МОНГОЛ УЛСЫН ЗАСГИЙН ГАЗАР
УУЛ УУРХАЙ ХҮНД ҮЙЛДВЭРИЙН ЯАМ

MINISTRY OF MINING AND HEAVY INDUSTRY

METHODICAL RECOMMENDATION APPLIED FOR CLASSIFICATION OF MINERAL RESOURCES AND CERTAIN TYPE DEPOSITS' RESERVES OF MONGOLIA

(PHOSPHATE)

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2022

This methodical recommendation was developed with the support of Australia Mongolia Extractives Program Phase 2 (AMEP 2). AMEP 2 is supported by the Australian Government through the Department of Foreign Affairs and Trade (Australian Aid) and implemented by Adam Smith International.

Project completed by: MUST, Geology and Mining engineering.

Center for mineral resources, geoinformation and training

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Preface

The paragraph 4.2.13 of the “Vision-2050” Action Plan for the Implementation of Mongolia's Long-Term Development Policy approved by the State Great Hural (Unicameral parliament of Mongolia) Resolution No. 52 of 2020 states that the development of value-added heavy industry based on the principles of environmentally friendly and sustainably promotes advanced forms of investment, and provides for the construction of a copper concentrate processing plant.

Issues of sulfur dioxide emissions that generated as by product from smelting and processing of copper concentrate can be solved through the production of phosphate fertilizers. Therefore, the study of phosphorite deposits will be important for the needs of the copper concentrate processing and smelting plants to be built in the near future.

Phosphorite, the main raw material for phosphate fertilizer, has been revealed by geological surveys in Mongolia in three deposits and about 70 occurrences, which distributed mainly in the Khövsgöl and Zavkhan basins. Geologists have identified the Khövsgöl Basin, which comprises about 45 deposits and occurrences, as the most promising in terms of phosphorite reserves and resources. The Bürenkhaan phosphorite deposit that located 20 to 30 km northwest of Mörön, the capital of Khövsgöl aimag, is estimated to have 192.2 million tons of ore reserves. The deposit had been explored in details during 1981 to1985 for the future purpose of processing copper ore, but has been abandoned for more than 30 years as a result of major social, political and economic changes in the states belonged socialist system.

The second most important phosphorite-bearing structure for Mongolia is the Zavkhan Basin, where there have been revealed phosphorite reserves and resources in range 7.9 million tons in Pass Alagiin Davaa and 23.6 million tons in the vicinity of Mt. Tsakhir Uul, Zavkhan Aimag during geological exploration based on private investment for 1997 to 1998. Since then, no additional research has been conducted to the sites.

In addition, a number of phosphorite occurrences have been revealed in Bayankhongor, Dundgovi, Dornogovi, Gobisümber and Gobi-Altai aimags; but they have not been adequately studied up to date.

Developing and implementing of methodological recommendations for exploration and research works on phosphate accumulation and phosphorite deposits will increase the mineral resources volume of Mongolia, extending the operation life of mine on non-ferrous metal deposit, producing value-added products and import-substituting products, and increasing foreign exchange reserves. Furthermore it is strategically important to support the domestic manufacturer's activities and increase employment.

1. Basic concepts

1.1. Phosphorus is a widespread element in the nature, with a Clark content of 0.093% in the Earth's crust. Phosphorus is never found as a free element on Earth, and is mainly observed in apatite rocks and phosphate ores, which are composing of mainly phosphorus-containing minerals. 90% of the extracted phosphate raw materials are used for fertilizers. Phosphorus compounds are used in the chemical industry, and sectors of medicine, metallurgy and agriculture.

1.2. It is more widely distributed in nature as a mineral compounds or isomorphic mixture of orthophosphates or aluminosilicates. From the phosphorus-containing minerals, calcium orthophosphate of the apatite group plays a key role in practice, and its chemical formula is $Ca_5(PO_4)_3(F, Cl, OH)$.

1.3. Apatite, like as accessory minerals, is found in intrusive, metamorphic, sedimentary, and effusive rocks. It is a major phosphorus-bearing mineral in apatite and phosphate ores, and is associated with nepheline, aegirine, diopside, ilmenite, sphene, some carbonates, and other endogenous minerals in apatite ore.

Calcium phosphate (P_2O_5 content takes 12% or more) is present in 1/3 or more of the phosphate ore in sedimentary rocks.

