smaller vein bodies are also abundant in the area. The Kharmorit fluorite field includes more than 10 fluorite occurrences. However, most of these are located within the territory of a protected area.

### 2.2.2 Fluorite ore and associated elements, opportunities for processing and sales

#### 2.2.2.1 Dornod Mongolian metallogenic province

Most fluorite deposits in this region are epithermal deposits of the quartz-fluorite and carbonate-quartz-fluorite types. These deposits are characterized by high fluorite content. A few deposits also contain other minerals such as barite (Galshar, Khongor, Saikhan Gashuun), cinnabar (Idermeg, Bayan Khaan), sphalerite, galena and pyrite (lower layers of Bor Undur, Nart, Hetsuu Tsav). Among these, the Galshar deposit has the highest barite content (up to 19.68%; Lkhamsuren et al., 2021, p328). However, barite has not yet been extracted as a by-product from this deposit and only fluorite mining is currently being conducted. The content of other associated minerals is very low (<0.1%) and therefore, they are not considered economically viable for by-product extraction or utilization as of today.

#### 2.2.2.2 Fluorite-Bearing deposits and occurrences in western mongolia

Other types of deposits containing fluorite were briefly mentioned in Chapters 2.1 and 2.2. Fluorite-bearing deposits and occurrences in Western Mongolia can be categorized as rare-metal deposits and rare-earth element deposits (associated with carbonatites and alkaline rocks). Additionally, there may be deposits associated with sedimentary rocks and phosphorites. In these deposits, fluorite could potentially be utilized as a by-product during the beneficiation of primary elements. This potential is demonstrated by laboratory test results conducted on ore from the Mushgai Khudag carbonatite deposit. As for rare-metal deposits, most of the rare-metal deposits in Eastern Mongolia were mined out during the 1950s-1960s, with fluorite being discarded as waste. These deposits are now no longer viable for exploitation. Newly discovered deposits, especially those containing rare earth elements (REE), Nb, Ta, Hf and Zr, such as the Khalzan Buregtei and Tsakhir deposits, present an opportunity to recover fluorite as a by-product. For example, the Khalzan Buregtei rare earth and rare metal ore contains fluorite with concentrations ranging from 3.5% to 7.0%. This potential adds value to these deposits and highlights the possibility of utilizing fluorite during the extraction of primary elements.

### 2.2.3 Factors affecting the quality and grade of fluorite ore

Mongolia's fluorite ores can be economically divided into two main types: quartz-fluorite epithermal type and carbonate-quartz-fluorite epithermal type.

#### *Quartz-fluorite epithermal type*

This type of deposit is relatively more widespread compared to other types and is mineralogically simple, consisting mainly of quartz-fluorite or pure fluorite. As a result, it has high fluorite content and is easier to mine and process, making it more economically efficient.

Representative deposits of this type include Berkh, Adag, Bor Undur, Ovoo Sum, Delgerkhaan and Khavtgai. The ore bodies consist of veins with a thickness of 1-10 meters, occasionally reaching up to 30 meters. These veins are predominantly steeply dipping and extend along strike for 40-1,300 meters and in rare cases, up to 2,000 meters. The mineralization occurs within argillized and silicified alteration zones that are 5-10 meters wide. The deposits extend to depths of up to 370 meters, but deeper sections have not yet been adequately studied (Lkhamsuren et al., 2021). In Eastern Mongolia, deposits of this type are located relatively far from transportation infrastructure (such as railways) and other facilities, resulting in high transportation costs that can reduce their economic efficiency.

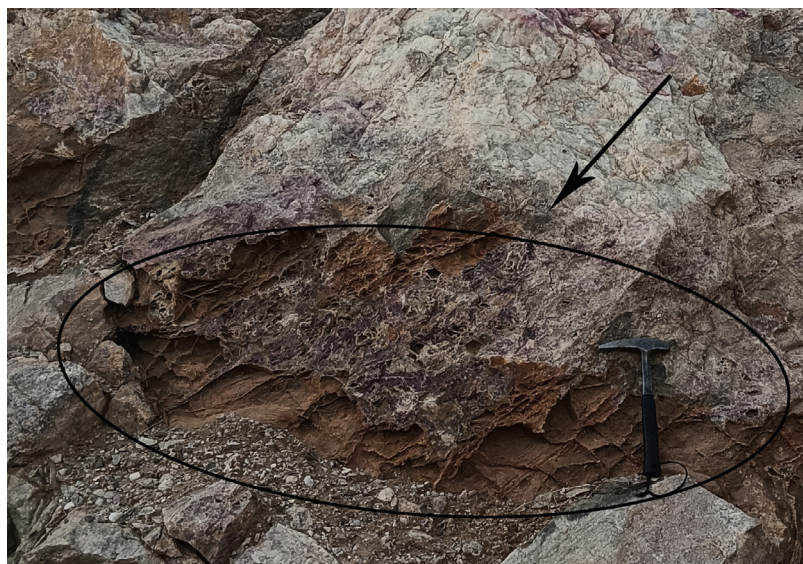


### ***Carbonate-Quartz-Fluorite epithermal type***

This type primarily includes fluorite deposits formed within limestone. Examples of such deposits are the Khar Airag group, Urgun, Baruun Tsagaan Del, Khongor, Maikhan, Sant Uul, Bujgar, Khongor, Chuluut Tsagaan Del, Bilkh Uul and Khairt. Approximately 40% of all Mongolian fluorite deposits fall into this category.

In carbonate-quartz-fluorite type deposits, fluorite ore often forms cavity-like bodies, which can complicate mining and beneficiation processes (Figure 2.7). Due to this, the ore bodies in carbonate rocks tend to have significant hollow spaces and a reticulated texture caused by carbonate replacement. These cavities are frequently filled with minerals such as fluorite, quartz, calcite, ankerite, kaolinite, marcasite and other carbonate-associated minerals causing the decrease of the fluorite grade (quality) during mining, due to these impurities. Examples of such deposits include Chuluut Tsagaan Del, (parts of) Urgun and Jandai. Beneficiating ore from these deposits requires advanced flotation techniques and precise adjustments, which increase processing costs and can negatively affect the economic efficiency of these deposits. Host rock factors also affect the quality of fluorite ore. For instance, fluorite deposits are widely distributed in areas with limestone belonging to the Proterozoic-aged Oortsog formation. Examples include the Khar Airag-Bilkh fluorite ore district, as well as the Urgun and Chuluut Tsagaan Del deposits. In contrast, fluorite is relatively less abundant in Devonian-aged limestones found in eastern Mongolia.

This may be related to the higher dolomite content (low Ca and high Mg) in these rocks, which creates less favorable conditions for fluorite formation.



*Figure 2.7: Fluorite ore body formed in carbonate rocks, with abundant cavity-filling structures Urgun deposit, photo by B. Tumenbayar 2024.*

Proterozoic limestones have undergone metamorphism over hundreds of millions of years, transforming into crystalline marble with enhanced permeability. This marbleization creates favorable conditions for deep fluorine-rich solutions to infiltrate and form fluorite deposits. As a result, fluorite deposits associated with marbleized limestone with low dolomite content are relatively easier to process and have a positive impact on ore quality (Figure 2.6 and 2.7).

On the other hand, impurity elements incorporated isomorphically into the fluorite structure can affect the final product quality of fluorite. Rare earth elements (REEs) with ionic radii similar to that of calcium in fluorite are particularly notable. For example, the presence of Y and Yb in fluorite indicates the level of purity of the ore (Figure 2.8).

Analyzing the concentrations of Y and Yb in fluorite of various origins shows that fluorite from epithermal deposits is relatively pure and has lower concentrations of these elements. In contrast, fluorite formed at higher temperatures contains up to 100 times more of these elements. This indicates that the origin and formation temperature of the deposit can significantly impact the quality of the ore (Tumenbayar, 1984).

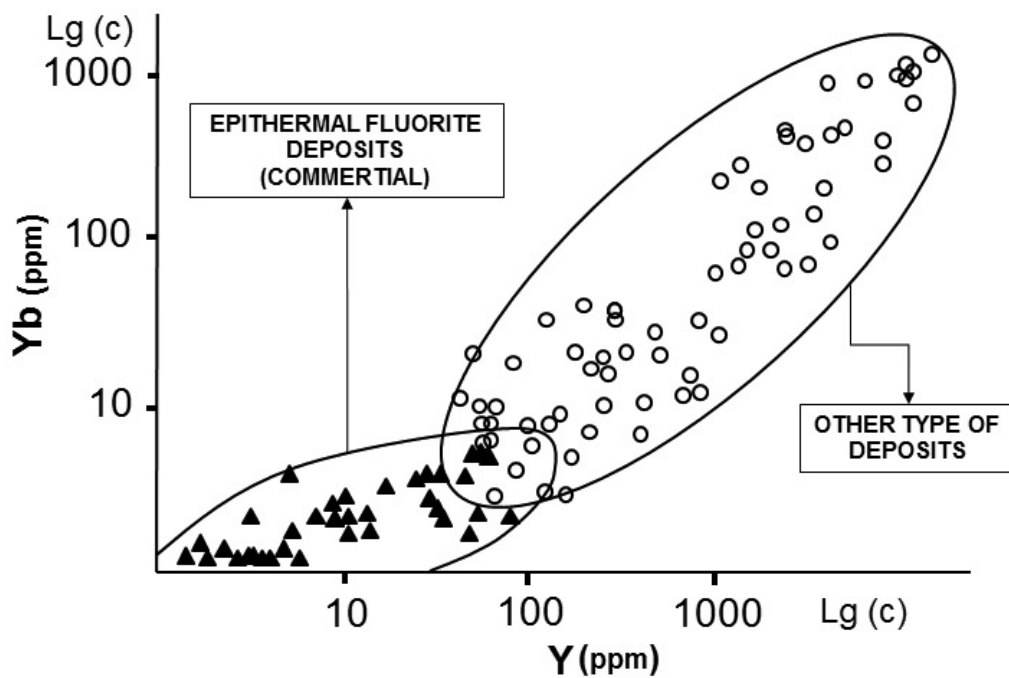


Figure 2.8: Concentrations of Y and Yb in fluorite (Tumenbayar, 1984).



### 2.2.4 Potential for discovering new deposits and exploration

Based on geological studies of fluorite and the distribution patterns of deposits in Mongolia, several prospective areas for discovering new deposits can be identified. When selecting prospective areas, priority should be given to locations in the eastern region of Mongolia where specialized exploration and prospecting for fluorite have not yet been fully conducted. These areas include the Lower Cretaceous volcanic zones, particularly regions with widely distributed alkaline volcanic rocks (Tsagaan Tsav formation) and favorable lithological and tectonic structures. Among these, the following areas are considered the most promising: marble- and limestone-rich areas associated with the Neoproterozoic Oortsog formation in Dundgovi and Umnugovi provinces, areas related to the Proterozoic Urgan formation in the Dornogovi region, regions in Dornod and Khentii provinces with widely distributed Devonian-aged limestone deposits. It is recommended to conduct exploration and prospecting in the seven sites mentioned below as shown in Figure 2.9 (deposits and occurrences are marked with black dots and prospective areas are outlined in red).

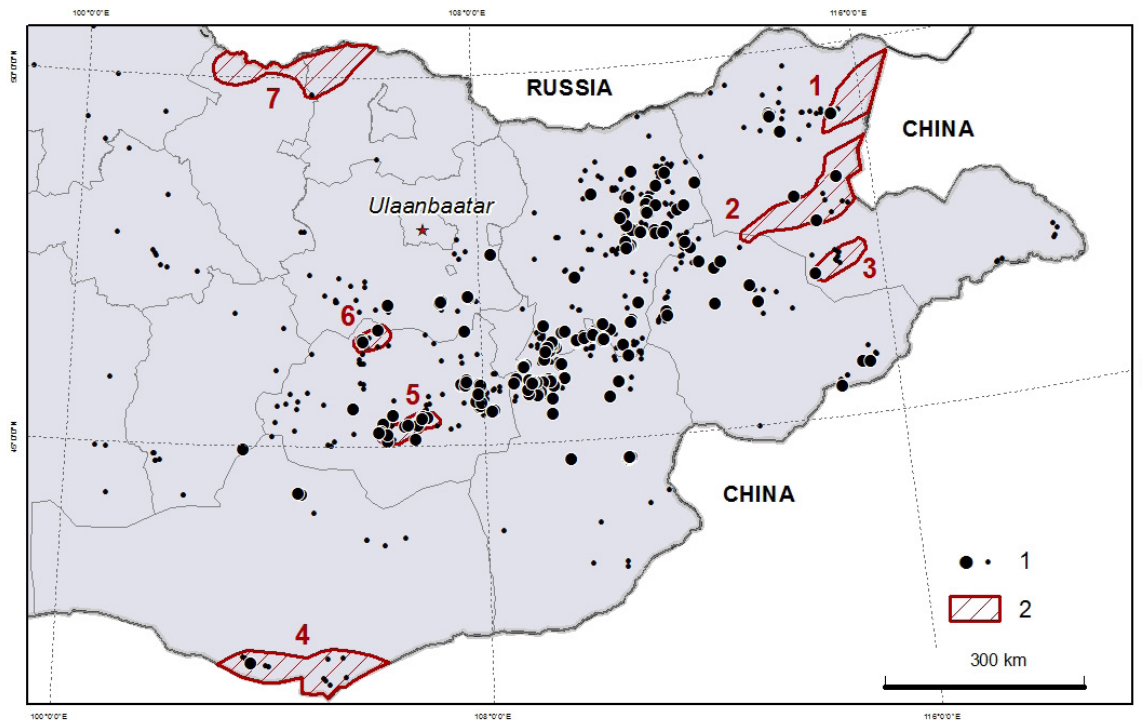


Figure 2.9: Prospective areas for fluorite deposits (Tumenbayar, 2024). 1-Murgutsug area, 2-Undur Ukhua area, 3-Rashaant area, 4-Khar Morit area, 5-Ulziit area, 6-Adaatsag area, 7-Buteeliin Nuruu area.

1. The Murgutsug area is located at the intersection of the Northern Kherlen fluorite sub province and the Argun River metallogenic province in Eastern Transbaikalia. This region is characterized by the presence of Cretaceous volcanic plateaus, Mesozoic granite massifs and fault zones, which are considered promising targets for exploration.
2. The Undur Ukhaa area is situated at the intersection of the Southern Kherlen fluorite sub province and the large metallogenic provinces of fluorite in Russia and China. This area hosts 5-6 mineralized fluorite zones. Of particular interest in this region are the northeast-oriented regional structural features.
3. The Rashaant area also belongs to the Southern Kherlen fluorite sub province and shares regional structural similarities with Undur Ukhaa. This area features Permian granites, trachyandesite lava flows, intersecting faults that cross regional fault zones and silicified veins that are of significant interest.
4. The Khar Morit area consists of uplifted blocks with Triassic and Jurassic magmatic activity that intruded along China's Hegeshan regional fault. It is a fluorite-rich area. However, being part of a National Protected area, it remains underexplored.
5. The Ulziit area is composed of the Proterozoic-aged Oortsog formation's limestone, surrounded by Upper Cretaceous basins. Deep fault zones bordering these basins are highly likely to host carbonate-quartz-fluorite type deposits, making it a prime target for exploration (Figure 2.6).
6. Adaatsag area. This field hosts the Chuluut Tsagaan Del, large fluorite deposit of the carbonate-quartz-fluorite type. Adjacent to it lies an underexplored area near the Bayan Ovoo granite massif, which has yet to undergo detailed exploration and evaluation, leading to its selection for further study.
7. The Buteeliin Nuruu area is located in the extension of the large fluorite province in Western Transbaikalia. While no significant prospective deposits or occurrences have been identified in this region within Mongolian territory, it has been selected for its promising potential (Figure 2.1).

## 2.3 Fluorite production

### 2.3.1 Main operating deposits in each fluorite ore district

In Chapters 2.1 and 2.2, the metallogenic provinces, sub-provinces and districts of Mongolia's fluorite deposits were described. This section will detail the main deposits within each fluorite district that are currently being mined or are actively preparing for production in the near future (Table 2.4).

Table 2.4: List of selected key deposits.

| Sub province               | District                       | Deposit name                             |
|----------------------------|--------------------------------|------------------------------------------|
| Northern Kherlen (I-1)     | Delgerkhaan (Berkh) (I-1-1)    | Delgerkhaan                              |
|                            | Baruun Suuj (I-1-2)            | Baruun Suuj                              |
| Southern Kherlen (I-2)     | Bor Undur, Galshar (I-2-1)     | Bor Undur, Khamar-Us, Zuun Tsagaan Del   |
|                            | Tumentsogt (I-2-2)             | There is no significant fluorite deposit |
| Central and Dundgobi (I-3) | Adaatsag-Maanit Uul (I-3-1)    | Chuluut Tsagaan Del                      |
|                            | Khar Airag-Bilkh Uul (I-3-2)   | Khongor, Bayan-Ovoo (Avdrant)            |
| Southern Mongolia (II)     | Khalkh Gol-Nukhet Davaa (II-1) | No information available                 |
|                            | Urgun-Kharmorit (II-2)         | Urgun                                    |

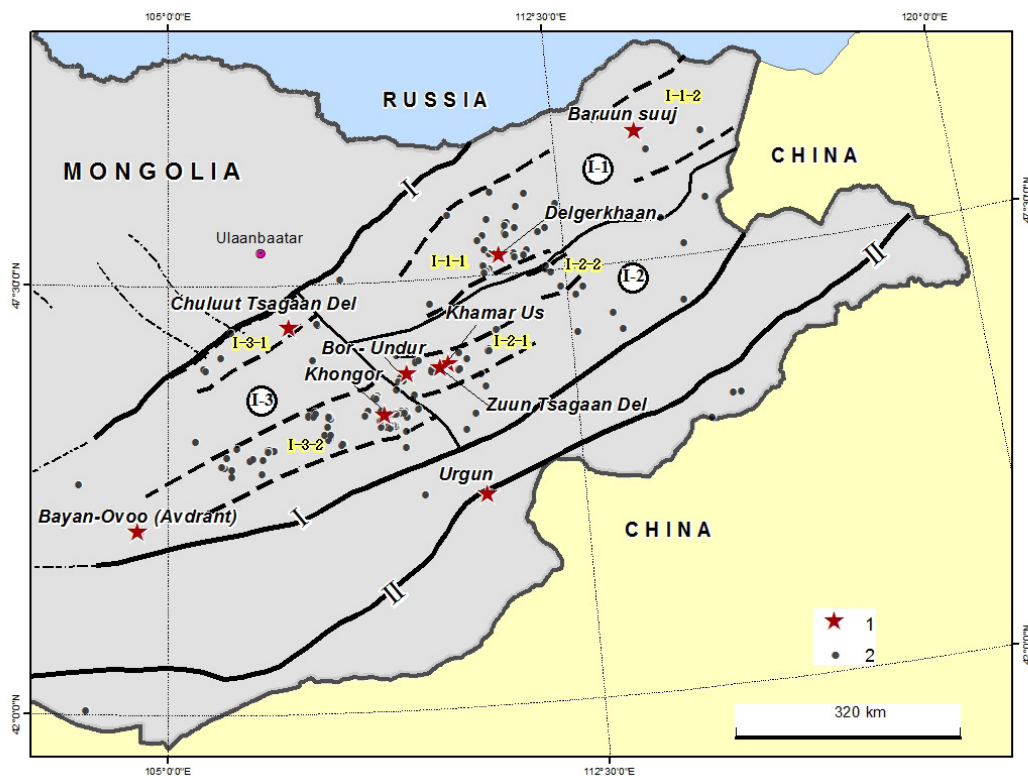


Figure 2.10: Fluorite provinces and selected deposits (Tumenbayar, 2024).

### 2.3.1.1 Delgerkhaan deposit

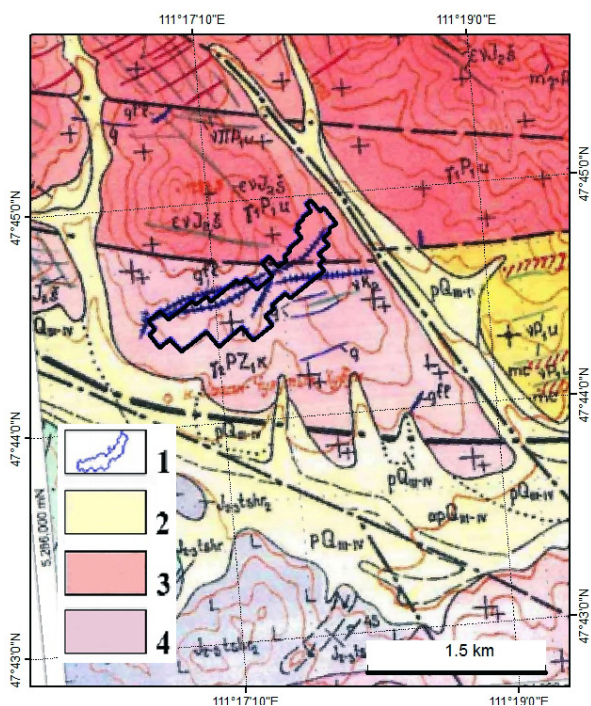
#### *Location and infrastructure*

The Delgerkhaan deposit is located in Batnorov soum, Khentii province. It is situated 450 km east of Ulaanbaatar along a paved road, 80 km north of Chinggis City and 13 km east of Berkh village. The nearest railway station is Khar Airag, located 350 km away from the deposit.

#### *Geological structure*

The Delgerkhaan fluorite deposit is located within the Northern Kherlen sub province of the Dornod Mongolian fluorite metallogenic zone and forms part of the Delgerkhaan (Berkh) ore district. The regional geological structure includes the following formations: Middle Proterozoic Khaichingol formation: shale, marble, amphibolite, quartzite, Middle to Upper Jurassic Jargalant formation: trachyte, trachidacite, quartz porphyry, rhyodacite andesite, basalt, tuff, gravel and sandstone layers with conglomerates, Lower Cretaceous Tsagaan Tsav formation: rhyolite, dacite, rhyodacite andesite, basalt, tuff, gravel and sandstone layers with conglomerates, Lower Cretaceous Zuun Bayan formation: argillite, aleurolite, sandstone, conglomerates, Upper Quaternary-Modern: loose sediments such as sand, silt, clay, gravel and alluvial deposits, Deep Rocks from Early Paleozoic Kherlen formation: leucocratic granite, Early Permian Ulzgol formation: leucocratic granite, Middle Jurassic Sharkhad formation: medium-to-coarse-grained leucocratic semi-alkaline granite, Late Jurassic Khai-Delgerkhaan formation: quartz-syenite, syenite-diorite, granosyenite (Figure 2.11).

In this region, in addition to the Delgerkhaan fluorite deposit, several fluorite and tin mineralized occurrences have also been identified.



**Figure 2.11: Geological map of the Delgerkhaan fluorite deposit.**

1-License boundary, 2-Quaternary deposits, 3-Low Permian granite, 4-Early Paleozoic intrusive complex

#### *Mineralization*

The ore body of the Delgerkhaan deposit is located along fractures, faults and breaks that follow the eastward and longitude-latitude directions in the Early Paleozoic granite. The ore veins have a steep dip of 60-80° to the southeast. The length of the ore body extends up to 1,460 meters along the strike and it continues 100-300 meters along the dip. The thickness of the ore body can reach 10-20 meters in certain sections (Figure 2.12).

#### *Mineralogy*

The mineral composition of the ore includes quartz and fluorite, along with small amounts of kaolinite and mica. The ore contains an average of 18.0-96.0%  $\text{CaF}_2$ , 0.1-3.6%  $\text{CaCO}_3$ , 0-0.01%  $\text{P}_2\text{O}_5$  and 0-0.1% S. The arsenic (As) content is very low. The high and relatively pure fluorite content is a distinctive advantage of the deposit.

### ***Current status of reserves and production***

It is reported that the Delgerkhaan deposit contains approximately 2.128 million tonnes of ore with an average  $\text{CaF}_2$  content of 50.52%, which equates to approximately 1.075 million tonnes of fluorite. However, based on updated information from the Wayo Fluorite LLC that holds the deposit, a 2012 survey revision updated the average grade to 33.7% with ore reserves now at 6.2 million tonnes (<https://wayo-fluorite.com/>). The deposit was operated as an underground mine until 2003, after which operations were temporarily suspended. There are plans to resume mining activities and restart production in the near future. Below is a map showing the main ore veins, the licensed area and completed underground work (Figure 2.12).

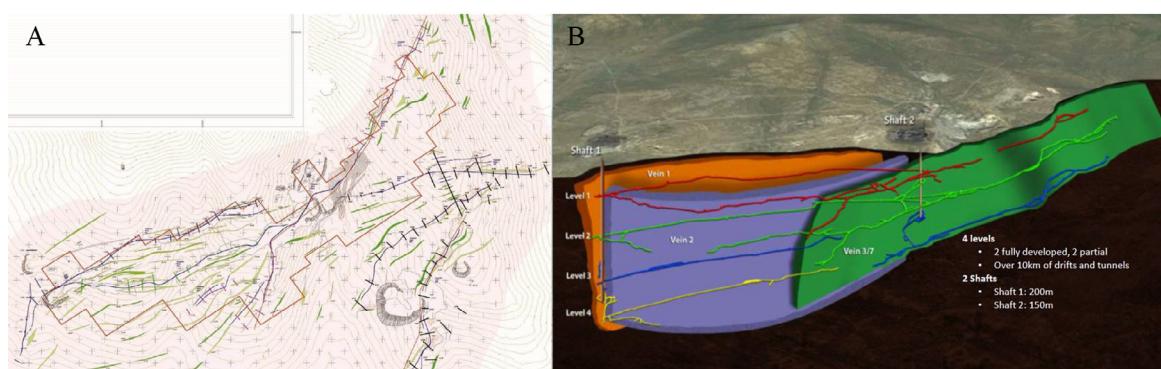


Figure 2.12: Delgerkhaan fluorite deposit A) Plan view, B) Vertical ore section

### **2.3.1.2 Baruun Suuj deposit**

#### ***Location and infrastructure***

The Baruun Suuj deposit is located 600 km northeast of Ulaanbaatar, 35 km southwest of Dashbalbar soum, Dornod province, 8 km southeast of Baruun Suuj mountain and near the eastern side of Mukhar Khuviin canal, situated in the water fracture zone of the Mardai River and Mukhar Khuviin canal. Compared to other deposits, information about this deposit, including its infrastructure, is limited.

#### ***Geology***

The area comprises uplifted blocks of Late Proterozoic to Early Cambrian schists and Permian granites, bordered by Upper Jurassic to Lower Cretaceous volcanic rocks. Basic volcanic rocks are intruded by rhyolites, trachyrhyolites, and syenite porphyries. Late Cretaceous fluorite mineralization developed along longitudinal faults cutting through these formations (Figure 2.13).

#### ***Mineralization***

Two types of mineralization have been formed at the Baruun Suuj deposit: epithermal quartz-fluorite veins and volcanic breccia type. The quartz-fluorite vein type is most commonly found in the central part of the area, where shallow volcanic rocks are widely distributed. According to initial research by J. Banzragch, a total of 56 quartz-fluorite veins have been discovered in the field. The length of the ore bodies ranges from several tens of meters to up to 800 meters. The average fluorite content is 30-45% and the thickness of the veins is 1.0-5.0 meters. Currently, the deeper sections of the deposit have not been fully explored.



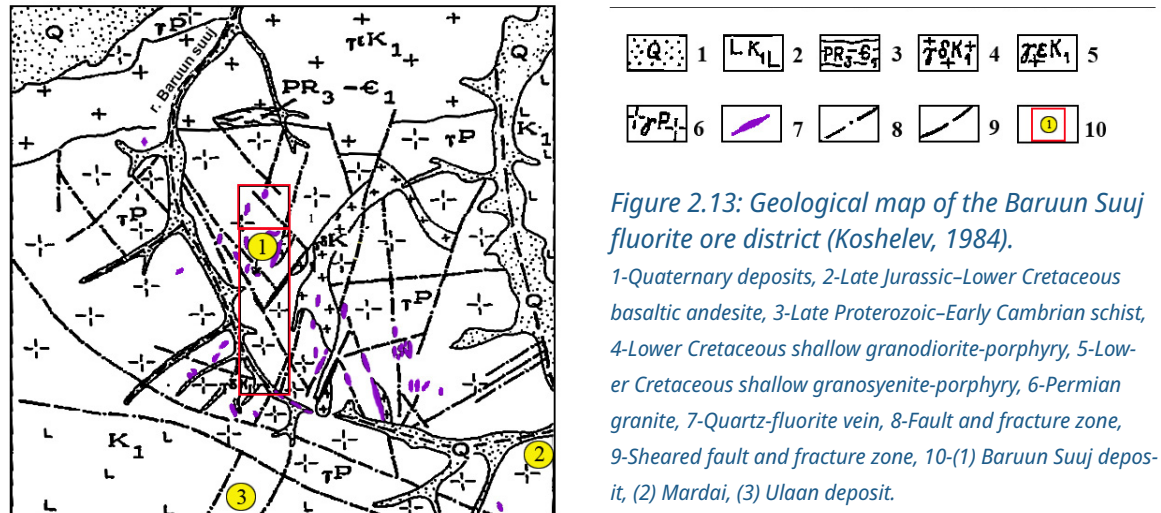


Figure 2.13: Geological map of the Baruun Suuj fluorite ore district (Koshelev, 1984).

1-Quaternary deposits, 2-Late Jurassic-Lower Cretaceous basaltic andesite, 3-Late Proterozoic-Early Cambrian schist, 4-Lower Cretaceous shallow granodiorite-porphyry, 5-Lower Cretaceous shallow granosyenite-porphyry, 6-Permian granite, 7-Quartz-fluorite vein, 8-Fault and fracture zone, 9-Sheared fault and fracture zone, 10-(1) Baruun Suuj deposit, (2) Mardai, (3) Ulaan deposit.

**Breccia type:** The breccia type of mineralization is found near by Ulaan polymetallic deposit as a cementing mineral of sulfide minerals, such as galena, sphalerite and pyrite (Taotao et al., 2024). Here the fluorite content can reach up to 15%.

The fluorspar ore reserves of this deposit are recorded as 1.3 million tonnes with an average  $\text{CaF}_2$  content of 43% (Lkhamsuren et al., 2021).

### 2.3.1.3 Bor Undur deposit

#### Location and infrastructure

The Bor Undur deposit is located 280 km southeast of Ulaanbaatar, 78 km east-southeast of Choir soum, Govisumber province, 48 km north-northeast of the Khar Airag railway station and 42 km southeast of Darkhan soum, Khentii province. The Bor Undur processing plant is connected to Khar Airag by paved roads and railway, offering strong infrastructure support.

#### Geological structure

The geological structure of the Bor Undur fluorite deposit includes Lower Permian volcanic rocks, Upper Jurassic-Lower Cretaceous volcanic-sedimentary rocks, Triassic granitoids and Lower Cretaceous hydrothermalites.

The Bor Undur fluorite deposit is situated at the boundary of the Proterozoic-Mesozoic Bor Undur tectonic uplift and the Late Mesozoic Alag Tsav volcanic-tectonic basin. Tectonic fractures significantly influenced the formation of the deposit, playing a crucial role in the fluorite mineralization process (Figure 2.14).

#### Mineralization

The Bor Undur deposit consists of 2 sections (Bor Undur 1 and Bor Undur 2). Bor Undur 1 consists of 3-4 steeply dipping ore bodies with an average length of 250 meters, a thickness of 1.5-2.0 meters, and an average  $\text{CaF}_2$  content of 47%. Bor Undur 2 is larger, consisting of 10 steeply dipping ore bodies with a length of 1,100 meters (Koshelev 1984), a thickness of 4-5 meters that increases to up to 10 meters in the middle section, and a proven depth of 370 meters. The average  $\text{CaF}_2$  content of the ore is 40-45% (Figures 2.14 and 2.15). Thermobarogeochemical studies indicate that fluorite formed at temperatures between 125-50°C.



More than 20 ore bodies have been identified at the surface in total. The largest and most ore-rich among these are the 5th and 11th ore bodies (Figures 2.15 and 2.16).

The ore body 5 is 810 meters long with an average thickness of 9 meters. When traced with a 400-meter deep borehole, it was found to consist of multiple branches with high-grade (19-85%) ore. The richest section is located between the 1,160-1,260 meters depth.

As seen in Figure 2.15, the majority of the ore body is more than 10 meters thick and this thick section is found at depths between 1,060-1,260 meters.

### Mineralogy

The main ore minerals are quartz and fluorite. Accompanying minerals in smaller quantities include kaolinite, chlorite, clay mica, montmorillonite, iron and manganese oxides, calcite and, less commonly, pyrite, marcasite, barite, sphalerite, galena, wulfenite and anglesite.

The fluorite ore exhibits vertical zoning in their mineral composition. In the lower section, chalcedony-quartz is dominant, with fluorite and small amounts of pyrite, galena and sphalerite are present. In the middle section, there is a minor accumulation of kaolinite. In the upper section, the amount of calcite increases, accompanied by pyrite, kaolinite, clay mica, montmorillonite and iron and manganese oxides.

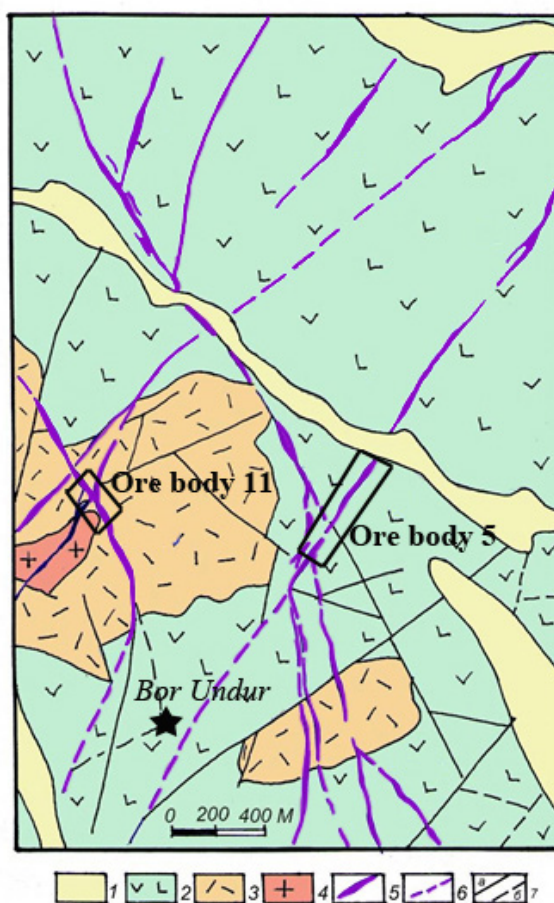


Figure 2.14: Geological map of the Bor Undur fluorite deposit (Lamukhin et al., 1982 and Ukhnaa et al., 2019).

1-Quaternary deposits, 2-Lower Cretaceous- Upper Jurassic volcanic-sedimentary rocks, 3-Lower Permian volcanic rocks, 4-Triassic granite, 5-Ore body, 6-Ore-bearing fractures, 7-Tectonic fractures, a-confirmed, b-hypothesized.

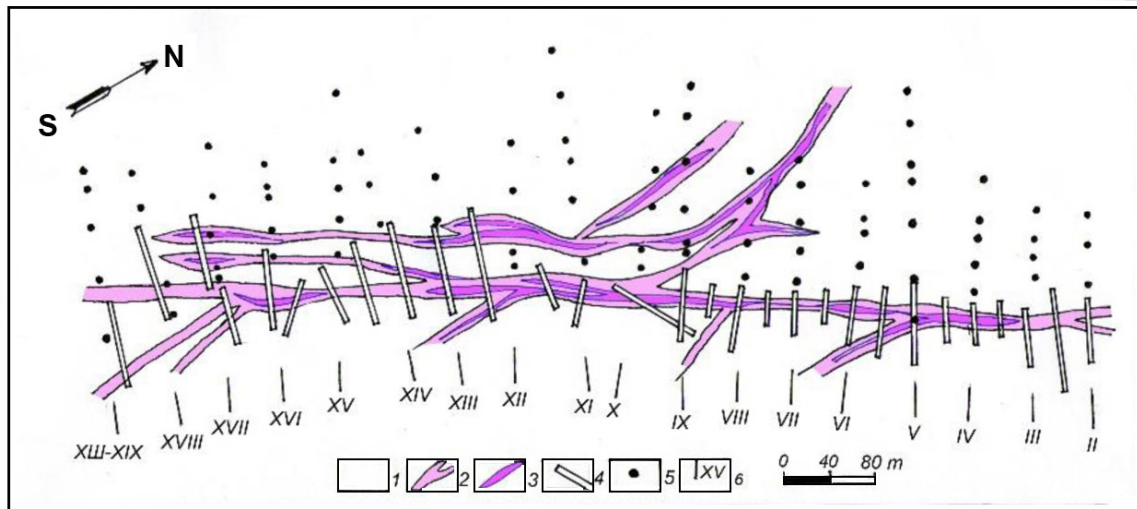


Figure 2.15: Bor Undur deposit, exploration plan of ore body 5 (Lamukhin et al., 1982 and Ukhnaa et al., 2019). 1-Host rock, 2-Mineralized zone, 3-Ore body, 4-Trench, 5-Borehole, 6-Exploration line and its number.

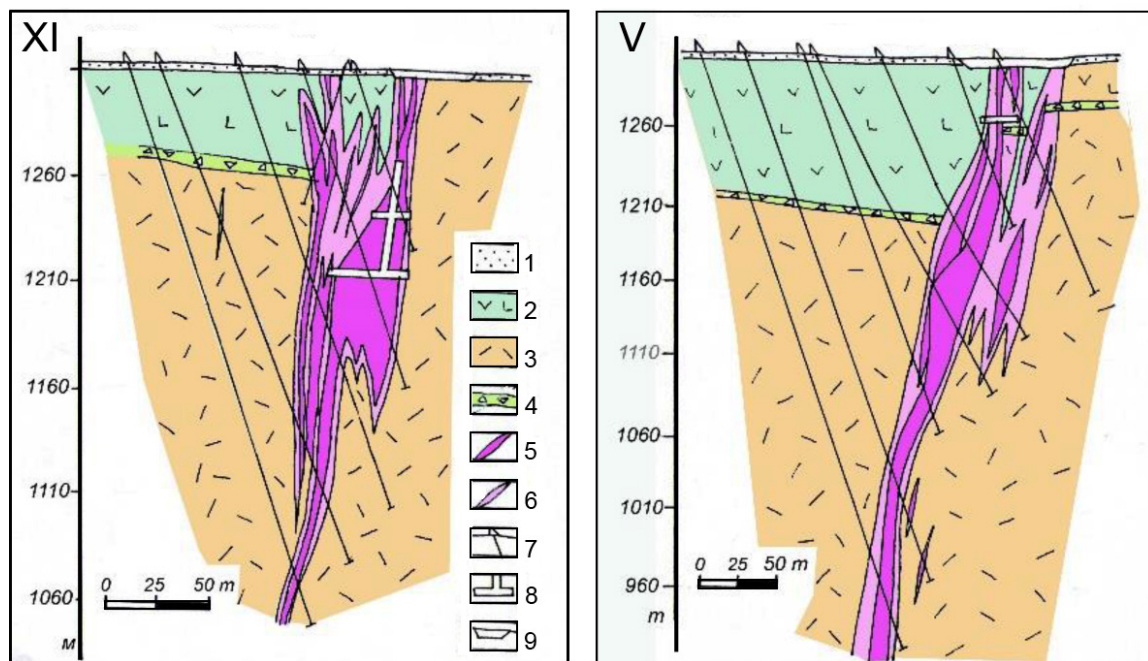


Figure 2.16: Bor Undur deposit, ore body 5, cross section along exploration lines 5 and 11 (Lamukhin et al., 1982 and Ukhnaa et al., 2019).

1-Quaternary sediment, 2-Volcanic-sedimentary rocks, 3-Permian volcanics, 4-Horizontal fracture, 5-Ore body, 6-Mineralized zone, 7-Borehole, 8-Underground workings, 9-Exploration trench.

### 2.3.1.4 Khamar-Us deposit

The Khamar-Us deposit is located 440 km southeast of Ulaanbaatar, 22 km north of Ikh Khet soum, Dornogobi province. The nearest railway stations are Khar Airag (110 km) and Choir (170 km), with access provided by a third-class gravel road. The infrastructure in the area is relatively well-developed

#### Geological structure

The Khamar-Us fluorite deposit is located in the western part of the Khamar-Us tectonic uplifted block. The deposit is formed within tectonic fractures in Permian and Middle to Upper Jurassic effusive rocks. The structure of the deposit is characterized by faulting along longitudinal fractures (Figure 2.17). The Lower Permian brecciated effusive rocks are widely distributed in the central and eastern parts of the deposit.

#### Mineralization

The deposit area is characterized by the ore bodies of epithermal quartz-fluorite and occasionally carbonate-quartz-fluorite vein-type bodies. The most widespread mineralization is the quartz-fluorite veins. The most significant ore bodies are Ore bodies I and II (Figure 2.18).

The quartz-fluorite ore bodies extend continuously along the strike for 150-280 meters, with average thickness of 4.4-5 meters (sometimes reaching up to 16-18 meters.) There is significant hydrothermal alteration, including argillization, silicification and smaller-scale alterations such as chloritization, carbonatization, fluoritization, pyritization and limonitization. The average  $\text{CaF}_2$  content ranges from 35% to 45% (Ukhnaa, 2019).

The host rock is heavily altered. Ore bodies I and II, rocks are commonly affected by kaolinization. The thickness of clay alterations, such as argillization and kaolinization, ranges from 4 to 46.5 meters at the surface.

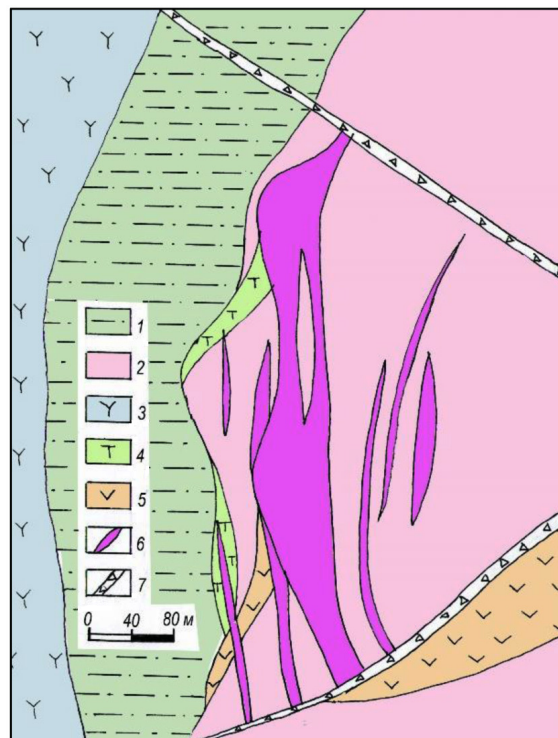


Figure 2.17: Geological map of the Khamar Us deposit (Petrenko et al., 1980 and Ukhnaa et al., 2019).

1-Paleogene-Neogene gravel, clay, conglomerate, 2-Lower Permian volcanic rocks, 3-Basaltic andesite, 4-Tuff-gravelite, tuffargillite, 5-Andesite porphyry, 6-Ore body, 7-Fracture zone

#### Mineralogy

The main useful minerals and harmful impurities in the ore body are shown in Table 2.5.

Technological tests showed promising results in ore beneficiation using the froth flotation method, achieving a concentrate with a  $\text{CaF}_2$  content of over 95%.

The fluorspar ore reserves of this deposit are recorded at 1.6 million tonnes, with an average  $\text{CaF}_2$  content ranging from 35.6% to 43.4% (Lkhamsuren et al., 2021).



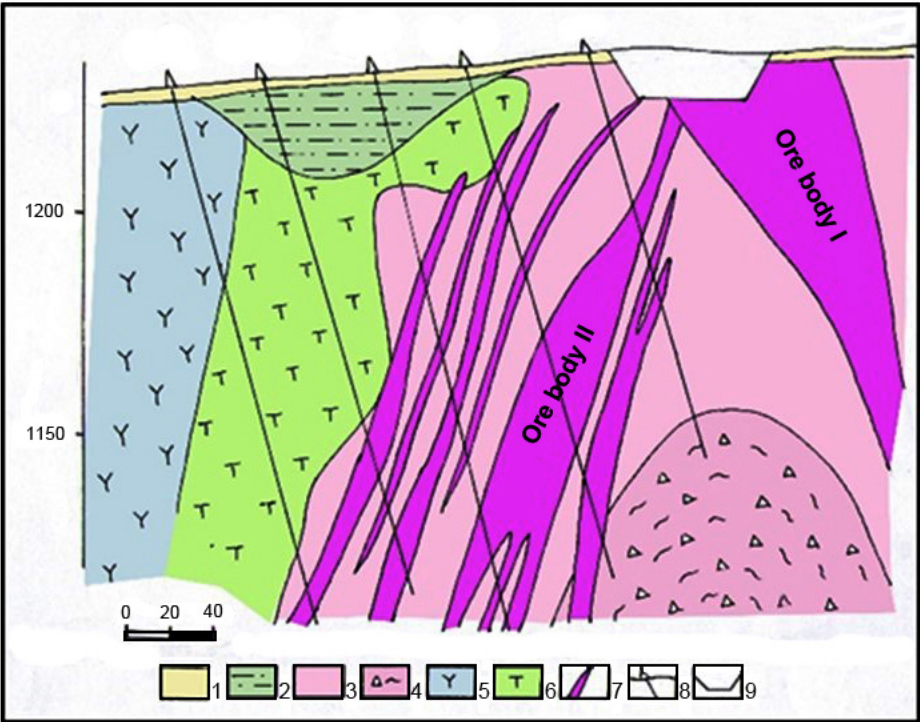


Figure 2.18: Geological section of the Khamar Us deposit (Petrenko et al., 1980 and Ukhnaa et al.,2019).  
1-Quaternary sediment, 2-Paleogene-Neogene gravel, clay, conglomerate, 3-Lower Permian volcanic rocks, 4-Tuff breccia, 5-Ba-  
saltic andesite, 6-Tuff-gravelite, tuffargillite, 7-Ore body, 8-Borehole, 9-Quarry boundary.

Table 2.5: Chemical composition of the ore at Khamar Us deposit.

| № | Minerals                       | Open pit   | Open pit    | Underground |
|---|--------------------------------|------------|-------------|-------------|
|   |                                | Ore body I | Ore body II |             |
| 1 | CaF <sub>2</sub>               | 40.53      | 41.73       | 42.92       |
| 2 | SiO <sub>2</sub>               | 40.49      | 42.32       | 38.79       |
| 3 | CaCO <sub>3</sub>              | 1.68       | 1.9         | 2.23        |
| 4 | BaSO <sub>4</sub>              | 0.38       | 0.37        | -           |
| 5 | P <sub>2</sub> O <sub>5</sub>  | 0.04       | 0.16        | 0.02        |
| 6 | Fe <sub>2</sub> O <sub>3</sub> | 1.07       | 3.05        | 3.36        |
| 7 | Stotal                         | 0.43       | 0.3         | 0.02        |

### 2.3.1.5 Zuun Tsagaan Del deposit

The Zuun Tsagaan Del fluorite deposit is located in the Ikh Khet soum of Dornogobi province. It is situated 400 km southeast of Ulaanbaatar, 20 km northwest of Ikh Khet soum and 100 km northeast of the Khar Airag railway station. The surrounding towns are connected by gravel roads.

#### **Geological structure**

The Zuun Tsagaan Del deposit is located on the western edge of the Olon Uhaa Basin, which is filled with Middle to Upper Jurassic volcanic rocks. The geological structure of the deposit includes the presence of basalt, basaltic andesite and porphyrite from the Middle to Upper Jurassic periods (Figure 2.19). The quartz-fluorite and quartz-carbonate-fluorite mineralization follows longitudinal fractures.

#### **Mineralization**

The largest and main ore bodies are Ore Bodies I, V, and VII, with lengths ranging from 300 to 550 meters and thicknesses varying from 3-5 meters to 8-10 meters. Smaller veins are located along fractures adjacent to the main vein. These smaller veins are typically 50-300 meters long and 1-2 meters thick (Figure 2.19 and 2.20).

The fluorspar ore reserves of this deposit are recorded as 7.5 million tonnes with an average  $\text{CaF}_2$  content of 32.7% (Lkhamsuren et al., 2021). According to the official website of Mongolrostsvetmet SOE, as of 2018, the remaining ore reserves of the Zuun Tsagaan Del fluorite deposit, classified as category B+C, amounted to 4.478 million tonnes with an average grade of 33.35%. The company plans to extract the ore using underground mining methods. (<https://www.mongolros.mn/a/9>)

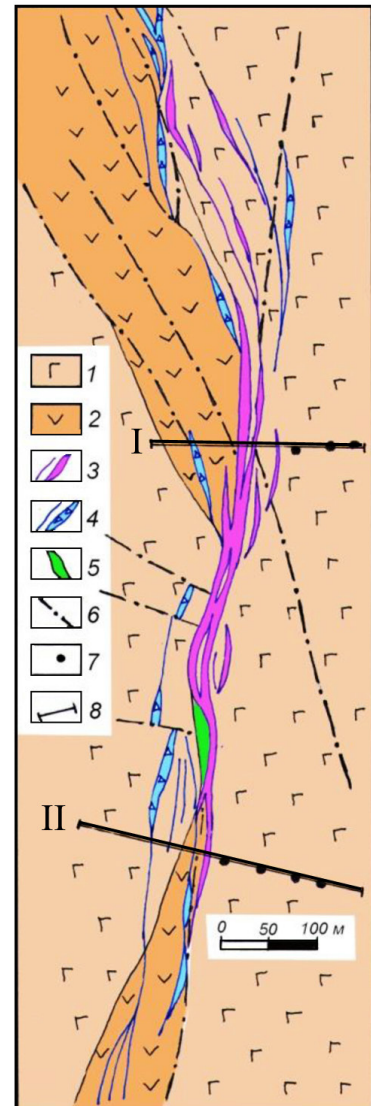


Figure 2.19: Geological map of the Zuun Tsagaan Del deposit (Bykov et al., 1975 and Ukhnaa et al., 2019).

1-Basalt, basaltic andesite, 2-Porphyrite, 3-Quartz-fluorite vein, 4-Quartz vein and siliceous breccia, 5-Carbonate-quartz-fluorite vein, 6-Tectonic fracture, 7-Borehole, 8-exploration line.

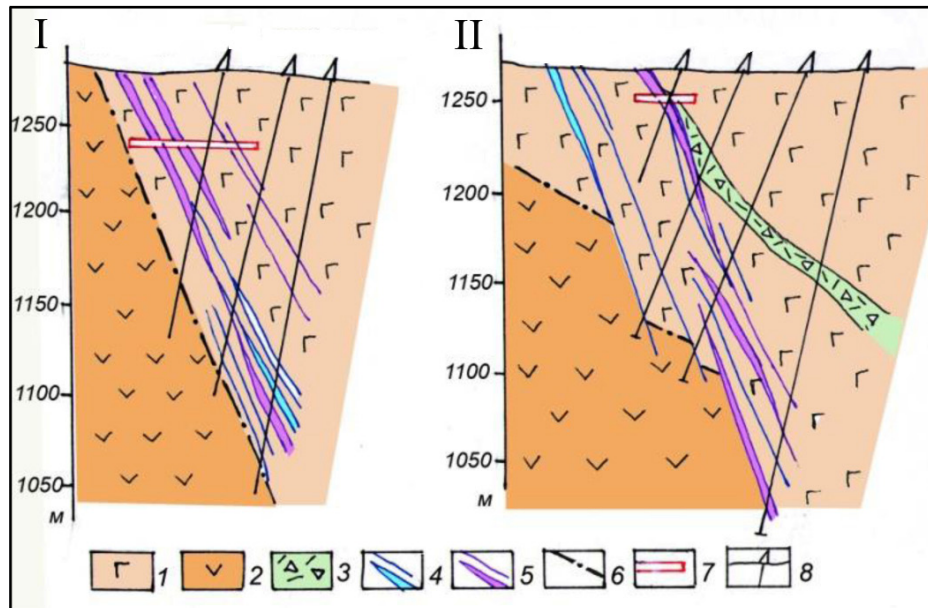


Figure 2.20: Geological and exploration sections of the Zuun Tsagaan Del deposit (Bykov et al., 1975 and Ukhnaa et al., 2019). 1-Basalt, basaltic andesite, 2-Porphyrite, 3-Tuff breccia, 4-Quartz vein and siliceous breccia, 5-Quartz-fluorite vein, 6-Tectonic fracture, 7-Underground workings, 8-Borehole.



Figure 2.21: Zuun Tsagaan Del mine, 70-meter depth, 65%  $\text{CaF}_2$ , 14 meters thick ore body 7 (Photo by Buyanbal, May 2024).



### Mineralogy

At greater depths, the quartz-fluorite veins are replaced by quartz-carbonate-fluorite veins. Hydrothermal-metasomatic alterations such as argillization, silicification, chloritization, carbonatization, pyritization and limonitization have occurred around the ore bodies.

The crude ore consists of following minerals, listed in decreasing order of abundance: fluorite, quartz, carbonate (calcite, siderite), clay minerals, iron oxide, manganese oxide, pyrite, apatite, chlorite, hematite, magnetite and jarosite.

By hand sorting the ore, a concentrate with an average  $\text{CaF}_2$  content of 76.31% can be obtained, achieving a recovery rate of 40.6%. By applying gravity and flotation methods, a concentrate with an average  $\text{CaF}_2$  content of 92.91% is produced, achieving a recovery rate of 46.6% (Ukhnaa, 2019). To reduce the carbonates in the ore, it is mixed with low-carbonate ore (from the Adag mine) for beneficiation (Batbold, geologist, Monrosvetmet SOE, 2024, oral communication).

#### 2.3.1.6 Khongor deposit

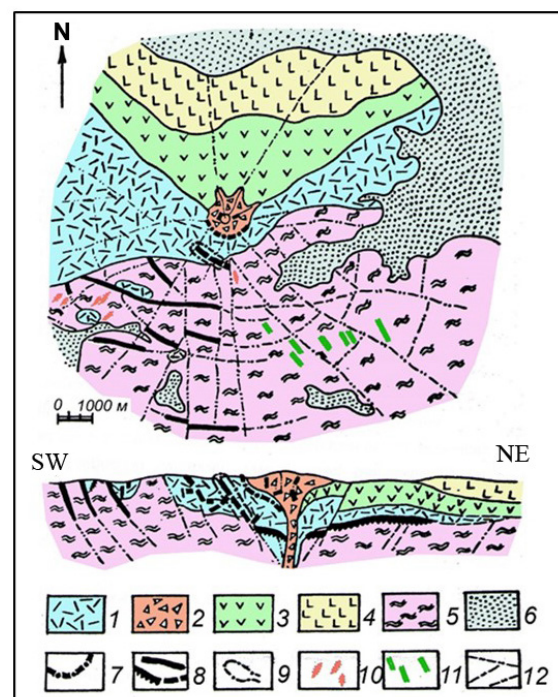
The Khongor fluorite deposit is located in the Airag soum, Dornogobi province. It is situated 290 km southeast of Ulaanbaatar, 27 km west of the Khar Airag railway station and 20 km southwest of Dalanjargalan soum, near the southeastern side of Ikh Khongor Ovoo. The deposit is located in the central part of the Khongor fluorite deposit area.

### Geological structure

The deposit consists of a group of 10 ore bodies known as the Khongor fluorite deposits. These deposits are located in the southwestern part of the Khongor volcanic-plutonic uplift. The geological structure of the uplift includes Pre-Cambrian crystalline shale and limestone, which are cut by Lower Paleozoic medium-grained granite formations and covered by Mesozoic acidic volcanic rocks. Around the center of the structure, near the paleovolcanic crater with a diameter of 150-250 meters, explosive breccias containing rhyolitic fragments with fluorite inclusions are spread (Figure 2.22).

Figure 2.22: Geological structure of the Khongor volcanic- tectonic structure (Batjargal et al., 1979).

1-4 - Upper Jurassic-Lower Cretaceous formations: 1-Trachyte, 2-Dacite, 3-Trachyandesite agglomerate, trachyandesite, 4-Basalt, basaltic andesite, their lava breccia and tuff breccia, 5-Fissile shale containing limestone layers, 6-Quaternary sediment, 7-Secondary quartzite, 8-Fluorite ore body, 9-Kaolinitic mineralized area, 10-Acidic vein bodies and subvolcanic bodies, 11-Basic dyke bodies, 12-Tectonic fractures



Among these deposits, Khongor-2 has been selected as an example. There are more than 20 ore bodies, with the 1st and 5th being the most significant.

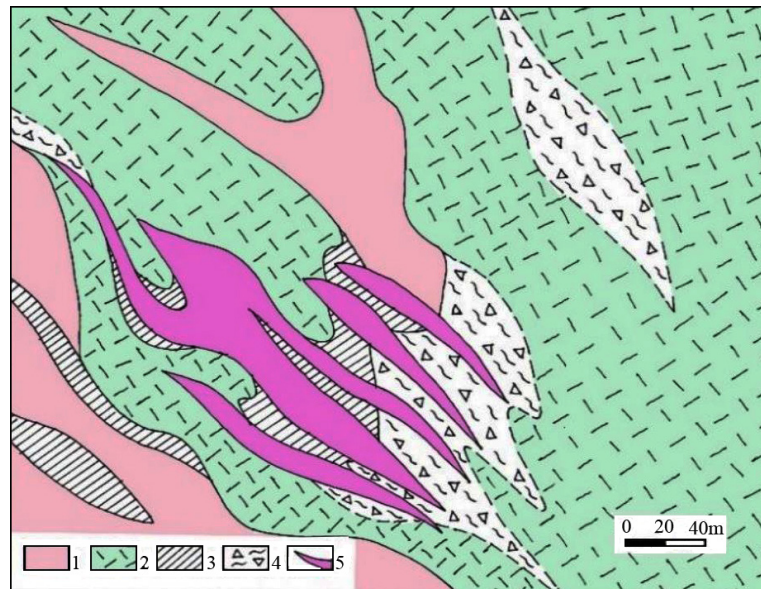


Figure 2.23: Geological map of the Khongor-2 deposit (Petrenko et al., 1979 and Ukhnaa et al., 2019).  
1-Sedimentary-metamorphic rocks, 2-Rhyolite, 3-Silicified zone, 4-Brecciated and silicified effusive rocks, 5-Fluorite ore bodies.

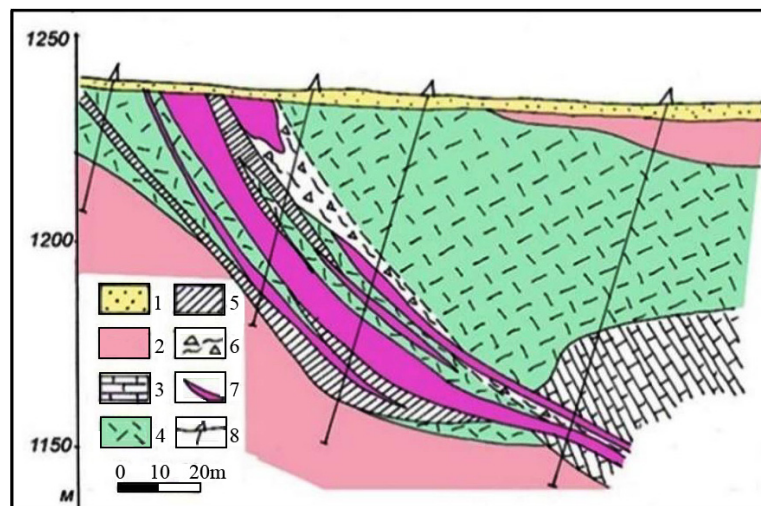


Figure 2.24: Geological section of the Khongor-2 deposit (Petrenko et al., 1979 and Ukhnaa et al., 2019).  
1-Covering sediment, 2-Metamorphic rocks, 3-Limestone, 4-Rhyolite, 5-Silicified zone, 6-Brecciated and silicified effusive rocks, 7-Fluorite ore bodies, 8-Exploration borehole.

### Mineralization

The quartz-fluorite veins and lenses extend along the strike for 100-350 meters, with thicknesses ranging from 1-2 meters to 15-20 meters (in some cases their thickness reaches 50-60 meters). At a depth of 120-150 meters, the ore body is hosted within marbled limestone, where its thickness sharply decreases and ultimately ends (Figures 2.23 and 2.24).

### Mineralogy

Chemical analysis to determine the contents of  $\text{CaF}_2$ ,  $\text{SiO}_2$  and  $\text{CaCO}_3$  in the samples was conducted at the Central Geological Laboratory of Mongolia. The beneficiation of the technological sample with 20.85% calcium fluoride ( $\text{CaF}_2$ ) resulted in a concentrate with  $\text{CaF}_2$  content of 93.94% (FF-92 grade).

The fluor spar ore reserves of the Khongor 1 and 2 deposits (apparently owned by CM Kings LLC) are recorded as 0.25 million tonnes with an average  $\text{CaF}_2$  content of 33.9% and 0.52 million tonnes with an average  $\text{CaF}_2$  content of 33.6%, respectively (Lkhamsuren et al., 2021).

#### 2.3.1.7 Bayan-Ovoo (Avdrant) deposit

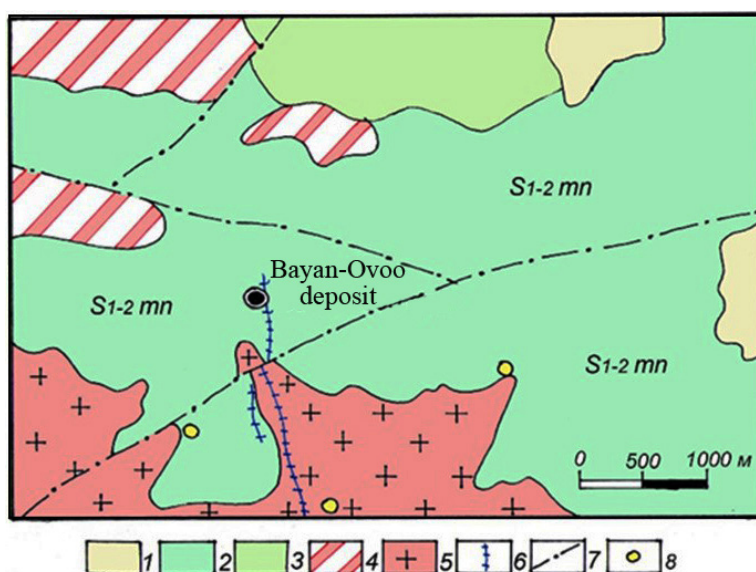
The Bayan-Ovoo fluorite deposit is located in the Mandal-Ovoo soum, Umnogobi province. It is situated 470 km southeast of Ulaanbaatar, 46 km southeast of Mandal-Ovoo soum and 2 km from Bayan Khoshuu. Detailed information regarding specific infrastructure such as transportation networks, power supply and processing facilities in the area is limited.

### Geological structure

The deposit is located in the Central Mongolia major fault zone that stretches along the latitude. This zone has been active from the Lower Paleozoic to the Late Mesozoic and contains a variety of valuable minerals, including rare metals and rare earth elements. For example, deposits such as Mushgai Khudag, Khotgor rare earth elements, iron, Bayan Khoshuu-strontium and Olon Ovoo-gold are situated not far from the fluorite deposit. In the ore field Silurian sedimentary and metamorphic rocks, Permian granite and Cretaceous sedimentary-volcanic rocks are present (Figure 2.25).

Figure 2.25: Geological map of the Bayan-Ovoo deposit area (Ozonov et al., 2012 and Ukhnaa et al., 2019).

1-Quaternary sediment, 2-Lower-Middle Silurian sandstone, aleurite, shale, 3-Lower Cretaceous conglomerate, sandstone, gravel, 4-Rhyolite, 5-Permian granite, 6-Quartz-fluorite vein, 7-Tectonic fracture, 8-Gold mineralization points.





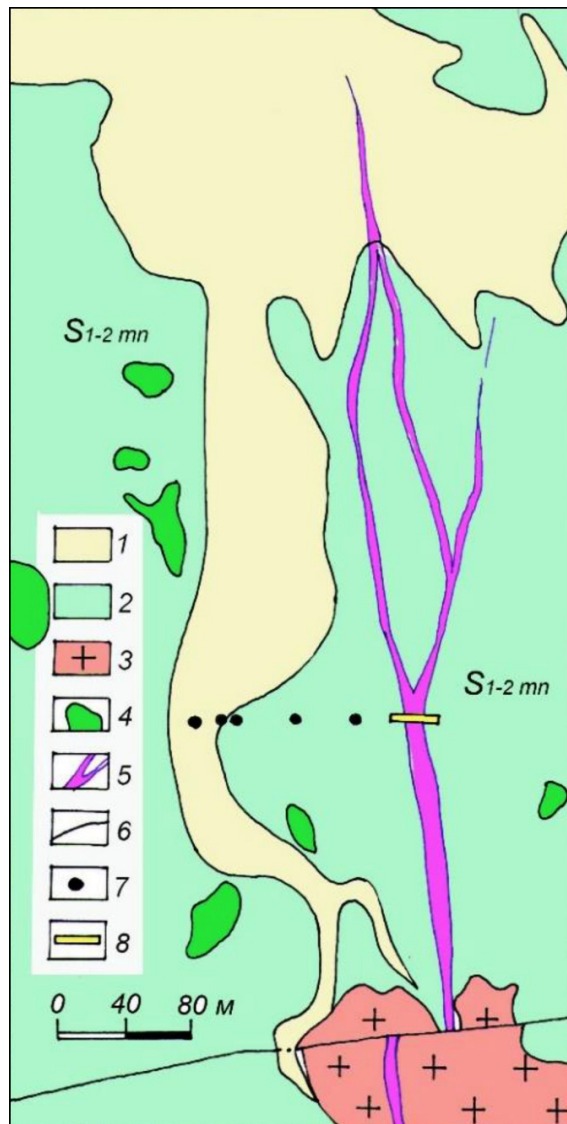


Figure 2.26: Ore body 1. Geological map of the northern part of the Bayan Ovoo deposit (Ozonov et al., 2012 and Ukhnaa et al., 2019).

1-Quaternary sediment, 2-Lower-Middle Silurian sedimentary-metamorphic rocks, 3-Permian granite, 4-Small bodies of diorite, 5-Fluorite ore body, 6-Fracture, 7-Borehole, 8-Channel.

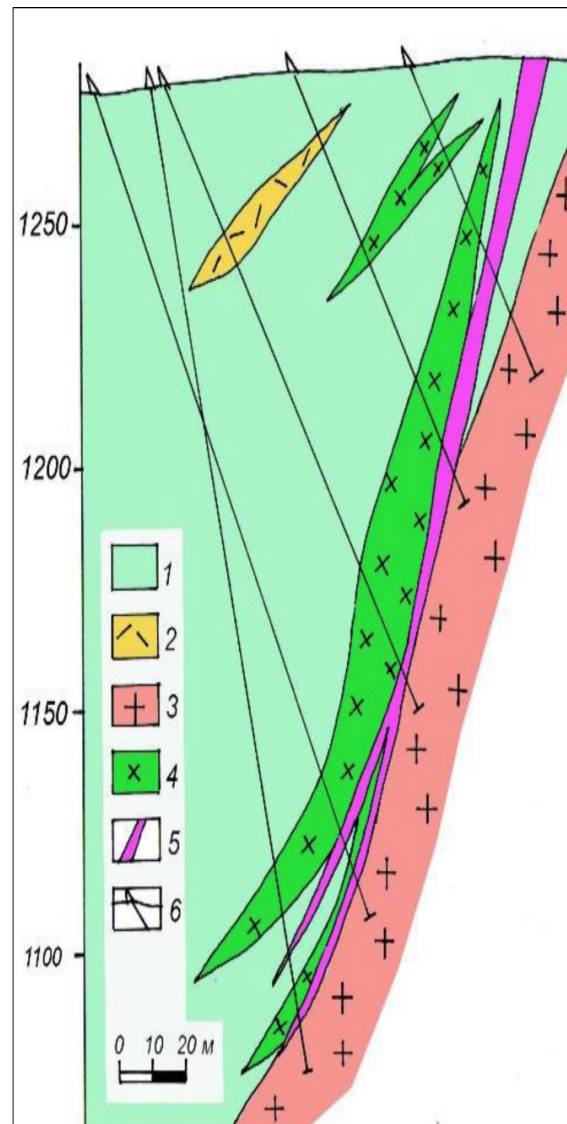


Figure 2.27: Exploration section (Ozonov et al., 2012 and Ukhnaa et al., 2019).

1-Lower-Middle Silurian sedimentary-metamorphic rocks, 2-Rhyolite body, 3-Permian granite, 4-Small diorite body, 5-Ore body, 6-Exploration borehole

### Mineralization

The mineralization type is epithermal quartz-fluorite vein. The Bayan-Ovoo fluorite deposit covers a total area of 10 km<sup>2</sup>, divided into four sections: Central, Western, Eastern and Southern. In the Central section, 15 ore bodies have been identified and only the exploration results for Ore Body 1 are presented here (Figure 2.26).

The Ore Body 1 to the north of this fracture continues for 800 meters. The ore body extends to a depth of 220 meters. The thickness of the ore body varies from 3.0 to 11.7 meters at the surface but decreases with depth. The average CaF<sub>2</sub> content in the ore is 54% (occasionally reaching up to 72%), while carbonate content ranges from 0.1% to 2.5% (Figure 2.27).

### Mineralogy

Laboratory analysis using spectral analysis of 44 elements revealed that the contents of S and P are within acceptable limits. The accompanying minerals include  $\text{CaCO}_3$ ,  $\text{SiO}_2$  and  $\text{BaSO}_4$ . Other minerals found in the ore include magnetite, ilmenite, limonite, amphibole, epidote, zircon, apatite, feldspar, fluorite-containing limonite, quartz and mica (Ukhnaa, 2019). The average content of  $\text{CaCO}_3$  ranges from 0.1% to 2.6%.

The fluorspar ore reserves of this deposit are recorded as 2.3 million tonnes with an average  $\text{CaF}_2$  content ranging from 44.5% to 88.2% (Lkhamsuren et al., 2021).

#### 2.3.1.8 Chuluut Tsagaan Del deposit

The Chuluut Tsagaan Del deposit is located in the Bayantsagaan soum, Tuv province. It is situated 145 km south of Ulaanbaatar, 20 km northeast of the center of Bayantsagaan soum, 45 km northeast of the Maanit railway station and 10 km southeast of Duut Tsagaan-Ovoo mountain.

The Chuluut Tsagaan Del deposit is located at the outer boundary of the Mesozoic granite massif, where it forms a stratiform ore with Upper Proterozoic to Lower Cambrian aged shale, limestone and porphyritic rocks. The deposit is situated within a folded anticline structure. During erosion and weathering processes, the top part of the anticline has been removed, leaving fluorite mineralization in the anticline's core and horizontal wings. The deposit consists of 8 ore bodies, with an estimated reserve of approximately 6.0 million tonnes of ore, classifying it as a large deposit. This deposit serves as a good representation of stratiform ore types (Figure 2.28).

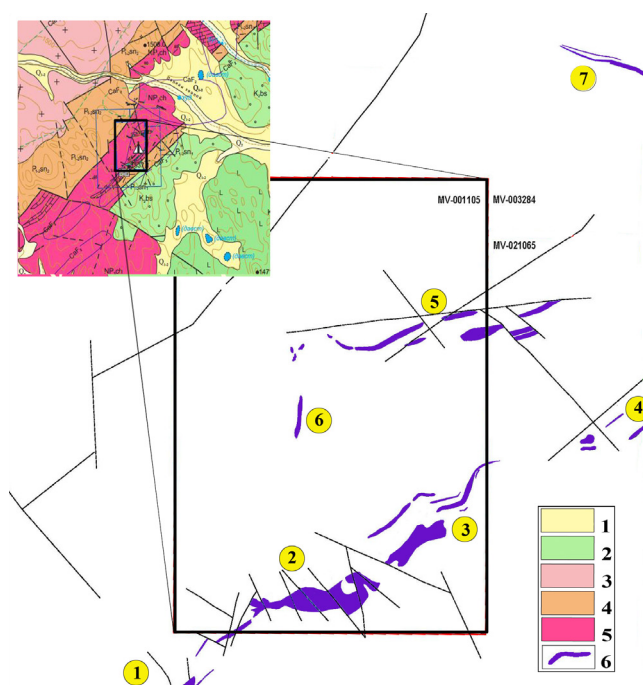


Figure 2.28: Geological and mineralization map of the Chuluut Tsagaan Del fluorite deposit (map created by consultant geologist Banzragch.J, 2024).

1-Quaternary sediments, 2-Cretaceous alkaline volcanics, 3-Late Triassic to Early Jurassic leucocratic granite, 4-Permian sedimentary rocks and quartzite, 5-Neoproterozoic schist and limestone, 6-Ore body.



Figure 2.29: Chuluut Tsagaan Del fluorite mine, ore body 2 (photo by Tumenbayar.B, 2023).  
1 Fluorite bearing limestone, 2. Metamorphic rock.



Figure 2.30: Chuluut Tsagaan Del fluorite concentration plant. (Commenced in 2024, photo: <https://www.unuudur.mn/a/260453>).



### **Geological structure**

There are 8 ore bodies in Chuluut Tsagaan Del, with Ore bodies 2 and 5 being the most significant. Ore body 2 has an average length of 700 meters, a thickness of 40 meters, a proven depth of 220 meters, and an average  $\text{CaF}_2$  content of 48%.

### **Mineralization**

The Chuluut Tsagaan Del mine is composed of 8 different ore bodies, with 3.6 million tonnes of fluor spar ore reserves that have an average content of calcium fluoride ( $\text{CaF}_2$ ) 43%. Currently, mining operations are being carried out in ore bodies 2 and 5. Additionally, exploration activities are ongoing to reassess the reserve of ore bodies 4 and 7. (Mongolczechmetall LLC, Fluorine Forum 2024)

### **Mineralogy**

An analysis of a selected ore sample shows  $\text{Fe}_2\text{O}_3$  at 0.51%, As at 17 ppm, Hg at 14 ppm, and  $\text{BaSO}_4$  at 212 ppm (Industrial Minerals, 2011).

Mongolczechmetall LLC, the owner of Chuluut Tsagaan Del deposit, annually produces 25,000-35,000 tonnes of metspar containing 65%-85% of  $\text{CaF}_2$  and 80,000 tonnes of low grade ore for the global market. The products are supplied through the border crossings of the Altanbulag and Zamiin-uud. (Mongolczechmetall LLC, Fluorine Forum 2024)

*Table 2.6: Mineral contents of metallurgical grade fluorspar (Mongolczechmetall LLC)*

| Type | $\text{CaF}_2\%$ min | $\text{SiO}_2\%$ max | $\text{CaCO}_3\%$ max | S% max | P% max |
|------|----------------------|----------------------|-----------------------|--------|--------|
| ΦK92 | 92                   | 5.0                  | 1.05                  | 0.03   | 0.03   |
| ΦK85 | 85                   | 5.0                  | 1.2                   | 0.03   | 0.03   |
| ΦK80 | 80                   | 5.6                  | 1.0                   | 0.03   | 0.03   |
| ΦK75 | 75                   | 17.5                 | 1.83                  | 0.06   | 0.06   |
| ΦK65 | 65                   | 28.6                 | 2.1                   | 0.06   | 0.06   |

In the future, Mongolczechmetall LLC will focus on construction of a new concentrator in an area with rich feldspar resources, establishment of a hydrofluoric acid (HF) plant based on the concentrate reserves and building of construction material factories using dry waste from its concentration plant. (Mongolczechmetall LLC, Fluorine Forum 2024)

### **2.3.1.9 Urgun deposit**

The Urgun fluorite deposit is located 490 km southeast of Ulaanbaatar in Urgun soum, Dornogobi province. It is situated 3 km southwest of Urgun soum and 60 km southeast of Sainshand. The deposit is well-connected to power, railway and paved road infrastructure, making it easily accessible with good infrastructure.

### **Geological structure**

The Urgun ore field is located in the northern part of the Bargin Ovoo uplift, covering an area of 12 km<sup>2</sup> and 17 fluorite ore zones have been identified within the deposit area (Tsetsenpil et al., 1988). This structure is composed of Riphean-Vendian-aged, hyperbasite-bearing, shale and marbled limestone sedimentary-metamorphic rocks, which are intruded by Permian granite. Fluorite mineralization occurs in layers within the Riphean-Vendian limestone and marbled limestone (Figure 2.31).

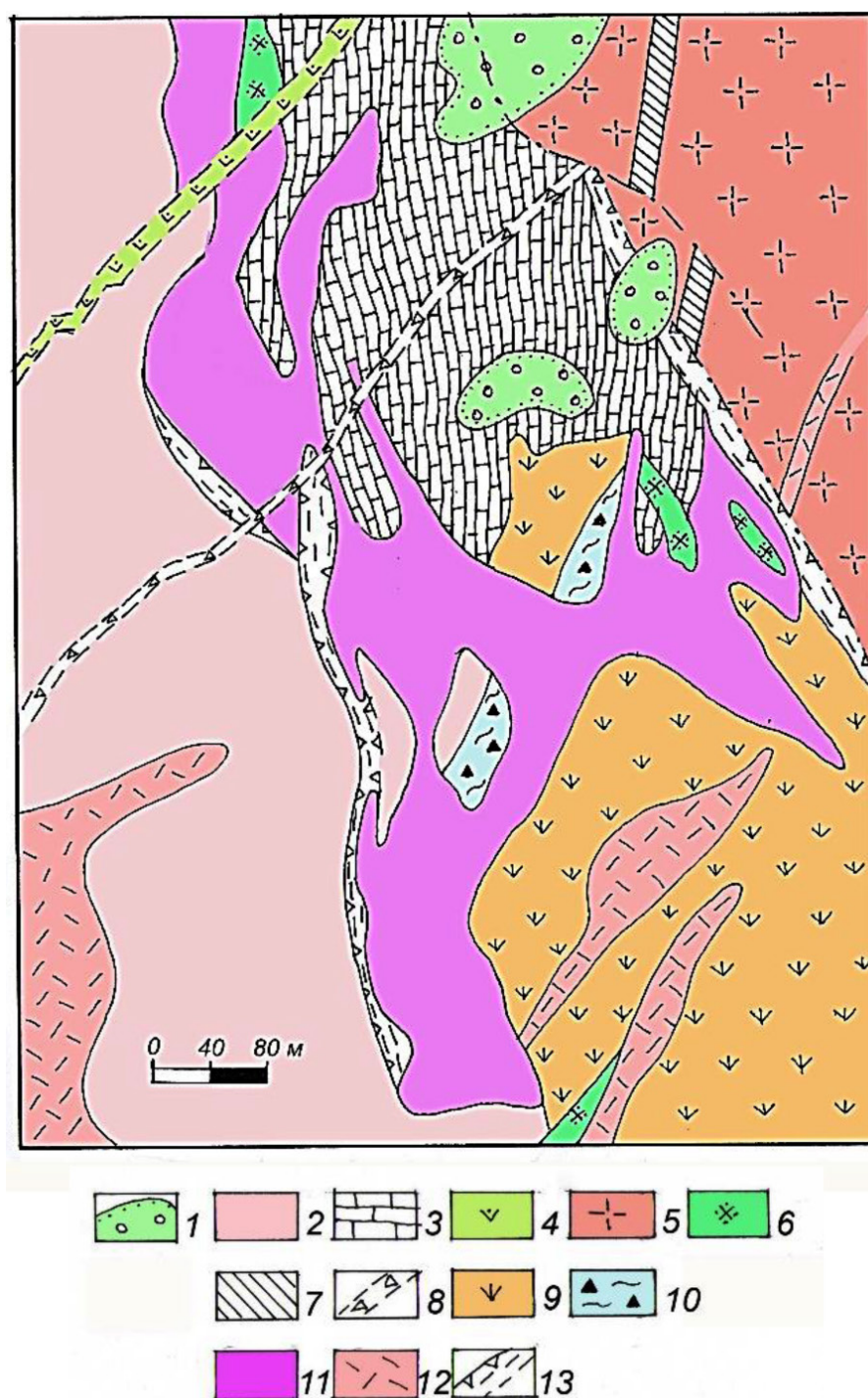


Figure 2.31: Geological map of the Urgun deposit (Tsetsenpil et al., 1987 and Ukhnaa et al., 2019).  
 1-Basaltic andesite, Upper Riphean-Vendian, 2-Shale, 3-Limestone, 4-Andesite-porphry, 5-Permian granite, 6-Diorite porphyry,  
 7-Siliceous rocks, quartz, 8-Post-mineralization fractures, breccia zones, 9-Listvenitized hyperbasite, 10-Karst-affected rocks,  
 11-Fluorite ore bodies, 12-Rhyolite- porphyry, 13-Pre-mineralization fracture breccia zones.

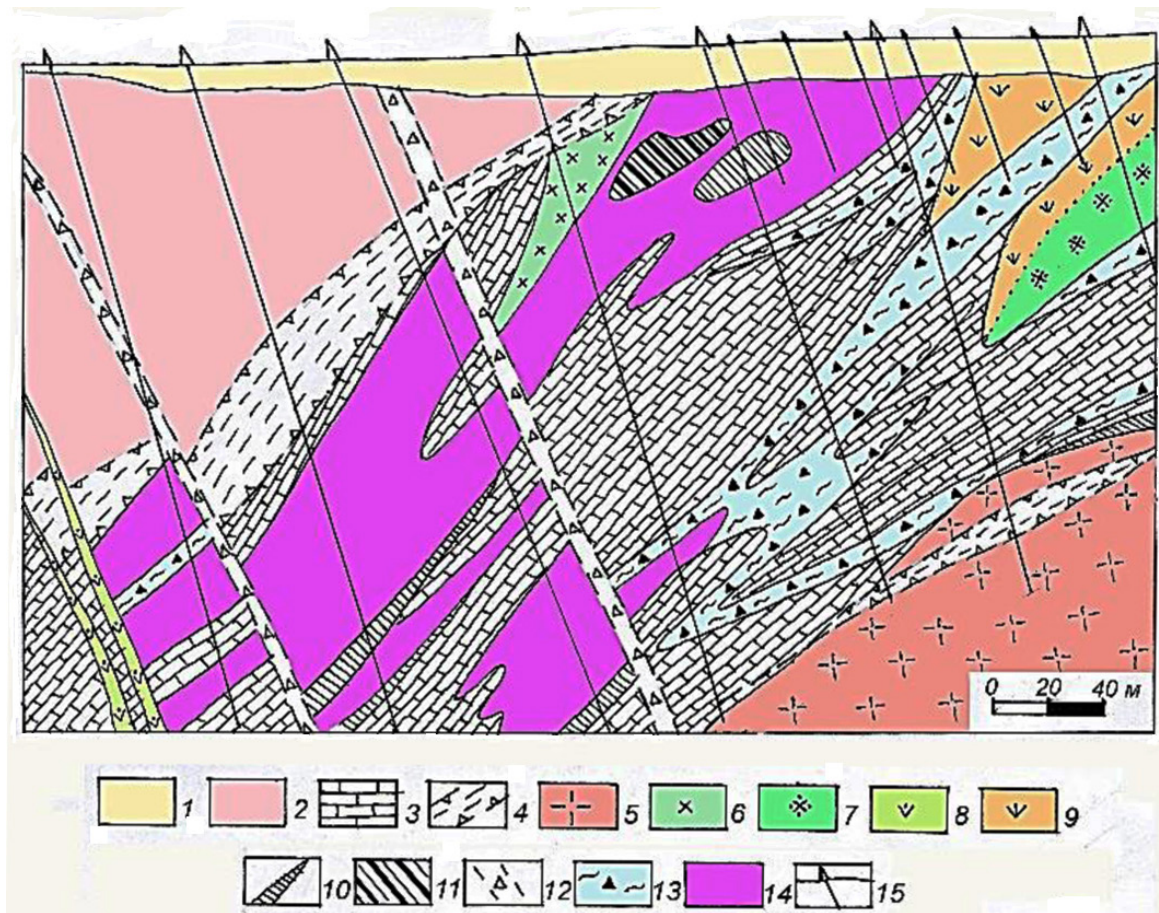


Figure 2.32: Geological section of the Urgun deposit, along exploration line VII (Tsetsenpil et al., 1987 and Ukhnaa et al., 2019)

1-Quaternary sediment and weathering soil, 2-Upper Riphean-Vendian: Shale, 3-Limestone, 4-Pre-mineralization, fractures, breccia zones, 5-Permian granite, 6-Microdiorite, 7-Diorite porphyry, 8-Andesite porphyry, 9-Listvenitized hyperbasite, 10-Siliceous rocks, quartz, 11-Skarn, 12-Post-mineralization fractures, breccia zones, 13-Karst-affected rocks, 14-Fluorite ore bodies, 15-Exploration boreholes, The unnumbered boreholes refer to exploitation exploration boreholes.

The fluorite-bearing limestone is approximately 200 meters thick, as elongated lens forms mesh-like bodies, occasionally associated with wollastonite, garnet-vesuvianite and skarn formations. The ore field is covered by Mesozoic volcanic rocks and Quaternary sediment to the north.

### Mineralization

Within the area, over 10 identified fluorite ore bodies, there are 6 ore bodies with an average thickness of 9-20 meters and 4 ore bodies with thicknesses ranging from 3.8 to 15.6 meters. The largest of these, Ore body 9, has a total length of 550 meters, a thickness ranging from 30 to 180 meters and a vertical mineralization extent of up to 250 meters. Ore body 9 is owned by Monrosvetmet LLC, while the other ore bodies are under the ownership of small private companies, both domestic and foreign.

Within this mineralized zone, the proportion of fluorite ore bodies and host rocks is nearly equal (Figure 2.32).



### ***Mineralogy***

Compared to other deposits with veins of similar composition, these veins have a higher  $\text{CaCO}_3$  content (4-30%) and an average  $\text{CaF}_2$  content of 30-45%. Deeper sections show a dominance of quartz-fluorite, carbonate-quartz-fluorite mineralization, with noticeable vertical zoning. The ore contains impurities such as iron, sulfur, phosphorus and barite, but technological sample analyses confirm that their levels are within acceptable limits. The beneficiation tests were conducted on two types of ores. These include:

- Low carbonate content ore (40.5%  $\text{CaF}_2$ , 5.5%  $\text{CaCO}_3$ ) was beneficiated with a fluorspar recovery rate of 73.6%, resulting in a concentrate with over 95% of  $\text{CaF}_2$ .
- High carbonate content ore (41%  $\text{CaF}_2$ , 13%  $\text{CaCO}_3$ ) was beneficiated with a fluorspar recovery rate of 84%, resulting in a concentrate with over 95% of  $\text{CaF}_2$ . These results were confirmed through laboratory testing.