There are observed quartz, chalcedony, opal, calcite and dolomite, glauconitic and other minerals in the phosphate ore. There are five types of apatite that are important for production, including fluoroapatite - $Ca_{10}(PO_4)_6F_2$; francolite - $Ca_{10}P_{5.2}C_{0.8}O_{23}.2F_{1.8}$ (OH); kurskite - $Ca_{10}P_{4.8}C_{1.2}O_{22.8}F_2 (OH)_{1.2}$; hydroxylapatite $Ca_{10} (PO_4)_6 (OH)_2$; carbonate apatite - $Ca_{10}P_6CO_{23} (OH)_3$.

In the case of phosphate minerals, the total components are replaced by in a very wide range, for example, phosphorus is replaced by carbon, strontium, sulfur and silicon, while fluorine is replaced by hydroxyl and calcium by sodium, strontium and aluminum. During enrichment, phosphorus can have been replaced by other elements and mixtures, i.e. by U, TR and Sr, and rarely by V, Ti, Zr, Au, B, Li, Pb, As, Ag, Mo, Ni, Co and Se.

When uranium occurs in phosphorite, it is trapped in the apatite crystal lattice, taking the uranium content is 0.0001-0.052%. REE’s such as yttrium, cerium and strontium are constantly present in marine phosphorite and their content reaches 0.06 to 0.10% for rare earth elements and 0.02-0.36% for strontium.

1.4. Phosphate deposits are divided into magmatic, carbonatitic, contact-metasomatose, sedimentary, metamorphic and weathering types according to their formation conditions, e.g., in the Commonwealth of Independent States, the following types of production are distinguished (Table 1.1).

Table 1.1: Industrial and potentially industrial types of phosphate deposits

Genetic type of deposits	Ore-formational type of deposits	Natural (mineral) type of ores	Average content of P_2O_5, %	Industrial (technological) type of ores	Deposit examples
Magmatic	layers and lenses in syenite-diorite	Apatite	3.5–5	Agrochemical phosphate	Oshurkovsk, Uktussk,
	Layered body in iolite - urtites	Nepheline-apatite	4–18	Agrochemical phosphate	Hibin group, occurrences of Khövsgöl
	layers and lenses in syenite-diorite in ultramafic rocks	Ilmenite-titanomagnetite-apatite	3.5–6	Agrochemical and titanium-iron-phosphate (flotation)	Kruchininsk, Zhugzhursky group of deposits
Carbonatite	Pipe-line and stock works in ultra-mafic and felsic rocks, carbonatite	Phoscorite, (magnetite-apatite and vermiculite-apatite)	3.5–8	Agrochemical zirconium-iron-phosphate (magnetic flotation)	Kovdor, Greast Sayan, Mushgai Hudag, Bayankhoshuu Apatite Hill
		Nelsonite (magnetite-apatite) and phenite (egirin-apatite)	3.5–8	Agrochemical iron-phosphate фосфат (magnetic flotation)	Maimecha-Kotuisky group of deposits
		Pyrochlorine-apatite	3.5–15	Agrochemical niobium-phosphate (gravity-flotation**)**	Beloziminsk (Lugiin Gol-?)
Sedimentary (marine)	Geosynclinal layered in siliceous-carbonate rocks	Phosphorite (fine-grained)	18–30	Agrochemical, phosphate (gravity-flotation)	Kara-Tau (Kazakhstan), Belkinsk, Seybinsk, Har nuur
		Phosphorite (granular)	17–32	Agrochemical, phosphate (flotation-gravity)	Jeroi-Sardarinsk (Uzbekistan)
	Platformic layered in sandy-carbonate rocks	Phosphorite (shell)	3–20	Agrochemical, phosphate (flotation-gravity)	Kingiseppsk
		Phosphorite (nodular)	12–13	Agrochemical phosphate (washing, flotation-gravity)	Egor'evsk, Vyatsko-Kamsk
		Phosphorite (sand-grained)	5–14	Agrochemical phosphate (flotation-gravity)	Unyechsk
Metamorphic	Layered bodies in marble	Phosphorite	5–24	Agrochemical phosphate (flotation)	Slyudyansk, Chulak-Tau (Kazakhstan)
Residual infiltration (weathering)	Cloak-like deposits on carbonate-terrigenous and igneous rocks	Phosphorite, apatite-francolite	11–22	Agrochemical phosphate (flotation-gravity)	Teleksk, Ashinsk, Oblajansk, Ukha-Golsky,, Kovdor

Magmatic deposits are represented by apatite ores. They are subdivided into apatite-nepheline, apatite and complex apatite-containing ores.

Nepheline-apatite deposits of the Khibiny group (Kukisvumchorr, Yukspor, Apatite Circus and Rasvumchorr Plateau) are associated with central intrusions of nepheline syenites. These deposits are characterized by a significant extension of ore zones along strike (2 to 4 km) and dipping direction (1 to 2 km), large and relatively stable thickness (100 to 200 m) of ore bodies, and their zonal structure, due to the difference in ore texture and P_2O_5 content in them, varying from 29% in rich spotty and spotty-banded ores down to 5% in poor ores of other textural varieties. There were observed more complex internal structures in ore bodies at Koashvinsky, Oleniy Ruchey, and Nyuorkpakhksky deposits, which are characterized by the presence of multi-staged ore horizons and variable morphology. In nepheline-apatite ores, it may have practical importance the rare earths, strontium and fluorine in the apatite; titanium, niobium and tantalum in sphene; as well as titanomagnetite and aegirine.

Apatite deposits (Oshurkovsk, Uktussk) are composed of massifs of diorites, syenites, metasomatites and other rocks containing disseminated impregnations of apatite. The relatively low contents of P_2O_5 and the relatively small size of the enriched areas determine their low industrial value; however, under favorable geographical, economic and mining conditions and sufficiently large reserves of easily enricheble ores, this type deposits can have industrial importance.

Complex deposits are represented by apatite-nepheline-rare-metal (Lovozersky massif), apatite-magnetite (Kiruna in Sweden), apatite-titanomagnetite (Volkovskoye) and apatite-titanomagnetite-ilmenite (Kruchininskoye) ores. Despite the relatively low average content (3–5%) and the uneven distribution of P_2O_5, the possibility of mining on a large scale makes it possible to economically extract apatite from them along the way.

This kind of apatite-bearing mineralization can be found in Mongolia, for example, Early-Mid Devonian alkaline gabbro-nepheline syenite of Ujig complex and Late Carboniferous alkaline syenite-nepheline syenite of Dund Hem River complex in the Khövsgöl District, and they have been studied in terms of aluminum mineralization. For example, in the case of the River Beltes Gol, the southern body is a circular shaped and taking 3.8 square km area, comprising of the outer zone generated by iyolite with 75 to150 m width, the middle zone generated by iyolite-urthite of 100 to 250 m width and the central zone is represented by a small body of diameter ranging 50-100 m transitioning from urthite to nepheline.

Carbonatite deposits include apatite-phlogopite (Maimecha-Kotuysk Oblast), apatite-magnetite (Kovdorsk), apatite-rare metal-magnetite (South Africa's Palabora) and apatite-rare metal (Belozimin) types of ores. The apatite content in the ore takes in average 5 to 10%. The ore body is shaped like a nest, stock, vein or tube. Although the ore is difficult to be concentrated, it has great practical importance to mine with the proper ore-processing technology when large reserves are available.

At Mushgia Khudag Deposit in Umnugobi (Southern Gobi), Mongolia, the mineralization is related to bastnesite carbonatite and alkaline rock complexes enriched by apatite that characterized by high content of phosphorus (P_2O_5 is 0.4 to 1.4%), fluorine (0.2 to 2.35%), strontium (SrO is 0.3 to 1.3%), barium (BaO is 0.2 to 0.8%) and REE. Apatite mineralization in

Mushgia Khudag Deposit can be divided into two subtypes: apatite and magnetite-phlogopite-apatite. Some researchers have differentiated the mineral composition of magnetite-apatite, fluorite-celestine-magnetite-apatite, pure apatite, phlogopite-apatite and feldspar-apatite.

The apatite ores are characterized by clearly developed crystals that seen in forms of porphyries, porphyric nests and sometimes veins have been saturated with apatite and its accompanying minerals at uneven levels. The main accumulator of rare earth elements in apatite ore is apatite itself, which is found in assiciation with phlogopite, magnetite and feldspar ore types in the nepheline syenite.

The ore zone that labelled as Khuren Khad has the highest concentration of rare earth elements within the Mushgia Khudag Deposit and has been affected relatively weakly by tectonic deformations and faults, forming an anticline structure along with contacts of syenite body turning suddenly to cross direction at the end of the syenite hill, which is about 150 m wide and pushing to southeast. There is outcropped to the surface only the central part of the second body of the five-layered ore body which is reminiscing hinge of the structure, forming a small hill called Mt. Apatite Uul. The thickness of these ore bodies are variously ranging from 5 to 30 m and sometimes observed as disrupted and overlapped layers; and they have almost vertical inclination dipping at 70 - 75° to 220° SW and at same degrees to 045° NE respectively on the sides of the anticline structure.

The ore bodies consist mainly of apatite and magnetite-phlogopite-apatite, and mineralogical and petrographic analyses show that phosphate (apatite) contains REE accompanying with celetine and barite within the microcline-, amphibole-, pyroxene-containing syenite, nepheline syenite, gypsum and anhydrite.