## 2.3.2 Summary information on active and promising deposits

Table 2.7: Summary information on the deposits

| No | Deposit name                   | Company name                          | Address                                                                                                                               | Phone No                   | Country   |
|----|--------------------------------|---------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------|----------------------------|-----------|
|    | Tsagaan Del/Bilkh MV-006233    | Miraifluoride LLC                     | Ulaanbaatar, Khan-uul district, 15 khoroo, Namuun Tugul town, 3B                                                                      | 94007521, 99027707, 321450 | Mongolia  |
| 1  | Tsagaan Del/Bilkh MV-015234    | New Fluorite LLC                      | Ulaanbaatar, Bayangol district, 18 khoroo, 4 khoroolol 45-1                                                                           | 99132286, 99085286         | Mongolia  |
|    | Tsagaan Del/Bilkh MV-022281    | Ochir Mandal Khairkhan LLC            | Dundgobi, Ulziit 6, Rashaant, Bulgijn 1-112                                                                                           | 88000012                   | Mongolia  |
| 2  | Delgerkhaan MV-000166          | Wayo Fluorite LLC                     | Ulaanbaatar, Sukhbaatar, 1 khoroo, Shangri La office, 12F, 1206                                                                       | 77775151                   | Japan     |
| 3  | Bayan-Ovoo/Avdrant-1 MV-019336 | Mineral exploration funding LLC       | Ulaanbaatar, Chingeltei district, 1 khoroo, Labor palace, 9/1,7F, Ulaanbaatar, Khan-Uul district, 18 khoroo, Park Garden Plaza, 9-901 | 88891339                   | Mongolia  |
| 4  | Bor Undur MV-000174            | Mongolrostsvetmet SOE                 | Ulaanbaatar, Bayanzurkh district, Peace Avenue-98, "Mongolrostsvetmet" SOE                                                            | 458072, 458380             | Mongolia  |
| 5  | Baruun Suuj MV-012031          | Irves-Inter trade LLC                 | Ulaanbaatar, Khan-Uul, 15 khoroo                                                                                                      | 89005627                   | Mongolia  |
|    | Baruun Suuj MV-006391          | Irves-Inter trade LLC                 | Ulaanbaatar, Khan-Uul, 15 khoroo                                                                                                      | 89005627                   | Mongolia  |
| 6  | Dai Uul MV-012412              | Taishanshin yuan Foreign invested LLC | Ulaanbaatar, Bayangol district, 5 khoroo, 10 khoroolol, XulugCenter -101                                                              | 95537729                   | China     |
|    | Dai Uul MV-017042              | Lotus Dai Uul LLC                     | 201B Palazzo Office Building, 8 Tokyo St., Bayanzurkh District, Ulaanbaatar 13380, Mongolia.                                          | 459068                     | Singapore |
| 7  | Tuv Unegt MV-004306 Khukh Del  | Mongolrostsvetmet SOE                 | Ulaanbaatar, Bayanzurkh district, Peace Avenue-98, "Mongolrostsvetmet" SOE                                                            | 458072, 458380             | Mongolia  |
| 8  | Urgun MV-000164                | Mongolrostsvetmet SOE                 | Ulaanbaatar, Bayanzurkh district, Peace Avenue-98, "Mongolrostsvetmet" SOE                                                            | 458072, 458380             | Mongolia  |



| No | Deposit name                                  | Company name                 | Address                                                                                                      | Phone No           | Country         |
|----|-----------------------------------------------|------------------------------|--------------------------------------------------------------------------------------------------------------|--------------------|-----------------|
|    | Tsakhir Tolgod MV-017291<br>Khongor           | Talst Dul LLC                | Dornogovi, Dalanjargalan, "Kevin Invest" LLC, manufacture, Ulaanbaatar, Sukhbaatar district, 1 khoroo 87-305 | 99096800           | Mongolia        |
| 9  | Khongor-3<br>MV-017256                        | Khudrent LLC                 | Ulaanbaatar, Sukhbaatar, 6 khoroo, Metro Business Center                                                     | 99006331           | Mongolia        |
|    | Khongor 1 and 2<br>MV-005692                  | CM Kings ForeignInvested LLC | Dornogovi, Airag 4, Tsagaan Durvulj, ZTSBE LLC building                                                      | 88101993           | Mongolia, China |
| 10 | Chuluut Tsagaan Del<br>MV-003284<br>MV-001105 | Mongolczechmetall LLC        | Ulaanbaatar, Khan-Uul, 11 khoroo, Dunjingarav, 48-2, Ulaanbaatar, Songinokhairkhan, 19 khoroo, Geology 30    | 631301, 631302     | Mongolia        |
|    | South Khar Airag/<br>Khar Airag<br>MV-008469  | BT Development LLC           | Ulaanbaatar, 3 khoroo, 5 khoroolol, KhD37, 49                                                                | 99096782, 88008632 | Mongolia        |
| 11 | Bor Tolgoi MV-000161<br>Khar Airag            | Mongolrostsvetmet SOE        | Ulaanbaatar, Bayanzurkh district, Peace Avenue-98, "Mongolrostsvetmet" SOE                                   | 458072, 458380     | Mongolia        |
|    | Nergui Tolgoi/Khar Airag<br>MV-015119         | Khos khuder miningLLC        | Ulaanbaatar, Bayanzurkh, 6 khoroo, 13 khoroolol, Peace Avenue, Anod 40-35                                    |                    | Mongolia        |
| 12 | Khamar Us<br>MV-000159                        | Mongolrostsvetmet SOE        | Ulaanbaatar, Bayanzurkh district, Peace Avenue-98, "Mongolrostsvetmet" SOE                                   | 458072, 458380     | Mongolia        |
| 13 | Zuun Tsagaan Del<br>MV-011722                 | Mongolrostsvetmet SOE        | Ulaanbaatar, Bayanzurkh district, Peace Avenue-98, "Mongolrostsvetmet" SOE                                   | 458072, 458380     | Mongolia        |

(<https://opendatalab.mn/> and other internet source)

### 2.3.3 Future prospects of fluorite production in Mongolia

#### **Current situation**

Most of Mongolia's fluorite exports come from major mines such as Bor Undur, Zuun Tsagaan Del, Chuluut Tsagaan Del, Khamar Us, Adag and Khukh Del. In recent years, the share of smaller mines and companies with beneficiation plants has increased. Additionally, many purchasing points for fluorite ore, such as Choir, Dalanjargalan and Khar Airag, are operational. These points are located near fluorite mines along the transportation routes and buy ore from local cooperatives, individuals and smaller companies at lower prices to supply foreign-invested beneficiation plants.

Currently, over 20 small beneficiation plants operate in Mongolia. These plants process and concentrate the ore, which is then exported at higher prices. Over 90% of these plants are foreign-invested (mainly from China) and they produce various types of fluorite, including hand-sorted high-grade fluorite, fluorite from dry separation and concentrate from flotation beneficiation methods. The ore supplied to these plants is mostly sourced from cooperatives, small companies and individuals, often extracted without proper planning (unsystematic mining). The increase in Mongolia's fluorite exports in recent years is also linked to the active involvement of these operations.

In Mongolia, fluorite deposits are classified into four categories based on reserves (Methodological Recommendations, 2019).

**Large and significant deposits:** These deposits with ore reserves of 1.5 to 5.0 million tonnes or more include major deposits such as Bor Undur, Chuluut Tsagaan Del, Zuun Tsagaan Del, Adag, Khukh Del, Urgun and Delgerkhaan. Among these, Bor Undur and Chuluut Tsagaan Del, which are actively mined, also have their own processing and beneficiation plants. Deposits like Urgun and Delgerkhaan are also confirmed to have significant reserves. Most of these deposits are under the control of state-owned and a few private companies.

**Medium-sized deposits:** These deposits have reserves of 0.5 to 1.5 million tonnes and are mainly under the control of private companies. This group includes many deposits such as Baruun Suuj, Bilkh, Avdrant, Khongor, Khavtsal and Zaraa. Most of these deposits are mined through open-pit mining, although a few, such as Zaraa and Khavtsal, which have high fluorite content, are mined using underground mining methods. These deposits have potential for increased reserves through further deep exploration. The extracted ore is mainly hand-sorted to separate high-grade *fluorite*, which is then exported, while the remaining material is sent to beneficiation plants for further processing and then exported.

**Small deposits and occurrences:** This group includes deposits with reserves of less than 0.5 million tonnes, mostly small mines that operate on a seasonal basis. These deposits account for approximately 50% of the total number of fluorite deposits. Mining is generally carried out through open-pit methods and in some cases, cooperatives or contracting companies lease the rights to mine. Sometimes, only a small part of the deposit is explored and mined. Additionally, micro-mining operations, where local cooperatives (or individuals) have obtained mining rights from local authorities, are also included in this group.

#### **Future prospects**

Most of the currently operating mines are conducting open-pit mining to depths of 20-30 meters, with a few mines extending to 50-70 meters. The reserves in open-pit mines are nearing depletion and there are prospects of transitioning to underground mining in the near future. However, at present,

this transition is still in its early stages. Many individuals, small businesses and cooperatives involved in underground mining are not meeting the technical safety requirements and lack professional expertise. This has led to collapses and even fatalities in some cases, as local workers, without sufficient training, carry out the mining operations. This situation poses challenges for future large-scale mining projects, as it could create uncertainty in planning and may have a negative impact on operations. The risk of accidents remains high and these issues will need to be addressed for the sector's sustainable growth and safety.

This indicates that a new phase in the development of fluorite mining is beginning in Mongolia, with the transition to underground mining methods.

The following image compares the fluorite deposits in Mongolia with those of major global deposits, based on reserves and grades. As shown, the fluorite deposits in Mongolia are comparable to those in other countries in terms of grade, but the reserves are relatively smaller (I), Figure 2.33). However, well explored Mongolian deposits with reserves of more than 1.0 million tonnes can compete with the large deposits of other countries (II), Figure 2.33). Considering that most of Mongolia's fluorite deposits have not been fully explored, the future prospects for increasing fluorite reserves in Mongolia look promising (Figure 2.33).

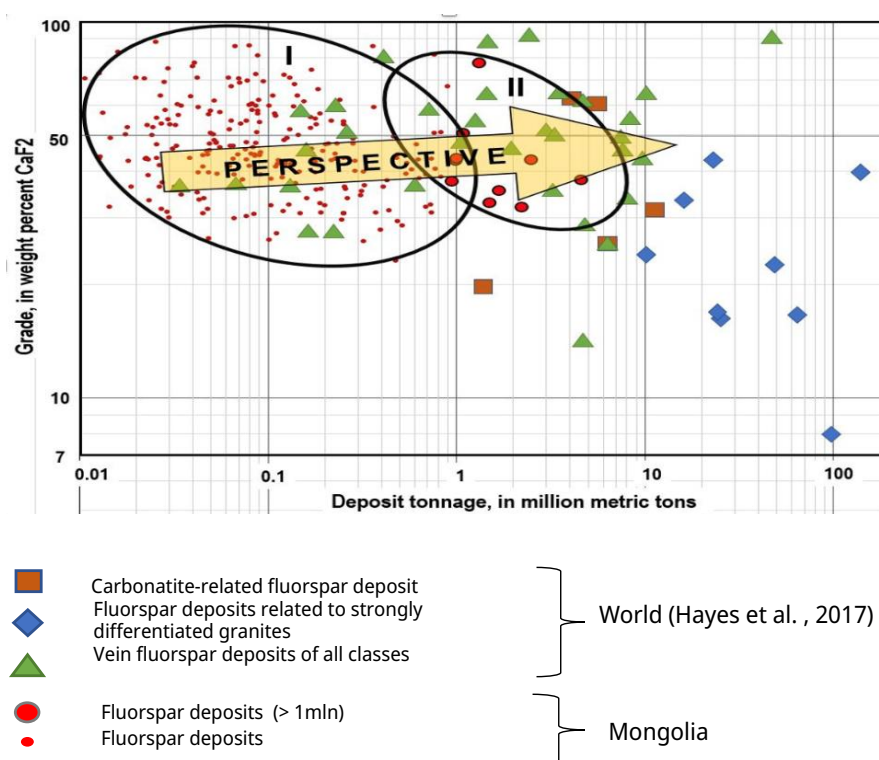


Figure 2.33: Future Prospects of Fluorite in Mongolia (Tumenbayar et al., 2024).

### 2.3.4 Possibility of extracting fluorite from tailings piles

Currently, all the low-grade ore piles (waste rock from the mining process) remaining from fluorite extraction in Mongolia have been depleted. Particularly in recent years, following the introduction of dry cyclone separation equipment funded by Chinese investment, waste rock from fluorite mines has been purchased, sorted into four categories and subjected to dry beneficiation. The high-grade ore is then mixed with the processed material and exported.

Currently, there could be two main methods for utilizing waste materials. These are: Reprocessing the low-grade tailings (8-10% grade) from beneficiation plants. This involves recovering fluorite from previously processed waste piles. Another approach is extracting fluorite from the residual ore at the boundaries of former underground mines. The latter method is still of interest to cooperatives and individuals but is considered dangerous to implement due to the risk of collapse. An example of this is the none balance ore from the Berkh mine (Figure 2.34).

On the diagram, areas marked in yellow represent unminable none balance ore and those marked in black indicate the mined-out blocks. (The diagram is from the Berkh Underground Mine Museum, by Ts. Zorig).

Brief Information: Berkh (Sanjaagiin Mine) is an epithermal quartz-fluorite deposit. It was mined for 40 years from 1954 to 1994, with high-grade ore reaching 97-98% content. The mining operation reached a depth of 417 meters, with 8 underground shafts extending 50 meters. Between the shafts, 3-4 meters thick fluorite ore was left behind. The company that privatized the Berkh Mine processed and sold out the high-grade tailings.

In Central and Eastern Mongolia, there are ore piles (waste rock from the mining process) from rare metal deposits such as Tumentsogt, Burentsogt, Egzur, Tsenkher Mandal, Chuluunkhoroot Ongon Khaikhan and Ikh Khaikhan, which contain metals like W, Mo, Sn, Pb, Nb and Ta. However, there is no available information on the fluorite content in these ore piles.

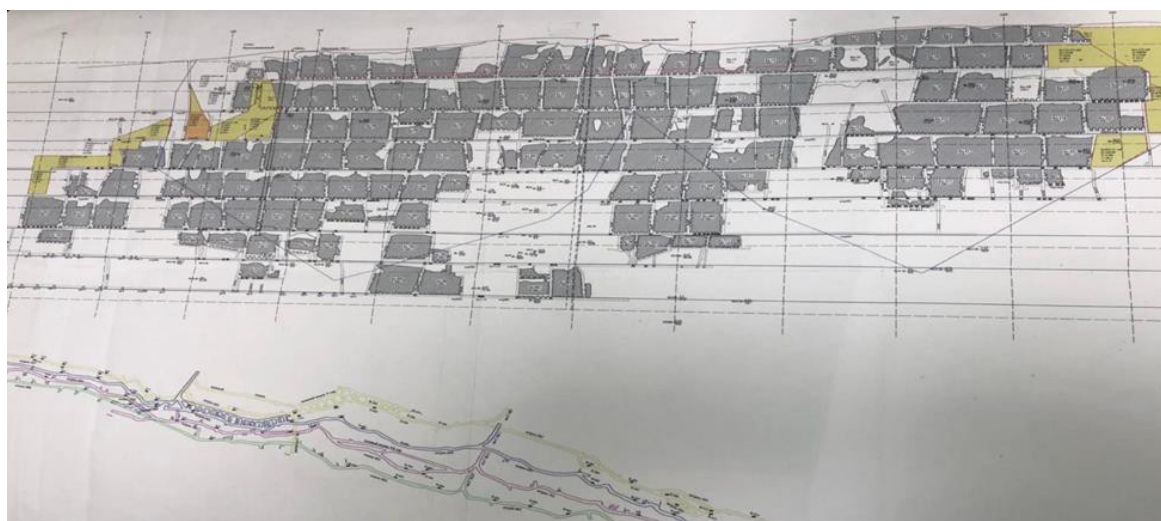


Figure 2.34: Schematic diagram of the underground mining operations at the Berkh Mine.

### Brief conclusion

The fluorite deposits of Mongolia can be categorized into two main types based on their practical significance: Quartz-Fluorite and Carbonate-Quartz Fluorite. Quartz-Fluorite deposits are relatively pure in terms of associated minerals and elements, with high fluorite content. Carbonate-Quartz Fluorite deposits are found within carbonate rocks, generally have lower fluorite content but are likely to form large stratiform deposits with substantial reserves.

Currently, most fluorspar production in Mongolia is transitioning from open-pit mining to underground mining. As a result, exploration efforts should be intensified below 300 meters to increase reserves. It is also essential to enhance the knowledge and skills of producers and miners, particularly in adopting advanced technologies and ensuring occupational health and safety.

Significant rare metal and rare earth element deposits containing fluorspar have been discovered in Central and Western Mongolia. These deposits present an opportunity to extract fluorspar as a by-product in the future. Therefore, thorough research and economic utilization of these resources are necessary to maximize the potential of the deposits.

In Eastern Mongolia, fluorspar (fluorine) is likely to be found in high concentrations within Upper Jurassic–Lower Cretaceous and Upper Cretaceous volcanic-sedimentary (tsagaan tsav) and sedimentary formations (shine khudag formation). It is critically important to accelerate exploration and research in these areas.

To process and enrich fluorspar ore domestically, and to produce fluorine compounds as final products, Mongolia needs to adopt advanced foreign technologies, expand and diversify its markets, and establish stable and reliable transportation and logistics systems, including transit routes through China and Russia.



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# 3

## **Mineralogy and geochemistry of samples from selected deposits**

*Dr. Khulan Berkh, BGR*

## Introduction

This chapter provides a detailed examination of the geochemistry and mineralogy of samples from selected fluorite deposits. The geochemical analysis will focus on the presence of accompanying raw materials and penalty elements, while the mineralogical study focuses on composition and textures of the samples to provide an important background information for the subsequent processing technology chapter.

## Materials and methods

Rock samples were collected from fluorite deposits in four major ore districts: Delgerkhaan (Berkh), Bor Undur-Galshar, Adaatsag-Maanit Uul, and Khar Airag-Bilkh Uul.

- Delgerkhaan (Berkh) ore district: Samples were collected from the Delgerkhaan deposit, operated by Bayan Chuluut Gazar.
- Bor Undur-Galshar ore district: Samples were obtained from the Bor Undur and Zuun Tsagaan Del deposits, both operated by the state-owned company Mongolroostvetmet.
- Adaatsag-Maanit Uul ore district: Samples were taken from the Tsagaan Del deposit, operated by Kherlen Impex.
- Khar Airag-Bilkh Uul ore district: Samples were collected from deposits including Khukh Del, Samartai, Altat, and Khongor (I, II, and III). These deposits are operated by Mongolroostvetmet, Kherlen Impex, BT Development, and CM Kings, respectively.

The selection of mines was based on their active status and reserve significance as well as mineralogical diversity as reported in the literature (Lkhamsuren & Majigsuren, 2021). Coordinates for all sampling locations are listed in Table 3.1. The number of samples collected at each site varied according to the heterogeneity of the rock formations. The companies Kherlen Impex and Mongolroostvetmet operate processing plants, which allowed an access to fluorite concentrates in addition to the crude ore samples.

The collected ore samples were cut using a diamond-coated saw blade and, along with the fluorite concentrates, sent to the Federal Institute for Geosciences and Natural Resources in Germany for analyses. The cut samples were scanned by a micro-energy dispersive X-ray fluorescence ( $\mu$ -EDXRF) spectrometer in order to obtain element distribution maps and bulk chemistry of the samples. The fluorite concentrates were investigated by a Scanning Electron Microscope (SEM) integrated with a Mineral Liberation Analyzer (MLA) in order to obtain modal mineralogy, grain size distribution, and mineral liberation characteristics.

Ore samples were named according to their respective deposits, whereas the fluorite concentrates were named after the owning companies, as the concentrates are produced from mixed materials sourced from several deposits.



Table 3.1: Summary information on deposits of analyzed samples

| Nr. | Deposit name      | Ore district name   | Locality                              | Owner               | Coordinates                 |
|-----|-------------------|---------------------|---------------------------------------|---------------------|-----------------------------|
| 1   | Delgerkhaan       | Delgerkhaan (Berkh) | Batnorov soum, Khentii province       | Bayan Chuluut Gazar | 47°44'18.1"N, 111°16'35.1"E |
| 2   | Bor Undur         | Bor Undur-Galshar   | Bor Undur soum, Khentii province      | Mongolros-tsvetmet  | 46°16'08.6"N, 109°26'33.1"E |
| 3   | Zuun Tsagaan Del* | Bor Undur-Galshar   | Ikh Khet soum, Dornogobi province     | Mongolros-tsvetmet  | 46°22'02.6"N, 110°02'28.8"E |
| 4   | Tsagaan Del       | Adaatsag-Maanit Uul | Airag soum, Dornogovi province        | Kherlen Impex       | 45°39'20.8"N, 109°05'52.7"E |
| 5   | Khukh Del*        | Khar Airag-Bilk Uul | Bayanjargalan soum, Dundgobi province | Mongolros-tsvetmet  | 45°30'51.7"N, 107°56'36.3"E |
| 6   | Samartai          | Khar Airag-Bilk Uul | Airag soum, Dornogovi province        | Kherlen Impex       | 45°21'56.0"N, 109°20'41.3"  |
| 7   | Altat             | Khar Airag-Bilk Uul | Airag soum, Dornogovi province        | BT Development      | 45°46'08.7"N, 109°23'13.1"E |
| 8   | Khongor I*        | Khar Airag-Bilk Uul | Airag soum, Dornogovi province        | CM Kings            | 45°48'13.3"N, 109°00'44.0"E |
| 9   | Khongor II        | Khar Airag-Bilk Uul | Airag soum, Dornogovi province        | CM Kings            | 45°48'22.7"N, 109°01'48.0"E |
| 10  | Khongor III       | Khar Airag-Bilk Uul | Airag soum, Dornogovi province        | CM Kings            | 45°47'54"N, 108°58'56.1"E   |

\*should contain calcite according to Lkhamsuren & Majigsuren (2021)

## 3.1 Geochemistry and mineralogy of ore samples

### 3.1.1 Delgerkhaan

The Delgerkhaan deposit is located in Batnorov soum, Khentii province. Several companies hold mining licenses for the Delgerkhaan deposit. However, majority of these companies are not yet operational. The samples for this study were collected from a section of the Delgerkhaan deposit operated by Bayan Chuluut Gazar.



*Figure 3.1: Adit to Delgerkhaan deposit (Photo: BGR).*

The majority of Mongolian fluorspar deposits were discovered using state funding during the Soviet era. Consequently, companies currently operating on these deposits are required to pay exploration fees to the Mongolian government. This requirement also applies to Bayan Chuluut Gazar.

The deposit features three ore horizons, which are being mined through two adits, each with a dip angle of 60 degrees. The fluorite veins in the deposit have a maximum width of approximately three meters.

The extracted material undergoes initial screening and washing before being sorted manually. The hand-sorted coarse ore lumps contain an average fluorspar grade of 60–75% and is directly exported to China. Fine materials generated during the sorting process are stockpiled in heaps.

A flotation plant is planned for the future to process these materials (oral communication).

Three samples (A-C) were taken at Delgerkhaan deposit shown in Figure 3.2. **Sample A** presents a strongly silicified and fluoritized country rock classified as low-grade ore. In the element distribution map, silicon (Si), potassium (K), calcium (Ca), and iron (Fe) are represented by green, purple, blue, and red, respectively. The image reveals a strongly silicified host rock intersected by fluorite veins. The fluorite veins contain lithoclasts enriched in K and Fe. A later generation of quartz veins cuts through this highly brecciated rock.



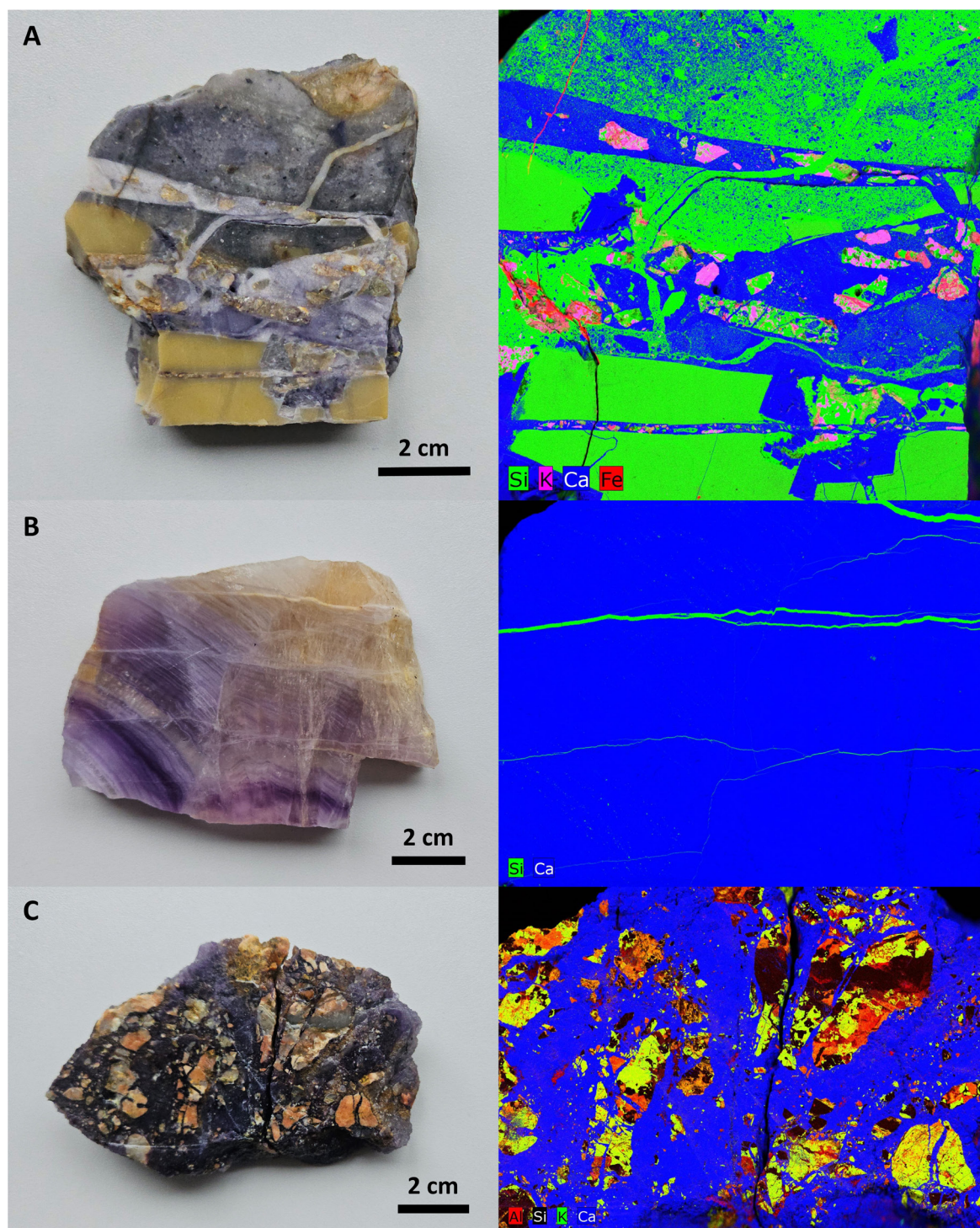


Figure 3.2: Photos (left) and element distribution maps in false colors (right) of hand specimens (A-C) from Delgerkhaan deposit.

**Sample B** consists of high-grade ore composed primarily of pure fluorite, with only minor quartz veinlets present. The layers exhibit varying colors, including white, yellow, and purple. The fluorite is nearly pure, containing strontium (Sr) concentrations ranging from 400 to 700 ppm. However, the distribution of Sr is diffuse and not restricted to specific layers.



**Sample C** is classified as moderate-grade ore. It consists of a fluorite vein containing strongly altered lithoclasts of the host rock, which are enriched in potassium (K), aluminum (Al), and silicon (Si). The host rock likely represents an andesitic composition, as the region is characterized by Upper Jurassic to Lower Cretaceous volcanic rocks, predominantly basalt and andesite, formed during tectonic-magmatic activity. Mineralogically, the deposit is classified as an epithermal fluorite deposit of the quartz-fluorite type (Lkhamsuren & Majigsuren, 2021).

In all three samples, hazardous elements such as arsenic (As), lead (Pb), cadmium (Cd) and mercury (Hg), as well as rare earth elements (REE) are below the detection limit (<100 ppm). Additionally, calcite is absent, which is advantageous for the flotation process. However, the presence of small lithoclasts intergrown with fluorite may negatively influence the grain liberation process.

#### 3.1.2 Bor Undur deposit

The Bor Undur deposit is located in Bor Undur soum, Khentii province and is operated by the state-owned company Mongolroostsvetmet. Mining at the Bor Undur deposit is conducted underground. Several ore bodies are identified. Currently, ore bodies 11 and 13 are being mined. The average fluorite content in the deposit is 27%, with a calcite content of 0.7%. Detailed geological information is provided in the previous chapter.



*Figure 3.3: Processing plant of Mongolroostsvetmet (Photo: BGR).*



*Figure 3.4: High grade ore lumps at Bor Undur Mine (Photo: BGR).*



Mongolroostsvetmet operates an ore processing plant at Bor Undur (Figure 3.3), capable of processing 550,000–600,000 tonnes of fluorspar ore annually from four different deposits including Bor Undur underground mine (230,000 tonnes), Hushuut-Adag underground mine (150,000 tonnes), Khukh Del open-pit mine (60,000 tonnes), and Urgun open-pit mine (100,000 tonnes) (Source: Mongolroostsvetmet website).

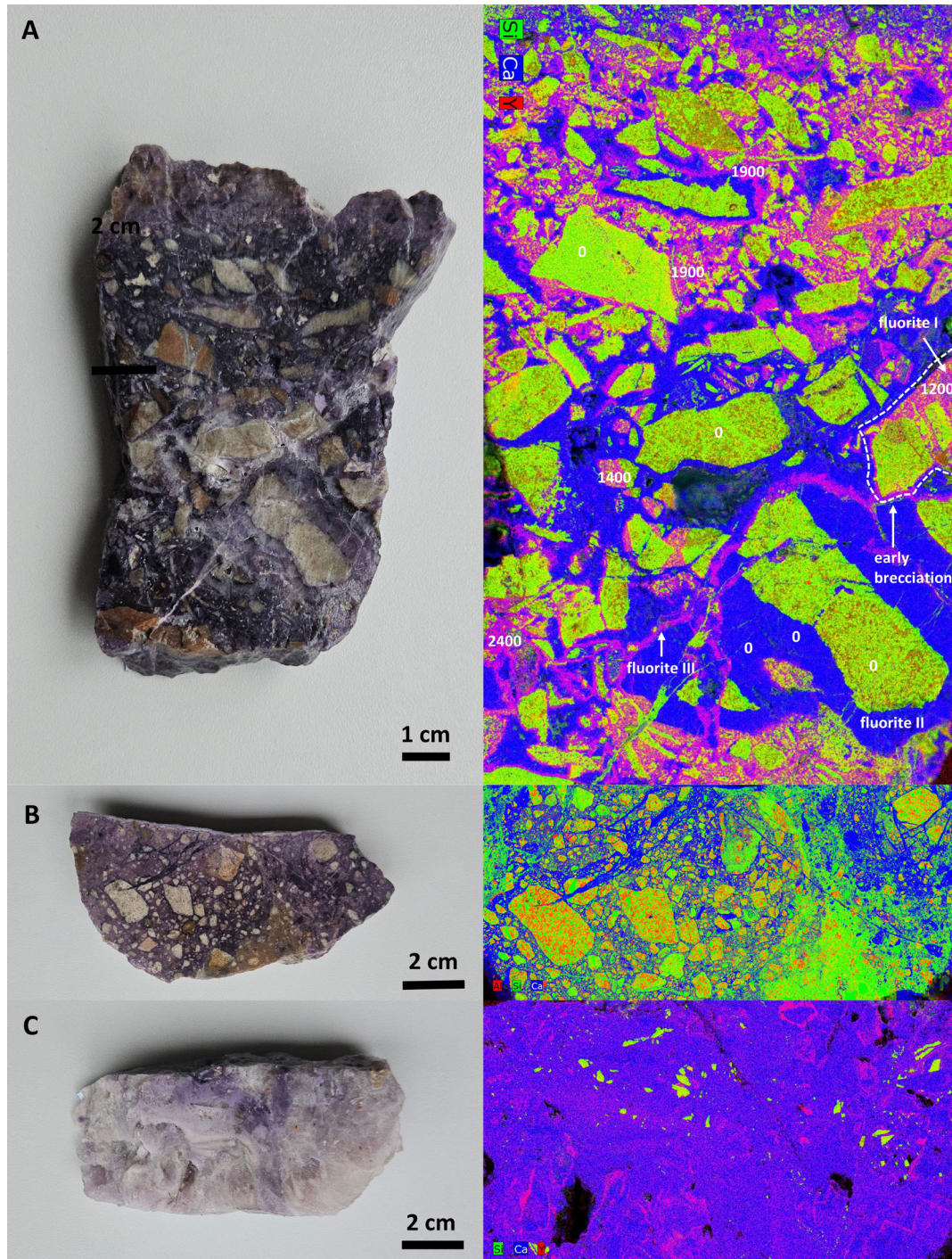


Figure 3.5: Photos (left) and element distribution maps in false colors (right) of hand specimens (A-C) from Bor Undur deposit.



At the Bor Undur plant, coarse ores with a high fluorite content are sold directly to China through stock exchanges (Figure 3.4). Low-grade coarse ores are sold domestically to smaller companies, which can process the material at a lower cost compared to the company's large-scale plant. Fine materials are typically processed through froth flotation, producing 100,000–120,000 tonnes of fluorite concentrates annually with a fluorspar grade of 95%. However, due to unfavorable market conditions, fluorite flotation is currently suspended, and the fine materials are stockpiled in heaps for potential future processing (oral communication).

Instead of producing fluorite concentrates, the Bor Undur plant is currently producing iron ore concentrates from ore sourced from the Bargilt open-pit mine, located 20 km northwest of the plant. The Bargilt mine produces up to 2.4 million tonnes of iron ore annually using a dry magnetic separation process (Source: Mongolroostsvetmet website). Detailed geological information about the deposit can be found in the previous chapter.

Three samples (A-C) were taken at Bor Undur deposit shown in Figure 3.5. **Sample A** exhibits a breccia-like texture, where lithoclasts of the host rock are cemented within a fluorite matrix. In the element distribution map, silicon (Si), calcium (Ca), and yttrium (Y) are represented by green, blue, and red, respectively. The lithoclasts are strongly silicified and embedded in fluorite, with some lithoclasts themselves displaying brecciation, indicating at least two generations of brecciation. The first generation of breccia consists of strongly silicified lithoclasts and fluorite matrix (fluorite I). Notably, the fluorite matrix in this stage contains elevated concentrations of Y, ranging from 1200 to 1400 ppm. The second generation of breccia is represented by the rock as a whole. In this stage, the silicified lithoclasts are embedded within a fluorite matrix (fluorite II). However, unlike the first stage, the fluorite matrix here is devoid of Y and is compositionally pure. Additionally, a late-stage generation of fluorite matrix (fluorite III) is observed, which contains a high concentration of Y, reaching up to 2400 ppm. This late-stage fluorite occurs as veinlets in fluorite II or as diffuse matrix. These observations suggest that the formation of the Bor Undur deposit involved multiple pulses of hydrothermal fluids. Some pulses were enriched solely in fluorine (F) and calcium (Ca), while others additionally carried significant amounts of Y, contributing to the distinct mineralogical and geochemical characteristics observed in the sample. **Sample B** exhibits a breccia-like texture, similar to sample A, with strongly silicified lithoclasts embedded in a fluorite matrix. Unlike sample A, the fluorite matrix in sample B is not enriched in Y and is compositionally pure. Additionally, the fluorite matrix itself shows strong silicification. **Sample C** consists entirely of fluorite and represents a high-grade ore. Only a single generation of fluorite is observed, which contains Y. The Y is either diffusely distributed throughout the fluorite or confined to specific growth zones within the crystals. This indicates that the concentration of Y in the mineralizing fluid fluctuated during the formation of the fluorite.

In all three samples, hazardous elements such as arsenic (As), lead (Pb), cadmium (Cd) and mercury (Hg) are absent. Calcite is also absent, which is advantageous for the flotation process. Y is the only REE present and associates with fluorite matrix. However, the fluorite matrix is strongly cemented with small lithoclasts, which is difficult to be processed.

#### 3.1.3 Zuun Tsagaan Del

The Zuun Tsagaan Del fluorite deposit is located in the Ikh Khet soum, Dornogobi province. It is located 50 km to the east-northeast of the Bor Undur mine and is also owned by Mongolroostsvetmet. Zuun Tsagaan Del was initially operated as an open pit mine and has now been converted to an underground operation.

The deposit contains several ore bodies, with ore body 1 and ore body 7 being the most significant in size. Currently, mining activities are focused on ore body 7, while ore body 1 is scheduled for future extraction. Detailed geological information about the deposit can be found in the previous chapter.

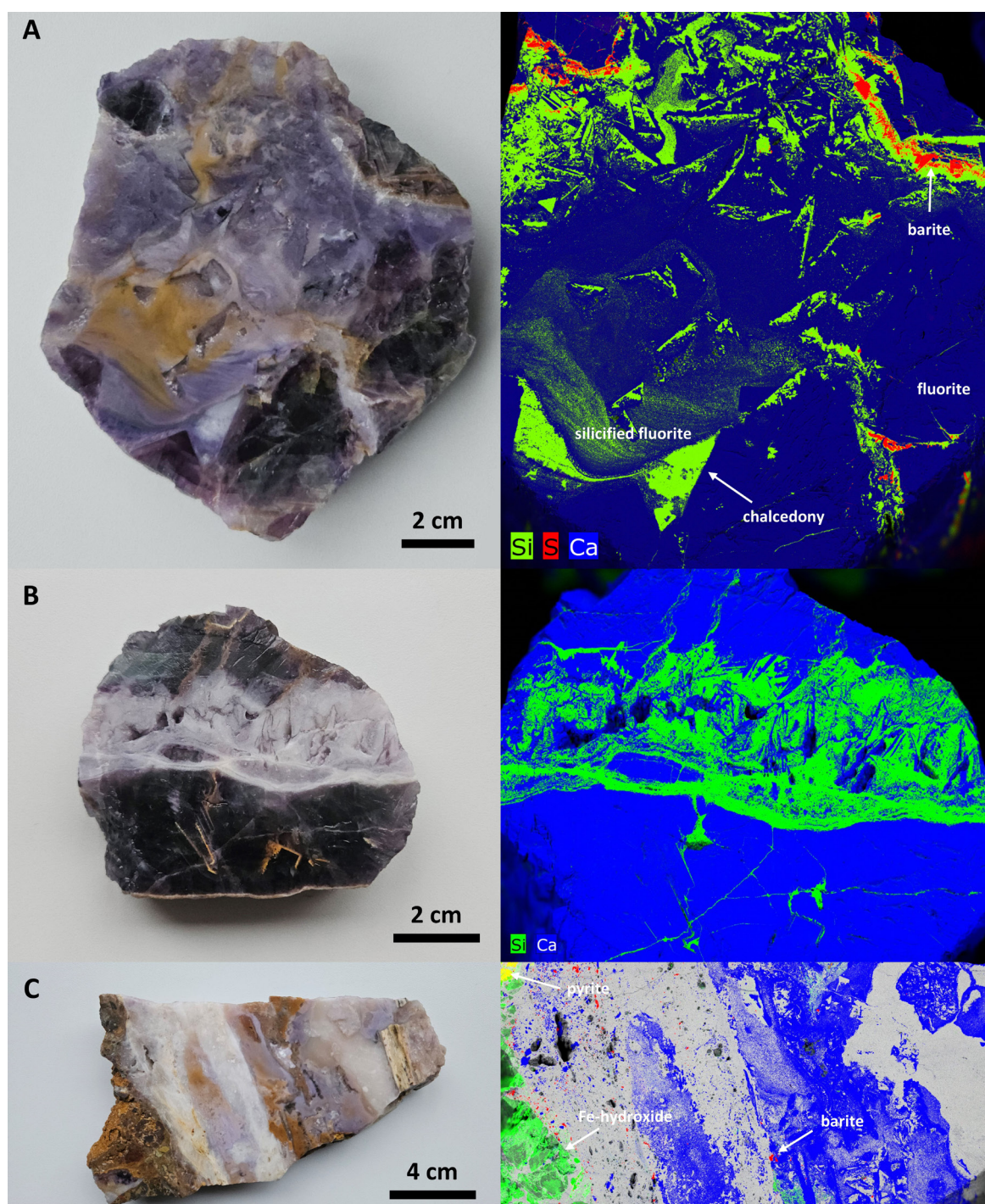


Figure 3.6: Photos (left) and element distribution maps in false colors (right) of hand specimens (A-C) from ore body 7 of Zuun Tsagaan Del deposit.

**Ore body 7** is characterized by its greenish color and a vein width of up to 10 meters. It has an average fluorite content of 40% and is almost free of calcite. Despite the moderate fluorite grade, the low calcite content (<1%) makes this ore body economically viable for processing. After manual sorting, the coarse lumps of mined material contain 75–80% fluorite. Samples collected from ore body 7 of Zuun Tsagaan Del deposit are shown in Figure 3.6.

**Sample A** represents a high-grade ore consisting of almost pure fluorite. Fluorite is partially silicified and intergrown with chalcedony. Barite is present as veinlets, which is consistent with the elevated levels of sulfur (S) and barium (Ba) observed in the bulk-rock geochemical analysis (see Table 3.2). **Sample B** is a moderate-grade ore, where fluorite hosts a quartz/chalcedony vein. **Sample C** represents a low-grade ore characterized by alternating sequences of fluorite and quartz/chalcedony. Strongly oxidized, iron-bearing wall rock is visible, along with trace amounts of barite and pyrite occurring as inclusions.

**Ore body 1** has a grey shade and a vein width of about 8 meters. Similar to ore body 7, it has an average fluorite content of 40%. However, it contains 17% calcite, which poses challenges for processing. The nearby Bor Undur processing plant is limited to handling ore with a maximum calcite content of 7%. To address this, a new processing plant designed to handle higher calcite content is planned for construction at the mining site in 2026 (oral communication). Samples collected from ore body 1 of Zuun Tsagaan Del deposit are shown in Figure 3.7.

**Sample A** represents a low-grade ore. In the element distribution map, fluorine (F), silicon (Si), and calcium (Ca) are depicted in red, green, and blue, respectively. Fluorite, composed of Ca and F, appears purple in the false-color image, while calcite appears blue because it does not contain F. In the photo, distinguishing between fluorite and calcite is difficult. However, the element distribution map clearly reveals that fluorite mineralization occurs as veins within calcite. The dark areas are enriched in Si and Fe. **Sample B** resembles sample A in appearance and represents a low-grade ore. It contains calcite and quartz, where both minerals are strongly interstratified. Calcite is partially replaced by quartz, particularly the bladed calcite, which indicates boiling of the mineralizing fluid, while massive and compact calcite is less affected by replacement. Fluorite exhibits a sharp boundary with calcite and quartz, which is advantageous for the fluorite liberation process through grinding prior to flotation. **Sample C** is a moderate-grade ore containing fluorite, chalcedony, and calcite. Chalcedony contains variable amounts of Ca and F, as well as trace amounts of S, Fe, and Al. Fluorite is massive and exhibits a sharp boundary with calcite. All samples from ore body 1 contain Fe-oxyhydroxide, indicating an Fe-bearing host rock. Additionally, gypsum and manganese oxide are occasionally present.

While ore body 7 lacks calcite, ore body 1 contains calcite, which poses challenges for the flotation process. However, the processing effectiveness of fluorite ore is more influenced by mineral texture than calcite content alone. Fine-scale intergrowth of calcite and fluorite, as observed in sample A of ore body 1 (Fig 3.7A), complicates mineral liberation process. Conversely, coarse-grained calcite, even at higher amount, can be effectively separated if it associates with coarse-grained fluorite without complex intergrowth, as seen in sample C of ore body 1 (Fig 3.7C).



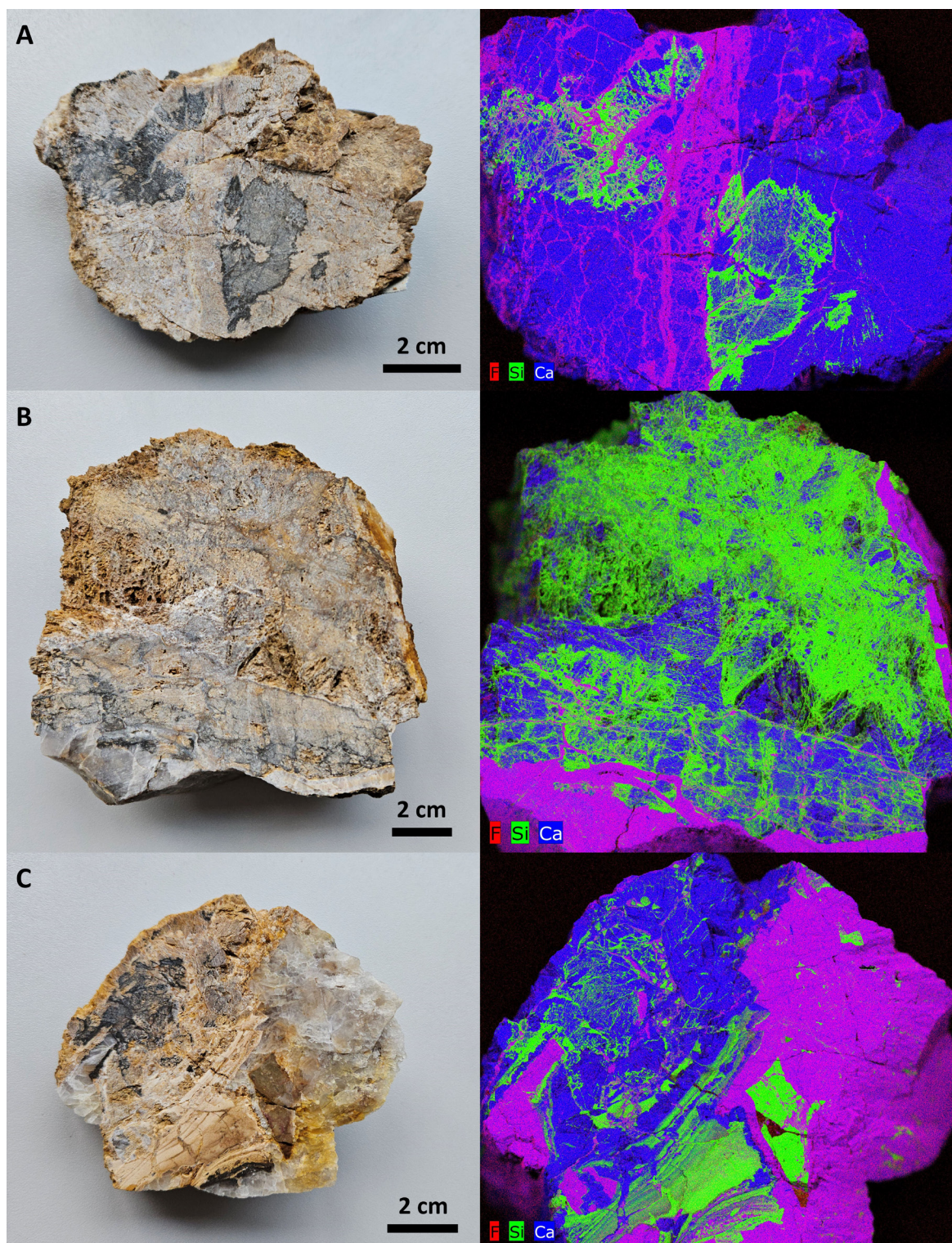


Figure 3.7: Photos (left) and element distribution maps in false colors (right) of hand specimens (A-C) from ore body 1 of Zuun Tsagaan Del deposit.