There was observed ferruginous phopshate in the strictly brittle and destructed apatite-bearing rocks. During microsound probe analysis, there has been revealed fine-grained light yellow mineral that generated due to hypergenic process of the apatite-bearing rocks and is containing 16.6% REE, 40.8% P_2O_5, and 37.35% FeO (ferrous oxide).

In addition to these minerals, there are also "secondary phosphates" that fill microfractures of fine-grained, light brown apatite (crystalline). Beside these two minerals, the “green phosphate” or staffelite, which has a hidden crystalline surface and fills the micro-veinlet space, is rarely marked.

Metamorphogenic apatite ore deposits are formed by the regional metamorphism and contact metamorphism along with phosphorite boundaries, so they usually form 1 to 15 m thick layers and bed-like horizontal bodies. Sometimes the apatite ores are transferred to weakly metamorphosed phosphorite ore along with strike direction. The distribution of apatite is usually irregular; the average content of P_2O_5 is unstable within significant limits (5.4% at the Slyudyanskoye deposit in Russia, and 20–24% at the Chulak-Tau deposit in Kazakhstan).

Weathering crust deposits are formed by enrichment of rocks containing phosphate material due to leaching of limestone, dolomite and marl. These deposits are most often associated with apatite-bearing carbonatite massifs, but they can be formed during the weathering of deposits of other types (Laokai apatite-bearing basin in Vietnam at metamorphogenic deposits). The thickness of the deposits varies from 10 to 30 m, and the content of P_2O_5 is from 4 to 14%.

Sometimes, in the process of weathering along apatite, francolite develops with the formation of rich apatite-francolite ores (Kovdorskoye deposit).

Sedimentary deposits are represented by phosphorite ores. They are common in folded belts (granular and microgranular) and platform areas (nodular and shell).

Granular phosphorite ore deposits take more than half of its resources in the world balance of phosphate raw materials. Arabian-African phosphate-bearing province is being the largest one of granular phosphate with reserves of more than 5100 million tons of P_2O_5, contained in the deposits of Western Sahara, Morocco, Algeria, Syria, Iraq, Egypt, Tunisia and other countries. The phosphates occur mainly in deposits of marl, organogenic limestone, cherty beds, dolomites, clay and gypsum belonging to shallow marine facies of Late Cretaceous, Paleocene, Eocene, and Miocene ages. The thickness of the phosphorite ore beds ranges from 1.5 to 12 m, often up to 40 m in close horizons; the phosphorite beds are composed of phosphate grains (oolites, pseudo-oolites, pellets, biomorphoses) of silty, sandy, and gravelly varieties, cemented by carbonate or siliceous material into varying degrees. In most cases, the ores are friable or easily disintegrated in water, which makes it possible to obtain conditioned concentrates by simple enrichment. The content of P_2O_5 in phosphate grains is from 24 to 36%, in ores - from 17 to 32%, and in fish bone detritus reaches 20%.

In the CIS (Commonwealth of Independent States) countries, deposits of the Central Asian phosphate-bearing basin in the Central Kyzylkum and Syrdarya regions are classified as granular phosphorites. They are composed of carbonate-phosphate and, more rarely, monophosphate pseudomorphs filling and replaceming after foraminifers, pteropods, coprolites, and pelecypods (biomorphic grains).

Sandy-granular phosphorites of Unechsky Deposit that discovered in the 1980s in the Bryansk region, Russia, and adjacent regions of Ukraine, is occupied a special position by their geological settings; for example, the elements of their geological structure are partially similar to granular and to pebbled phosphorites. These deposits are represented by complex of titanium-zirconium-phosphate placers.

Deposits of microgranular phosphorites are widely distributed in the USA (Rocky Mountain Basin), China (Yangtze Basin), and Mongolia (Khövsgöl Basin), Australia (Georgina Basin), India (Rajasthan and Udaipur states) and Kazakhstan (Karatau Basin). In Russia, they are represented by the Ukha-Golsky and Kharanursky deposits in the Eastern Sayan (in Buryatia, on the extension of the Khövsgöl Basin), as well as Belkinsky, Seybinsky and others in the Altai-Sayan region.

Phosphorite ores of microgranular and aphanitic types usually compose of one to six productive beds 0.5 to 25 m thick, occurring among dolomite, limestone, phosphate-siliceous and quartz-mica schist and organogenic siliceous rocks (radiolarites, spongalites, etc.). Calcium phosphate in the ore deposits represented by siliceous-carbonaceous and carbonaceous formations can be specified in different ways: in the form of monophosphorus oolites and pellets about 0.01 to 1.0 mm in size, monophosphate layers with a thickness of 1 mm to 1 cm, as well as pseudomorphosis according to the waste products of algae (stromatolites and oncolites). The average content of P_2O_5 in the ores ranges from 14 to 24%.

Classical examples of sedimentary phosphorite are the 300 km long and 100 m thick Khövsgöl phosphorite basin that comprised of terrigenic-carbonaceous sediments of the Heseen formation belonging to the Ediacaran-Cambrian Khövsgöl group in Tuva-Mongolia Province in Mongolia and Okinsky in Russia, and the Zavkhan Basin represented by shelf sediments of Tsagaan-Olom and Bayangol formations in Central Mongolia.

In Khövsgöl Deposit, which is the largest one in the Khövsgöl basin, the phosphorite layer is represented by dolomite containing limestone horizons about 100 m thick, while the Bürenkhaan Deposit is dominated by limestone with some silica and infiltration phosphorite horizons,which distribed irregularly.

Khövsgöl Basin phosphorite is composed of aphanitic (homogenous phosphate) layer, micro-granular, granular (pellet), as well as breccia and debris types of ores. The granular phosphorite consists of pellets and oolites (in diameter from 0.05 to 0.2 mm), while unstructured, homogenous phosphate is characterized by collomorphic texture, with radial-shaped aggregates of 0.5 to 1.0 μm apatite crystals viewed under an electron microscope. The P_2O_5 content in the homogenous phosphate and layered and brecciaed phosphorites takes 20 to 40%, while in the granular phosphorites - from 5 to 26%. The contents of the admixture elements such as U, V, Mo, Ag, Ni, Zn are higher than normal, and presence of Pb, Sn, Co, Cr, Cu, Mn, Sr are in range 0.03 to 1.0%, and Th and Ba are less than 0.27%, and F is about 1.37% in the ore.

The composition of phosphorite is determined by mineral ratio of silica (chalcedony and quartz ranging 5 to 85%), carbonate (dolomite and calcite – 5 to 50%), phosphate (isomorphic fluorine apatite and fluorine-hydroxylapatite – 10 to 98%) and admixture minerals (pyrite, limonite, sericite, mica and clay minerals <10%), accessory minerals (rutile, sphene, spinel, phlogopite, amphibole, pyroxene and garnet) and organic matter (0.05 to 5.0%).

There are two main types of origins, i.e. (1) marine sediments (chemogenic and clastogenic), (2) secondary terrestrial (karst and infiltration-metasomatite).

During the detailed exploration of the Bürenkhaan Deposit (Osokin et al., 1984), there have been estimated total 205.6 million tons of phosphate reserves in 21 isolated areas, of which the Area Group-1 contains more than 50 percent of the total ore reserves. The phosphorite–bearing sediments belong to middle part of lower member of Heseen Formation are represented by homogenous, black colored thick platy limestone bed, which sized about 30 up to 260 m thickness and 1 to 3 km length. Also, there are revealed dolomite beds containing oncolith (in areas #6, 10, 11, 14 and 19).

There were identified five phosphorite beds with thickness ranging between 1.75 and 136.6 m and length between 530 and 2700 m in the deposit. Ores are composed of carbonate-silica (46%), silica (31%), carbonate (11%), and mono-phosphate (12%).

There are identified three horizons of phosphorite-bearing rocks; the lowermost and uppermost horizons contain sedimentation layers (chemogenic and clastogenic) of phosphorite, while the middle horizon (or part of it) contains secondary (karstic) one. The host rocks are mainly composed of carbonate rocks such as limestone, dolomite and calcareous conglomerate, and sandstone, siltstone, and breccia, which sometimes contain silicified rocks or siliceous layers.

The Zavkhan basin catches over 20,000 sq km, and an isometric area is confirmed by the findings of the Late Proterozoic-Early Paleozoic (Ediacaran-Early Cambrian) continental depression labeled Tsagaan Olom, and finding of stromatolite and oncolith that existed along with sea shelf in Paleo Asian Ocean. Here, the phosphorite ores are interbedded with siliceous dolomite of Tsagaan-Olom Formation and carbonate-terrigenous rocks of Bayangol Formation, generally composing of siliceous-, carbony-siliceous schist and greenish-gray colored platy mudstone, usually ranging from a few meters to a few 10 m. The ore is abandoned in granular, brecciaed and aphanitic forms and phosphorite fragments, and is containing chalcedony and quartzite (20%), and feldspar (3 to 5%).