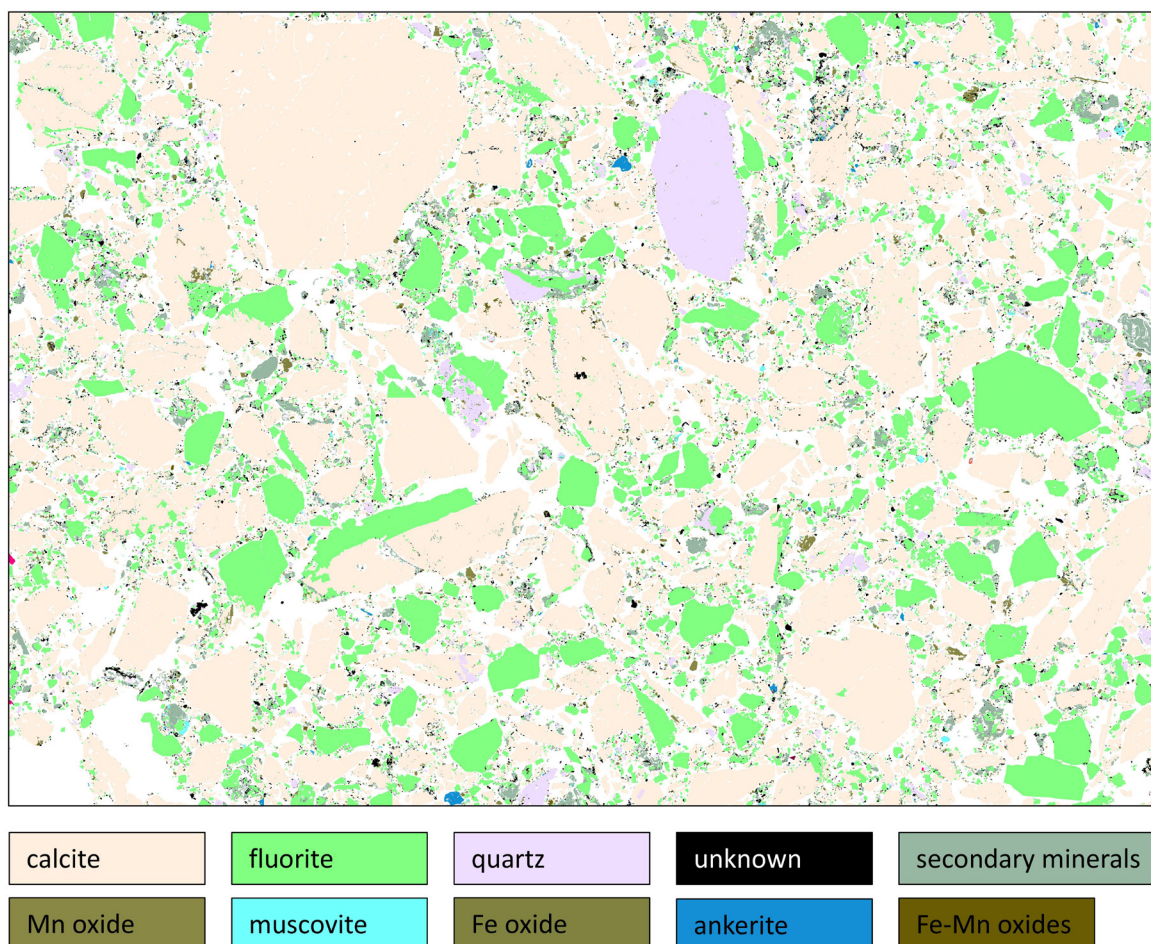


### 3. Mineralogy and geochemistry of samples from selected deposits

In all coarse ore samples from both ore bodies of the Zuun Tsagaan Del deposit, hazardous elements such as arsenic (As), lead (Pb), cadmium (Cd), and mercury (Hg), as well as rare earth elements (REE), are below the detection limit.

In addition to the coarse ore samples, a fine-grained ore material was collected from ore body 1. Due to its fine-grained nature, the fine ore material was investigated by MLA.

The fine-grained ore material primarily consists of 58.5% calcite, 28.5% fluorite, 4.6% secondary minerals, and 3.9% quartz. Additionally, 1.8% of the material is an unknown mineral, which is likely chalcedony containing variable amounts of Ca and F, as well as trace amounts of S, Fe, and Al. The remaining minerals include Mn-oxide (1.8%), muscovite (0.2%), Fe and Fe-Mn oxyhydroxides (0.4 %), and ankerite (0.2%). A classified image of the fine-grained ore material is shown in Figure 3.8. Although this material directly originate from the mine site and has not yet been milled, the fluorite grains are largely free of other minerals. There is hardly any complicated fine intergrowth with calcite or quartz, which is advantageous for the liberation process.



*Figure 3.8: Classified Mineral Liberation Analyzer (MLA) image of the fine ore from ore body 1 of the Zuun Tsagaan Del deposit.*



### 3.1.4 Khukh Del

The Khukh Del fluorite deposit is located in Bayanjargalan soum, Dundgobi province. It is an open-pit mine operated by Mongolroostsvetmet (Source: Mongolroostsvetmet website). After hand sorting, coarse-grained lumps contain 65–75% fluorite and 5% calcite, while fine-grained material contains 35% fluorite and 9% calcite (oral communication).

The Khukh Del deposit comprises 21 ore bodies distributed over an area of 30 km<sup>2</sup> and is characterized by a carbonate-quartz-fluorite mineralization (Lkhamsuren & Majigsuren, 2021).

Samples from the Khukh Del deposit are shown in Figure 3.9. **Samples A** and **B** represent moderate-grade ore consisting of fluorite and quartz. Strongly silicified lithoclasts are embedded within fluorite. A trace of galena inclusion is present in sample A.  $\mu$ -EDXRF did not detect calcite. However, an hydrochloric acid (HCl) test confirmed minor calcite presence due to bubbling observed on Fe-oxyhydroxides and in druses.

Hazardous elements such as arsenic (As), lead (Pb), cadmium (Cd) and mercury (Hg) or advantageous elements like rare earth elements (REE) are below the detection limit in all four analyzed samples.

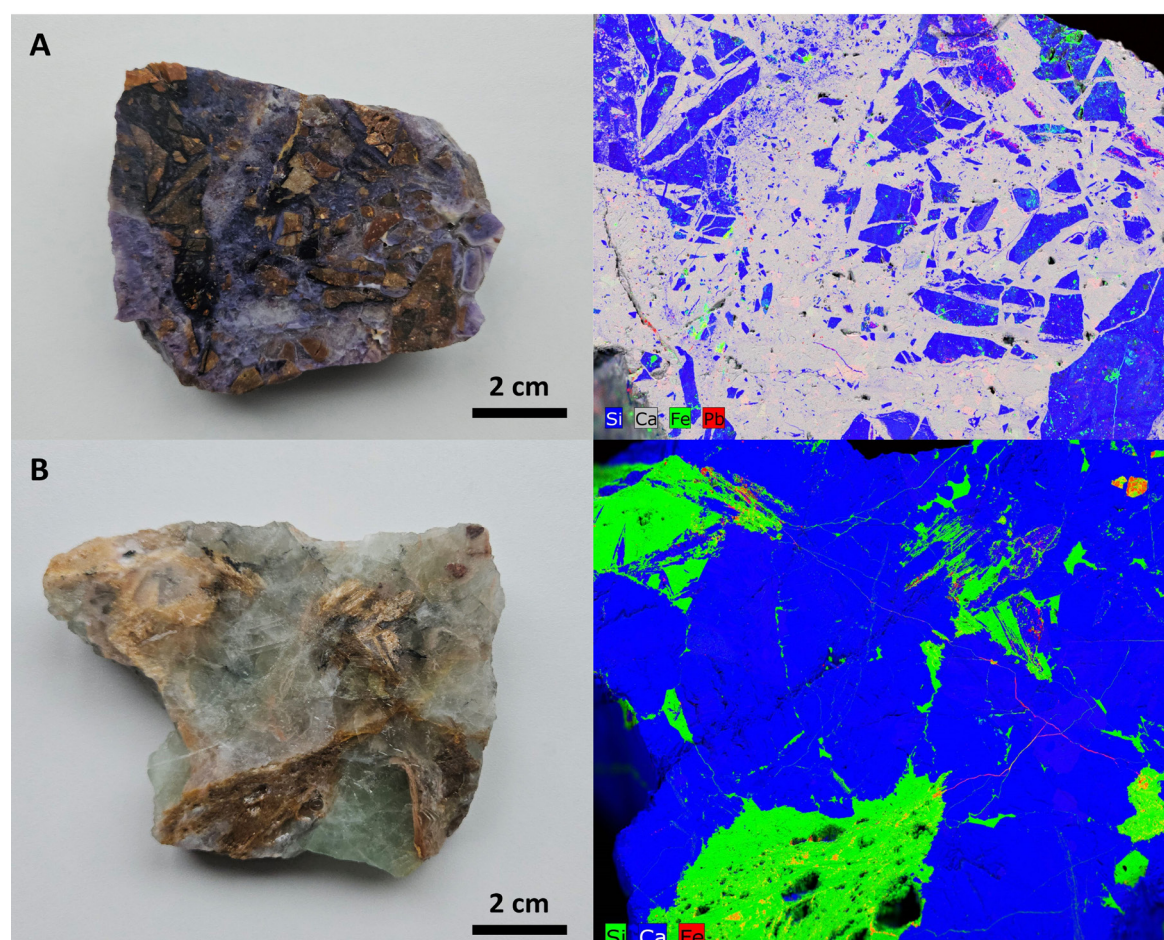


Figure 3.9: Photos (left) and element distribution maps in false colors (right) of hand specimens (A and B) from Khukh Del deposit.



#### 3.1.5 Tsagaan Del

The Tsagaan Del deposit is located in Airag soum, Dornogovi province and operated by Kherlen Impex. Kherlen Impex operates an ore processing plant with an annual capacity of 15,000 tonnes of fluorspar ore, producing a fluorite concentrate with a grade of <97% fluorite. The plant is limited to processing crude ore with a maximum calcite content of 14% (oral communication).

Three samples (A-C) were collected from the Tsagaan Del deposit, as shown in Figure 3.10. **Sample A** consists entirely of fluorite and represents a high-grade ore. Visually, three distinct fluorite types are present: white, brown, and green.

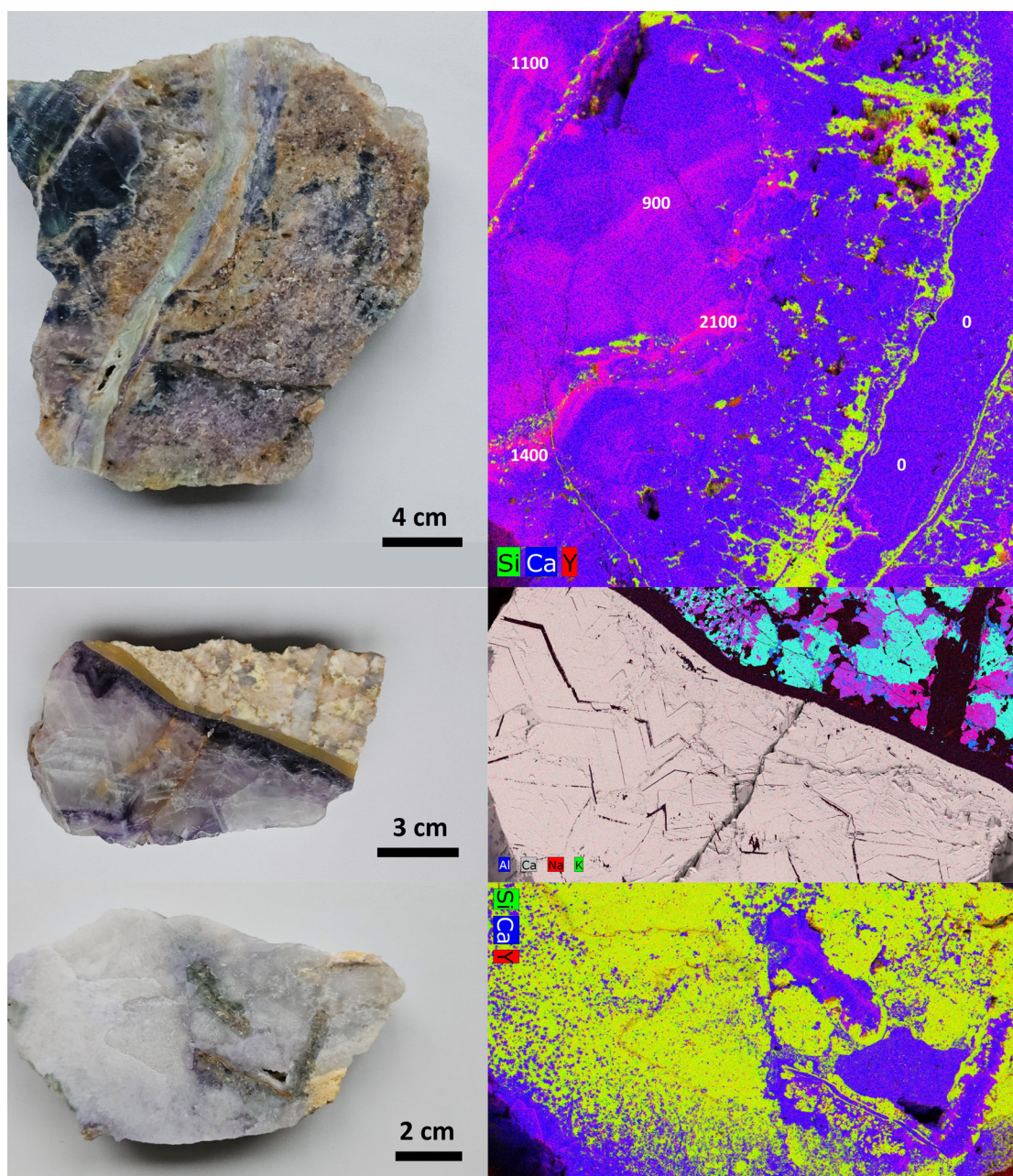


Figure 3.10: Photos (left) and element distribution maps in false colors (right) of hand specimens (A-C) from Tsagaan Del deposit. The numbers on the image present Y-contents in ppm.



Only green fluorite contains up to 2100 ppm yttrium (Y). Brown fluorite contains up to 1 wt.% iron (Fe) but no Y and white fluorite is pure. All have up to 700 ppm strontium (Sr). **Sample B** represents a moderate-grade ore. The wall rock seems to be alkali-feldspar-syenite. It contains up to 900 ppm Rb and 200 ppm Sr and shows alteration by Fe-oxyhydroxide and  $\text{TiO}_2$ . Fluorite in this sample is pure. **Sample C** consists predominately of quartz and represents a low-grade ore. Fluorite in this sample bears up to 600 ppm Y.

According to oral communication with the owner, the ore contains 30% fluorite and 10-14% calcite. However,  $\mu$ -EDXRF analysis did not detect calcite. An hydrochloric acid (HCl) test confirmed the presence of trace amounts of calcite, evidenced by bubbling in voids and pores. This suggests that calcite precipitated during the final stage of mineralization as a thin coatings on fluorite crystals within voids.

### 3.1.6 Samartai

The Samartai deposit, also operated by Kherlen Impex, is located in Airag soum, Dornogovi province, approximately 50 km from Kherlen Impex. Mining activities at the Samartai deposit are conducted underground.

A sample from the Samartai deposit, shown in Figure 3.11, represents a low-grade ore. The fluorite vein cuts through a strongly silicified wall rock with Fe-oxyhydroxide alteration. The fluorite is pure.

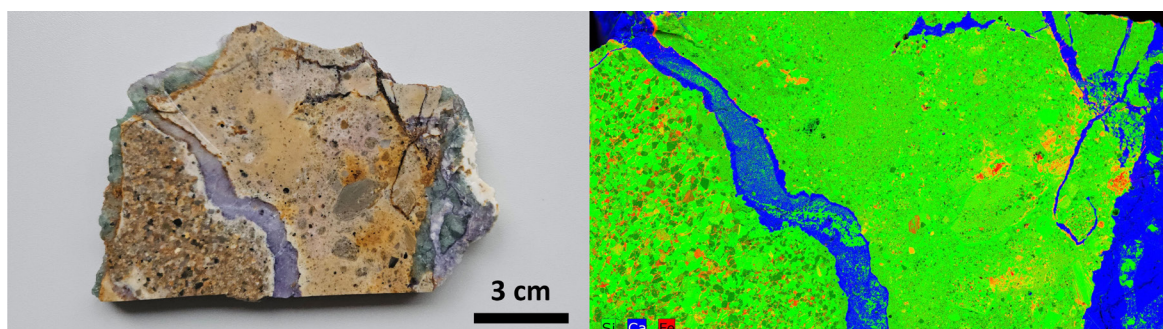


Figure 3.11: Photo (left) and element distribution map in false colors (right) of hand specimen from Samartai deposit.

### 3.1.7 Altat

The Altat deposit is located in Airag soum, Dornogovi province and operated by BT Development. Mining is conducted underground, with a previously closed 50 m shaft now replaced by excavation through tunnels. The fluorite vein has a width of 20-40 cm and an average fluorite content of 92%. An annual production of 2,400 tonnes of fluorite ore is planned.



Figure 3.12: High grade ore lumps at Altat deposit (Photo: BGR).

Four samples (A-D) were collected from the Altat deposit, as depicted in Figure 3.13. **Sample A** represents a moderate-grade ore. It contains interlayered quartz and fluorite, with a strongly altered host rock. The altered rock is characterized by phenocrysts of quartz and alkali feldspar, with Na-rich cores, embedded in a fine-grained matrix. Two generations of fluorite are present. The earlier generation of fluorite is purple in color and chemically pure, while the later generation is green, hosted by quartz, and contains up to 400 ppm of yttrium (Y). **Sample B** is a high-grade ore consisting of fluorite with alternating layers of different colors. Some of these layers contain up to 800 ppm Y. **Sample C** is also a high-grade ore consisting exclusively of fluorite and exhibits oscillating zoning. Alternating layers of white, gray and green fluorite follow the crystallographic structure. The green fluorite contains up to 1900 ppm Y. **Sample D** is also only fluorite, consisting of layers of white, yellow, and purple color. The yellow layer contains up to 500 ppm Sr.

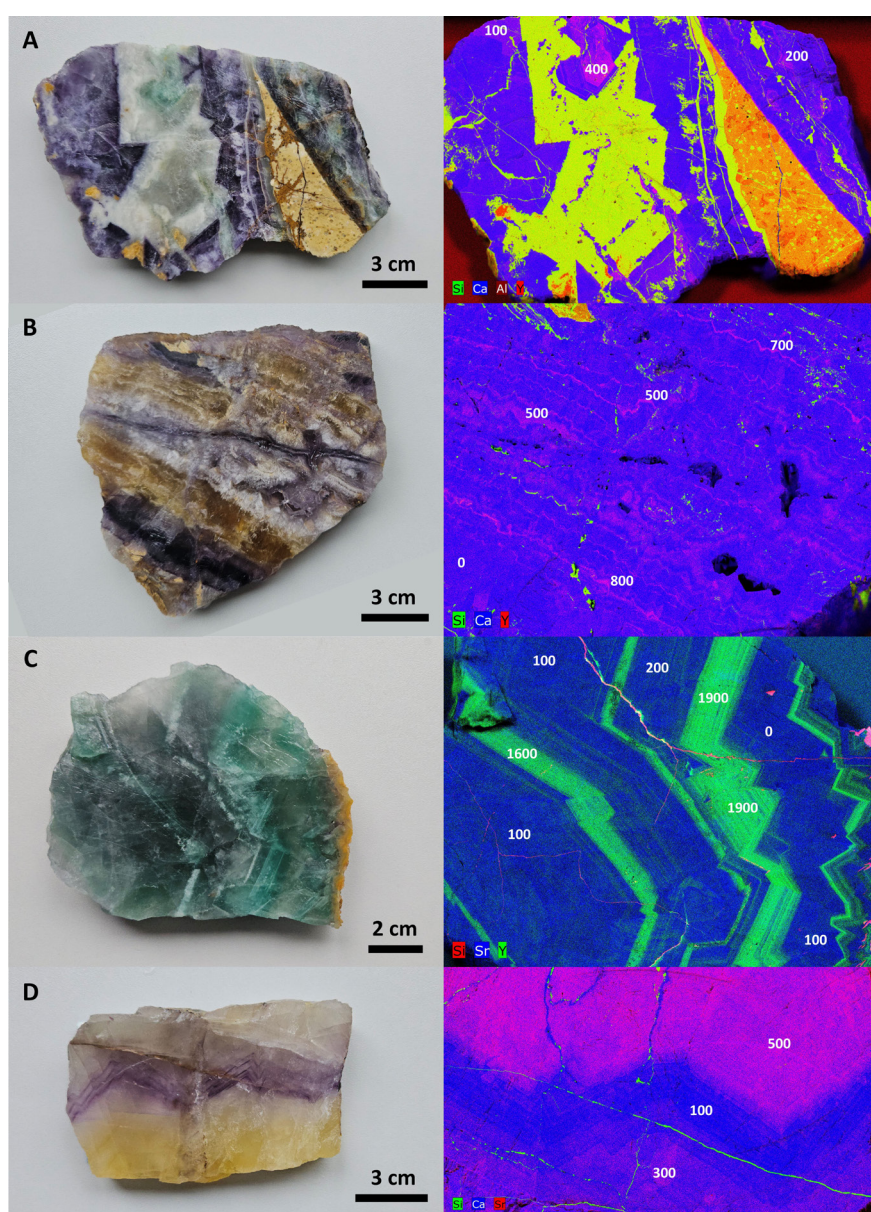


Figure 3.13: Photos (left) and element distribution maps in false colors (right) of hand specimens (A-D) from Altat deposit. The numbers on the images present Y-contents in ppm.





Figure 3.14: Ore body at Khongor I deposit (Photo: BGR).



Figure 3.15: Open pit mining at Khongor II deposit. (Photo: BGR).

### 3.1.8 Khongor I, II, and III

The Khongor I, II and III deposits are located in Airag soum, Dornogovi province and owned by CM Kings. They are all relatively small, lie close to each other and belong to a common volcanic structure (Figures 3.14 and 3.15).

**Khongor I** consists of a single steeply dipping vein ( $63^{\circ}$ - $80^{\circ}$ ) with a length of 680 m, a depth of 65 m, and a thickness ranging from 1.6 to 11.3 m (with an average thickness of 4.9 m). Khongor I was initially operated as an open pit mine and has now been converted to an underground operation. The fluorite content varies between 26.4% and 51.6%, while the calcite content ranges from 2.0% to 5.5%, with an average of 3.9% (Lkhamsuren & Majigsuren, 2021). The collected samples are shown in Figure 3.16.

Sample A presents a low-grade ore. The wall rock is fractured, strongly silicified and later fluoritized. The silicified wall rock is black and fluorite is white in the sample photo. Sample B is a high-grade ore, primarily composed of fluorite with quartz veinlets. A trace amount of pyrite exists as small veinlets, which is partly oxidized to Fe-oxyhydroxides. Fluorite is here black to dark purple and quartz is white in the photo.

**Khongor II** comprises over 20 ore bodies, with an average fluorite content of 33.7% (Lkhamsuren & Majigsuren, 2021). Detailed geological information is provided in the previous chapter. The deposit is currently operated as an open-pit mine, and a processing plant is planned for construction at the mining site. Samples were collected from ore bodies 5 and 10. A sample from ore body 10 is shown in Figure 3.17.

The sample from the ore body 10 of Khongor II represents low-grade ore (Figure 3.17). The K- and Al-bearing lithoclasts are strongly silicified and embedded within quartz and fluorite. Some of the lithoclasts have been partially replaced by a small amount of sphalerite, which is displayed as red in the element distribution map.

**Khongor III** contains three steeply dipping veins. The average fluorite grade is 33.2% (Lkhamsuren & Majigsuren, 2021). The collected sample is shown in Figure 3.18.

The sample from Khongor III represents moderate-grade ore, where vuggy quartz is associated with chalcedony and purple to black fluorite.



### 3. Mineralogy and geochemistry of samples from selected deposits

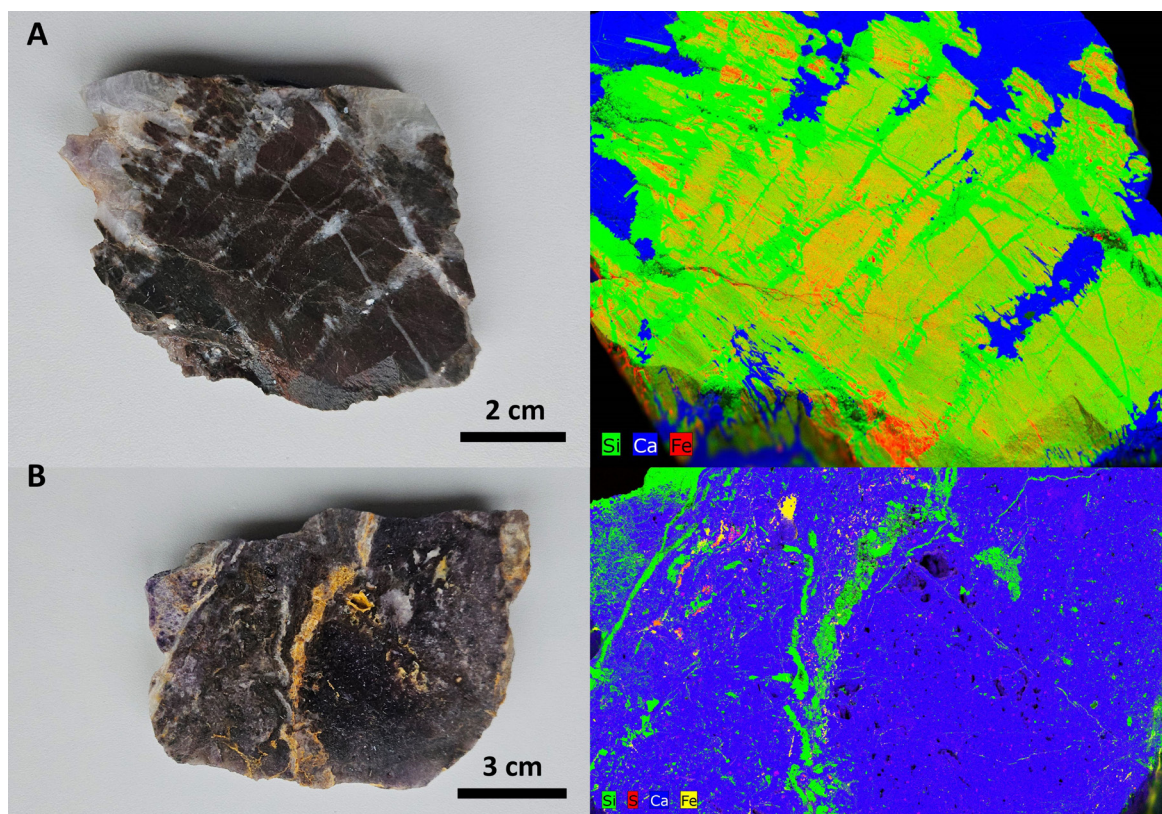


Figure 3.16: Photos (left) and element distribution maps in false colors (right) of hand specimens (A and B) from Khongor I deposit.

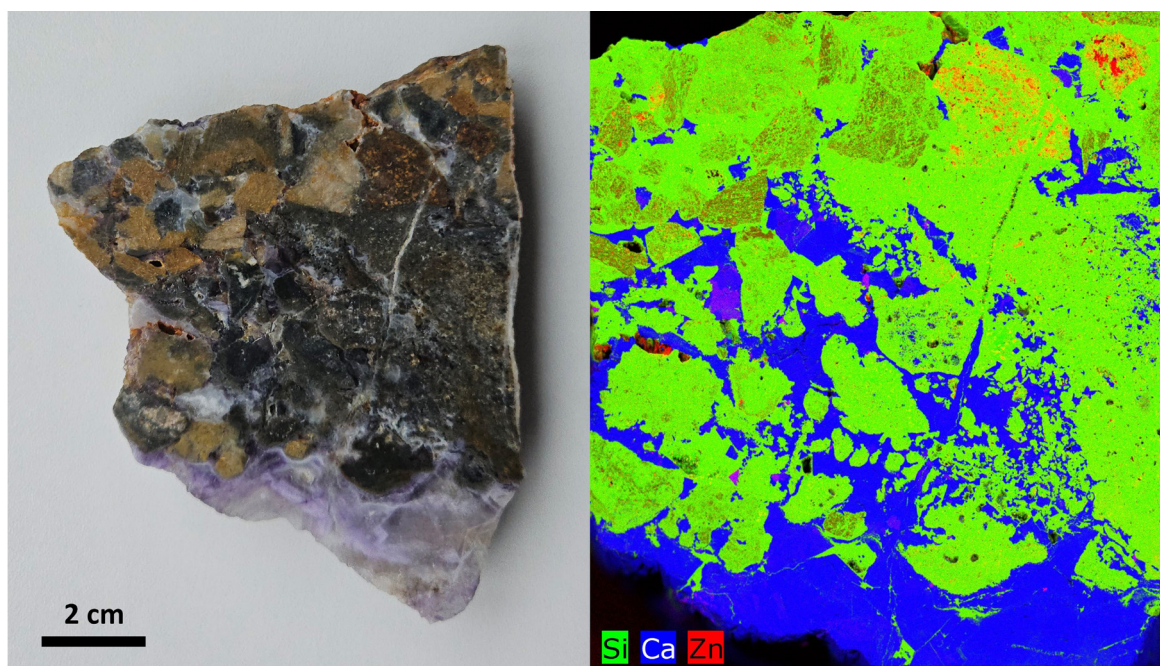
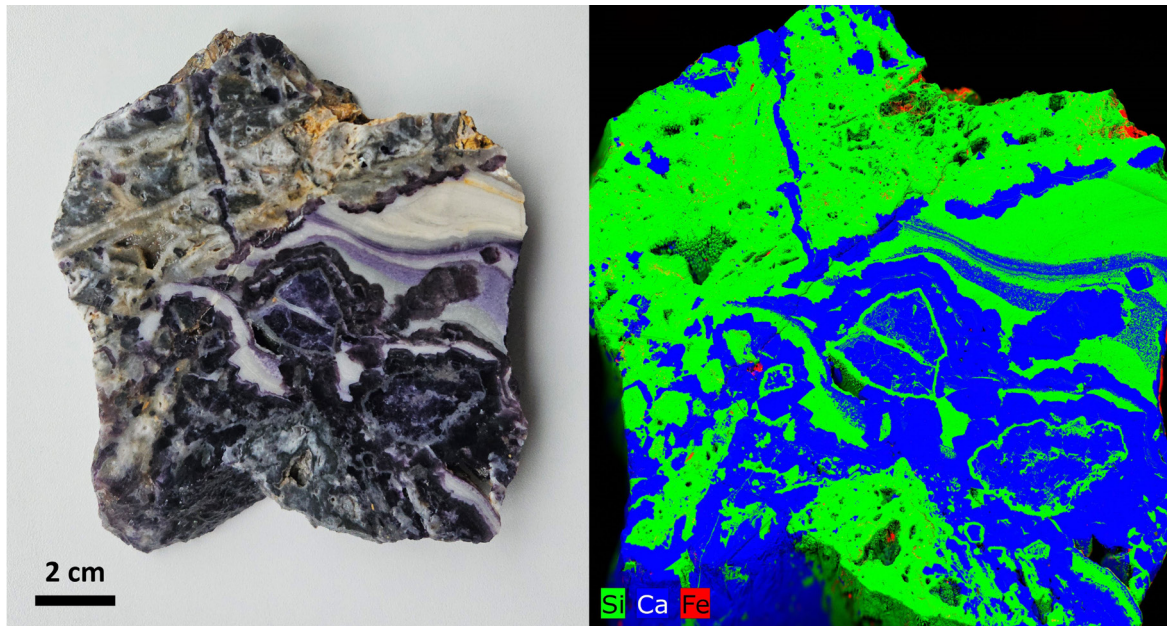


Figure 3.17: Photo (left) and element distribution map in false colors (right) of hand specimen from ore body 10 of Khongor II deposit.





*Figure 3.18: Photo (left) and element distribution map in false colors (right) of hand specimen from Khongor III deposit.*

According to  $\mu$ -EDXRF analyses, no calcite was detected in any of the samples from the Khongor deposit. Additionally, the samples were tested with hydrochloric acid (HCl), and no foaming occurred, further confirming the absence of calcite. Furthermore, hazardous elements such as arsenic (As), lead (Pb), cadmium (Cd), and mercury (Hg), as well as advantageous rare earth elements (REE), were not present in all samples.

## Brief conclusion

Mineralogy and geochemistry of 36 samples from 10 deposits in 4 ore districts were investigated in detail. The geochemical analysis focused on identifying accompanying raw materials and hazardous elements, while the mineralogical study examined the composition and texture of the samples to better understand the challenges associated with fluorite ore processing.

The only rare earth element (REE) present in the analyzed samples is yttrium (Y), which occurs in the Bor Undur, Tsagaan Del and Altat deposits. Point analyses revealed Y concentrations of up to 2100 ppm, which occur predominantly in green-colored fluorite. However, Y is not homogeneously distributed. It is mainly restricted to certain layers, which are usually no more than 2 cm thick. As a result, the total Y content in the entire sample remains below 300 ppm (Tab 3.2). This shows that the separation of Y-bearing fluorite from Y-free fluorite prior to processing is of crucial importance, but represents a major challenge.

In all samples, hazardous elements such as arsenic (As), lead (Pb), cadmium (Cd), and mercury (Hg) were not detected. Only trace amounts of galena (PbS) were observed, but its occurrence is scarce and considered negligible.

A high calcite content in ore presents a significant challenge in fluorspar processing due to the similar chemical and physical properties of fluorite and calcite, which hinder efficient separation. According to Lkhamsuren & Majigsuren (2021), Zuun Tsagaan Del, Khukh Del, and Khongor I deposits contain calcite. However, our study revealed that only ore body 1 of the Zuun Tsagaan Del deposit contains calcite. The fine-grained ore material from ore body 1 consists of 58.5% calcite. It should be noted, however, that the limited number of samples analyzed in this study may not be fully representative of the overall deposit composition.

A successful liberation of fluorite grains prior to flotation is also essential in achieving the high-grade concentrate. Here, mineral texture plays the most important role. Fine-scale intergrowth of calcite and fluorite, as shown in Figure 3.7A, hinders effective liberation. In contrast, coarse-grained calcite, even at higher content, can be effectively separated, if it is associated with coarse-grained fluorite without complex intergrowth, as illustrated in Figure 3.7C. Similarly, quartz can also be problematic, if it is finely intergrown with fluorite, as demonstrated in Figure 3.5B.



Table 3.2: Bulk-rock geochemistry of the samples.

| Nr. | Sample name  | F (%) | Cu (%) | Zn (%) | Rb (%) | Zr (%) | Rh (%) | SrO (%) | Na <sub>2</sub> O (%) | MgO (%) | K <sub>2</sub> O (%) | CaO (%) | TiO <sub>2</sub> (%) | MnO (%) | Fe <sub>2</sub> O <sub>3</sub> (%) | Al <sub>2</sub> O <sub>3</sub> (%) | SiO <sub>2</sub> (%) | P <sub>2</sub> O <sub>5</sub> (%) | SO <sub>3</sub> (%) | Y <sub>2</sub> O <sub>3</sub> (%) | BaO (%) |
|-----|--------------|-------|--------|--------|--------|--------|--------|---------|-----------------------|---------|----------------------|---------|----------------------|---------|------------------------------------|------------------------------------|----------------------|-----------------------------------|---------------------|-----------------------------------|---------|
| 1   | DKh_1 A      | 13.96 | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.00    | 0.00                  | 0.00    | 0.42                 | 26.23   | 0.05                 | 0.00    | 0.21                               | 3.19                               | 55.92                | 0.00                              | 0.00                | 0.00                              | 0.00    |
| 2   | DKh_2 B      | 37.26 | 0.01   | 0.00   | 0.00   | 0.00   | 0.00   | 0.04    | 0.00                  | 0.00    | 0.00                 | 59.85   | 0.00                 | 0.00    | 0.04                               | 0.23                               | 2.57                 | 0.00                              | 0.00                | 0.00                              | 0.00    |
| 3   | DKh_3 C      | 23.07 | 0.00   | 0.00   | 0.01   | 0.00   | 0.00   | 0.02    | 0.15                  | 0.10    | 1.61                 | 41.59   | 0.11                 | 0.00    | 0.94                               | 5.11                               | 27.26                | 0.00                              | 0.00                | 0.00                              | 0.02    |
| 4   | BU_1 A       | 21.01 | 0.01   | 0.00   | 0.01   | 0.00   | 0.00   | 0.01    | 0.00                  | 0.00    | 1.05                 | 36.27   | 0.04                 | 0.00    | 0.19                               | 3.18                               | 38.20                | 0.00                              | 0.00                | 0.03                              | 0.00    |
| 5   | BU_2 B       | 13.52 | 0.00   | 0.00   | 0.02   | 0.00   | 0.00   | 0.01    | 0.00                  | 0.00    | 3.27                 | 23.30   | 0.08                 | 0.01    | 0.27                               | 6.72                               | 52.79                | 0.00                              | 0.00                | 0.00                              | 0.00    |
| 6   | BU_3 C       | 37.54 | 0.01   | 0.00   | 0.00   | 0.00   | 0.00   | 0.04    | 0.00                  | 0.00    | 0.00                 | 59.51   | 0.00                 | 0.00    | 0.08                               | 0.40                               | 2.40                 | 0.03                              | 0.00                | 0.00                              | 0.00    |
| 7   | ZTsD_087_1 A | 31.79 | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.03    | 0.00                  | 0.00    | 0.00                 | 48.99   | 0.03                 | 0.00    | 0.07                               | 0.51                               | 17.83                | 0.00                              | 0.19                | 0.00                              | 0.57    |
| 8   | ZTsD_087_2 * | 27.02 | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.02    | 0.00                  | 0.00    | 0.00                 | 43.17   | 0.01                 | 0.00    | 0.04                               | 0.42                               | 29.23                | 0.00                              | 0.03                | 0.00                              | 0.06    |
| 9   | ZTsD_087_3 B | 28.07 | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.02    | 0.00                  | 0.00    | 0.00                 | 44.79   | 0.01                 | 0.00    | 0.06                               | 0.40                               | 26.63                | 0.00                              | 0.02                | 0.00                              | 0.01    |
| 10  | ZTsD_087_2 C | 12.82 | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.01    | 0.00                  | 0.00    | 0.25                 | 23.05   | 0.07                 | 0.01    | 0.44                               | 1.43                               | 61.71                | 0.00                              | 0.09                | 0.00                              | 0.11    |
| 11  | ZTsD_087_5 * | 34.24 | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.03    | 0.00                  | 0.00    | 0.00                 | 56.29   | 0.02                 | 0.00    | 0.11                               | 0.54                               | 8.73                 | 0.00                              | 0.00                | 0.00                              | 0.04    |
| 12  | ZTsD_081_1 * | 14.47 | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.03    | 0.00                  | 0.00    | 0.00                 | 77.43   | 0.01                 | 1.23    | 2.15                               | 0.15                               | 4.40                 | 0.00                              | 0.14                | 0.00                              | 0.00    |
| 13  | ZTsD_081_2 A | 10.90 | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.02    | 0.00                  | 0.00    | 0.00                 | 70.79   | 0.00                 | 1.15    | 2.95                               | 0.08                               | 13.55                | 0.00                              | 0.55                | 0.00                              | 0.02    |
| 14  | ZTsD_081_3 * | 12.98 | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.01    | 0.67                  | 0.00    | 0.00                 | 81.46   | 0.00                 | 0.76    | 2.26                               | 0.10                               | 0.87                 | 0.00                              | 0.89                | 0.00                              | 0.00    |
| 15  | ZTsD_081_4 B | 12.02 | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.01    | 0.32                  | 0.00    | 0.00                 | 83.59   | 0.00                 | 0.66    | 2.07                               | 0.07                               | 0.56                 | 0.00                              | 0.70                | 0.00                              | 0.00    |
| 16  | ZTsD_081_5 C | 5.94  | 0.01   | 0.00   | 0.00   | 0.00   | 0.00   | 0.01    | 0.10                  | 0.00    | 0.00                 | 35.78   | 0.01                 | 0.36    | 2.60                               | 0.27                               | 53.55                | 0.00                              | 1.37                | 0.00                              | 0.00    |
| 17  | Khd_1 A      | 25.32 | 0.00   | 0.00   | 0.00   | 0.00   | 0.00   | 0.02    | 0.00                  | 0.00    | 0.10                 | 41.55   | 0.03                 | 0.01    | 0.35                               | 1.39                               | 31.19                | 0.00                              | 0.03                | 0.00                              | 0.00    |

### 3. Mineralogy and geochemistry of samples from selected deposits

| Nr. | Sample name | F (%) | Cu (%) | Zn (%) | Rb (%) | Zr (%) | Rh (%) | SrO (%) | Na <sub>2</sub> O (%) | MgO (%) | K <sub>2</sub> O (%) | CaO (%) | TiO <sub>2</sub> (%) | MnO (%) | Fe <sub>2</sub> O <sub>3</sub> (%) | Al <sub>2</sub> O <sub>3</sub> (%) | SiO <sub>2</sub> (%) | P <sub>2</sub> O <sub>5</sub> (%) | SO <sub>3</sub> (%) | Y <sub>2</sub> O <sub>3</sub> (%) | BaO (%) |
|-----|-------------|-------|--------|--------|--------|--------|--------|---------|-----------------------|---------|----------------------|---------|----------------------|---------|------------------------------------|------------------------------------|----------------------|-----------------------------------|---------------------|-----------------------------------|---------|
| 18  | KhD_2       | B     | 29.37  | 0.00   | 0.00   | 0.00   | 0.00   | 0.02    | 0.00                  | 0.00    | 0.00                 | 49.07   | 0.00                 | 0.08    | 0.18                               | 0.23                               | 21.04                | 0.00                              | 0.00                | 0.00                              | 0.00    |
| 19  | KhD_        | *     | 4.01   | 0.00   | 0.00   | 0.00   | 0.00   | 0.02    | 0.00                  | 0.00    | 0.09                 | 11.08   | 0.01                 | 0.01    | 0.02                               | 1.24                               | 83.51                | 0.00                              | 0.00                | 0.00                              | 0.00    |
| 20  | KhD_4       | *     | 33.57  | 0.00   | 0.00   | 0.00   | 0.00   | 0.07    | 0.00                  | 0.00    | 0.00                 | 53.56   | 0.03                 | 0.00    | 0.17                               | 0.43                               | 12.12                | 0.00                              | 0.00                | 0.00                              | 0.06    |
| 21  | TsD_1       | A     | 34.02  | 0.00   | 0.00   | 0.00   | 0.00   | 0.03    | 0.00                  | 0.00    | 0.00                 | 53.86   | 0.01                 | 0.00    | 0.21                               | 0.42                               | 11.45                | 0.00                              | 0.00                | 0.01                              | 0.00    |
| 22  | TsD_2       | B     | 26.81  | 0.01   | 0.00   | 0.02   | 0.00   | 0.03    | 0.52                  | 0.00    | 1.24                 | 43.10   | 0.05                 | 0.00    | 0.22                               | 3.78                               | 24.24                | 0.00                              | 0.00                | 0.00                              | 0.00    |
| 23  | TsD_3       | C     | 13.30  | 0.00   | 0.00   | 0.00   | 0.00   | 0.01    | 0.00                  | 0.00    | 0.00                 | 23.77   | 0.02                 | 0.01    | 0.05                               | 0.92                               | 61.92                | 0.00                              | 0.01                | 0.00                              | 0.00    |
| 24  | S_1         | A     | 3.92   | 0.00   | 0.00   | 0.03   | 0.01   | 0.00    | 0.00                  | 0.00    | 4.37                 | 10.63   | 0.22                 | 0.01    | 0.48                               | 6.26                               | 74.00                | 0.00                              | 0.00                | 0.00                              | 0.03    |
| 25  | A_1         | A     | 21.33  | 0.00   | 0.00   | 0.00   | 0.01   | 0.00    | 0.18                  | 0.00    | 0.22                 | 35.46   | 0.02                 | 0.00    | 0.33                               | 1.93                               | 40.50                | 0.00                              | 0.00                | 0.00                              | 0.00    |
| 26  | A_2         | B     | 39.23  | 0.00   | 0.00   | 0.00   | 0.00   | 0.03    | 0.00                  | 0.00    | 0.00                 | 58.84   | 0.00                 | 0.00    | 0.07                               | 0.16                               | 1.64                 | 0.03                              | 0.00                | 0.00                              | 0.00    |
| 27  | A_3         | C     | 39.88  | 0.00   | 0.00   | 0.00   | 0.00   | 0.04    | 0.00                  | 0.00    | 0.00                 | 58.99   | 0.00                 | 0.00    | 0.01                               | 0.04                               | 1.00                 | 0.00                              | 0.00                | 0.03                              | 0.00    |
| 28  | A_4         | D     | 39.88  | 0.03   | 0.00   | 0.00   | 0.00   | 0.08    | 0.00                  | 0.00    | 0.00                 | 59.20   | 0.00                 | 0.00    | 0.07                               | 0.06                               | 0.69                 | 0.00                              | 0.00                | 0.00                              | 0.00    |
| 29  | Khli        | A     | 5.71   | 0.00   | 0.01   | 0.01   | 0.00   | 0.00    | 0.00                  | 0.65    | 0.66                 | 12.53   | 0.26                 | 0.03    | 2.61                               | 3.69                               | 73.85                | 0.00                              | 0.00                | 0.00                              | 0.00    |
| 30  | Kh1_2       | B     | 33.75  | 0.00   | 0.00   | 0.00   | 0.00   | 0.03    | 0.00                  | 0.00    | 0.00                 | 53.29   | 0.00                 | 0.00    | 0.42                               | 0.23                               | 12.26                | 0.00                              | 0.02                | 0.00                              | 0.00    |
| 31  | Kh1_3       | *     | 23.56  | 0.00   | 0.00   | 0.00   | 0.00   | 0.01    | 0.00                  | 0.00    | 0.00                 | 40.06   | 0.00                 | 0.01    | 0.03                               | 0.50                               | 35.81                | 0.00                              | 0.02                | 0.00                              | 0.00    |
| 32  | Kh2_O810_1  | A     | 10.38  | 0.00   | 0.01   | 0.00   | 0.00   | 0.00    | 0.00                  | 0.00    | 0.51                 | 21.06   | 0.15                 | 0.01    | 0.59                               | 2.66                               | 64.63                | 0.00                              | 0.00                | 0.00                              | 0.00    |
| 33  | Kh2_O810_2  | *     | 14.34  | 0.00   | 0.00   | 0.00   | 0.00   | 0.00    | 0.00                  | 0.00    | 0.00                 | 28.94   | 0.02                 | 0.01    | 0.17                               | 0.77                               | 55.73                | 0.00                              | 0.02                | 0.00                              | 0.00    |
| 34  | Kh2_085_1   | *     | 0.11   | 0.01   | 0.02   | 0.00   | 0.00   | 0.00    | 0.00                  | 0.00    | 0.00                 | 10.69   | 0.01                 | 0.00    | 0.57                               | 42.46                              | 45.42                | 0.00                              | 0.71                | 0.00                              | 0.00    |
| 35  | Kh3_j       | *     | 10.72  | 0.00   | 0.00   | 0.00   | 0.00   | 0.01    | 0.00                  | 0.00    | 0.00                 | 21.87   | 0.01                 | 0.01    | 0.10                               | 1.04                               | 66.22                | 0.00                              | 0.01                | 0.00                              | 0.00    |
| 36  | Kh3_2       | A     | 16.35  | 0.00   | 0.00   | 0.00   | 0.00   | 0.01    | 0.00                  | 0.00    | 0.09                 | 28.98   | 0.01                 | 0.01    | 0.16                               | 1.00                               | 53.38                | 0.00                              | 0.00                | 0.00                              | 0.00    |

\*not described in the study

## 3.2 Mineralogy of concentrates

### 3.2.1 Modal mineralogy

In this section, fluorite concentrates obtained from processing plants operated by Mongolroostsvetmet and Kherlen Impex were analyzed.

The fluorite concentrate from Mongolroostsvetmet consists of 94.7% fluorite, 4.5% calcite, and 0.7% quartz. The remaining trace minerals are apatite, muscovite, secondary minerals, dolomite, albite and ankerite. The processing plant of Mongolroostsvetmet treats fluorspar ores from four different deposits including Bor Undur, Hushuut-Adag, Khukh Del, and Urgan (Source: Mongolroostsvetmet website). Thus, the coarse ore samples from Bor Undur and Khukh Del deposits analyzed in our study contain no calcite, while the final fluorite concentrate contains 4.5% calcite due to the mixing of ores during processing.

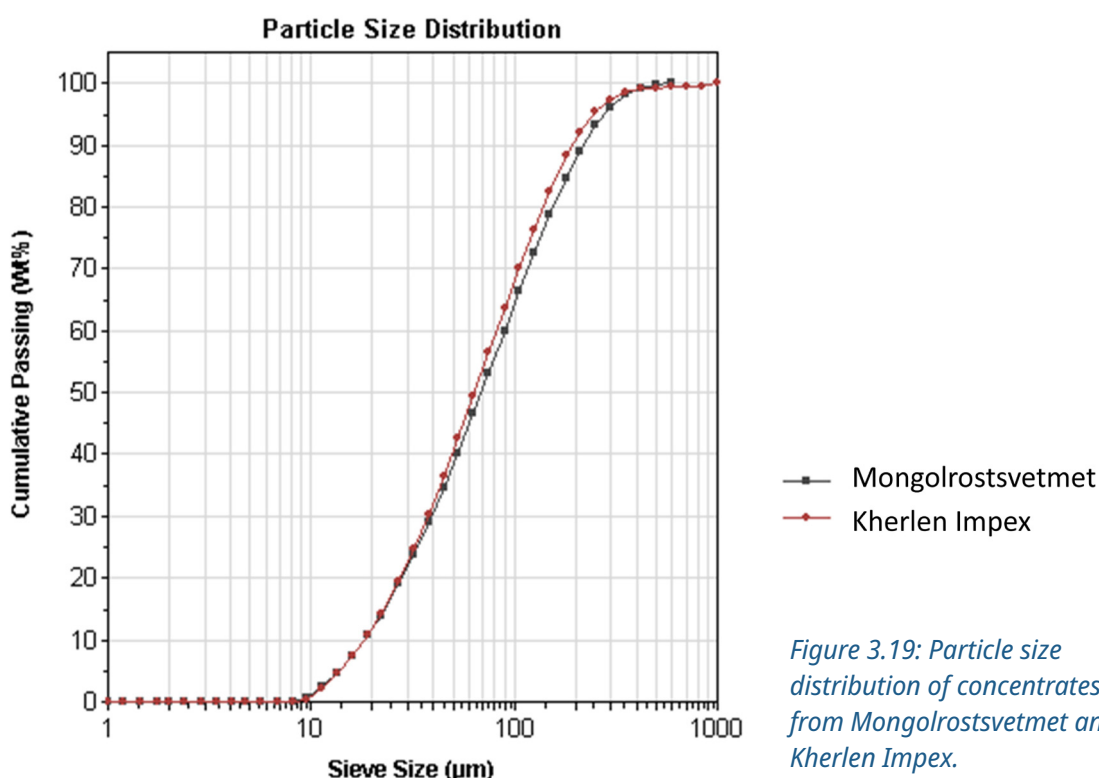
The fluorite concentrate from Kherlen Impex consists of 94.5% fluorite, 2.6% calcite and 1.4% quartz. The remaining trace minerals are sphalerite, arsenopyrite, apatite, secondary minerals, muscovite, Fe-oxyhydroxides, and barite. However, the ore samples collected from the Tsagaan Del and Samartai deposit contain no calcite. Thus, the presence of 2.6% calcite in the produced concentrate also indicates that the feed materials were likely a mixture of ores from different deposits. Additionally, it should be noted that the small number of analyzed samples are not representative.

*Table 3.3: Modal mineralogy of fluorite concentrates from Mongolroostsvetmet and Kherlen Impex.*

| Mineral             | Mongolroostsvetmet (area%) | Kherlen Impex (area%) |
|---------------------|----------------------------|-----------------------|
| Fluorite            | 94.68                      | 94.49                 |
| Calcite             | 4.45                       | 2.62                  |
| Quartz              | 0.60                       | 1.36                  |
| Sphalerite          | 0.00                       | 0.56                  |
| Arsenopyrite        | 0.00                       | 0.22                  |
| Apatite             | 0.17                       | 0.15                  |
| Fine-grained phases | 0.01                       | 0.14                  |
| Muscovite           | 0.04                       | 0.14                  |
| Barite              | 0.00                       | 0.11                  |
| Fe-oxide            | 0.00                       | 0.05                  |
| Ca-sulfate          | 0.00                       | 0.05                  |
| Albite              | 0.01                       | 0.04                  |
| Mg-silicate         | 0.00                       | 0.03                  |
| Dolomite            | 0.01                       | 0.03                  |
| Pyrite              | 0.00                       | 0.01                  |
| Molybdenite         | 0.00                       | 0.01                  |
| Ankerite            | 0.01                       | 0.01                  |
| <b>Total</b>        | <b>99.99</b>               | <b>99.99</b>          |

#### 3.2.2 Grain size

The grain size distributions of fluorite concentrates from Mongolroostvetmet and Kherlen Impex are presented in Figure 3.19, showing the cumulative percentage passing through sieves of varying sizes. The two curves are nearly identical, indicating that both concentrates exhibit similar particle size distributions. The majority of particles fall within the 10-100  $\mu\text{m}$  range, as demonstrated by the steep increase in cumulative passing in this region. The S-shaped curves suggest that the material is well-graded, with particles spanning a range of sizes but predominantly concentrated within the central range.



*Figure 3.19: Particle size distribution of concentrates from Mongolroostvetmet and Kherlen Impex.*

#### 3.2.3 Liberation analyses

**Figure 3.20a** illustrates the fluorite recovery across different locking states for concentrates from Mongolroostvetmet and Kherlen Impex. The locking states are categorized as:

- Liberated: Particles completely free of other minerals.
- Binary: Particles locked with one other mineral.
- Ternary or Greater: Particles locked with two or more other minerals.

The results show that the majority of fluorite recovery in both concentrates is liberated, representing over 90% of the total mineral content. A small proportion of fluorite, less than 10%, is locked in binary associations. Since the other major minerals in both concentrates are calcite and quartz, fluorite is associated with either calcite or quartz.



**Figure 3.20b** shows that calcite is predominantly liberated in both samples, with the Mongolrostsvetmet concentrate exhibiting a slightly higher liberation percentage. In contrast, the Kherlen Impex concentrate contains a greater proportion of binary-locked calcite. The proportion of ternary or greater locking is minimal in both samples, indicating an overall efficient liberation process. Although 80% of the calcite grains were liberated, the presence of calcite in the fluorite concentrate indicates that the selective flotation process was not sufficiently effective and the separation of fluorite and calcite remains suboptimal.

**The Figure 3.20c** reveals that quartz liberation is limited, particularly in the Mongolrostsvetmet concentrate, where only a small fraction of quartz is fully liberated. A binary-locked quartz constitutes the largest proportion in both samples and counts nearly 80%, certainly associated with fluorite. This incomplete liberation of quartz has likely contributed to the elevated quartz content observed in both concentrates.

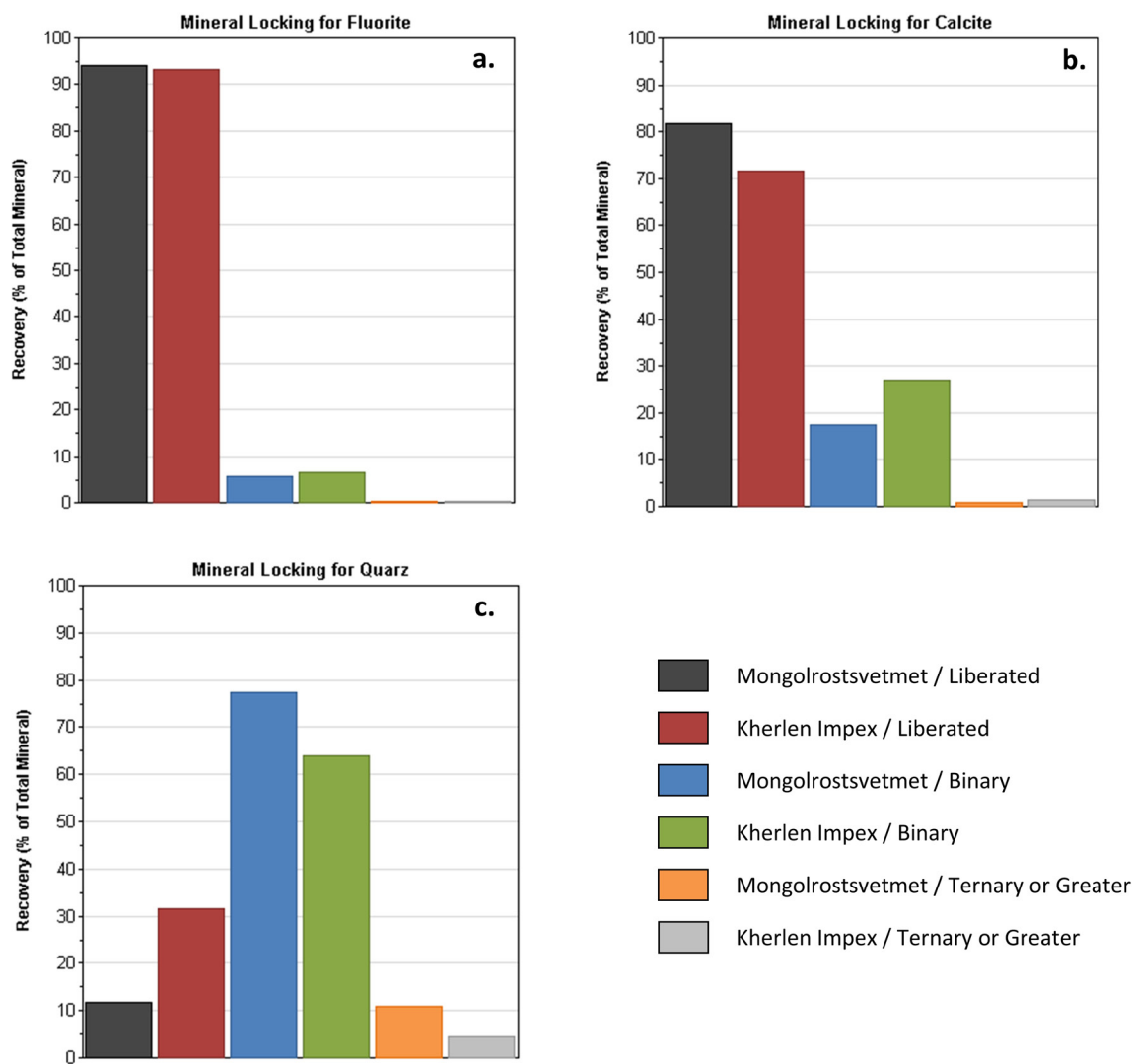


Figure 3.20: Mineral locking for fluorite, calcite and quartz

#### 3.2.4 Texture

The texture of the fluorite concentrates were investigated by a backscattered electron (BSE) imaging. Descriptive backscattered electrons (BSE) images of the concentrates are shown in Figure 3.21. In the Mongolroostvetmet concentrate, the majority of calcite grains are liberated, whereas most of the quartz grains are intergrown with fluorite, primarily occurring in binary associations (Figure 3.21a). In the Kherlen-Impex concentrate, on the other hand, calcite grains intergrown with fluorite predominate over the association of quartz and fluorite (Figure 3.21b). These observations are consistent with the results of the liberation analyses.

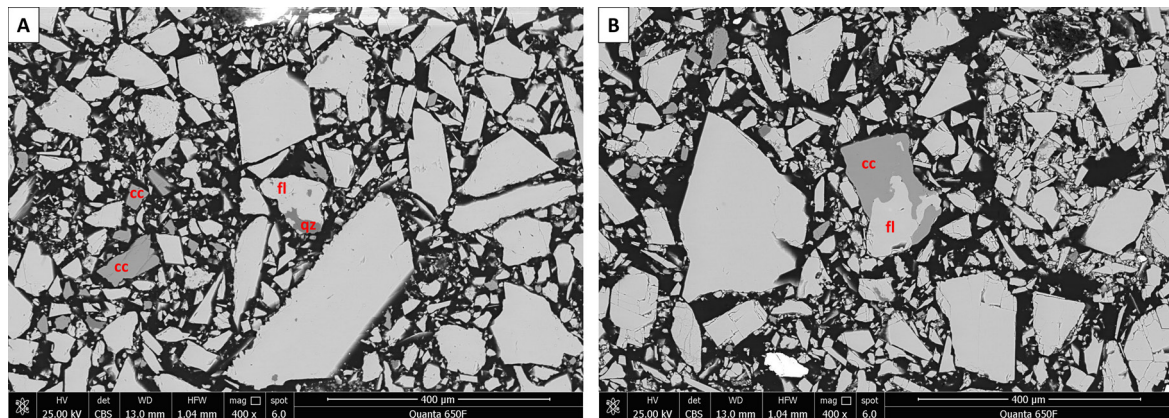


Figure 3.21: Backscattered electrons (BSE) images of concentrates from Mongolroostvetmet (a) and Kherlen Impex (b)

## Brief conclusion

Mongolroostsvetmet concentrate has 94.7% fluorite. The remaining is mostly calcite with 4.5%. Calcite is mostly fully liberated with liberation percentage of >80%. Only <20% of the grains are intergrown with other minerals. That means the problem for not reaching acid grade fluorite concentrate is not insufficient milling and grinding before flotation it is rather insufficient selectivity between calcite and fluorite during flotation process.

Mongolroostsvetmet can only process ores with a calcite content of less than 7%; otherwise, they cannot produce a concentrate with 95% fluorite. Assuming the feed material initially contained ca. 7% calcite and the Mongolroostsvetmet concentrate now contains 4.5% calcite, this suggests that Mongolroostsvetmet removes only about one-third of the total calcite during the flotation process. This limitation has led Mongolroostsvetmet to plan the construction of a new processing plant at the Zuun Tsagaan Del deposit, scheduled for 2026, specifically designed to handle ore with a higher calcite content, as its ore body 1 contains 17% calcite on average (oral communication) and the analyzed fine-grained ore material from ore body 1 in this study contains 58.5% calcite.

The Kherlen Impex concentrate contains 94.5% fluorite, with the remaining portion consisting primarily of 2.6% calcite and 1.4% quartz. Approximately 30% of the calcite and 70% of the quartz are intergrown with fluorite, which hinders selective flotation. This suggests that the challenge in achieving acid-grade fluorite concentrate lies in insufficient milling and grinding prior to the flotation process and enhanced liberation of the minerals is necessary for improved separation.

## References

Lkhamsuren, J. & Majigsuren, Y. (2021). Fluorite deposits. In *Mineral Resources of Mongolia* (pp. 319–347). Springer. [https://doi.org/10.1007/978-981-15-5943-3\\_11](https://doi.org/10.1007/978-981-15-5943-3_11)



# 4

## **A review of fluorspar processing methods in Mongolia**

*Dr. Purev-Ochir Togtokhbaatar, German-Mongolian Institute for  
Resources and Technology (GMIT)*



The aim of this chapter is to evaluate Mongolia's fluorspar (also called fluorite) sector, focusing on processing methods, beneficiation technologies, and their alignment with international standards. By analyzing the mineralogical composition of high-purity fluorspar concentrates (+97%  $\text{CaF}_2$ ) and exploring synergies with sulfuric acid production from copper smelting, we seek to provide actionable insights for enhancing local hydrofluoric acid (HF) production. The chapter will also assess alternative processing techniques for calcite-rich fluorspar ores, which present unique challenges and opportunities for beneficiation.

Key objectives include:

- **Evaluating the Mongolian Fluorspar Industry:** Assess the current state of fluorspar production in Mongolia, including prevalent processing methods (e.g., hand-sorting, flotation), operational capacities, and key challenges (e.g., technological limitations).
- **Sulfuric Acid Production:** Identify sources of sulfuric acid in Mongolia (e.g., copper smelting byproducts), evaluate its production processes, and define the quality requirements (e.g., concentration, purity).
- **Hydrofluoric Acid Production:** Analyze the fluorspar quality requirements (e.g., minimum  $\text{CaF}_2$  purity, impurity thresholds), detail production methods (e.g., reaction with sulfuric acid, purification techniques), and explore feasible high-value products (e.g., aluminum fluoride, cryolite, fuel additives).
- **Strategic Plans for Hydrofluoric Acid Production:** Outline plans for establishing hydrofluoric acid facilities within Industrial Technological Parks (ITPs), including optimal locations (e.g., proximity to fluorspar and sulfuric acid sources), infrastructure needs, and operational requirements (e.g., energy, technology, investment).

Through collaboration with local experts, this chapter details Mongolia's fluorspar mining and processing potential, providing strategic recommendations for industrial growth. These efforts aim to strengthen Mongolia's position as a key player in the global fluorspar market.

## 4.1 Mongolian fluorspar beneficiation plants

Mongolia has significant potential to boost exports by producing value-added products like HF and its derivatives from  $\text{CaF}_2$ . Fluorspar is a key and strategical mineral through hydrofluoric acid to expand industrial products battery material, industrial solvent, and some other industrial material likewise cryolite, aluminum fluoride etc. As of January 2025, approximately 224 fluorspar licenses were valid in Mongolia, covering 61,132.81 hectares (MRPAM 2025). Also, Figure 4.1 shows the biggest fluorspar processing plants and they are located next to each other in East Mongolia and its capacity per annum. In this graph, it can be seen that top 5 mines can produce 1.2 million tonnes of fluorspar per year. This is more than enough for advanced processing plants due to increase value added products for Mongolian economy.

In addition, several small-scale fluorspar processing plants have been established in provinces such as Airag, Baganuur, Dalanzadgad, Bichigt, and Batnorov. However, some of these plants are facing with challenges such as stable operation and achieving full capacity production. Also, most of these plants are funded by foreign investment, it is primarily from China. Figure 4.1 illustrates the geographic distribution and capacities of major fluorspar plants and the most of them are operating in east Mongolia.

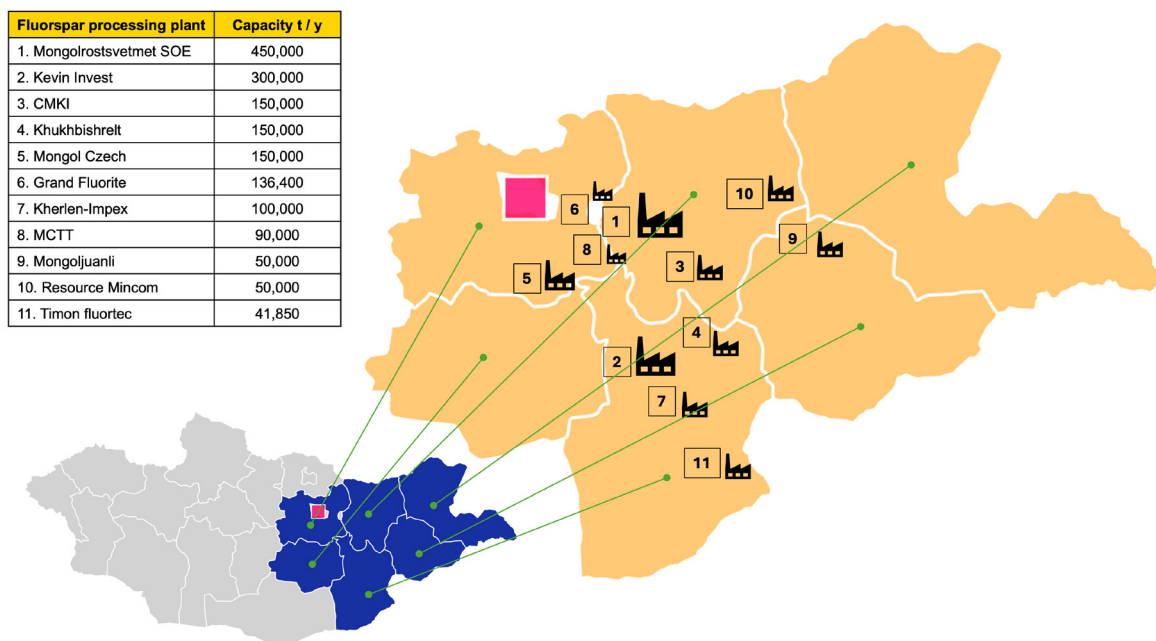


Figure 4.1: Map of Mongolia showing the locations and capacities (in tonnes per year) of major fluorspar processing plants, including Mongolrostsvetmet SOE, Kevin Invest, and others, highlighting their geographic distribution and production capacities (Glogex 2020).

#### 4.1.1 Bor-Undur fluorspar beneficiation plant



Figure 4.2:  $\text{CaF}_2$  concentrate production plant (A), flotation cells (B,C) and packaged concentrates (D).

Mongolrostsvetmet LLC extracts fluorspar ore from the Bor-Undur underground mine and open-pit mines called the Khukh-Del, Tuv Urgen, and Zuun Tsagaan Del (see detailed information Table 4.1). The ore from these sites is processed at the Bor-Undur ore dressing plant (ODP), which produces acid-grade fluorspar concentrates (FF-95) and metallurgical-grade (hand sorted) concentrate (FK-75) as final products (see details in Table 4.2). Recognized as the largest fluorspar concentrate processing facility in Mongolia, the Bor-Undur plant processes approximately 450,000 tonnes of fluorspar ore in the highest year in 2022.

Table 4.1: Fluorspar reserves of Mongolrostsvetmet LLC (Mongolrostsvetmet, 2024).

| Deposit name     | Category | Balance Ore (1000 t) | Mineral Residue (1000 t) | Remarks                                |
|------------------|----------|----------------------|--------------------------|----------------------------------------|
| Bor-Undur        | A+B+C    | 3360.302             | 1172.867                 | Underground mine                       |
| Khukh-Del        | B+C      | 999.706              | 393.094                  | Open pit mine                          |
| Zuun Tsagaan Del | B+C      | 4478.0               | 1493.4                   | Underground mine /planning to operate/ |
| Urgen            | B+C      | 3856.86              | 1646.0                   | Open pit mine                          |
| Total            | A+B+C    | 16954.93             | 6335.32                  | The company has 13 operating licenses  |

Table 4.2: Products and chemical composition of Mongolroostvetmet's beneficiation plant.

| Product type   | Mineral and chemical composition (%) |                  |      |                   |      |
|----------------|--------------------------------------|------------------|------|-------------------|------|
|                | CaF <sub>2</sub>                     | SiO <sub>2</sub> | P    | CaCO <sub>3</sub> | S    |
| Acidspar FF-95 | 95.0                                 | 3.0              | 0.04 | 2.0               | 0.02 |
| Acidspar FF-97 | 97.0                                 | 1.0              | 0.03 | 1.0               | 0.01 |
| Metspar FK-75  | 75.0                                 | 20.0             | 0.20 | 3.0               | 0.20 |

Furthermore, Table 4.3 provides information about fluorspar ore's mineral composition and ore is in category of fluorspar rich ore. Also, Figure 4.3 shows that XRD analysis of both fluorspar ore and its concentrate. This information is provided from GMIT's laboratory test work of the fluorspar flotation and result shows that quartz and calcite are removed significantly.

Table 4.3: Major minerals composition and chemicals content of Bor-Undur's ore sample.

| Content of major minerals (%) |                   |                  |             |      |
|-------------------------------|-------------------|------------------|-------------|------|
| CaF <sub>2</sub>              | CaCO <sub>3</sub> | SiO <sub>2</sub> | S (general) | P    |
| 34.65                         | 4.21              | 56.2             | 0.05        | 0.05 |

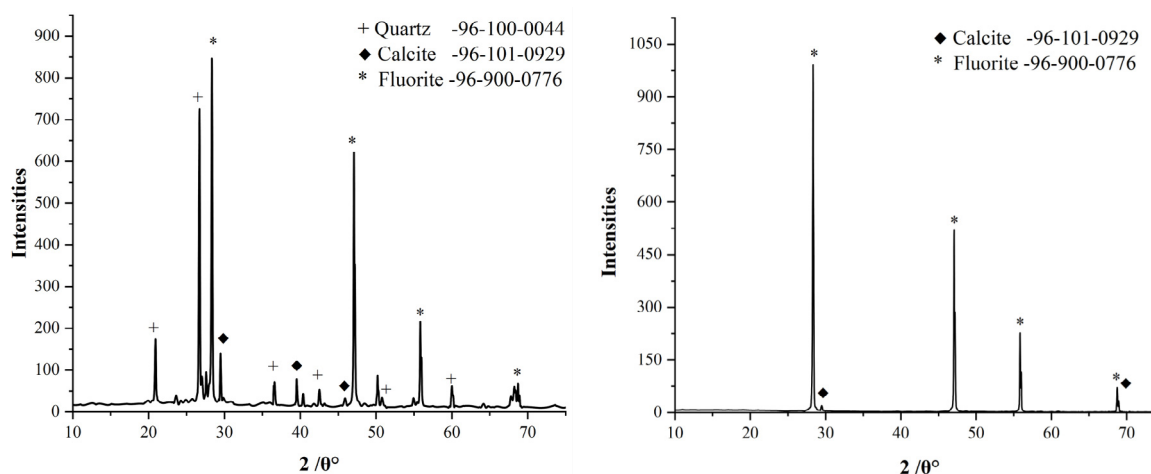


Figure 4.3: Compared XRD pattern of fluorspar ore (left) and its 97 %wt concentrate (right) from Bor-Undur plant.



Table 4.4 shows the detailed data of fluorspar analyses conducted by us are based on traditional silicate analysis methods in Germany. Dry, fine-grain samples (<63 µm) are dissolved using acid or fusion techniques. Major element contents are determined by classic wet-chemical methods, such as complexometric titration and gravimetry. Trace and ultra-trace levels being analyzed using techniques such as ion-selective electrodes (ISE), photometry, and atomic absorption spectroscopy (AAS). The table 4.4 below shows that Fluorspar concentrate meets HF production requirements.

*Table 4.4: Concentrate analysis of fluorspar from Mongolroostsvetmet SOE (Date Received: November 6, 2023).*

| Parameter                                                               | Content (%)  |
|-------------------------------------------------------------------------|--------------|
| Fluorspar (CaF <sub>2</sub> )                                           | 97.31        |
| Calcium carbonate (CaCO <sub>3</sub> )                                  | 0.43         |
| Magnesium oxide (MgO)                                                   | 0.009        |
| Silica (SiO <sub>2</sub> )                                              | 1.24         |
| Barium sulfate (BaSO <sub>4</sub> )                                     | 0.43         |
| Sulfide/disulfide as S (S <sup>2-</sup> /S <sub>2</sub> <sup>2-</sup> ) | 0.0092       |
| Total residual oxides (R <sub>2</sub> O <sub>3</sub> )                  | 0.128        |
| Iron(III) oxide (Fe <sub>2</sub> O <sub>3</sub> )                       | 0.102        |
| Aluminum oxide (Al <sub>2</sub> O <sub>3</sub> )                        | 0.026        |
| Manganese dioxide (MnO <sub>2</sub> )                                   | 0.004        |
| Sodium oxide (Na <sub>2</sub> O)                                        | 0.045        |
| Potassium oxide (K <sub>2</sub> O)                                      | 0.014        |
| Phosphate (P <sub>2</sub> O <sub>5</sub> )                              | 0.060        |
| Chloride (Cl <sup>-</sup> )                                             | 0.004        |
| Flotation oil                                                           | 0.036        |
| Nickel (Ni)                                                             | 0.0027       |
| Lead (Pb)                                                               | 0.0132       |
| Copper (Cu)                                                             | 0.0012       |
| Zinc (Zn)                                                               | 0.0030       |
| Arsenic (As)                                                            | 0.0001       |
| <b>Total</b>                                                            | <b>99.74</b> |

### 4.1.2 Mongol Czech Metal fluorspar beneficiation plant

On September 30<sup>th</sup>, 2023, the fluorspar beneficiation plant of “Mongol Czech Metal” LLC started operation in Bayantsagaan soum, Tuv Province in Mongolia. In this plant, about 200 local people work and this company contributes significant income for this province. The beneficiation plant focuses on reducing environmental impact by blending low-grade ore, discarded from previous years’ operations, with newly mined ore to produce high-grade concentrate with over 97% CaF<sub>2</sub> content. For this project, GMIT’s project staffs visited beneficiation plant for deep investigation. Furthermore, Table 4.5 shows the fluorspar reserves in 2020, which can be increased with further improvement action.

#### 4. A Review of Fluorspar Processing Methods in Mongolia



Figure 4.4: GMIT Project team visited Mongol Czech Metal's fluorspar (CaF<sub>2</sub>) ore beneficiation plant (A.), open pit mine (B.), hand sorted fluorspar (C.), milling section (D.), flotation section (E.) and concentrate drying kiln (F.) (Photos: GMIT).

Table 4.5: Fluorspar reserves of Mongol Czech Metal LLC -2020 (Glogex 2020).

| No. | Reserve classification | Ore (in 1000 t) | Average Grade (%) | Fluorspar (in 1000 t) |
|-----|------------------------|-----------------|-------------------|-----------------------|
| 1   | Proven (B) Reserves    | 2,139           | 45.59             | 975.4                 |
| 2   | Probable (C) Reserves  | 1,242           | 39.82             | 494.5                 |
|     | Total (B+C)            | 3,381           | 43.47             | 1,469.9               |

Table 4.6: Typical mineral content of metallurgical grade fluorspar from Chuluut Tsagaan Del mine and its mineral processing plant in 2023.

| Concentrate type | min CaF <sub>2</sub> (%) | Mineral content (%) |                   |      |      |
|------------------|--------------------------|---------------------|-------------------|------|------|
|                  |                          | SiO <sub>2</sub>    | CaCO <sub>3</sub> | S    | P    |
| FK 92            | 92                       | 5.0                 | 1.05              | 0.03 | 0.03 |
| FK 85            | 85                       | 5.0                 | 1.2               | 0.03 | 0.03 |
| FK 80            | 80                       | 5.6                 | 1.0               | 0.03 | 0.03 |
| FK 75            | 75                       | 17.5                | 1.83              | 0.06 | 0.06 |
| FK 65            | 65                       | 28.6                | 2.1               | 0.06 | 0.06 |

Table 4.7 shows the detailed information of Mongol Czech Metal's fluorspar ore beneficiation plants. The ore beneficiation plant has an annual production capacity of 200,000 tonnes. The project is expected to last for 19 years. The ore preparation stages include two stages of crushing and two stages of grinding. The ratio of ground ore is -0.074 mm (70%) and 0.044 mm (95%). The ore beneficiation method used is flotation, and the tailings type is dry. Figure 4.5 shows XRD results of both fluorspar ore and its concentrate.

Table 4.7: Parameters of fluorspar ore beneficiation plant of Mongol Czech Metal LLC.

| No. | Plant parameters                             | Remarks                                      |
|-----|----------------------------------------------|----------------------------------------------|
| 1   | Annual production of ore beneficiation plant | 200,000 tonnes                               |
| 2   | Project duration                             | 19 years                                     |
| 3   | Ore preparation stages                       | 2 stages of crushing<br>2 stages of grinding |
| 4   | Ratio of ground ore                          | -0.074 mm (70%), 0.044 mm (95%)              |
| 5   | Ore beneficiation method                     | Flotation                                    |
| 6   | Tailings type                                | Dry                                          |



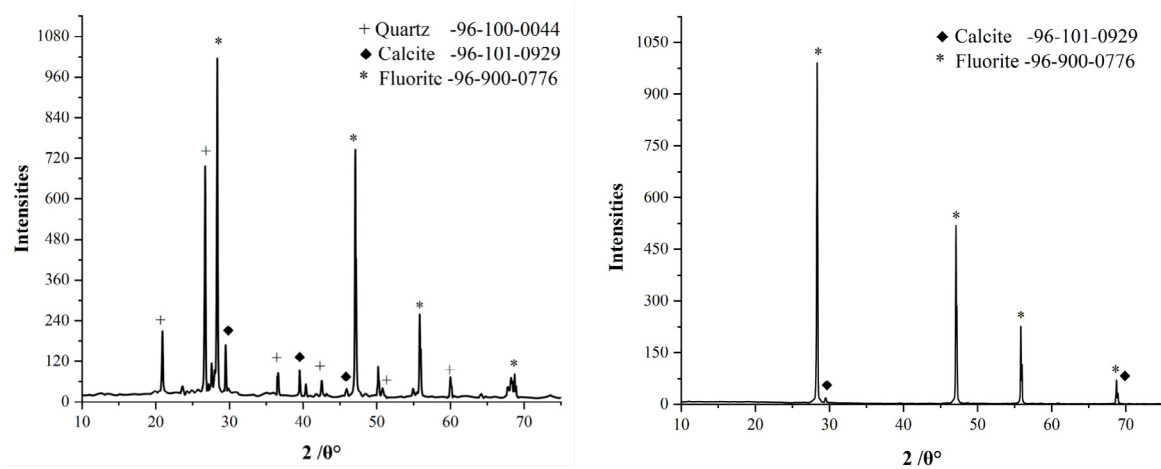


Figure 4 5: Compared XRD pattern of fluorspar ore (left) and its 97 %wt concentrate (right) for BGR project.

Table 4.8 shows the fluorspar ore's mineralogical composition and other elements. This is the fluorspar rich ore (usually more 30%) and calcite has to be less (Gao et al. 2016).

Table 4.8: Chemical analysis for fluorspar ore (Glogex 2020).

| Content of major minerals (%) |                   |                  |             |      |
|-------------------------------|-------------------|------------------|-------------|------|
| CaF <sub>2</sub>              | CaCO <sub>3</sub> | SiO <sub>2</sub> | S (general) | P    |
| 48.56                         | 1.43              | 43.11            | 0.10        | 0.05 |

Recently, for this project, a sample sent from production line was investigated by the MLA-SEM analysis at Freiberg University of Mining and Technology (TUBAF), Germany. Table 4.9 shows the modal mineralogy of the scanning area (MLA-SEM) and fluorspar concentration reached 97.52 % and it is because of well performed technology and combination of drying kiln, which may calcinated the concentrates. However, this mineralogical data only belongs to the sample, which was analyzed in Germany.

Table 4.9: MLA-SEM analysis of the fluorspar concentrate by scanning area from Mongol Czech Metal plant.

| Mineral                    | Chemical formula                                                                       | Wt%   | Area (micron) |
|----------------------------|----------------------------------------------------------------------------------------|-------|---------------|
| Fluorspar                  | CaF <sub>2</sub>                                                                       | 97.52 | 28,110,335.00 |
| Calcite                    | CaCO <sub>3</sub>                                                                      | 1.13  | 376,385.00    |
| Gypsum                     | CaSO <sub>4</sub> ·2H <sub>2</sub> O                                                   | 0.00  | 1,951.00      |
| Quartz                     | SiO <sub>2</sub>                                                                       | 0.69  | 236,752.00    |
| Albite                     | NaAlSi <sub>3</sub> O <sub>8</sub>                                                     | 0.05  | 16,167.00     |
| Orthoclase                 | KAlSi <sub>3</sub> O <sub>8</sub>                                                      | 0.01  | 2,861.00      |
| Garnet–Grossular–Andradite | Ca <sub>3</sub> (Al,Fe) <sub>2</sub> (SiO <sub>4</sub> ) <sub>3</sub>                  | 0.26  | 57,962.00     |
| Hornblende (Amphibole)     | Ca <sub>2</sub> (Mg,Fe) <sub>5</sub> Si <sub>8</sub> O <sub>22</sub> (OH) <sub>2</sub> | 0.18  | 57,247.00     |
| Titanite                   | CaTiSiO <sub>5</sub>                                                                   | 0.09  | 23,011.00     |



| Mineral  | Chemical formula                                          | Wt%    | Area (micron) |
|----------|-----------------------------------------------------------|--------|---------------|
| Fe-oxide | Fe <sub>2</sub> O <sub>3</sub> (typically hematite)       | 0.01   | 2,018.00      |
| Barite   | BaSO <sub>4</sub>                                         | 0.01   | 1,553.00      |
| Apatite  | Ca <sub>5</sub> (PO <sub>4</sub> ) <sub>3</sub> (F,Cl,OH) | 0.03   | 9,596.00      |
| Total    | –                                                         | 100.00 | 29,305,120.00 |

## 4.2 Typical fluorspar ore processing plant

Fluorspar ores are extracted from both open-pit and underground mining. Those mainly contain fluorspar (CaF<sub>2</sub>), quartz (SiO<sub>2</sub>), limestone (CaCO<sub>3</sub>) and minor constituents containing sulfur (S) and phosphor (P) etc. Hence, target mineral (CaF<sub>2</sub>) needs to be liberated from its association with the gangue minerals. The entire beneficiation process is displayed in Figure 4.6.

### 4.2.1 Hand sorting

In Mongolia, hand-sorting is used for Metspar due to its low cost of high-grade lump ores, this process usually takes places in open pit mining and on the belt conveyor. For lower-grade ores or those with relatively coarse mineral interlocking, gravity separation techniques such as jigs, tables, or heavy media separation are employed.

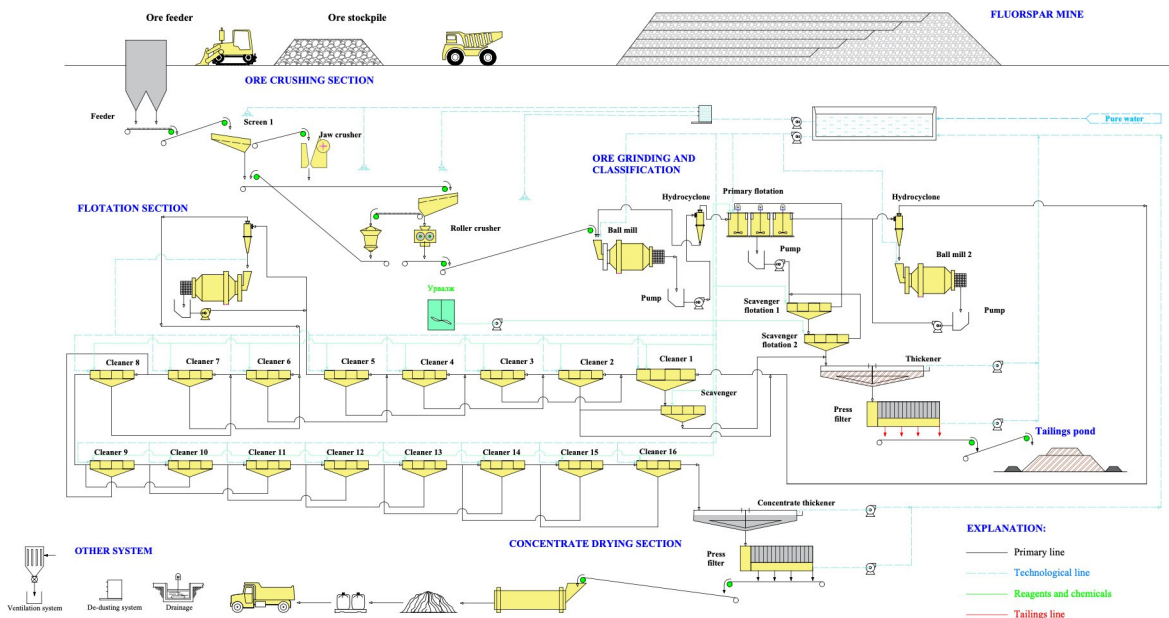


Figure 4.6: Typical CaF<sub>2</sub> ore beneficiation flow diagram. This detailed diagram illustrates the complete processing flow of fluorspar concentrate production, highlighting key stages such as ore crushing, grinding, flotation, concentrate drying, and tailings management. It emphasizes the integration of classification, cleaning, and dewatering systems to achieve high-purity fluorspar concentrate.

### 4.2.2 Mining and crushing

After extraction the raw ore is crushed into smaller fragments to prepare it for further processing. Crushing is often carried out in multiple stages to ensure size reduction. This ore preparation technique is dependent on mineralization and its intergrowth. Figure 4.6 shows the typical ore preparation section that includes jaw crushers, roller crushers and multi-purpose screens.