Within frame of Zavkhan Basin, there have been extensively exploring the Alagiin Davaa and Tsakhir Uul deposits. And in 2021, Erdenet Mining Corporation conducted a mineral analysis using a Bruker XRD Endeavor X-ray diffractometer, determining the main ore mineral is Fluor-apatite ($Ca_{10}(PO_4)_6(F)_2$), and the others are from quartz, dolomite, calcite, muscovite and goethite in the ore. Furthermore, it is clarified that the apatite grains have got mostly open growths with quartz, while they have been forming complicated intergrowth with grains of siderite, dolomite and clay minerals.

According to electron microscopy analyses, the apatite grains were forming intergrowth with particles of quartz (up to 11.9%), calcite (5.3%) and other minerals (3.6%). Chemical analysis revealed content of P_2O_5 from 10.7% (at Alagiin Davaa Deposit) up to 17.97% (at Tsakhir Uul Deposit), and 15.5 to 25.6% CaO, 49.9 to 66.8% SiO_2, 0.23 to 0.51% Fe_2O_3 and 0.62 to 0.77% Al_2O_3. In results of laboratory enrichment test taken on phosphorite ore of the deposits, phosphate concentrate was obtained containing 28 to 30% P_2O_5.

Sedimentary phosphorite accumulations of this age in Mongolia are expected to be detected in several areas in Central Mongolia, such as siliceous carbonate (Oortsog Formation) in Dundgobi District.

In addition, there was revealed phosphorite occurrence at content of 1.53 to 2.56% P_2O_5 in Ikher Nuur Area, Gobisumber Aimag, and the occurrence was spatially related to iron-manganese layers of recent and Cretaceous sediments. And its phosphate content has previously been recorded as <24.08%, and the occurrence was subjected to prospecting survey.

Platform nodular (nodule) phosphorites (deposits: Yegoryevskoye in the Moscow Region, Polpinskoye in the Bryansk Region, Vyatsko-Kamskoye in the Kirov Region) are represented by concretion-like accumulation of phosphorites in sandy-clayey rocks that can be tightly cemented with the host rock (“phosphorite plate”). The content of P_2O_5 in nodules is 15 to 26%, in deposits it is usually 6 to 10% (up to 16% in some deposits), the thickness of phosphorite layers is 0.5 to 1.2 m. In most deposits of this type, the main amount of phosphorus is included in ore fractions larger than 0.5 mm; and typically, 30-40% of the phosphate substance is in the lemon-soluble form, which makes it well absorbed by plants.

Shell phosphorites are an accumulation of phosphate-bearing shells enclosed in sand or sandstone. The thickness of productive seam is from 1 to 14 m, the content takes from 3 to 20% P_2O_5, according to the mineral composition of the ore, which belongs to quartz-dominated type. Shell phosphorites were mainly developed in the Baltic basin, Estonia (deposits Maardu, Toolse and Rakvere-Kabala) and in Leningrad Oblast (Kingiseppsky Deposit).

Deposits of residual infiltration type (weathering crusts) are formed mainly on paleo formations, which composed of carbonate and siliceous-carbonate rocks containing phosphorite at varying degrees. Depth of the occurrence of secondary phosphorites varies from 0.5 to 15 m from the surface (deposits Ashinskoye, Obladzhanskoye, Seybinskoye, etc.). The thickness of the weathering zones containing phosphorites with fragments of host rocks reaches several tens of meters and is extremely unstable. The phosphorites are represented mainly by a loose mass in the form of complex-structured accumulations in karsts sinkholes within carbonate sediments at their contact with terrigenous or igneous rocks. Among them, earthy, clayey and stony varieties are distinguished with P_2O_5 content from a few percent to 30%. The main type of the phosphate mineral is represented by carbonate hydroxylfluorapatite - $9Ca(PO_4)_2CaF_2\ Ca(OH)_2CaCO_3$.

1.5. Apatite and phosphorite ores are recommended to be considered as complex raw materials. In addition to phosphorus itself, the ores can serve as raw materials for the production of fluorine, strontium, rare earths, titanium, niobium, tantalum and other elements and compounds.

The geological settings and ore types of phosphorite deposits in Mongolia are shown in Table 1.2.

In Bürenkhaan Deposit, the cut-off grade of P_2O_5 is 10%, the minimum production grade in the reserve block is 16.0%, the minimum thickness of the ore layer or unconditioned ore and the maximum thickness of gangue rock is 5.0 m, the limit of soil stripping coefficient is 10 m^3/m^3, and content of harmful impurities: MgO is not exceeding 7.0%, CO_2 is not exceeding 20.0%, Fe_2O_3 is not exceeding 1.3% and Insoluble residue is not exceeding 30.0%.