### 4.2.3 Ore comminution

After crushing, the ore is ground into finer particles using rod or ball mills in the presence of water (see details in Figure 4.6). Grinding is a critical step to achieve the liberation of fluorspar particles from associated minerals, such as quartz, calcite, and barite. Proper grinding enhances the efficiency of subsequent separation processes such as hydro cyclone or screw classifier.

### 4.2.4 Froth flotation

Flotation is the three-phase (solid, liquid, gas) system that is most common method for upgrading fluorspar concentrate to significant purity.  $\text{CaF}_2$  flotation in flotation cells is optimized by selective collectors, such as fatty acids, and precise pH control to maximize fluorspar recovery while effectively depressing gangue minerals. Also, successful flotation requires high technical knowledge from operators and optimal conditions of reagents, conditioner and flotation cell design. Detailed information is given below:

- Reagents: Collectors like fatty acids or alkyl sulfonates are added to make the fluorspar hydrophobic. Depressants, such as sodium silicate, are used to suppress gangue minerals like silica and calcite.
- Conditioning: The slurry is conditioned in a tank where reagents are mixed thoroughly with the ground ore.
- Flotation Cells: The conditioned slurry is introduced into flotation cells, where air bubbles attach to the fluorspar particles, carrying them to the surface as froth. The froth is skimmed off as a concentrate. Flotation cells are connected in series due to increase fluorspar concentrations and reduce fluorspar amount in the tailings.

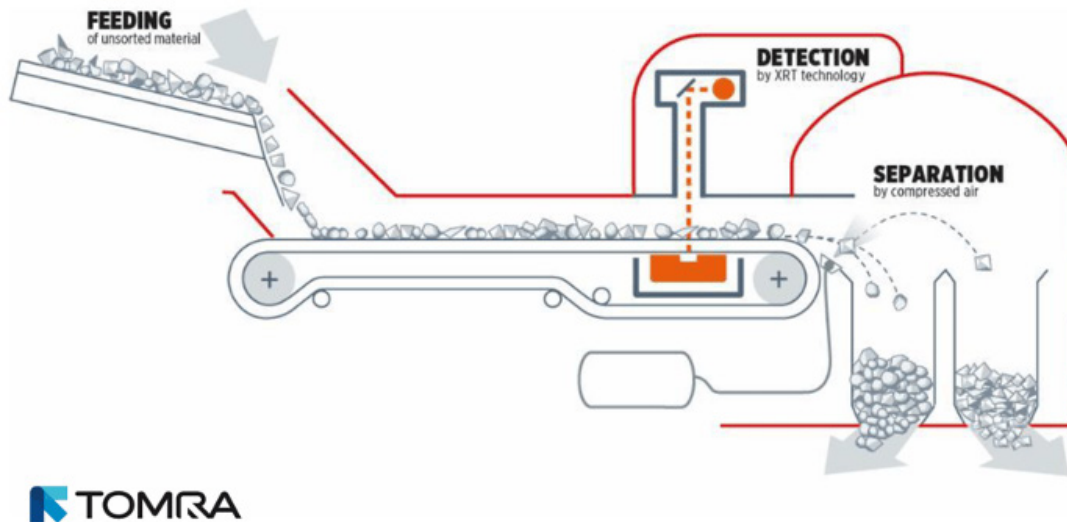
### 4.2.5 Calcite rich ore processing

Fluorspar and calcite have same surface  $\text{Ca}^{2+}$  ions, which have common response when typical used fatty acids collectors are being applied (Pradip et al. 2002). Mechanically, advanced sorting systems may help to produce acid spar concentrate such as X-ray transmission (XRT). XRT sorting systems (Figure 4.7) can process fluorspar ores by removing the calcite and silicates during transport (Tomra 2024a). Such an instrument is planned for use in the Las Cuevas fluorspar mine in Mexico (Tomra 2024b). After that, the fluorspar pre-concentrate obtained can be processed by flotation and acid spar can be produced easier.

Also, reverse flotation was efficient method for the desilication of the fluorspar concentrate (Zhang et al. 2021). For the reverse flotation, Table 4.10 shows that pH and right reagents are playing an important role. These findings demonstrate that the novel reagent schedule achieves high separation efficiency between calcite and fluorspar, resulting in a fluorspar concentrate with minimal calcite

contamination. Also, Sulfoleic acid (SOA) enhances fluorspar separation when combined with citric acid and NaF at pH 9.

The figure below shows the functional principle of the COM Tertiary XRT:



**TOMRA**

Figure 4.7: Illustration of TOMRA XRT 2.0 sorter

Table 4.10: Selective flotation of calcite from fluorspar ore, synthetic minerals (0.33 g  $\text{CaF}_2$  + 1.67 g  $\text{CaCO}_3$ ) (a), 495 g of run-of-mine fluorspar ore (b) flotation tests using the reagent schedule of Citric Acid + NaF + Sulfoleic acid (SOA) at pH 9 adapted from (Gao et al. 2016) W: Weight (g), G: Grade (%), R: Recovery (%).

|             | W<br>(a) | W<br>(b) | G<br>Fluorspar<br>(a) | G<br>Calcite<br>(a) | G<br>Fluorspar<br>(b) | G<br>Calcite<br>(b) | R<br>Fluorspar<br>(a) | R<br>Calcite<br>(a) | R<br>Fluorspar<br>(b) | R<br>Calcite<br>(b) |
|-------------|----------|----------|-----------------------|---------------------|-----------------------|---------------------|-----------------------|---------------------|-----------------------|---------------------|
| Concentrate | 0.4      | 121.6    | 27.07                 | 72.93               | 18.59                 | 66.67               | 6.5                   | 88.1                | 11.2                  | 85.2                |
| Tailings    | 1.6      | 373.4    | 97.57                 | 2.43                | 48.01                 | 3.78                | 93.5                  | 11.9                | 88.8                  | 14.8                |
| Total       | 2.0      | 495      | 66.7                  | 33.3                | 40.78                 | 19.23               | 100.00                | 100.00              | 100.00                | 100.00              |

Figure 4.8 shows that Qinlong's (Guizhou Province, China) low-grade carbonate type fluorspar ore, which contains usually 32.25% of  $\text{CaF}_2$  and 11.78% of  $\text{CaCO}_3$ .

#### 4. A Review of Fluorspar Processing Methods in Mongolia

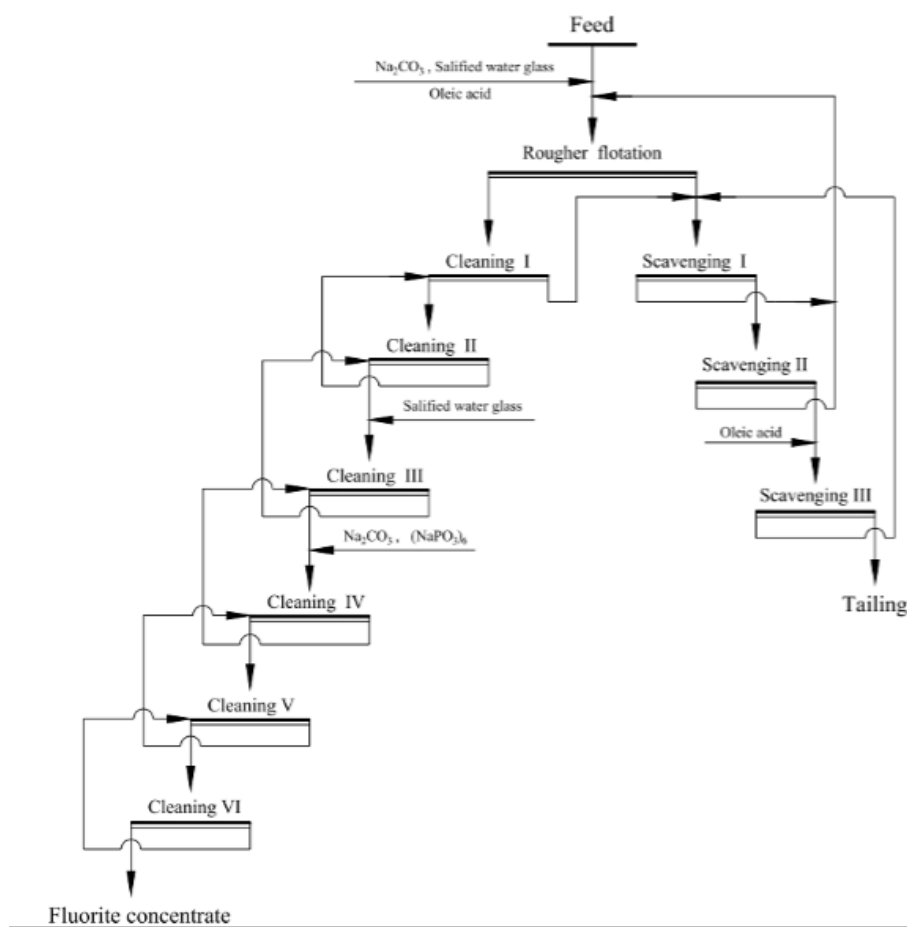


Figure 4.8: A flow diagram illustrating the beneficiation process of a Chinese fluorspar plant producing high-grade acid spar ( $\text{CaF}_2$ ) concentrate (98.1 %), adapted from (Huang et al. 2022)

Table 4.11: Reagents used for the fluorspar processing in Qinlong's beneficiation plant.

| Component    | Reagent                                             | Role                             | Additional Notes                                                                           |
|--------------|-----------------------------------------------------|----------------------------------|--------------------------------------------------------------------------------------------|
| pH Regulator | Sodium Carbonate ( $\text{Na}_2\text{CO}_3$ )       | Adjusts and maintains optimum pH | Establishes favorable conditions for selective flotation                                   |
| Depressant   | Sodium Hexametaphosphate                            | Depresses calcite flotation      | When combined with modified water glass, greatly enhances the depression effect on calcite |
| Depressant   | Modified Water Glass salified with Aluminum Sulfate | Depresses calcite flotation      | Used in tandem with sodium hexametaphosphate for improved calcite depression               |
| Collector    | Oleic Acid                                          | Collects fluorspar particles     | Facilitates selective attachment to fluorspar, improving recovery efficiency               |



Table 4.12: Fluorspar concentrate performance.

| Parameter                 | Value  | Remarks                                            |
|---------------------------|--------|----------------------------------------------------|
| CaF <sub>2</sub> Content  | 98.10% | Indicates high-purity fluorspar in the concentrate |
| Recovery Rate             | 83.68% | Demonstrates efficient recovery of fluorspar       |
| CaCO <sub>3</sub> Content | 0.83%  | Reflects minimal calcite contamination             |

4.2.6. Concentrate

The collected concentrate is thickened to remove excess water. It is then filtered to reduce moisture content, producing a partially dry fluorspar concentrate. To achieve a high purity (CaF<sub>2</sub> 97%) level, the concentrate may need acid washing or chemical treatment. This step removes residual impurities, such as silica and calcite, that may have persisted through flotation (Huang et al. 2022). Hydrochloric acids or other acids may be used depending on the impurity profile.

Below is an updated, detailed overview that includes essential additional information regarding each concentrate type, highlighting key attributes and considerations for their use (Table 4.13):

Table 4.13: Detailed fluorspar concentrates and its utilization.

| Concentrate type    | Grade (%) | Consumer sector         | Examples of usage                                                                                                       | Key attributes & additional information                                                                                                                                                                                         |
|---------------------|-----------|-------------------------|-------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Metallurgical Grade | 60–90     | Metallurgy              | Primarily used in the steel industry                                                                                    | Typically, cost-effective and produced in high volumes<br>Contains controlled levels of impurities acceptable in steel manufacturing<br>Optimized for large-scale processing and energy efficiency                              |
| Ceramic Grade       | 85–96     | Glass, Ceramic, Welding | Glass production, production of ceramics and welding materials                                                          | Offers higher purity for enhanced performance in ceramic and glass applications<br>Minimizes contaminants to ensure quality finish in polishing processes<br>Essential for high-end, precision products                         |
| Acid Grade          | 97–99     | Chemical Industry       | Utilized in the production of aluminum fluoride (AlF <sub>3</sub> ), HF-substance manufacturing, and uranium processing | Demands the highest purity levels to ensure efficiency in chemical reactions<br>Critical for the production of specialty chemicals<br>Subject to stringent quality control and handling requirements due to its reactive nature |

This comprehensive overview emphasizes not only the specific grade ranges and applications but also the essential characteristics that distinguish each type of concentrate in its respective industry.

The concentrate is dried in rotary or fluidized-bed dryers to achieve the final moisture for further processing. Proper drying ensures that the product meets industry standards and is easier to

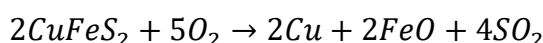
handle and transport. The dried fluorspar concentrate is screened to achieve uniform particle size distribution, an essential requirement for various industrial applications. The final product is then packed in bulk bags or smaller containers for shipment.

## 4.3 Sulfuric acid production

Sulfuric acid production from copper smelting plants is an efficient and sustainable process that utilizes sulfur dioxide (SO<sub>2</sub>) generated as a byproduct during the smelting of copper ores. This method not only minimizes harmful SO<sub>2</sub> emissions but also provides a valuable chemical for various industrial applications.

### 4.3.1 Copper smelting and sulfur dioxide generation

Copper smelting involves the extraction of copper metal from its sulfide ores, such as chalcopyrite (CuFeS<sub>2</sub>). During smelting process (800-1500°C), the sulfide component of the ore is oxidized, producing sulfur dioxide as a major byproduct:



This process occurs in high-temperature furnaces such as flash smelters, reverberatory furnaces, or electric-arc furnaces.

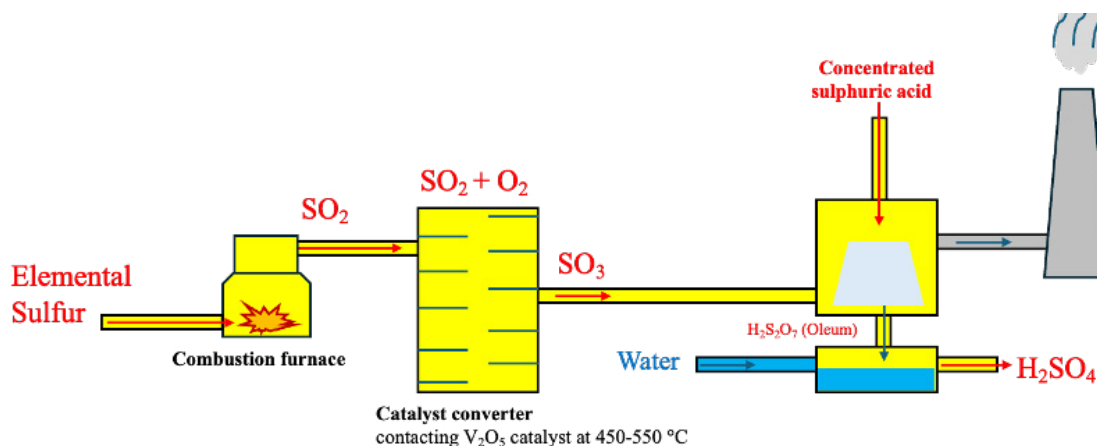


Figure 4.9: Sulfuric acid production from the elemental sulfur.

### 4.3.2 Sulfuric acid production process from smelter off-gases

During the smelting process in the furnace, copper sulfide minerals release harmful gases that pose risks to humans, animals, and vegetation, including acidic sulfur dioxide (SO<sub>2</sub>). Therefore, SO<sub>2</sub> must be removed before the off-gases are released into the atmosphere. Once captured, SO<sub>2</sub> can serve as a valuable resource for producing sulfuric acid. To convert SO<sub>2</sub> emissions into sulfuric acid, smelter off-gases undergo the following steps:

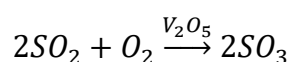
### 4.3.3 Gas cleaning

The goal is to clean smelter gases by removing impurities like dust, arsenic, and heavy metals. This is done first by using electrostatic precipitators or baghouse filters to catch particles, and then by wet scrubbers or cooling towers to cool the gases and wash away soluble impurities.

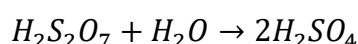
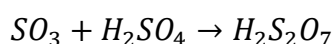
### 4.3.4 Sulfur dioxide conversion

The cleaned gas, which contains sulfur dioxide (SO<sub>2</sub>), undergoes the contact process where it reacts with oxygen in the presence of a vanadium pentoxide (V<sub>2</sub>O<sub>5</sub>) catalyst to form sulfur trioxide (SO<sub>3</sub>). The optimal conditions for the process are a temperature of 450–600°C and a pressure slightly above atmospheric.

*Sulfur trioxide absorption:*



In the process, sulfur trioxide is absorbed into concentrated sulfuric acid to produce oleum (H<sub>2</sub>S<sub>2</sub>O<sub>7</sub>), which is then diluted with water to create sulfuric acid.

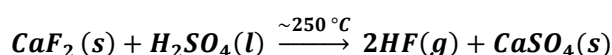


Sulfuric acid concentration must be between 98 % and 99% in order to be suitable for the production of HF. Hence, sulfuric acid plant must consider sulfuric acid concentration. Because, diluted sulfuric acid (<98 %) causes technical issues, such as reactor corrosion, while overly concentrated acid (>99 %) promotes fluorosulfonic acid (HSO<sub>3</sub>F) formation (Aigueperse et al. 2000).

## 4.4 Hydrofluoric acid (HF) production abroad

HF was first identified in the late 18<sup>th</sup> century by Scheele. Also, hydrofluoric acid is a colorless liquid boils at 19 °C and which is dangerous acid by its toxicity and chemical reactivity (Aigueperse et al. 2000). However, this is a critical industrial chemical derived from fluorspar (CaF<sub>2</sub>), with widespread applications in petroleum refining, semiconductor manufacturing, fluorocarbon production, and other advanced industries. The production of HF involves a chemical reaction between high-purity fluorspar (≥97 % CaF<sub>2</sub>) and concentrated sulfuric acid (98-99 %), carried out at elevated temperatures (approximately 250°C). The process yields gaseous anhydrous hydrogen fluoride (AHF or HF), which can be converted into aqueous hydrofluoric acid (usually also abbreviated as HF) (Figure 4.10).

*Key reaction:*



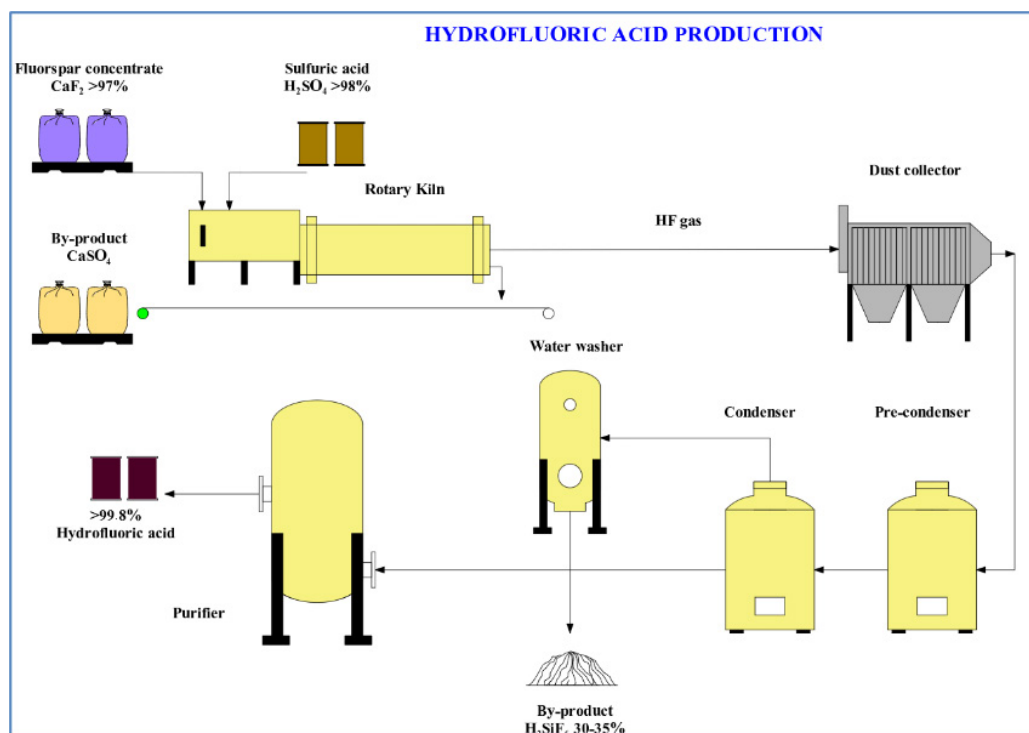


Figure 4.10: Flow diagram of hydrofluoric acid production, illustrating the process from fluorspar concentrate ( $\text{CaF}_2$ ) and sulfuric acid ( $\text{H}_2\text{SO}_4$ ) in a rotary kiln, through HF gas purification, condensation, and by-product generation such as  $\text{CaSO}_4$  and  $\text{H}_2\text{SiF}_6$  (adapted from British Geological Survey 2011).

### 4.4.1 Stages of HF production

#### 1. Raw material preparation:

Acid-grade fluorspar with a minimum of 97%  $\text{CaF}_2$  content is sourced and purified to remove impurities like calcite, quartz, and silicates. Pure concentrate contains  $\text{CaF}_2 >97\%$ ,  $\text{SiO}_2 <1\%$ ,  $\text{CaCO}_3 <1.2\%$  and other elements. However, some HF producers (e.g. in China) can accept fluorspar 95% and 96% concentrates. Impurities such as sulfur, phosphorous, and heavy metals are minimized to enhance reaction efficiency and product quality. An increased  $\text{SiO}_2$  content in fluorspar results in yield losses of HF. During the decomposition process in the rotary kiln,  $\text{SiO}_2$  reacts with HF to form volatile silicon tetrafluoride ( $\text{SiF}_4$ ), which subsequently reacts with an excess of HF to form hexafluorosilicic acid ( $\text{H}_2\text{SiF}_6$ ). As  $\text{SiO}_2$  is always present in fluorspar concentrate,  $\text{H}_2\text{SiF}_6$  becomes a by-product of the production process. While it can usually be marketed, its profitability is far below that of HF.

#### 2. Chemical reaction:

High-purity fluorspar reacts with sulfuric acid in specialized reactors at controlled temperatures. Calcium sulfate (anhydrite,  $\text{CaSO}_4$ ), a co-product, is separated and often used in other industries, such as cement production.

#### 3. Hydrofluoric acid recovery:

The gaseous HF produced is captured and cooled for anhydrous hydrofluoric acid or diluted with water to form aqueous hydrofluoric acid. Advanced purification techniques ensure the removal of



any residual contaminants, producing high-grade HF suitable for industrial use. Table 4.14 shows a Chinese example standard (GB 7746-2011) of hydrogen fluoride and China will be main consumer of Mongolian hydrofluoric acid.

*Table 4.14: Standard for dry hydrogen fluoride for industrial use by the People's Republic of China (PRC).*

| No. | Component              | I grade cat. | II grade cat.<br>Good | II grade cat.<br>Medium | II grade cat.<br>Poor |
|-----|------------------------|--------------|-----------------------|-------------------------|-----------------------|
| 1   | Fluorine (F)           | 99.98 %      | 99.96 %               | 99.92 %                 | 99.8 %                |
| 2   | Silicon (Si)           | 0.005 %      | 0.02 %                | 0.04 %                  | 0.06 %                |
| 3   | Fluorine-bearing acids | 0.005 %      | 0.008 %               | 0.015 %                 | 0.05 %                |
| 4   | Heavy metal impurities | 0.003 %      | 0.005 %               | 0.010 %                 | 0.03 %                |
| 5   | Hydrofluoric acid (HF) | 0.005 %      | 0.005 %               | 0.010 %                 | 0.05 %                |

#### **4. Transportation and storage:**

Liquid HF must be stored in corrosion-resistant containers and transported via specialized tankers to ensure safety and compliance with international standards.

#### **4.4.2 Innovations and sustainable practices in abroad**

To minimize environmental impacts, modern HF production facilities are adopting innovative and sustainable practices:

- **Recycling Co-products:** Calcium sulfate by-products are processed for industrial reuse.
- **Energy Efficiency:** Advanced reactors with optimized thermal efficiency lower energy consumption during HF synthesis.
- **Water Recycling:** Closed-loop water systems are implemented to reduce freshwater usage and enhance sustainability.
- **Emission Control:** Scrubbing systems capture and neutralize hazardous emissions, ensuring environmental compliance.

#### **4.4.3 Applications of hydrofluoric acid**

Hydrofluoric acid (HF) is a highly corrosive chemical substance commonly utilized across a wide range of industrial applications. It serves as an essential compound in processes such as cleaning agents, glass etching, dye production, leather tanning, fireproofing materials, rust removal, and the petroleum industry. Additionally, hydrofluoric acid acts as a critical precursor for numerous high-value products and industrial processes, including:

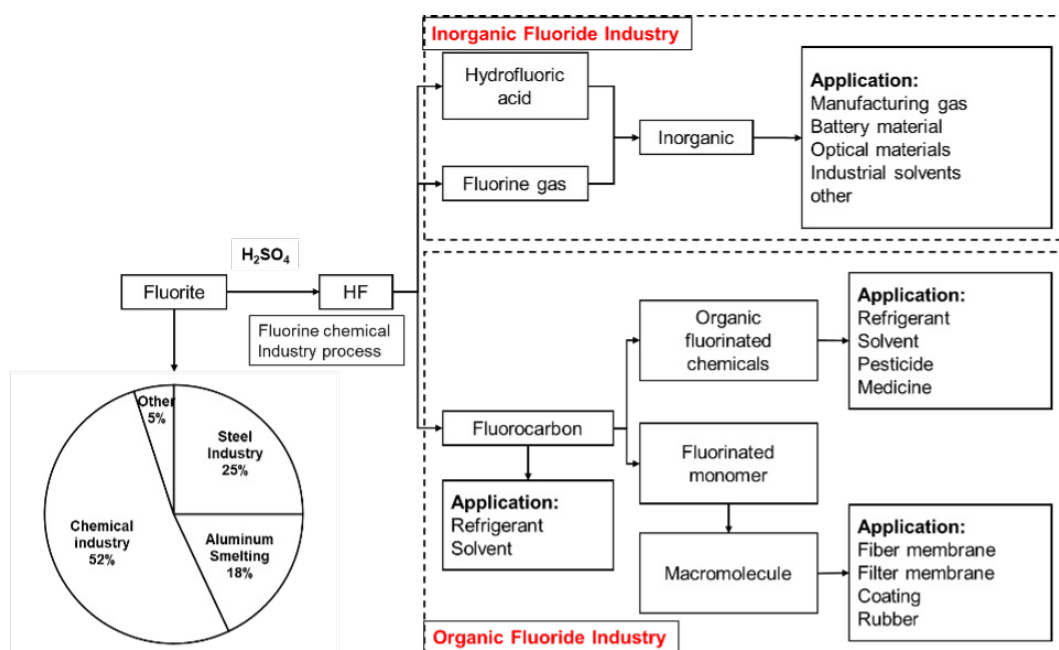


Figure 4.11: Application of fluorspar versus fluorine chemical industry (adapted from Gao et al. 2021).

- **Petroleum Refining:** Alkylation units use HF to produce high-octane gasoline components.
- **Semiconductor Manufacturing:** HF is critical for etching and cleaning silicon wafers.
- **Fluorocarbon Production:** It is a key ingredient in the synthesis of refrigerants and other fluorinated compounds.
- **Chemical Synthesis:** Used in the production of fluoropolymers, pharmaceuticals, and agrochemicals.

### 4.4.4 Possible products from Mongolian hydrofluoric acid

Hydrofluoric acid (HF) is a valuable industrial chemical with diverse applications across various sectors. If Mongolia develops a robust hydrofluoric acid production capacity, it can unlock opportunities to manufacture high-value products. Here are some potential products derived from Mongolian hydrofluoric acid:

#### **Aluminum fluoride ( $AlF_3$ )**

Aluminum fluoride plays a crucial role as an additive in the electrolysis process for producing aluminum. In combination with cryolite ( $Na_3AlF_6$ ), it reduces the melting point of the bauxite ore to below  $1000^\circ C$  and enhances the solution's conductivity. This molten salt mixture serves as the medium in which aluminum oxide is dissolved and subsequently electrolyzed to produce metallic aluminum (Aigueperse et al., 2000). Mongolia possesses several aluminum deposits that remain underutilized due to their limited economic significance. However, the establishment of an HF plant could activate these resources.

#### **Cryolite ( $Na_3AlF_6$ )**

Molten cryolite serves as a solvent for aluminum oxide ( $Al_2O_3$ ) in the Hall-Héroult process, which is essential for aluminum refining (Cassayre, 2010). By lowering the melting point of aluminum oxide

from 2000–2500 °C to 900–1000 °C and enhancing its conductivity, cryolite significantly improves the efficiency and cost-effectiveness of aluminum extraction. Also, cryolite is used for ceramics production and other chemical industries.

### ***Applications:***

- Improving efficiency in aluminum smelting.
- Flux in glass and ceramics production.

### ***High-Octane fuel components***

In petroleum refining, HF is used in alkylation units to produce high-octane fuel components. By integrating HF production into the energy sector, Mongolia could support the development of advanced fuels for both domestic consumption and export.

## 4.5 Strategic plans for future HF production in Mongolia

### 4.5.1 Bor-Undur industrial technological park

Mongolia's fluorspar industry is well-positioned (see Figure 4.12) to support HF production, leveraging its vast reserves of high-quality fluorspar. Collaborations with international partners and the adoption of advanced processing technologies can enable Mongolia to establish itself as a significant player in the global HF market. For example, Erdenes ITP LLC is planning to establish HF plant for local and international consumers by 2030. By integrating sustainable practices and enhancing infrastructure, Mongolia can meet the growing global demand for HF while minimizing environmental impacts.

Figure 4.13 shows the production processes of coal (C), fluorspar ( $\text{CaF}_2$ ), iron ore (Fe), and silicon (Si), highlighting their interconnections, energy consumption, and resulting outputs Bor-Undur ITP. In this ITP plan, Bor-Undur's beneficiation plant is scheduled to produce 490 thousand tonnes of fluorspar ( $\text{CaF}_2$  30–40%) due to produce 80,000 tonnes of FF 97 concentrate (acid-grade concentrate 9%) for HF production.

On the other hand, about 80,000 tonnes of elemental sulfur can be supplied from Erdenet ITP and which will be converted to 240,000 tonnes of sulfuric acid (97–99%) in the sulfuric acid plant in Bor-Undur ITP.

As a result, chemical plants can produce about 80 thousand tonnes of hydrofluoric acid (HF). By-products like anhydrite (also called fluorogypsum, 330 thousand tonnes) and hexafluorosilicic acid (20 thousand tonnes) can be generated during these processes.

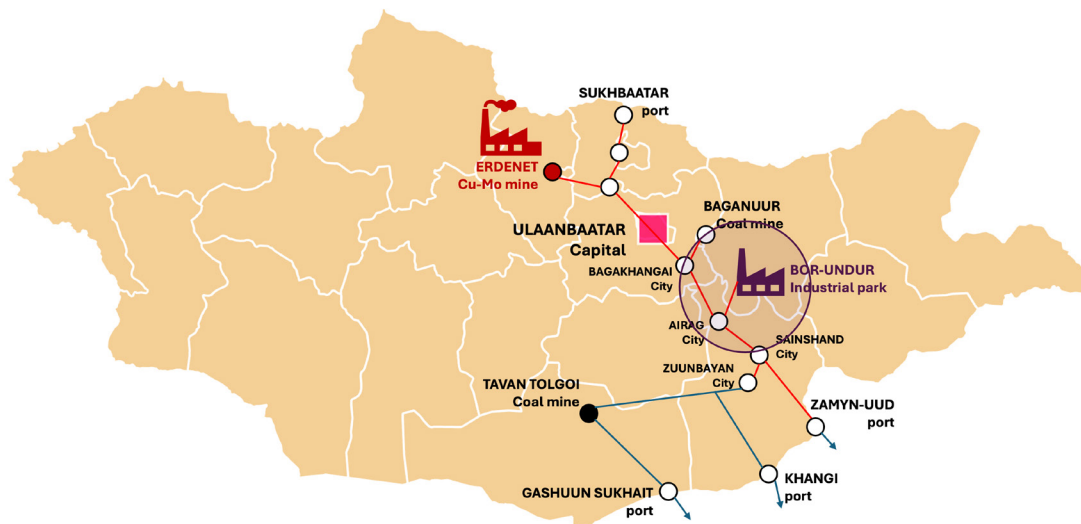


Figure 4.12: Map of Mongolia's key mining locations and industrial locations, highlighting the Erdenet Cu-Mo mine, Baganuur coal mine, Tavan Tolgoi coal mine, and Bor-Undur industrial park, along with key cities and transportation links.

Iron ore production yields 440 thousand tonnes, with further processing into iron concentrate (200 thousand tonnes) and pellet (200 thousand tonnes), which are used in ferrosilicon production and other industrial applications. Silicon production includes 170 thousand tonnes of raw silicon, resulting in ferrosilicon (100 thousand tonnes) and industrial silicon (30 thousand tonnes), consuming 375 million kWh/year of electricity.

The final outputs, such as semi-coke, ferrosilicon, pellets, billet metal, and aluminum fluoride, are distributed domestically and internationally, including exports to Russia (Baganuur ITP). The diagram highlights an interconnected system of raw material extraction, energy generation, and production, with significant industrial output and by-products supporting various industries.



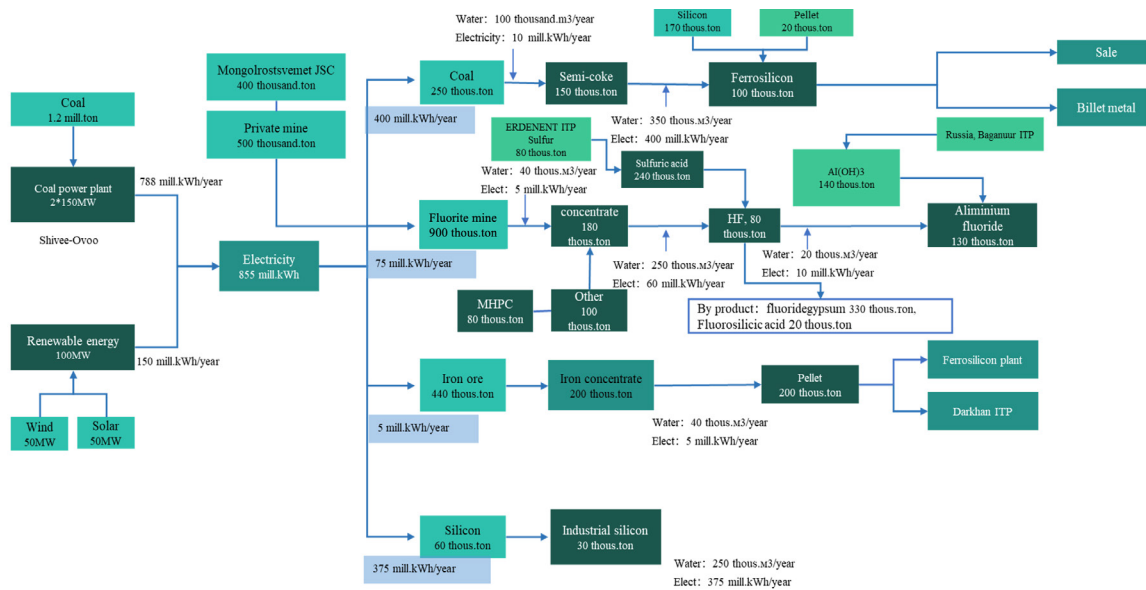


Figure 4.13: Bor-Undur industrial technological park (ITP) scheme.

### 4.5.2 Erdenet industrial technology park

The Erdenet Industrial Technology Park (Erdenet ITP) is situated in Erdenet, Orkhon Province, adjacent to the Erdenet mining area. Established under the Industrial Technology Park Act, the heavy industrial complex was planned as a business operator by the Erdenet Mining Company (EMC) in May 2021. Covering a total area of 1,217.4 hectares, the park is a flagship project in Mongolia's heavy industrial development.

Engineering designs for the park's infrastructure began in June 2022, following the completion of a feasibility study and budget in April 2022. A dedicated development promotion team was formed at EMC to oversee the project, with infrastructure investment secured by June 2022.

Erdenet ITP focuses on advancing Mongolia's copper industry and includes plans for a 10,000 tonne copper cathode plant and a copper smelter. The copper smelter will produce sulfuric acid ( $H_2SO_4$ ) as a byproduct of processing sulfidic concentrates. Notably, sulfuric acid is a critical raw material for hydrofluoric acid (HF) production, making it an indispensable resource for industrial processes in Mongolia.

Additionally, EMC aims to expand and modernize its ore processing plant, as well as upgrading its machinery repair and molybdenum refining facilities. The park is set to play a pivotal role in driving the country's heavy industrial growth.

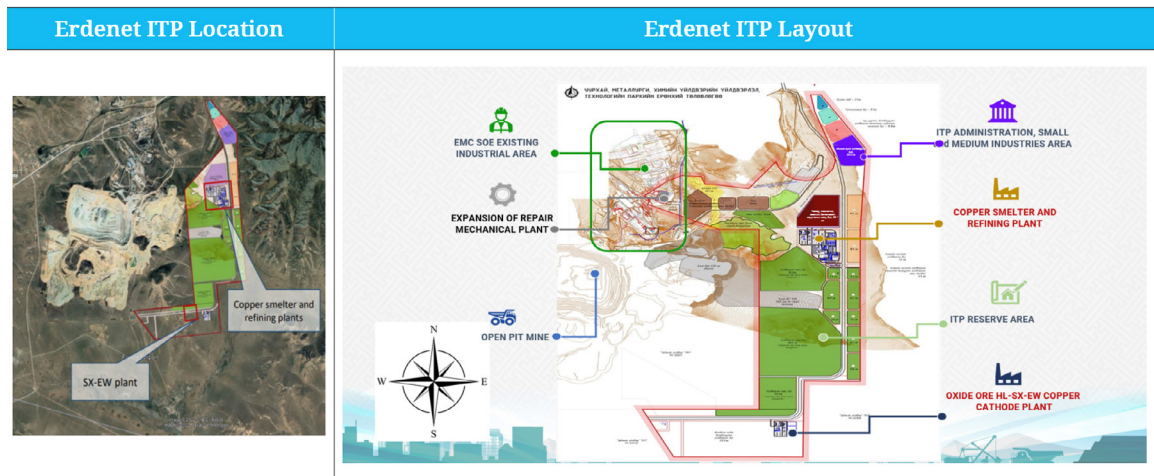


Figure 4.14: The location of Erdenet Industrial Technological Park adapted from (You, 2022).

## Conclusion

Mongolia has the potential to emerge as a key player in the production of fluorspar products in East Asia. Prior to COVID-19, Mongolian companies produced approximately 2.2 million tonnes of fluorspar products annually, including roughly 220,000 tonnes of acid-grade concentrates (FF-97), 210,300 tonnes of ceramic-grade concentrates (FF-95), and metallurgical-grade concentrates (MGF 55-85%) (MRPAM 2025). This chapter focuses on hydrofluoric acid (HF) production in Mongolia, which necessitates the use of acid spar concentrates.

Processing fluorspar-rich ores (with  $>30\%$   $\text{CaF}_2$ ) presents minimal technological challenges, although some process optimization – such as integrating the drying process with rotary kiln calcination – may be required. In contrast, calcite-rich ores pose significant challenges for producing acid-grade concentrates. These difficulties are further compounded by the limited collaboration between mining companies and research institutions in developing tailored processing strategies for different ore types. To address these challenges, this study recommends exploring Reverse flotation and XRT sorting systems that could unlock additional capacity for calcite-rich ores.

Our investigation concentrated on the beneficiation plants of Bor-Undur SOE and Mongol Czech Metal LLC due to their significant reserves and established infrastructures. Both facilities have demonstrated potential for producing acidspar concentrates, as confirmed by previous studies, laboratory tests, and analyses of industrial stream samples. Assays were performed in local laboratories as well as using MLA-SEM at TUBAF in Freiberg, Germany.

For HF production, high-grade sulfuric acid (98–99%) is required. This can be produced from elemental sulfur obtained as a byproduct from Erdenet ITP. At Bor-Undur ITP, the sulfuric acid plant may need to be adapted to achieve the necessary acid grade. Furthermore, the Mongolian government plans to establish several industrial technology parks position Bor-Undur as a strategic hub for producing key products. Finally, the study concludes that the most feasible applications of HF in Mongolia include the production of aluminum fluoride, cryolite, and petroleum additives. For other high-technology products, Mongolia requires substantial investment, thorough research, robust infrastructure, and supportive legal frameworks.

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# 5

## Fluorspar market study

*Dr. Manlaibaatar Zagdbazar, Ms. Nomun Enkhbold and  
Ms. Nomunaa Ganbold, Economic Research Institute (ERI)*



# Introduction

Mongolia ranks 4th in the world in terms of fluorspar reserves and 3rd in terms of production, after China and Mexico, and is one of the main suppliers of this raw material.

During the socialist era, geological exploration and mining activities for fluorspar were actively carried out, playing a significant role in industrial development. In the 1980s, 700,000 tonnes of fluorspar were mined annually. During the early stages of the market transition, production in this sector declined, and major fluorspar mines ceased operations. However, from the mid-2000s, the fluorspar sector revived, attracting the interest of foreign investors. Consequently, in 2023, fluorspar exports exceeded 1 million tonnes, setting a new record.

According to the Cadastre Department of the Mineral Resources and Petroleum Authority of Mongolia (MRPAM), the number of valid fluorspar mining licenses increased from 181 in 2018, covering an area of 26,775 hectares, to 218 in 2023, covering an area of 58,172 hectares. However, the number of companies with registered mining licenses at the Mongolian Tax Administration (MTA) was lower, with 126 in 2018 and 171 in 2023.

Although Mongolia is rich in this commodity and mining and export activities have recently been revived, the level of processing is low, and the tax revenue from the fluorspar sector is insufficient. For example, in 2023, the fluorspar sector accounted for 1.8% of the country's total exports but contributed only 0.2% of the state budget revenue.

However, there is a lack of research on the market conditions and future development opportunities of this sector. This chapter aims to clarify these issues and provide an overview of the external and internal landscape of the fluorspar market.

In recent years, changes in Mongolia's fluorspar sector have been related to both domestic and international market factors, which will be discussed in detail in the following sections. Section 5.1 will introduce recent trends in global fluorspar supply, demand, and prices, while Section 5.2 will discuss the domestic market, including fluorspar ore and concentrate production, exports, and issues in the fluorspar sector. Finally, the study's conclusions on the fluorspar market will be briefly presented.

## 5.1 Global fluorspar market

### 5.1.1 Global fluorspar supply

As of 2023, the world reserves of fluorspar total 280 million tonnes. Of these reserves, 80% are concentrated in five countries. Mexico holds 24% of the total reserves, equivalent to 68 million tonnes, followed by China with 24% or 67 million tonnes, South Africa with 15%, Mongolia with 12% or 34 million tonnes, and Spain with 5.4% or 15 million tonnes (Figure 5.1).