For Alagiin Davaa and Tsakhir Uul deposits, Zavkhan Aimag, the cut-off grade of P_2O_5 is 10%, average block grade - 16%, minimum thickness - 5%, volume weight is 2.75 t/m^3.

Table 1.2: Brief description and types of phosphorite deposits in Mongolia

№	Name of deposit	Ore composition type	Major and accompanying components	Content of Profitable composition	Ore type and ore volume	Mining method and technology	Types of ore concentrating and processing technology	Registered phosphate reserves and resources
1	2	3	4	5	6	7	8	9
1	Area 1-21, Bürenkhaan	Phosphorite-bearing rocks in carbonate rock sequence (silica-carbonate-hosphate) Impurities (pyrite, limonite, sericite, mica, clay minerals <10%); Accessory minerals (rutile, sphene, spinel, phlogopite, amphibole, pyroxene and garnet); Organic matter (0.05 to 5.0%).	In addition to P_2O_5, further elements: U, Th, Sr, Be, and MgO (0.4 to 7.75%), CO_2 (0.43 to 20.50%), Fe_2O_5 (0.25 to 6.21%), AI_2O_3 (0.44 to 7.57%), IRW (16.27 to 39.10%), F (1.46%)	P_2O_5 at 21.08%	Phosphorite of Heseen and Erkhilnuur formations varies in thickness from 5.0 to 100.0 m, is in form of 1.0 to 3.0 km long strata or flattened lenses. Phosphorite-bearing packages in carbonate sequences range in thickness from 30.0 to 270.0 m and in length - from 0.5 to 3.5 km. In their structure, the number of productive strata, layered bodies, ore bodies vary from 1 to 4 having different widths and lengths, with a thickness of 5.0 up to 108.0 m, on average 11.0 (or 22.0) reaching 50.0 m .	Open pit mining	The most suitable is the combined suspension-flotation method. Initial ore of content 14 to 25% P_2O_5 ore enriched to concentrate at 25 to 31% P_2O_5 and was enriched to 57-90% P_2O_5. Concentrate yield is 62.0%. Yellow phosphorus is produced and used in the production of animal feed phosphate.	Balance reserves in ranks (B + C1 + C2) are 192.24 million tons of ore and 40.52 million tons of P_2O_5, according to the protocol No.152 in 1984 of Minister of Geology and Mining Industry
2	Lake Ongilog Nuur	Phosphorite-bearing rocks in carbonate rock sequence containing 9 to 14% monophosphate, 1.3% silica and 2 to 42% silica-carbonate	Content of P_2O_5 is from 18.28 to 35.13%, MgO - 1.81 to 11.23%, CO_2 - 8.00 to 25.25%, IRW - 0.76 to 3.26%, CaO -33.0 to 48.25%, AI_2O_3 - 0.28 to 3.32% and Fe_2O_3 -0.33 to 2.75%.	Phosphorite with granular dolomite at 46% P_2O_5, phosphorite with oolite-granular dolomite at 10 to 33% P_2O_5, brecciaed aphanitic phosphorite at 50% P_2O_5,	5 beds are in the deposit: Bed I (lower) is fine-layered, lenticular-layered and brecciaed. Thickness is 1.6 to 28.2 (11.8) m. Bed II consists of phosphate-containing dolomite and dolomitized silica and black colored phosphorite layers, lenticular-layers, rarely lenses and phosphate granules; it is 8.2 km thick and 5.4 km long, containing 16.34% P_2O_5. Bed III composes of layered and lenticular shaped phosphate-containing dolomite, thickness is 1.0 to 40.0 (14.6) m, length is 2.0 km, at content 17.23% P_2O_5. Bed IV composes of dark grey and black colored, coarse–grained, massive phosphate-bearing siliceous and dolomitic limestone, and rarely thin silica layers; average thickness is 6.0 m. Its length is 2.3 km, at content of 16.54% P_2O_5. Bed V is composing of black and dark gray coarse-grained, massive phosphated silica and dolomitized limestone, and small amounts of phosphate granules and thin silica layers. Its thickness is 5.0 to 34.7 (14.5) m thick and length is 18.0 km.	Open pit mining; mining and technical conditions are in medium level, average stripping coefficient is 2.41 t/m^3.	The most suitable is the floatation method, showing the grade of initial ore at content 31.26% P_2O_5 following ore processing at concentrate yield ranging 73 to 75%.	It is stated the reserves are 43.1 million tons of P_2O_5 at content 18.9% in C_1 rank, 66.9 million tons of P_2O_5 at content 18.1% in C_2, and 145.7 million tons of P_2O_5 in P_1 at content 18.8% in accordance to Protocol No. 3 of 1986.