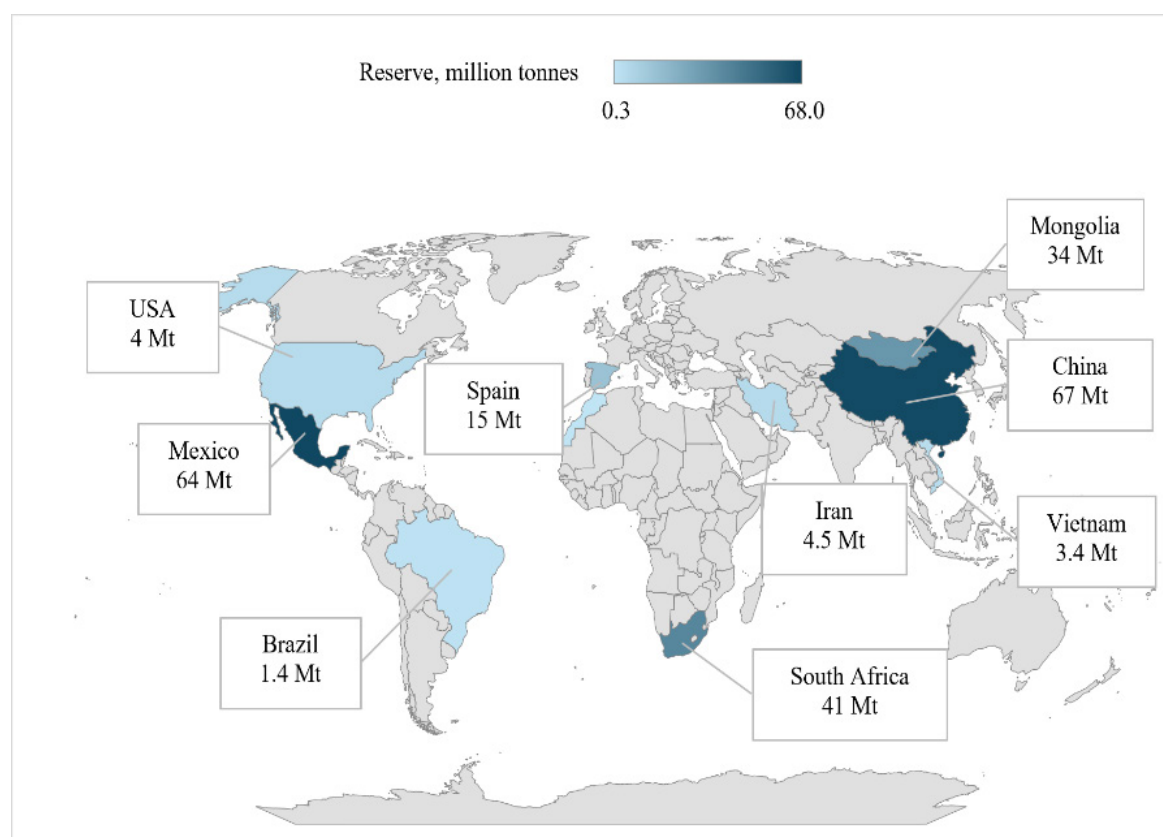


Figure 5.1: World fluorspar reserves, by countries, 2023 (Source: USGS Mineral commodity summary, 2023, 2024).

Geological exploration for fluorspar, which is listed as a critical mineral in many countries, is being conducted intensively worldwide, suggesting that the above-mentioned reserves are likely to increase in the future. As of 2024, Mongolia has recorded 157 fluorspar deposits and 36 million tonnes of remaining reserves in its mineral resource register (MRPAM, 2024).

Global fluorspar production has been growing at an average annual rate of 3.8% since 2000. As depicted in Figure 5.2, total production reached 8.8 million tonnes in 2022 (USGS, 2000-2024).

China remains the world's largest producer of fluorspar, accounting for 5% of global production in 2002, with its share increasing to 70% in 2022. It is followed by Mexico with 11%, Mongolia with 4.8%, South Africa with 4.6%, and Vietnam with 2.5% (Figure 5.3). Production data indicates that France, Italy, Brazil, Kenya, Namibia, Romania, and Argentina have seen their production decline

and eventually stop, while Vietnam, Canada, Myanmar, and Nigeria have recently emerged as new producers.

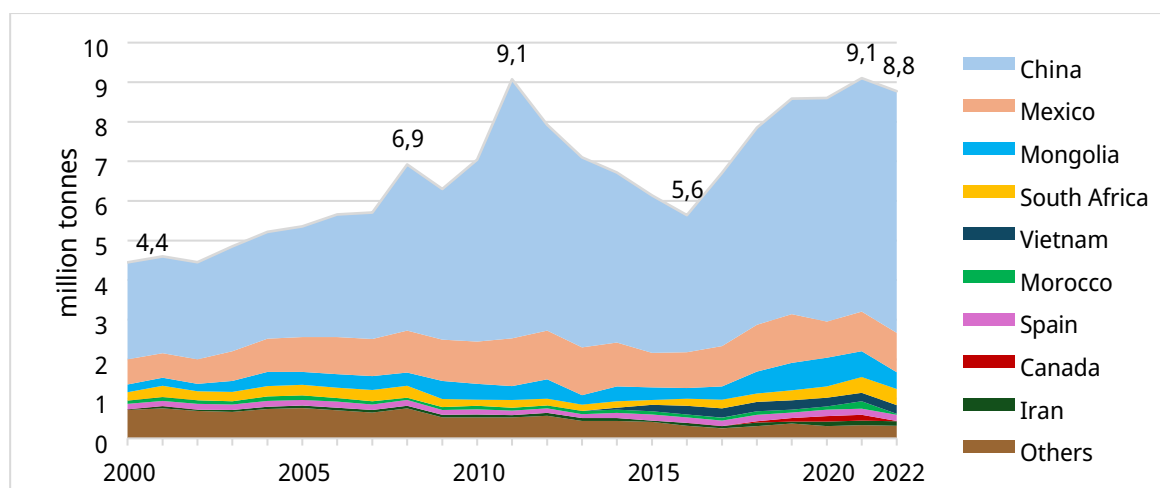


Figure 5.2: World fluorspar mine production, by countries, million tonnes, 2000-2022  
(Source: USGS Minerals yearbook 2000-2022).

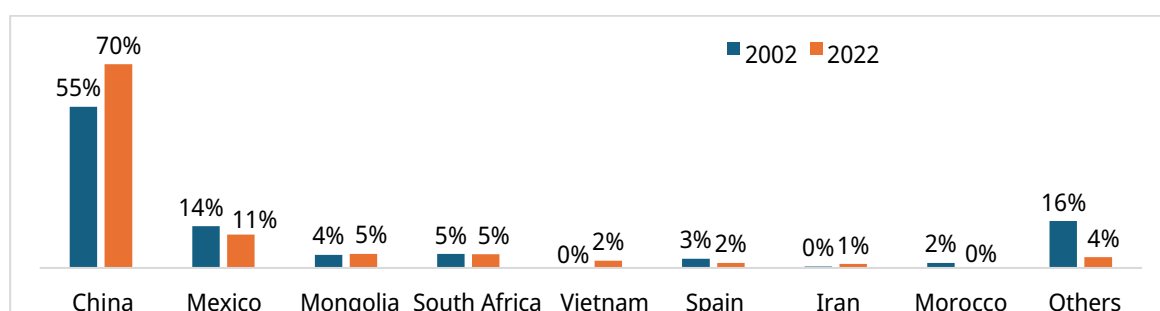


Figure 5.3: Share of world fluorspar production by countries, in 2002 and 2022  
(Source: USGS Minerals yearbook (2000-2022)).

Fluorspar qualities are classified into two main categories based on its composition: i) acidspar (= acid grade fluorspar), containing more than 97% calcium fluoride by weight and sold as concentrate; and ii) metspar (= metallurgical grade fluorspar), containing 60-97% calcium fluoride by weight and sold as fluorspar ore lumps or as concentrate<sup>1</sup>. In addition to the classic metspar for the iron and steel industry (often 85-95%  $\text{CaF}_2$ ), the trade name metspar also includes cement spar ( $\text{CaF}_2 > 60\%$ ) as well as glass and ceramic spar (often 85-96%  $\text{CaF}_2$ ). While cement spar is primarily used in cement production, glass and ceramic spar are specifically utilized in the glass and ceramics industry as well as in the production of welding materials. In contrast to classic metallurgical spar, glass and ceramic spar must meet significantly higher quality parameters and is therefore more expensive to produce. For the production of fluor and fluorophosphate glasses for optical applications such as spectroscopy, microscopy or laser systems, small quantities of optical-grade fluorspar with a content of  $> 99\%$   $\text{CaF}_2$  is traded.

<sup>1</sup> In Mongolia, the acid-grade fluorspar is produced as a flotation concentrate, which may include some material below the 97%  $\text{CaF}_2$  threshold.

When broken down by grade, acid-grade fluorspar (acidspar) typically accounts for more than half of total production. In 2022, 66% was classified as acid grade, 29% as metallurgical grade (metspar), and 5% as other and unspecified fluorspar (Figure 5.4).

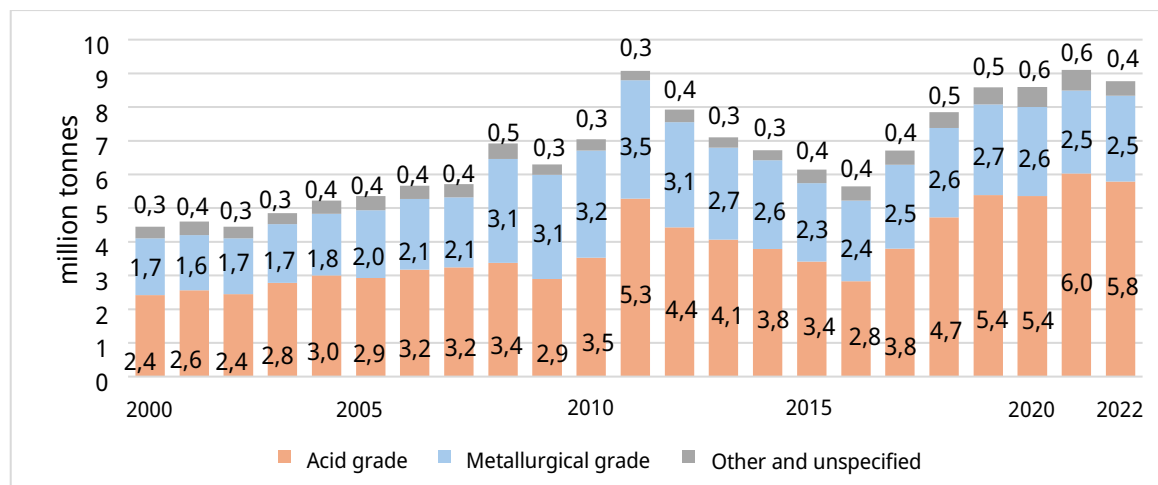


Figure 5.4: World fluorspar production, by grade, million tonnes, 2000-2022 (Source: USGS Minerals yearbook (2000-2022), Project Blue (2024a), and Roskill (2021)). Note: Countries that did not report their classification were grouped into the 'Other and unspecified' category.

World production of acidspar has grown at an average rate of 5.1% per year since 2000, reaching 5.8 million tonnes in 2022 (Figure 5.5 A). Mexico is the second-largest producer of acidspar after China, with production also increasing by an average of 5.1% per year since 2000. In 2022, China produced 4.4 million tonnes, Mexico 820,000 tonnes, South Africa 360,000 tonnes, Spain 140,000 tonnes, Germany 23,000 tonnes, and Mongolia 25,000 tonnes of acidspar.

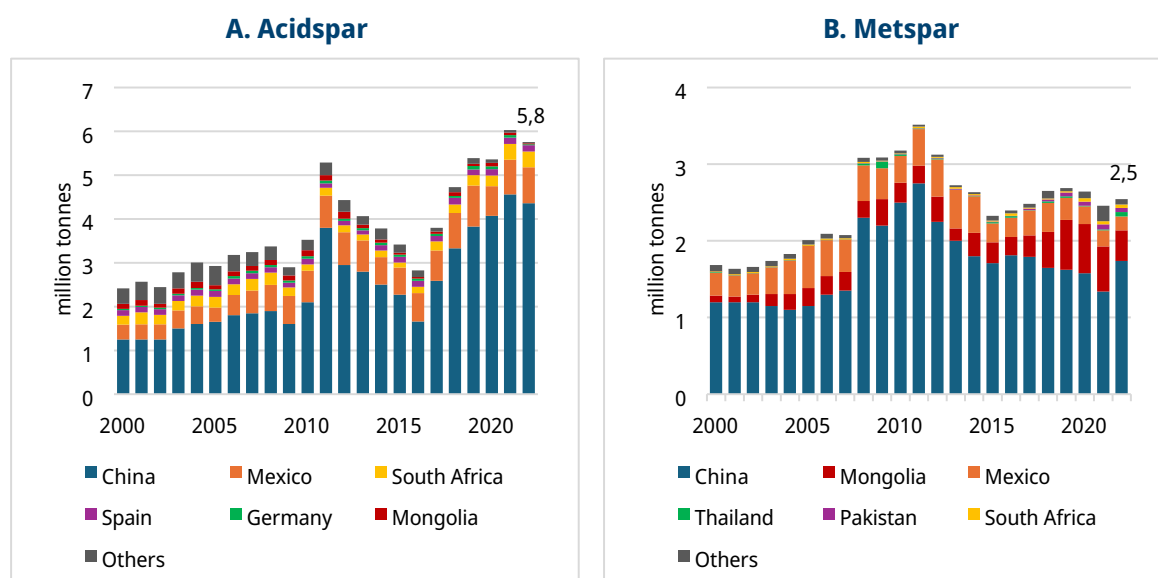


Figure 5.5: Fluorspar production, by countries, million tonnes, 2000-2022 (Source: USGS Minerals yearbook (2000-2022)).



The average annual growth rate of metspar production is 2.6%, with 2.5 million tonnes produced in 2022. Mongolia's metspar production has grown at an average rate of 15% per year since 2000, making it the second-largest producer after China. In contrast, Mexico's production of this fluorspar quality has fallen by an average of 8% per year since 2014. In 2022, China produced 1.7 million tonnes, Mongolia 400,000 tonnes, Mexico 180,000 tonnes, Thailand 59,000 tonnes, Pakistan 52,000 tonnes, and South Africa 46,000 tonnes of metspar (Figure 5.5 B)

### Fluorspar trade

Fluorspar is an important raw material in both the metal processing and chemical industries, with countries that mine fluorspar exporting it to industrialized nations. Historically, China and Mexico were the primary exporters of fluorspar; however, in recent years, Mongolia has emerged as the leading exporter (Figure 5.6).

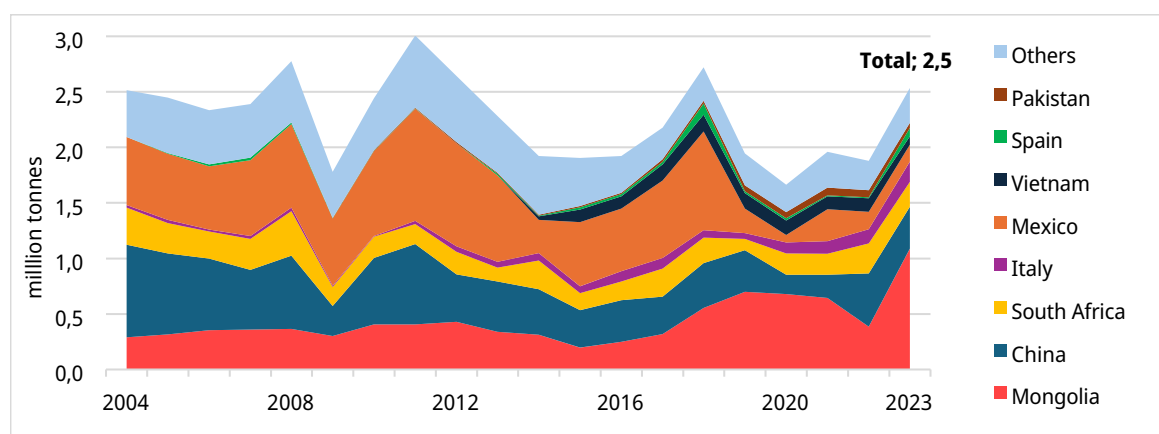


Figure 5.6: Fluorspar exports, by countries, million tonnes, 2004-2023 (Source: International Trade Centre (2024)).

Global exports of fluorspar<sup>2</sup> in 2023 totaled 2.5 million tonnes. Mongolia accounted for a substantial 43% of these exports (Table 5.1).

In 2023, the global fluorspar export market was valued at \$846 million, with Mongolia accounting for \$272 million of that total. Calculating the average export price reveals a global average of \$334 per tonne. However, there was significant price variation among exporting countries. Vietnam and the Netherlands, for example, saw average export prices exceeding \$600 per tonne, while Mongolia, Italy, and the USA reported average prices below \$250 per tonne.

<sup>2</sup> Export and import data for the year were identified using the Harmonized Commodity Description and Coding System (HCS) product codes 252921 Fluorspar containing by weight  $\leq 97\%$   $\text{CaF}_2$ , and 252922 Fluorspar containing by weight  $> 97\%$   $\text{CaF}_2$ .

Table 5.1: Fluorspar export, by countries, kt = 1000 tonnes, 2023 (Source: International Trade Centre (2024)).

| No | Exporter countries | Quantity, kt | Share in world export % | Value, million USD |
|----|--------------------|--------------|-------------------------|--------------------|
| 1  | Mongolia           | 1,087.8      | 43%                     | 272.4              |
| 2  | China              | 377.6        | 15%                     | 165.6              |
| 3  | South Africa       | 224.5        | 9%                      | 102.1              |
| 4  | Italy              | 181.9        | 7%                      | 17.2               |
| 5  | Mexico             | 151.5        | 6%                      | 65.4               |
| 6  | Vietnam            | 76.7         | 3%                      | 51.1               |
| 7  | Spain              | 73.5         | 3%                      | 39.8               |
| 8  | Pakistan           | 48.6         | 2%                      | 13.8               |
| 9  | Netherlands        | 46.9         | 2%                      | 30.3               |
| 10 | USA                | 40.4         | 2%                      | 5.4                |
| 11 | Others             | 225.8        | 2%                      | 82.6               |
| 12 | <b>Total</b>       | 2,535.3      | 100%                    | 845.7              |

Fluorspar imports are primarily concentrated in large industrialized nations (Figure 5.7). While the United States was the leading global importer prior to 2017, China has since become the dominant importer.

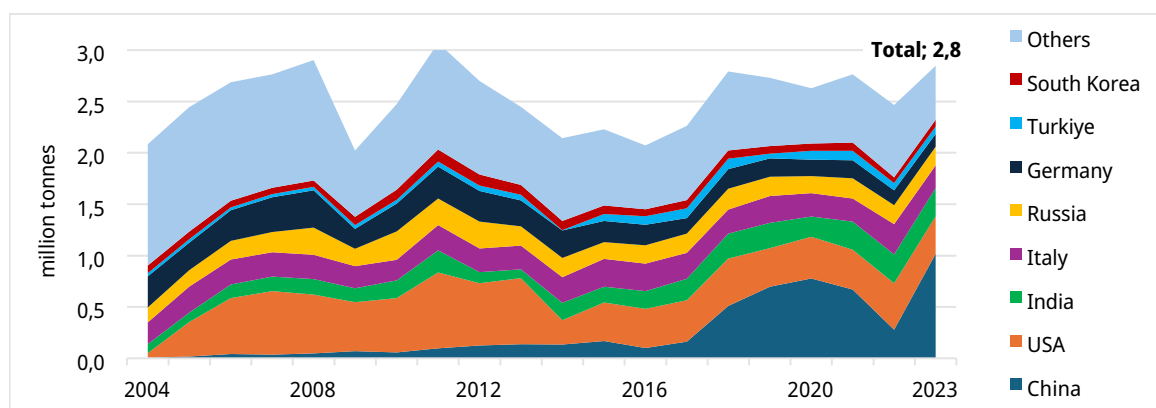


Figure 5.7: Fluorspar imports, by countries, million tonnes, 2004-2023 (Source: International Trade Centre (2024)).

Global fluorspar imports in 2023 totaled 2.8 million tonnes, valued at \$983 million. China was the largest importer, accounting for 35% of the total volume, followed by the United States (13%) and India (10%) (Table 5.2). However, when considering import value, the United States led at \$157 million, followed by China at \$153 million, and India at \$135 million. This discrepancy suggests that China's average import price for fluorspar was significantly lower than that paid by the United States and India.

In recent years, China's imports of fluorspar have been largely met by Mongolian exports, and it is noteworthy that the average export price of Mongolian fluorspar is much lower than that of other countries. This will be discussed in more detail in the next section.

*Table 5.2: Fluorspar import, by countries, kt = 1000 tonnes, 2023 (Source: International Trade Centre 2024).*

| No        | Importer countries | Quantity, kt   | Share in world import % | Value, million USD |
|-----------|--------------------|----------------|-------------------------|--------------------|
| 1         | China              | 1,017.2        | 36%                     | 152.9              |
| 2         | USA                | 366.9          | 13%                     | 156.8              |
| 3         | India              | 273.3          | 10%                     | 134.5              |
| 4         | Italy              | 220.4          | 8%                      | 100.1              |
| 5         | Russia             | 180.5          | 6%                      | 51.7               |
| 6         | Germany            | 126.3          | 4%                      | 71.1               |
| 7         | Turkiye            | 72.9           | 3%                      | 12.6               |
| 8         | South Korea        | 64.9           | 2%                      | 28.6               |
| 9         | Indonesia          | 59.3           | 2%                      | 28.5               |
| 10        | Japan              | 57.4           | 2%                      | 33.4               |
| 11        | Others             | 408.4          | 14%                     | 212.8              |
| <b>12</b> | <b>Total</b>       | <b>2,847.3</b> | <b>100.0%</b>           | <b>982.9</b>       |

As the global supply of fluorspar is highly concentrated, the fluorspar market has been dependent on major supplier countries, especially China. Since the 2000s, to meet its growing domestic demand, China has implemented policies to reduce its fluorspar exports each year, including issuing export licenses, setting quotas, increasing export duties, and establishing minimum prices.

As China, a major global producer, began reducing its supply to the international market, supply issues emerged, further exacerbated by the closure of fluorspar mines in countries such as France and Italy in 2006. As a result, fluorspar prices began to rise due to the supply shortage, reaching their highest level in 2008. In 2009, the European Union (EU), Mexico, and the United States filed a complaint with the World Trade Organization (WTO) against China's export restrictions. During this period, demand for fluorspar declined due to the global financial crisis, resulting in a decrease in prices. Although demand for fluorspar rebounded in 2010, prices did not return to their 2008 peak. Some South African mines, which had been forced to shut down due to the decline in demand and prices in 2009, resumed operations. To compensate for the reduction in Chinese supply, some countries have taken steps to increase their mining capacity and initiate new mining projects. In the early 2000s, the EU primarily imported fluorspar from China but has since reduced its imports from China by progressively increasing imports from Mexico each year. In 2011, the price of fluorspar began to rise, with Chinese prices seeing the largest increase as export costs grew in line with China's policy. The WTO ruled that China's export reduction policy was inconsistent with its obligations as a trading member. Since 2012, a global economic slowdown, new regulations, and the replacement with less harmful substances have led to a decline in demand within the fluorochemical industry, which in turn resulted in lower demand and falling prices of fluorspar.

By 2015, due to prolonged unfavorable market conditions, many mines in countries such as India, Namibia, Russia, and South Africa had been completely closed, while many exploration and development projects were abandoned or significantly delayed. Another factor affecting the market was the introduction of regulations related to global warming, including the Kigali Amendment<sup>3</sup> to the Montreal Protocol on Substances that Deplete the Ozone Layer, which impacted the global fluorochemical industry.

Global fluorspar supply improved in 2019 as production resumed and new mines in Canada and South Africa came online, but fluorspar production declined in 2022 due to bankruptcies and idled operations in some Canadian mines, as well as force majeure conditions at major mines in Mexico.

By 2033, the supply of fluorspar is expected to exceed 9.7 million tonnes, with the supply of metspar projected to reach 2.8 million tonnes and the supply of acidspar anticipated to total 6.9 million tonnes. If new projects are implemented, the supply could increase to 11 million tonnes (Project blue (2023), (2024a)).

#### **Trade routes**

The world's major producers and exporters trade metspar and acidspar through the following transport modes (Indmin Data, 2013):

- China utilizes sea transport to ship metspar to India, the United States, Japan, South Korea, Italy, Germany, and other countries.
- Mongolia primarily uses rail transport to deliver metspar to Russia and China.
- Mexico uses sea transport to export metspar to the United States.
- South Africa utilizes sea transport to ship metspar to China, India, the United States, and various European countries.

This highlights a key disadvantage for Mongolia: while other fluorspar exporters utilize maritime shipping, Mongolia relies solely on rail transport. This reliance on rail freight increases transportation costs for the bulky commodity, negatively impacting competitiveness and potentially driving down export prices.

### **5.1.2 Global fluorspar demand**

The consumption of metspar and acidspar nearly doubled from 2004 to 2022, reaching 9.4 million tonnes in 2022 (Figure 5.8). China was the largest consumer, accounting for 63% of total fluorspar consumption in 2022. It was followed by Mexico, which consumed 9%, the United States with 4.3%, India with 3%, Russia with 2.4%, and Germany and Italy, each with 1.8%.

Global demand for acidspar and metspar is expected to be around 9 billion tonnes in 2024, with a compound annual growth rate (CAGR) of 0.6% between 2024 and 2034, reaching over 13 billion tonnes by 2034 (Project Blue, 2024a). By 2034, approximately 65% of the demand will be for acidspar, while the remaining share will be for metspar.

<sup>3</sup> The goal of the Kigali Amendment is to reduce the production and consumption of hydrofluorocarbons (HFCs), which are widely used in aerosols, refrigerants, and solvents, by 80% by 2047, thereby contributing to a reduction in global warming by 0.5 degrees Celsius by the end of this century.



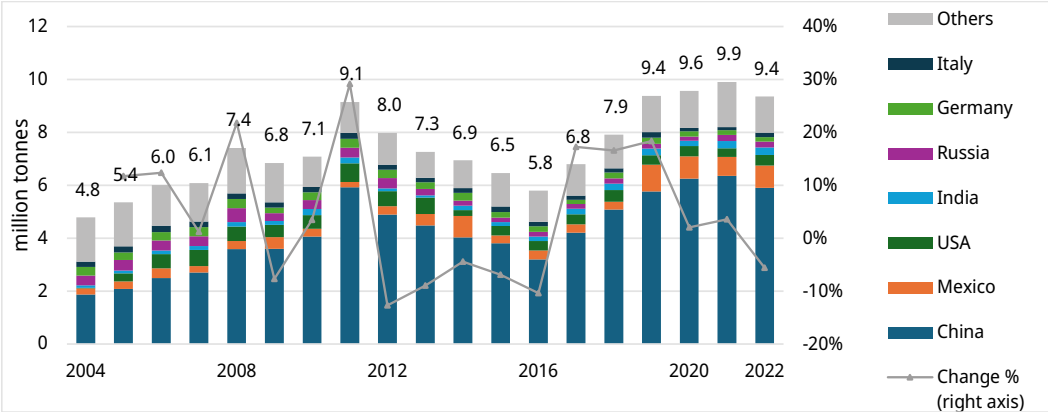


Figure 5.8: Fluorspar consumption, by countries, million tonnes, 2004-2022 (Source: Researchers' estimation based on data from USGS and ITC).

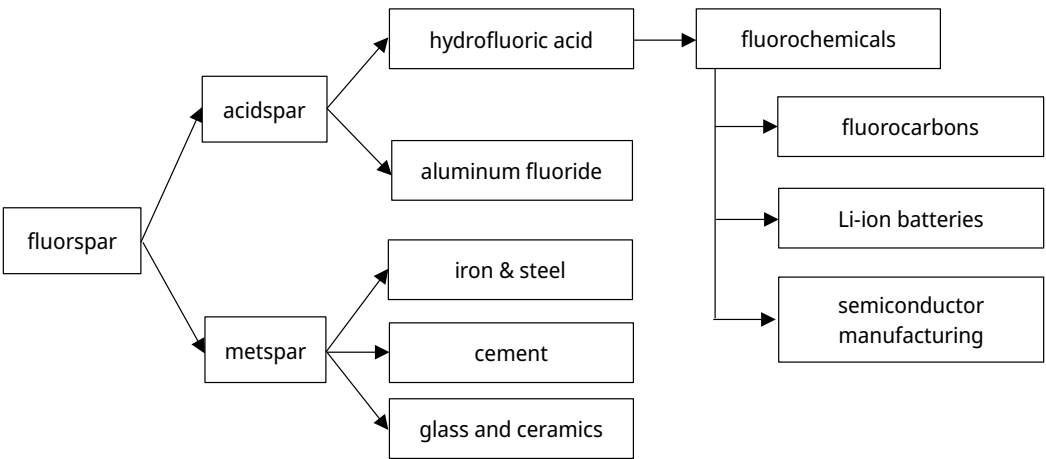


Figure 5.9: Fluorspar classifications and applications (Source: Informed).

Acidspar is primarily used in two key applications: producing hydrofluoric acid (HF), the main precursor for all fluorochemicals, including fluorocarbons and electronic applications such as semiconductor production, and lithium-ion and other batteries; and manufacturing aluminum fluoride (AlF<sub>3</sub>), which serves as a flux to reduce bath temperature in aluminum production (Figure 5.9; Informed, 2019). Metspar, by contrast, is used in the production of iron and steel, cement, glass, ceramics, and welding rods.

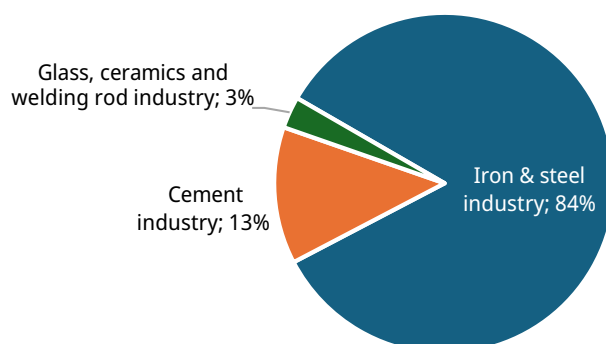


Figure 5.10: Main drivers in the metspar industry (Source: Project Blue (2024a)).

### **Metspar demand**

Metspar is primarily used in steel production, with the following purposes: 1) reducing the melting temperature of the production process and lowering the energy required for melting, 2) enhancing the electrolyte fluidity to increase ion movement, which allows for more efficient extraction of steel, and 3) helping to remove unwanted impurities, contributing to the production of high-quality steel. As seen in Figure 5.10, in 2024, the steel industry accounted for 84% of the demand for metspar, while the cement industry and the production of glass, ceramics, and welding rods each made up 13% and 1%, respectively.

In 2024, crude steel production was 1.87 billion tonnes, and it is expected to grow by 10% to reach 2.06 billion tonnes by 2034 (Project Blue, 2024a). In 2024, China accounted for 55% of global crude steel production, but by 2034, this share is expected to decrease to 47%. The reduction in China's share of total crude steel production is linked to the country's efforts to reduce its steel consumption and achieve carbon dioxide neutrality by 2060.

In 2024, stainless steel production was 59 million tonnes, and it is expected to increase by 29%, reaching 77 million tonnes by 2034. In 2024, China accounted for 56% of global stainless steel production, but by 2034, this share is expected to decrease by 4.8 percentage points to 50%. This growth will heavily depend on China's production expansion, which is focused on value-added products.

As urbanization accelerates and infrastructure construction and automobile production increase, the growth of steel production will support the rising demand for metspar. The scarcity of natural resources and energy security will further enhance the strategic importance of metspar, driving demand, particularly influencing the Asian market, with China's production playing a major role. However, in the context of combating climate change, technologies for producing carbon-free steel may alter the demand for the mineral, creating new opportunities while posing risks of reduced consumption.

Following China's construction trends, which are the largest consumers of metspar for improving cement kiln energy efficiency, demand for metspar in cement production is expected to rise. However, the use of metspar in other smaller industries such as glass, ceramics, and welding is likely to remain stable and not grow in the coming years. Additionally, if metspar is phased out of production due to environmental protection measures – particularly efforts to eliminate fluorine from industrial for environmental reasons – or as steel production transitions to "green steel" where hardly any flux is required, there is a risk of reduced demand.

### **Acidspar demand**

The demand for HF, derived from acidspar, is projected to increase by 3% between 2024 and 2030, reaching 2,314 thousand tonnes by 2030 (BMI, 2024). China used this acid to make fluorocarbons (67%) and battery electrolytes (10%) in 2024 (S&P Global Commodity Insights, 2024).

Fluorocarbons are used in the production of raw materials for refrigerants such as hydrochlorofluorocarbon (HCFC) and hydrofluorocarbon (HFC). In 2023, when classifying global consumption of fluorocarbons by chemical type, HCFC accounted for 53%, while HFC made up 41%. Since the phase-out of the production of halogenated chlorofluorocarbon (CFC) by the signatories of the Montreal Protocol, CFCs have been replaced by hydrochlorofluorocarbon (HCFC), which, however, also have a certain ozone depletion potential. With the realization that it is not the fluorine but primarily the chlorine is problematic for the ozone layer, chlorine-free hydrofluorocarbon (HFC) were developed which do not damage the ozone layer. However, as they contribute to global warming, fluoroolefin hydrocarbons (HFO) are currently being developed and tested.

Fluorocarbons have numerous potential applications, and by 2028, projections indicate that polymers will account for 65% of global fluorocarbon consumption (Figure 5.11) (S&P Global Commodity Insights, 2024).

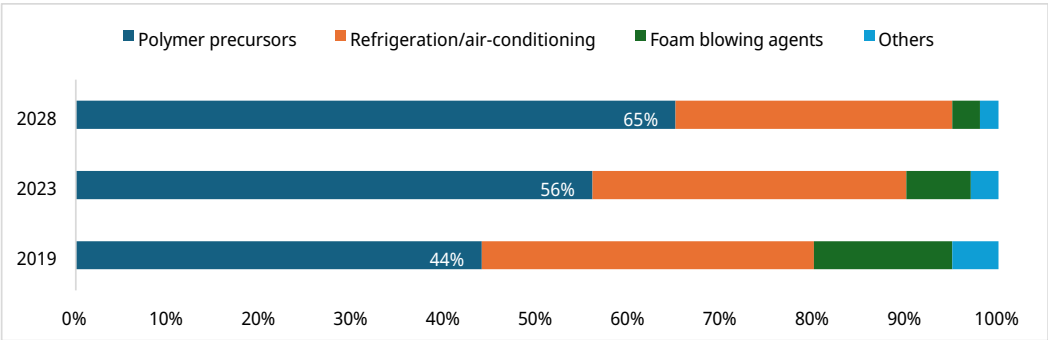


Figure 5.11: Total global fluorocarbon consumption, by type of use, 2019-2028. (Source: S&P Global Commodity Insights Conference Presentation).

Due to the rapidly growing market for lithium-ion batteries used in electric vehicles and energy storage systems, the demand for acidspar is expected to increase. In 2020, batteries accounted for 1% of acidspar demand, but with the green transition, this figure is expected to rise to 6% by 2024 and potentially reach 18% by 2030 (Figure 5.12). Breaking down battery demand by sector, electric vehicle batteries accounted for 76% of total battery demand in 2024, while energy storage systems made up 17%. By 2030, the demand for electric vehicle batteries is expected to increase, making up 83% of total demand. As a result, by 2030, total battery demand is expected to reach 1.8 million tonnes, and the overall demand for acidspar 9.8 million tonnes.

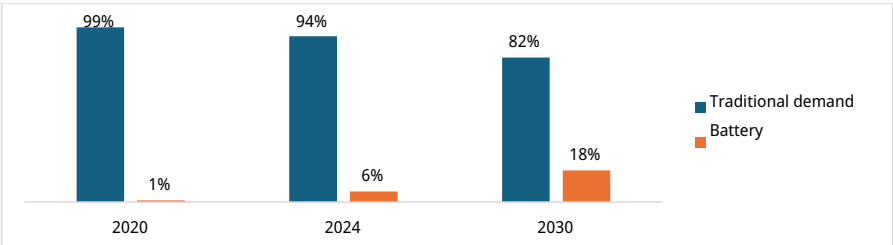


Figure 5.12: Traditional and emerging demand for acidspar (Source: Project Blue, 2024a).

The components of a battery include the electrolyte, binder, anode, and separator. Among these components, acidspar is most commonly used for producing fluorine-containing liquid and solid-state electrolytes, binders and separators as well as for purifying graphite for production of anodes, with approximately 0.23 kg of acidspar being consumed in the manufacturing process per 1 kWh of battery energy capacity. Additionally, the amount of acidspar required to produce lithium iron phosphate (LFP) batteries is higher compared to other types of batteries. The demand for the LFP batteries, which require significant amounts of acidspar, was 532 GWh in 2024 and is expected to triple to 1,695 GWh and exceed 1.6 million tonnes by 2030 (Benchmark Source, 2024). The demand of China's acidspar for battery components is projected to increase around threefold by 2030 (BMI, 2024).

Acidspar is an essential component in semiconductor production, as it is used in the wet etching process and for cleaning chemical vapor deposition (CVD). Semiconductors are a key technology, with demand driven by the growing use of chip production and artificial intelligence (AI). The global semiconductor chemicals market was valued at US Dollars (USD) 12 billion in 2023 and is expected to grow to USD 22 billion by 2028, with annual growth rate of 12% from 2023 to 2028 (Markets and Markets, 2024). As the semiconductor industry expands, the demand for HF is anticipated to rise.

Aluminium fluoride ( $\text{AlF}_3$ ) is a key additive in the Hall-Héroult process, where it (in combination with synthetic cryolite ( $\text{Na}_3\text{AlF}_6$ )) lowers the melting point of the aluminium ore (bauxite), improving energy efficiency in aluminium production. It also enhances electrolyte conductivity and stabilizes bath chemistry, making the electrolysis process more efficient. With increasing aluminium production and demand from industries such as automotive and renewable energy, the aluminium fluoride market is projected to grow from USD 1.6 billion in 2022 to USD 1.7 billion by 2030 (Yahoo Finance, 2023)

Although the demand for products that require acidspar is expected to increase, there are factors that could slow or reduce this demand in the future. Investment in recycling technologies for battery components such as electrolytes and separators may reduce dependence on fluorspar over the long term. Additionally, research is being conducted to develop alternative sources of fluorine, such as fluosilicic acid, in order to reduce dependence on fluorspar mining (Benchmark Source, 2024). Fluosilicic acid, a byproduct of the production of phosphoric acid, is being used by some companies, such as TSMC, as a raw material for hydrofluoric acid production instead of acidspar (TSMC, 2023). Additionally, the European Commission is also discussing a ban on per- and polyfluoroalkyl substances (PFAS) in consumer products, allowing only limited exceptions for critical industrial uses, which could take effect as early as 2026. However, compared to the potential supply shortages that may arise in the future, the risks on the demand side are considered to be lower.

According to the estimation by Benchmark Mineral Intelligence (BMI, 2024), fluorspar reserves are declining worldwide, with the fastest depletion occurring in China. Moreover, primary production is expected to remain the main source of supply, leading to a projected structural shortage starting in 2026. By 2030, the supply deficit is projected to reach a 900,000-tonne, equating to approximately 10% of global demand, primarily affecting the acidspar market (Tivan, 2024). Further, HF has been facing supply shortages since 2022, and the gap between supply and demand is projected to widen further by 2030 (BMI, 2024).



### Hydrofluoric acid and aluminum fluoride market

One of the main downstream products derived from fluorspar is a hydrofluoric acid (HF). According to Project Blue (2024b), HF production doubled between 2010 and 2023, reaching 1.7 million tonnes in 2023. China alone produced more than half of this amount, accounting for 54%, followed by the United States (14%), Mexico (8%), Germany (5%), Russia (4%), India (1%), and others (14%). All the countries mentioned, except for the United States, are producers of acidspar and metspar and use their domestic fluorspar resources to produce HF.

The export volume of HF<sup>4</sup> has shown an upward trend, doubling between 2004 and 2021 to reach 646 thousand tonnes. However, it decreased to 398 thousand tonnes in 2023<sup>5</sup>. In 2023, the total value of HF exports amounted to \$702.8 million (Table 5.3). More than two-thirds of the total exports were exported from China.

Table 5.3: Hydrofluoric acid (HF) exports, by countries, kt = 1000 tonnes, 2023 (Source: International Trade Centre, 2024).

| No | Exporter countries | Quantity, kt | Share in world export % | Value, million USD |
|----|--------------------|--------------|-------------------------|--------------------|
| 1  | China              | 274.0        | 69%                     | 413.0              |
| 2  | Germany            | 38.9         | 10%                     | 110.8              |
| 3  | USA                | 23.1         | 6%                      | 37.4               |
| 4  | Japan              | 18.2         | 5%                      | 45.1               |
| 5  | Taiwan             | 18.2         | 5%                      | 39.1               |
| 6  | Others             | 25.9         | 6%                      | 57.4               |
| 7  | <b>Total</b>       | 398.2        | 100%                    | 702.8              |

Table 5.4: Hydrofluoric acid (HF) imports, by countries, kt = 1000 tonnes, 2023 (Source: International Trade Centre, 2024).

| No | Importer countries | Quantity, kt | Share in world import % | Value, million USD |
|----|--------------------|--------------|-------------------------|--------------------|
| 1  | South Korea        | 94.2         | 19%                     | 166.1              |
| 2  | USA                | 86.8         | 18%                     | 209.5              |
| 3  | Japan              | 73.5         | 15%                     | 138.6              |
| 4  | Taiwan             | 41.3         | 9%                      | 91.9               |
| 5  | France             | 36.5         | 8%                      | 102.8              |
| 6  | Others             | 153.6        | 32%                     | 324.2              |
| 7  | <b>Total</b>       | 485.9        | 100%                    | 1,033.1            |

In terms of imports, 485.9 thousand tonnes of HF, valued at \$1 billion, were imported in 2023. Of this, 68.4% was accounted for by five countries: South Korea, the United States, Japan, Taiwan, and France (Table 5.4).

<sup>4</sup> Export and import data for the year were identified using the Harmonized Commodity Description and Coding System (HCS) product codes 281111 Hydrogen fluoride "hydrofluoric acid".

<sup>5</sup> It is worth noting that due to discrepancies in customs data from some countries, the total global export volume of this product is recorded significantly lower than the import volume in database of International Trade Centre.

Another product derived from fluorspar, aluminum fluoride ( $\text{AlF}_3$ ), plays an important role in aluminum smelting. The growing demand for aluminum-based products, such as electric vehicles, has led to an increase in the demand for aluminum, and consequently, a rising need for aluminum fluoride. This trend is driving a corresponding rise in supply. In 2022, a total of 1.6 million tonnes of aluminum fluoride were produced, with 1.44 million tonnes, or 90%, used in aluminum smelting (Global Growth Insights, 2025). According to data from the International Aluminum Institute (2025), 69 million tonnes of primary aluminum were produced in 2022. Given that up to 20 kg of aluminum fluoride is required to produce 1 tonne of primary aluminum<sup>6</sup>, it is estimated that up to 1.4 million tonnes of aluminum fluoride were produced and consumed in 2022, aligning with the production figures. As reported by Project Blue (2023), China accounted for approximately 60% of global aluminum fluoride production in 2022, followed by Italy with around 23%, Mexico with about 5%, Russia with about 3%, and other countries contributing the remaining 9%.

In 2023, USD 883 million worth of aluminum fluoride was traded in the global market (OEC, 2024). Of this, 43% was supplied by Singapore. The country's exports have increased significantly since 2015, which is related to Chinese manufacturers exporting through Singapore. The main importer of this product is Mozambique, accounting for 43% of the world's total imports. Table 5.5 shows information on the main exporting and importing countries of aluminum fluoride.

*Table 5.5: Main exporters and importers of aluminum fluoride, 2023 (Source: The Observatory of Economic Complexity, OEC)*

| # | Main exporters | Value, million USD | Main importers | Value, million USD |
|---|----------------|--------------------|----------------|--------------------|
| 1 | Singapore      | 378                | Mozambique     | 381                |
| 2 | Italy          | 155                | India          | 58                 |
| 3 | China          | 142                | Bahrain        | 56                 |
| 4 | Mexico         | 68                 | Canada         | 46                 |
| 5 | Tunisia        | 42                 | Brazil         | 46                 |
| 6 | Other          | 98                 | Other          | 296                |
| 7 | <b>Total</b>   | 883                | <b>Total</b>   | 883                |

To conclude, countries such as Mongolia, Mexico, and South Africa are among the leaders in the production and export of metspar and acidspar, with a tendency to act as raw material exporters. China, with its large reserves and leading production of metspar and acidspar, processes both domestic and imported metspar and acidspar to produce and export HF, while also consuming it. Countries such as South Korea, Japan, and the United States are consumer countries that process imported metspar and acidspar to produce HF and also import them. European countries produce and export metspar and acidspar, but import larger quantities, acting as consumer countries that process and produce HF while also importing it.

### 5.1.3 Global fluorspar price

Fluorspar isn't typically traded on commodity exchanges due to a combination of factors. Establishing standardized specifications is difficult, and the mineral's diverse applications across various industries lead to varying quality requirements. Consequently, fluorspar is primarily traded through direct, negotiated agreements between producers and consumers. Spot contracts are more

<sup>6</sup> This information is sourced from the International Aluminum Institute, under the section "Facts: Raw Materials /Aluminum Smelting." For further details, please visit <https://thealuminiumstory.com/primary-production/raw-materials/>.

sensitive to price fluctuations, while long-term export agreements allow buyers to hedge against potential future price increases. In Mongolia, the price information of fluorspar on Fastmarkets (Indmin is now part of Fastmarkets) is used as a reference price for levying the Mineral Resources Royalty on metspar and acidspar sales. Figure 5.13 illustrates the dynamics of the reference price of fluorspar since 2017. As seen in the figure, the price of metspar and acidspar surged sharply in 2018, experienced a significant decline in 2019, and remained stable during the COVID-19 pandemic. Subsequently, prices have shown an upward trend since 2022.

The sharp increase in fluorspar prices in 2018 was due to the fact that China, the world's largest fluorspar producer, imposed strict environmental regulations, safety controls, and mining restrictions in 2017, leading to a decline in the country's production. As a result, China, which had long been a net exporter of fluorspar, shifted to becoming a net importer in 2018. This change was driven by the rapid expansion of domestic industries with high fluorspar consumption, such as hydrofluoric acid production, aluminum smelting, and fluoropolymer manufacturing (US Geological Survey, 2020). As a result, China began importing significant quantities of fluorspar.

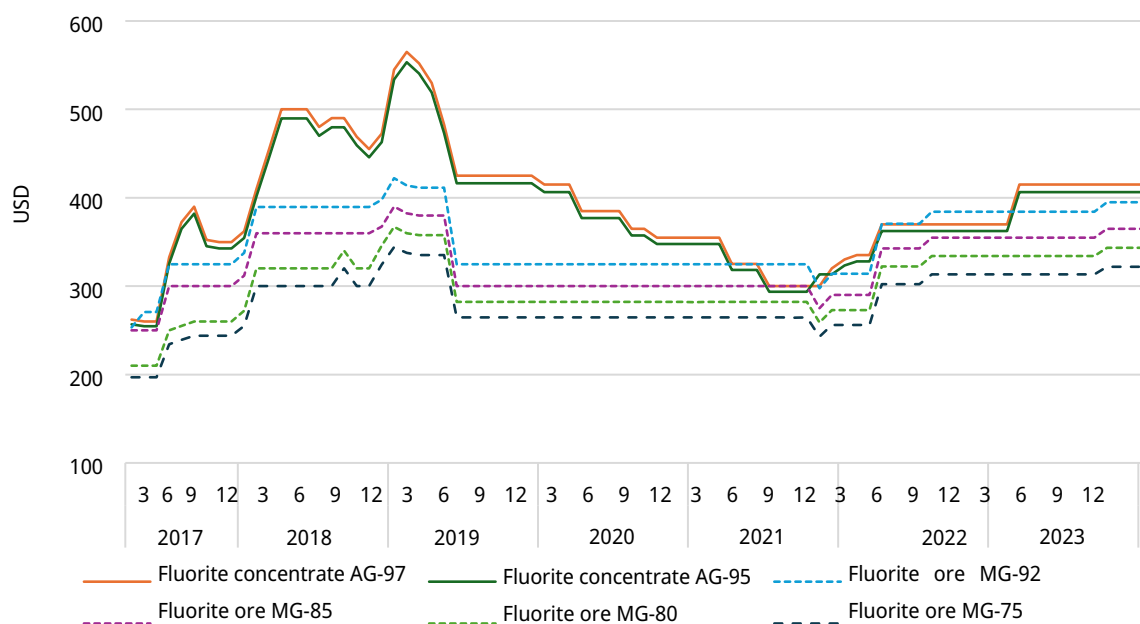


Figure 5.13: Global market fluorspar prices, US\$/tonne, by type (Source: MRPAM, Reference price announced by the MoF, [www.fastmarkets.com](http://www.fastmarkets.com) (formerly [www.indmin.com](http://www.indmin.com))).

However, China's reduced exports were not the only factor tightening global supply-several fluorspar mines worldwide, including those in South Africa, Russia, Kenya, and Namibia, closed over the past decade, significantly reducing output. Although new projects, such as Canada's St. Lawrence mine (2017/2018) and South Africa's Nokeng Mine (2019), have come online, their production, alongside expansions at existing sites, has not yet been sufficient to compensate for the overall decline. Temporary production slowdowns in Mexico, another major supplier, have further constrained availability.

In addition to production declines, logistical and economic factors have exacerbated supply shortages. The COVID-19 pandemic disrupted mining operations and supply chains, leading to delays and bottlenecks in global fluorspar trade. At the same time, shipping and freight costs have

risen due to higher fuel prices, port congestion, and geopolitical instability. More recently, the increasing risks associated with the Red Sea shipping route have forced some cargo carriers to take longer, costlier routes, adding further pressure to transportation expenses. These challenges have collectively contributed to the upward trend in fluorspar prices from 2018.

The impact of the policy mentioned above can be clearly seen in fluorspar prices. As shown in Figure 5.14, China's policy shift in 2017 to impose strict regulations and to become a net importer contributed to rising fluorspar prices. In 2020 and 2021, the COVID-19 pandemic disrupted supply chains, logistics, and transportation, leading to interruptions in fluorspar shipments and significantly higher freight and shipping costs. In recent years, acidspar prices have been rising due to increasing demand from the electric vehicle battery sector and semiconductor manufacturing, along with a significant increase in international freight costs.

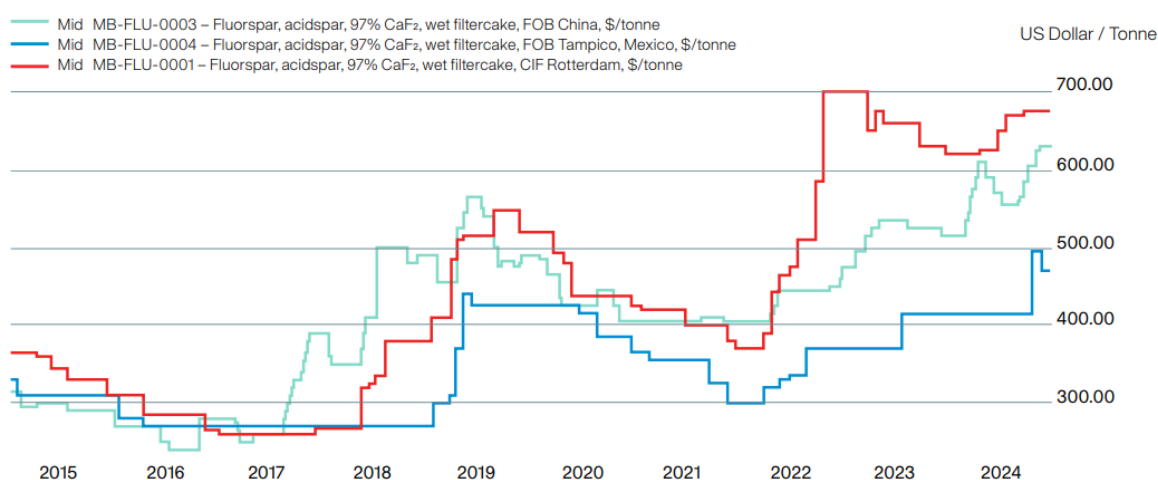


Figure 5.14: Acidspar prices, US\$/tonne, 2015-2024. (Source: Tivan, Fastmarkets).

As mentioned before, the anticipated shortages in fluorspar, acidspar, and hydrofluoric acid industries are expected to drive up fluorspar prices in the future. Moreover, China, the world's largest fluorspar producer, is experiencing rapid resource depletion, leading to reduced output and stricter export policies. On the demand side, the growing need for lithium-ion batteries, particularly for electric vehicles (EVs), is intensifying pressure on fluorspar market, as high-purity acidspar is essential for battery electrolytes and other key components. Additionally, fluorochemical applications in semiconductor manufacturing continue to expand, further straining global supply chains. As a result, the structural imbalance between supply and demand is expected to exacerbate price increases in the coming years.

## 5.2 Domestic fluorspar market

### 5.2.1 Fluorspar production

Fluorspar mining in Mongolia began in the 1960s and has since become an important product in the non-ferrous metallurgy sector. By 1986, fluorspar reserves were estimated at 24 million tonnes

(A+B+C categories), with 84% located in the South Kherlen region, 8.4% in the North Kherlen region, and 8.1% in the Chuluut Tsagaan Del area. In 1970, the fluorspar sector employed 316 people and produced 77 thousand tonnes of fluorspar. By 1985, the number of workers had increased to 1,514, and the production of ore and concentrate had reached a total of 755 thousand tonnes (Namjim, 2018).

During the market transition years of the 1990s, fluorspar ore production significantly declined, reaching 13 thousand tonnes in 1995. At its lowest point, the total production of ore and concentrate was 133 thousand tonnes per year (Figure 5.15). However, from the mid-2000s, fluorspar production, particularly ore extraction, began to recover. Mongolia's fluorspar production rebounded to socialist-era levels by 2018, but subsequently declined in 2021 and 2022 due to COVID-19 related restrictions.

To clarify fluorspar production, it is possible to analyze company-level data reported to organizations such as the MRPAM, the MTA, the Extractive Industries Transparency Initiative (EITI), and the NSO. However, it should be noted that the number of fluorspar miners reporting to government agencies is relatively small compared to the number of licensed and exporting companies. For example, the number of fluorspar mining and processing plants reporting to the MRPAM increased from 24 in 2016 to 53 in 2023. Meanwhile, the number of fluorspar exporters reporting to the General Customs Administration increased from 45 to 75 during this period (for further information on fluorspar exports, see the following section).

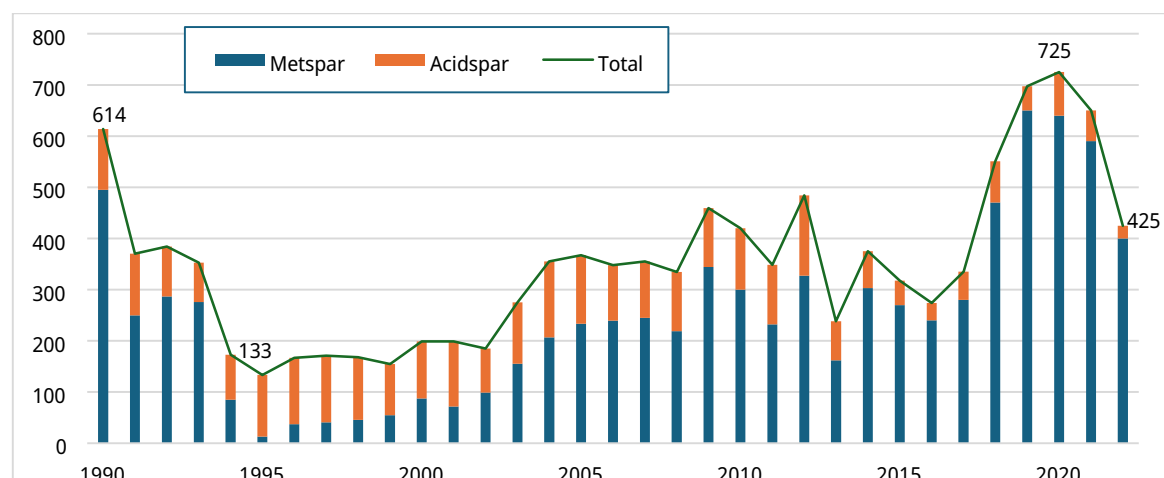


Figure 5.15: Fluorspar production in Mongolia, USGS, kt = 1000 tonnes. Note: In Mongolia, the acid-grade fluorspar is produced as a flotation concentrate, which may include some material below the 97%  $\text{CaF}_2$  threshold. (Source: Mineral commodity summary, USGS).

### Capacity

According to MRPAM records, as of 2024, the mining installed capacity of 141 registered fluorspar mining companies ranges annually from a minimum of 10 thousand tonnes to a maximum of 806 thousand tonnes of raw ore, with an average of 70 thousand tonnes. The annual installed processing capacity of 25 registered fluorspar processing companies ranges from 12 thousand tonnes to 550 thousand tonnes, with an average of 122 thousand tonnes. In total, the registered companies have an annual capacity to produce 9.898 million tonnes of fluorspar ore and 3.04 million tonnes of fluorspar concentrate.



Comparing the installed capacity of the fluorspar sector with actual production, capacity utilization is very low. For example, in 2023, fluorspar ore mined was only 2.1% of capacity, while fluorspar concentrate production (metspar and acidspar) was 3.6% of capacity.

#### **Production costs**

Based on data collected by the MRPAM from 31 fluorspar mining and processing companies, the average total cost of fluorspar mining operations in 2023 was 224 thousand Mongolian Togrogs (MNT), and the average total cost of fluorspar processing was 671 thousand MNT. Of this, the average stripping cost was 44 thousand MNT per ton, and the cost of mining operations excluding stripping was 99 thousand MNT per ton. However, there is no more detailed research or information available on the costs of domestic fluorspar miners broken down by cost item.

In a study of Project Blue (2023), in some countries, a 41% of the acidspar price was attributed to mining and processing costs, 24% to labor costs, and 12% to electricity costs (Figure 5.16).

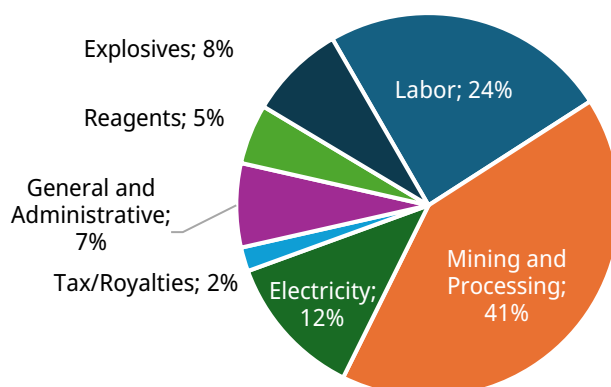


Figure 5.16: Acidspare cost breakdown in 2023 (Source: Project Blue Conference Presentation).

### **5.2.2 Fluorspar export**

In the last 10 years, Mongolian fluorspar exports have increased significantly. For instance, total exports were 314 thousand tonnes in 2014, but this number reached 1,088 thousand tonnes in 2023 (Figure 5.17). This growth is mainly due to the increase in the amount of fluorspar exported to China. Over this period, the amount of fluorspar exported to Russia has remained almost unchanged, with 179 thousand tonnes in 2014 and 168 thousand tonnes in 2023. However, fluorspar exports to China saw a sharp increase from 128 thousand tonnes in 2014 to 365 thousand tonnes in 2018, and then to 918 thousand tonnes in 2023. In recent years, Mongolia has exported negligible quantities of fluorspar to a limited number of countries, including Belarus and South Korea.

The sharp increase in the amount of fluorspar exported to China since 2018 is related to the tightening of environmental and safety standards for fluorspar mines in China, which led to a decrease in production and a significant increase in fluorspar prices. However, the sharp decline in exports during 2022 was primarily caused by China's continuation of its „Zero COVID“ policy, which resulted in stringent border crossing restrictions, and mid-year changes to the royalty tax reporting regulations for low-grade fluorspar ore.

## Fluorspar in Mongolia

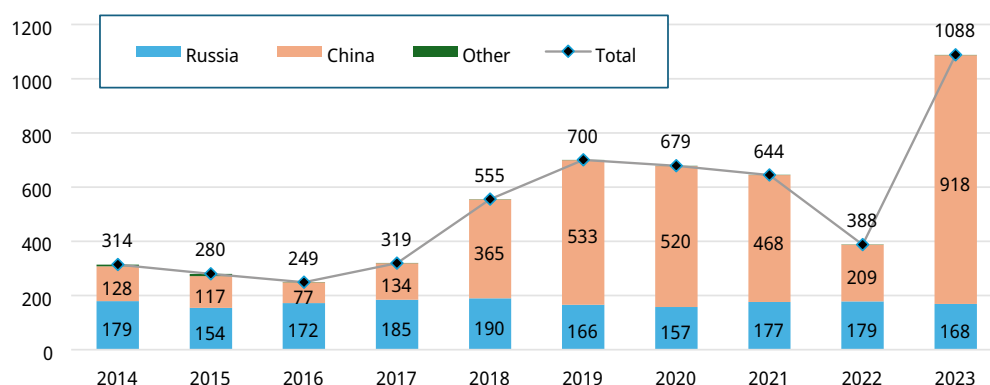


Figure 5.17: Fluorspar export by destination countries, kt = 1000 tonnes (Source: Customs Office).

The increase in fluorspar exports is related to the growing number of exporters. For example, as shown in Table 5.6, the total number of fluorspar exporters increased from 39 in 2017 to 56 in 2018, and to 75 in 2023. In other words, the increase in fluorspar export volume is due more to the addition of new exporters than to an increase in sales by existing miners. At the beginning of the period, most exporters were exporting fluorspar ore ( $\text{CaF}_2 < 97\%$ ), but as fluorspar prices generally increased, the export of more expensive fluorspar concentrate and lower-grade ore ( $\text{CaF}_2 < 55\%$ ) increased significantly.

Although fluorspar exports and the number of exporters are increasing, it is interesting to note that concentration among them is also rising. For example, in 2013, the top 5 companies exporting the largest amounts of fluorspar ore and concentrate accounted for 43% of total fluorspar exports, but this share increased to 59% in 2023. Additionally, the composition of the largest exporting companies has changed significantly. From 2013 to 2017, the leading exporters were Mongolrostsvetmet, Mongolczech Metal, Bayalag Fluorspar, Fluomon, and MGB companies. However, from 2018 to 2023, the leading exporters were Mongolczech Metal, Ariun Fluor, Bujgar-Ord, Mongoljuyuanli, and Tavin-Ekh companies.

Table 5.6: Number of fluorspar exporters by product type (Source: Customs Office).

| Year | Number of fluorspar exporters | Export of metspar concentrates < 97% $\text{CaF}_2$ | Export of acidspar > 97% $\text{CaF}_2$ | Export of Ore < 55% $\text{CaF}_2$ | Export of metspar lumps < 97% $\text{CaF}_2$ |
|------|-------------------------------|-----------------------------------------------------|-----------------------------------------|------------------------------------|----------------------------------------------|
| 2013 | 45                            | 8                                                   | 4                                       | 6                                  | 39                                           |
| 2014 | 42                            | 9                                                   | 4                                       | 3                                  | 36                                           |
| 2015 | 51                            | 12                                                  | 2                                       | 2                                  | 47                                           |
| 2016 | 38                            | 10                                                  | 5                                       | 2                                  | 32                                           |
| 2017 | 39                            | 12                                                  | 10                                      | 2                                  | 34                                           |
| 2018 | 56                            | 15                                                  | 13                                      | 9                                  | 50                                           |
| 2019 | 59                            | 15                                                  | 10                                      | 20                                 | 50                                           |
| 2020 | 59                            | 16                                                  | 8                                       | 30                                 | 46                                           |
| 2021 | 54                            | 18                                                  | 11                                      | 29                                 | 40                                           |
| 2022 | 64                            | 22                                                  | 10                                      | 21                                 | 47                                           |
| 2023 | 75                            | 23                                                  | 11                                      | 42                                 | 48                                           |

When breaking down export volumes by type of fluorspar (Figure 5.18), before 2018, exports of low-grade fluorspar ore ( $\text{CaF}_2 < 55\%$ ) did not exceed 30 thousand tonnes, but in 2018, it reached 60 thousand tonnes, 282 thousand tonnes in 2020, and 591 thousand tonnes in 2023. During this period, exports of metspar lumps with a calcium fluoride content of up to 97% remained relatively stable, ranging from 179 to 388 thousand tonnes per year. Similarly, over the past 10 years, exports of metspar concentrates ( $\text{CaF}_2 < 97\%$ ) increased sharply from 39 thousand tonnes to 232 thousand tonnes, while exports of acidspar ( $\text{CaF}_2 > 97\%$ ) fluctuated but were 37 thousand tonnes in 2013 and 39 thousand tonnes in 2023.

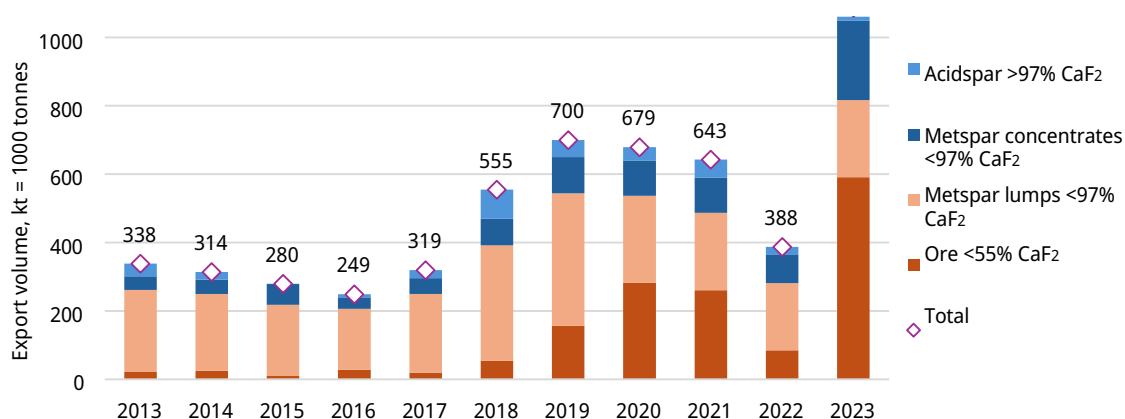


Figure 5.18: Fluorspar export by product type, kt = 1000 tonnes. (Source: Customs Office).

The changes in exports in monetary terms, compared to the total export value, are shown in Figure 5.19. From 2014 to 2017, the value of fluorspar exports ranged from 59 to 84 million USD, accounting for 1.2-1.4% of total exports of goods. In 2018, fluorspar exports increased to 190 million USD, representing 2.7% of total exports. However, due to foreign trade restrictions and changes in tax regulations during the COVID-19 pandemic, these figures declined from 2020 to 2022. In 2023, they recovered, with export value reaching 272 million USD, accounting for 1.8% of total exports. Additionally, comparing the 2023 fluorspar export value to the official foreign exchange reserves (4,922 million USD), it represents 5.5%.

Fluorspar exports are transported by rail and road. According to the Ministry of Road and Transport Development, 392 thousand tonnes of fluorspar were transported for export in 5,834 wagons in 2022, while 177 thousand tonnes were transported in 2,644 wagons in 2023 (EITI Mongolia, 2024). Therefore, improving the capacity of border checkpoints and expanding the road and rail network are crucial conditions for reducing transportation costs and increasing fluorspar exports.

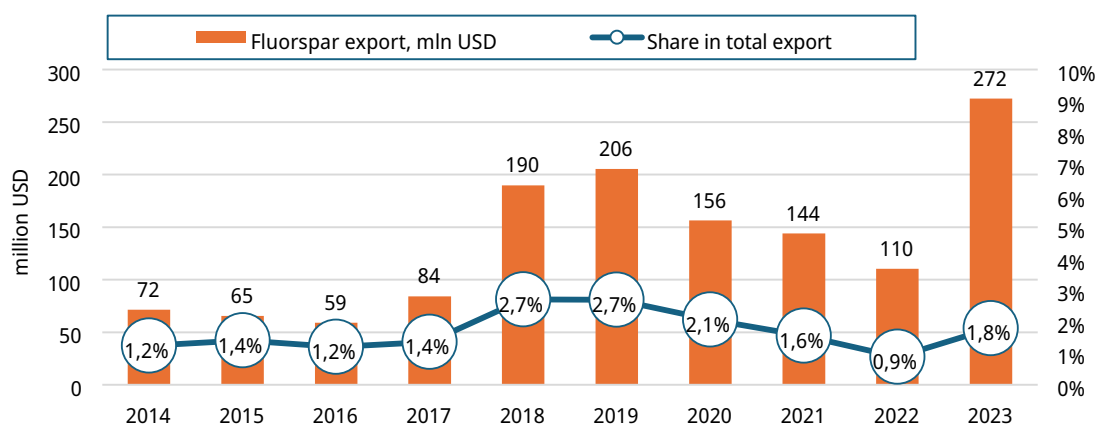


Figure 5.19: Fluorspar export amount and its share in total export. (Source: Customs Office).

### 5.2.3 Fluorspar price and taxation

#### Reference price

In Mongolia, the Minerals Law was enacted in 2006, introducing a royalty on mineral sales for mining companies, which led to the establishment of a reference price for fluorspar. In April 2007, the government issued a resolution to use the free on board (FOB) price of fluorspar published on [www.indmin.com](http://www.indmin.com) as the reference price for calculating royalty for fluorspar exporters. However, fluorspar exporters have criticized this reference price as being excessively high compared to their sales contract prices, resulting in unfair royalty payments (ERI, 2018).

This can be seen in the price comparison of fluorspar exporters in Figure 5.20. Here, the average prices reported by companies to the Customs Office and the MTA are compared. The Customs Office records the price of exported fluorspar based on the reference price announced by the Ministry of Finance (MoF) for that month. Meanwhile, fluorspar exporting companies report their sales revenue to the Tax Authority based on their contract prices when declaring royalty.

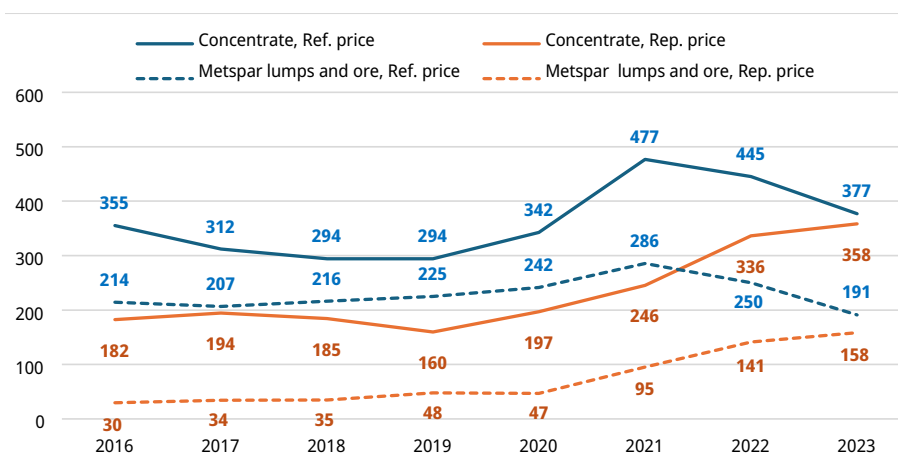


Figure 5.20: Reference and tax reported prices of fluorspar by product type, USD/tn ( Source: Customs Office and Tax Authority).

As shown in the figure, for both acidspar and metspar, the prices calculated from Customs Office data (reference prices) have been higher than the prices reported for tax purposes. This price discrepancy has been particularly significant for fluorspar lumps and ore, which constitutes the majority of exports. However, in 2023, the reference prices and the sales prices reported for tax purposes by fluorspar exporters have become much closer.

#### ***Trading at the mineral commodity exchange***

The significant discrepancy between the reference price of mining commodities and the reported sales price can be attributed to several factors, such as the quality and grade of the exported raw material being lower than the reference price standard, differences in trade terms (incoterms) such as taxes, transportation, insurance costs, and delivery ports.

Another major reason is considered to be tax evasion, which can be mitigated by increasing transparency in the extraction and sales information of natural resources. In this regard, the Parliament of Mongolia passed the Law on the Mining Products Exchange in December 2022, and from the second quarter of 2024, fluorspar lumps, ore and concentrate began to be traded on the Mongolian Mining Products Exchange. According to the Mongolian Stock Exchange, in 2024, 13 thousand tonnes of fluorspar ore and lumps and 4 thousand tonnes of concentrate were traded through 7 forward contracts. The forward contracts have the following conditions: each batch of fluorspar lumps, ore or concentrate traded is one wagon or 65 tonnes. The commodity specified in the contract will be delivered by rail to the Erenhot port in China under delivered-at-place (DAP) terms. The buyer will make full payment before delivery after the contract is signed. Payments for spot and forward contract trades will be processed through domestic commercial banks or authorized securities payment institutions.

The trading prices on the Mongolian Mining Products Exchange are initially announced at the border port prices of neighboring countries, and the contract price is determined when the seller and buyer agree on the price announced by the exchange. In 2024, fluorspar concentrate ( $\text{CaF}_2$ -95%) was traded on the exchange at USD 360 per tonne. Fluorspar lumps and ore was traded at prices ranging from USD 71 to 264 per tonne, depending on the grade<sup>7</sup>. Specifically, low-grade fluorspar ore ( $\text{CaF}_2$  35-63%) was sold at USD 71-85 per tonne. During this period, the reference price for fluorspar concentrate announced by the MoF was USD 460–473 per tonne, and the reference price for fluorspar ore was USD 329–373 per tonne. In other words, the exchange price for fluorspar concentrate was about 20% lower than the reference price, and the exchange price for fluorspar ore was about 30–70% lower than the reference price.

From the first year of trading on the Mining Products Exchange, it can be seen that the actual prices of fluorspar traded on the exchange are significantly lower than the international reference prices used for calculating royalty and customs export statistics.

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<sup>7</sup> Some trading prices were set in Chinese yuan. So these are converted to US dollars using the average exchange rate of the yuan to the dollar for that month.



### Taxes

In Mongolia, companies engaged in fluorspar mining, processing, and export activities pay several types of taxes, similar to other mineral extractors. The number of fluorspar sector companies reporting to the MTA and paying taxes increased from 125 in 2016 to 171 in 2023. Consequently, the total sales revenue reported for tax purposes increased from 137 billion MNT in 2016 to 594 billion MNT in 2023.

Following this general trend, the total amount of taxes paid by these companies has tended to increase, but it has fluctuated significantly depending on changes in fluorspar production and market prices. As shown in Table 5.7, fluorspar sector companies paid a total of 5.2 billion MNT in taxes in 2016, which increased to 110 billion MNT in 2021. Since then, the amount of taxes has decreased, reaching 38 billion MNT in 2023.

*Table 5.7: Tax amount paid by fluorspar mining companies, billion MNT (Source: Mongolian Tax Authority MTA).*

| Year | # of tax reported companies | Total sales revenue | Total taxable revenue | Paid tax amount |         |     |       |              |
|------|-----------------------------|---------------------|-----------------------|-----------------|---------|-----|-------|--------------|
|      |                             |                     |                       | CIT             | Royalty | VAT | Other | Total        |
| 2016 | 125                         | 137.0               | -29.7                 | 0.3             | 2.1     | 0.1 | 2.7   | <b>5.2</b>   |
| 2017 | 130                         | 207.7               | -1.0                  | 1.1             | 7.6     | 0.1 | 3.6   | <b>12.5</b>  |
| 2018 | 125                         | 227.3               | 2.5                   | 4.3             | 9.7     | 0.3 | 3.6   | <b>17.9</b>  |
| 2019 | 143                         | 309.8               | 45.5                  | 15.1            | 13.4    | 1.8 | 4.6   | <b>34.9</b>  |
| 2020 | 156                         | 371.9               | 86.9                  | 13.4            | 16.8    | 3.7 | 9.4   | <b>43.3</b>  |
| 2021 | 167                         | 424.6               | 107.5                 | 55.1            | 31.0    | 9.6 | 13.7  | <b>109.5</b> |
| 2022 | 169                         | 312.2               | 11.6                  | 3.9             | 13.8    | 1.9 | 8.1   | <b>27.7</b>  |
| 2023 | 171                         | 594.2               | 43.6                  | 8.5             | 17.9    | 0.4 | 11.5  | <b>38.3</b>  |

The main tax contributing to the total tax revenue of the fluorspar sector is the royalty on mineral sales. The share of royalty in total taxes averaged 46% from 2016 to 2023. This share was at its lowest in 2021 at 28% and reached its highest in 2017 at 61%. The royalty for fluorspar depends not only on the sales revenue of enterprises but also on the global market price and the level of processing, as stipulated by law.

According to the Minerals Law, holders of fluorspar licenses and exporters are liable to pay royalty. For sales valuation, the international reference price is used for exported fluorspar, and if the reference price cannot be determined, the sales revenue declared by the license holder is used. The base royalty rate for fluorspar is 5% of the sales valuation. Depending on the increase in reference prices, an additional royalty of up to 5% for metspar lumps, up to 4.5% for metspar concentrate, and up to 3.5% for acidspar concentrate is added, as shown in Table 5.8.

Table 5.8: Tax rate of royalty for fluorspar (Source: *The Minerals Law, ammendment in 2010*).

|                                   | Reference price (USD) | Ore/lumps | Concentration |
|-----------------------------------|-----------------------|-----------|---------------|
| Metspar ore, lumps, concentration | 0 - up to 80          | 0.00      | 0.00          |
|                                   | 80 - up to 90         | 1.00      | 0.90          |
|                                   | 90 - up to 100        | 2.00      | 1.80          |
|                                   | 100 - up to 110       | 3.00      | 2.70          |
|                                   | 110 - up to 120       | 4.00      | 3.60          |
|                                   | 120 and above         | 5.00      | 4.50          |
| Acidspar                          | 0 - up to 200         | -         | 0.00          |
|                                   | 200 - up to 230       | -         | 0.70          |
|                                   | 230 - up to 260       | -         | 1.40          |
|                                   | 260 - up to 290       | -         | 2.10          |
|                                   | 290 - up to 320       | -         | 2.80          |
|                                   | 320 and above         | -         | 3.50          |

The above royalty rules aim to encourage fluorspar miners to engage in value-added processing activities and to increase state budget revenue in case of excessively high commodity prices.

Following this, the main tax imposed on fluorspar sector enterprises is the Corporate Income Tax (CIT). The CIT rates are progressive, at 1%, 10%, and 25%. Enterprises with taxable income (sales revenue minus operating expenses) up to 300 million MNT (~87 thousand USD<sup>8</sup>) pay a 1% income tax, but this does not apply to mining companies. For taxable income up to 6 billion MNT (~1.73 million USD), the CIT rate is 10%. For annual taxable income exceeding this amount, companies pay 600 million MNT plus 25% of the taxable income over 6 billion MNT. Although specific taxable income information for each fluorspar mining company is not available, comparing the taxable income and the number of companies reporting taxes in Table 5.7 suggests that the majority of fluorspar miners have taxable income below 6 billion MNT and pay a 10% CIT.

Fluorspar miners pay relatively low value-added tax (VAT) because, under the VAT Law, export revenue from minerals is subject to a 0% VAT rate. Therefore, fluorspar mining and exporting companies pay only VAT on imported equipment and materials and on domestic sales revenue. Other taxes, aside from those mentioned above, also constitute a significant portion of the total taxes paid, as shown in Table 5.7. These include license fees, land fees, employee Personal Income Tax (PIT) withholdings, property tax, vehicle tax, and excise tax on imported passenger cars. However, the total tax does not include employee Social Insurance contributions. Additionally, there is no export tax on minerals.

The Minerals Law and other tax-related laws specify the base and rates for these taxes. For example, the fee for a fluorspar mining license is 21,750 MNT per hectare of the mining area. PIT is levied on salaries and labor income at progressive rates of 10%, 15%, and 20%, depending on the income amount. Excise tax on imported passenger cars ranges from 750,000 to 65,975,000 MNT, depending on the year of manufacture and engine capacity. All types of vehicles are subject to annual vehicle tax (local tax, air pollution tax, road usage tax), which varies based on the type of vehicle (passenger car, truck, tractor, special-purpose vehicle, etc.), load capacity, and the taxpayer's local jurisdiction.

<sup>8</sup> The exchange rate in 2023 was 1 USD = 3,465.78 MNT (National Statistics Office).

### 5.2.4 Informal mining

Fluorspar miners export the raw and processed materials either directly or through intermediaries. However, there is a significant discrepancy between the production and export figures presented in previous sections. For example, according to the Customs Office, fluorspar ore, lumps and concentrate exports were 388 thousand tonnes in 2022 and 1,088 thousand tonnes in 2023 (Figure 5.17). In contrast, the National Statistics Office (NSO) reported total fluorspar production of 163 thousand tonnes in 2022 and 313 thousand tonnes in 2023. Information from sources such as the MRPAM and the US Geological Survey (USGS) on Mongolia's fluorspar production also differs significantly from the figures published by the Customs Office.

This discrepancy is related to the fact that the number of companies reporting production data to government agencies like the MRPAM and the NSO is smaller than the number of companies filing export declarations with the Customs Office. In other words, many companies do not report their fluorspar mining and processing activities to the MRPAM and the NSO, or a large amount of fluorspar is being exported informally.

Small-scale mining operations by individuals and small enterprises play an important role in Mongolia's fluorspar mining. However, there is no official published information on small-scale mining of fluorspar. Therefore, it is not possible to determine the total number of small-scale miners and their production volume. Nevertheless, it is possible to extract information on fluorspar small-scale miners from the publicly available primary data of the NSO's „Small-Scale Miners Survey“ to get a general picture of them (NSO, 2016; 2021).

As shown in Table 5.9, the survey included 754 fluorspar miners in 2016 and 284 in 2021. During the COVID-19 pandemic in 2021, the number of micro-miners surveyed decreased compared to 2016, and the total reported production volume declined, but the production volume per miner did not change significantly. In 2016, 91% of fluorspar miners were engaged in open-pit mining and 8.9% in underground mining, while in the 2021 sample survey, 78% were engaged in open-pit mining and 18% in underground mining.

*Table 5.9: Number of survey participants by province, mining, and sales prices (Source: Researchers' calculation based on the primary data of NSO's Small-Scale Miners' Survey).*

|           | Number of miners |      | Extracted fluorspar, kt = 1000 tonnes |      | Average prices, 1000 MNT/tonne |      |
|-----------|------------------|------|---------------------------------------|------|--------------------------------|------|
|           | 2016             | 2021 | 2016                                  | 2021 | 2016                           | 2021 |
| Total     | 754              | 284  | 20.8                                  | 9.1  | 59                             | 385  |
| Of which  |                  |      |                                       |      |                                |      |
| Dornogovi | 77               | 15   | 5.8                                   | 0.09 | 57                             | 488  |
| Dundgovi  | 521              | 106  | 8.7                                   | 1.4  | 61                             | 296  |
| Khentii   | 102              | 160  | 6.3                                   | 7.6  | 62                             | 361  |

In 2021, small-scale miners participating in the survey invested only 181 million MNT in their mining operations, with nearly half of this amount spent on transportation vehicles. This indicates that small-scale miners have limited financial capacity to expand their production and lack long-term plans for sustainable operations.

In 2016, small-scale fluorspar miners earned an average monthly income of 1.23 million MNT during high-income periods and 0.46 million MNT during low-income periods. By 2021, these figures had increased to 2.31 million MNT and 0.66 million MNT, respectively. The average monthly income of small-scale fluorspar miners is lower than the national average monthly salary, indicating that small-scale miners have low productivity and sell their extracted commodity at excessively low prices.

In 2016, small-scale miners spent the largest portion of their operating expenses (41%) on wages, while in 2021, they spent 36% on fuel and lubricants. Although small, they contribute a certain amount of taxes to the state and local budgets annually. According to the 2016-2021 survey data, 45-50% of these taxes were paid as Personal Income Tax (PIT), and 24-31% as vehicle tax.

Small-scale miners typically operate in areas not connected to infrastructure, resulting in harsh working conditions. For instance, 17% of small scale fluorspar miners lacked electricity, and those with power mainly used renewable energy devices and small generators. The majority of small-scale miners (76% in 2016 and 78% in 2021) relied on portable water for their drinking needs.

In 2021, 57% of small-scale miners surveyed reported facing difficulties in their mining operations. The most common challenges included low mineral yield, excessive oversight and pressure from government agencies, and the lack of a legal framework for small-scale mining. Regarding sales, 75% of small-scale miners in 2021 reported encountering difficulties. They cited the main issues as traders purchasing their minerals at prices significantly below market value (42%) and the absence of official buyers in their local area (36%).

### 5.2.5 Downstream value chain development

In the 1980s, Mongolia's fluorspar sector was considered a key part of the non-ferrous metallurgy industry. Plans were made to increase production at newly opened mines and to establish a major processing plant in Bor-Undur by the year 2000, capable of processing 400-600 thousand tonnes of ore annually and producing 168 thousand tonnes of high-quality fluorspar concentrate (Namjim, 2018). Although this plan was disrupted during the early market transition period, many processing plants have been built and put into operation with domestic and foreign investment since the 2000s. Currently, major processing (beneficiation) plants such as the Bor-Undur plant of the state-owned Mongolrostsvetmet, the Chuluut Tsagaan Del and Tevsh plants of „Mongolczech Metal“ LLC, the Ihhet plant of Khukhbishrelt LLC, the Tsagaan chuluut plant of Shashir-Orgil LLC, and the Tumentsogt plant of Mongoljuyuanli LLC are in operation.

To support the development of the sector, the Ministry of Mining and Heavy Industry (MMHI) drafted a „Five-Year Program to Support Fluorspar Production and Export“ in 2018, but it has not yet been approved. The draft program included major goals such as prohibiting the export of raw fluorspar ore, increasing the utilization of installed capacity at processing plants to 70% by 2023, and initiating studies and preparations for establishing a final product plant for fluorine compounds.

Currently, enterprises operating in the fluorspar sector can benefit from other general regulations and measures to support manufacturing sector. For example, under the Investment Law, investors making investments of over 500 billion MNT for 5-18 years can sign an investment agreement with the government and obtain a stabilization certificate for certain taxes and fees. According to the Minerals Law, the progressive royalty rate for fluorspar concentrate is set lower than that for ore.

In addition to these incentives, the Customs Tariff Law allows for the exemption of customs duties and import VAT on equipment for mineral processing and beneficiation projects with approved feasibility studies. However, the number of fluorspar sector enterprises benefiting from this exemption has been low in recent years. According to the Customs Office, fluorspar mining enterprises were exempted from only 271 million MNT in customs duties and import VAT on equipment and materials from 2014 to 2023 (Table 5.10).

*Table 5.10: Exempted customs tax amount by fluorspar mining companies, million MNT (Source: Customs Office).*

|             | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2023 |
|-------------|------|------|------|------|------|------|------|
| Customs tax | 58   | 4    | 177  | 1    | 0    | 0    | 0    |
| Import VAT  | 21   | 6    | 0    | 0    | 1    | 2    | 1    |

On one hand, known global fluorspar reserves are becoming increasingly limited. On the other hand, the global demand for value-added fluorspar products continues to rise. In recent years, Mongolia's fluorspar reserves have not significantly increased, yet the country continues to export this critical mineral in large quantities and in its raw form.

In response, the Government of Mongolia has included in its 2024-2028 action plan the goal of establishing a fluorspar ore processing complex based on the Bor-Undur mine. This complex aims to produce value-added products, particularly hydrofluoric acid. Therefore, it is necessary to conduct a feasibility study and detailed economic analysis for this complex.

According to global market data on downstream products like hydrofluoric acid and aluminum fluoride, China is the main producer, consumer, and exporter of these products (see section 5.1.2). Consequently, the primary market for the hydrofluoric acid plant based on the Bor-Undur mine will be China, with the main competitors being Chinese manufacturers. Thus, the feasibility study should include a comprehensive analysis and evaluation of the current market conditions and future trends in China.



## Conclusion

Global consumption of fluorspar, a critical mineral used in a wide range of industries including chemical, metallurgical, and others, is on the rise. Mongolia is one of the key players in terms of fluorspar reserves, and in recent years, mining and export activities have intensified. The number of mining licenses for fluorspar is increasing, indicating the potential for significant growth in mining and processing activities. Additionally, the expected increase in global demand for fluorspar, particularly from China, creates favorable conditions for the development of Mongolia's fluorspar sector.

There is a significant discrepancy between the official production and export figures for Mongolia's fluorspar sector. Most of the commodity being exported is not registered with the Tax Authority and other government agencies, indicating widespread informal mining. As a result, miners sell their products to informal intermediaries at very low prices, reducing state budget revenue.

One of the main reasons for the high level of informal activity in the fluorspar sector is the excessively high royalty imposed on fluorspar ore and concentrate, which is based on international reference prices rather than actual sales contract prices. Trading fluorspar on the domestic Mining Products Exchange and calculating royalty based on exchange prices could resolve tax disputes and improve the tax environment. Observations from the first year of trading on the exchange show that the average trading price of fluorspar is significantly lower than the reference price, potentially reducing the tax burden on miners.

Despite the high installed capacity of fluorspar processing companies, most of Mongolia's fluorspar exports consist of low-grade ore. At the current export rate of 1 million tonnes per year, the identified reserves are projected to be depleted within 30 years. Therefore, a two-pronged strategy is crucial: intensifying geological exploration to expand fluorspar reserves and increasing concentrate production to enhance the value of the raw material. The Government's 2024-2028 Action Plan, which includes the establishment of a fluorspar processing plant at the Bor-Undur mine, marks a significant step forward.

However, attracting private sector and foreign investment is crucial for long-term sustainability. This requires not only improving the tax environment, protecting property rights, and enhancing dispute resolution mechanisms, but also increasing the availability of public information. Specifically, making more data on Mongolian fluorspar sellers and potential exploration areas publicly accessible would be highly beneficial in attracting both foreign buyers and potential investors.

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Bundesanstalt für Geowissenschaften und Rohstoffe (BGR)  
Stilleweg 2  
30655 Hannover  
[mineralische-rohstoffe@bgr.de](mailto:mineralische-rohstoffe@bgr.de)