№	Name of deposit	Ore composition type	Major and accompanying components	Content of Profitable composition	Ore type and ore volume	Mining method and technology	Types of ore concentrating and processing technology	Registered phosphate reserves and resources
3	Uran Dösh	Phosphorite-bearing rocks composing of phosphate, phosphated limestone, silica and siliceous limestone in the carbonate sequences	Siliceous-phosphorite, siliceous-calcareous phosphorite, and banded phosphorite	Cut-off grade 7 to 13% P_2O_5 for the low-mid contented ore	The middle sub unit of the member is characterized by chemogenic and terrigenous origin in marine environment, composing of dark grey dolomite, dolomitized limestone, and occasionally siltstone that with a weak sulfuric odor. It contains a 5 to 24 m thick phosphorite layer and a 30 m thick silica layer. An ore body observed in length about 4 km and bordered to fault zone within the deposit. The body is branched into two layers (3 to 8 m and 84 m thick) in dolomitized limestone bed, on southern foothills of Mt. Urandush Uul. The thickness of the phosphorite layer reaches 24 (average 3) m in the North and 7 m in the South.	Mining and technical conditions are in medium level	Pilot tests taken on the limestone have shown that it is suitable for the production of building lime fitting to 2nd variety of Class B, characterized by low-magnesium content, slow-extinguishing ability and hardening under open air.	According to 1989 general prospecting work at scale 1:50K, the estimated reserves are 99.9 million tons of ore and 17.87 million tons P_2O_5.
4	Alagiin Davaa and Tsakhir Uul	Laminated and nodular textured phosphate ore is hosted by silica, silica-carbonate rocks and sandstone beds.	Harmful impurities are from Fe2O3; Al_2O_3; Na_2O; K_2O; MgO; and Pb (at low level), but Cr content is high.	P_2O_5 content is 10 to 32.3%	The Ediacaran-Early Cambrian carbonate sequence of Tsagaanolom Formation contain 3-20 m thick siltstone and mudstone layers and three phosphate-bearing beds (40m thick) that formed in dark grey sandstone unit. The total length of the deposit is 7 km. It strikes to the latitude direction. The thickness and content of the ore body are unstable and dipping at 20-30°.	Open pit mining at depth down to 25 m	It is possible to produce fertilizers using mechanic-chemical method due to silica sandstone content is poor ranging 16 to 27%, P_2O_5. According to pilot test taken at Erdenet Plant in 2011, it is expected to be able to produce fertilizer if the ore is enriched by flotation and reaching 30% P2O5.	1999 resource estimation: in C_2+P_1 takes 7989.6 thousand tons of ore, 1274.9 thousand tons P_2O_5 in Alagiin Davaa Deposit and in C_2 takes 23623.7 thousand tons of ore and 4362.8 thousand tons P_2O_5 in Tsakhir Uul Deposit.

IR - Insoluble residue

IRW - Insoluble residue in water

II. Grouping deposits by geological complexity for exploration purposes

2.1. The main factors in choosing methods of exploration on deposits are the shape and size of ore bodies, their depositional conditions, internal structure and ore distribution and nature of useful components' distribution. Depending on the complexity level of the geological structure of the apatite and phosphorite ore bodies, the deposits (areas) of the phosphorite ores are corresponded to three groups (Groups 1, 2 and 3), in accordance with the "Classification and instructions for mineral resources and deposit reserves may be adapted based on the specifics of the type of mineral" approved by Order No. 203 of the Minister of Mining of Mongolia on September 11, 2015. These include:

The 1st group consists of mainly large beds or lenticular beds that characterized by horizontal and continuous length, relatively sustained thickness, having relatively stable quality, evenly distributed apatite including deposits (Plato Rasvumchorr, Yukspor, Kukisvumchorr, Oshurkovskoye deposits), concretion phosphorite deposits (Vyatsko-Kamsk Polpinsk, Yegoryevsk); shel phosphate deposits (Kingiseppsk and others) and most granular and gravel-granular phosphorite deposits (in Asia, Africa and Americas).

The 2nd group includes the vast majority of apatite ore deposits, represented by deposits of complex shape (bedding-, pipe- and lenticular ore horizons and layers) of unsustainable thickness and with an uneven distribution of apatite (Koashvinskoye, Oleniy Ruchey, Neworkpakhkskoye, Seligdarskoye), as well as deposits of phosphorite ores with steeply dipping large stratified and lenticular accumulations and beds, complicated by tectonic faults, with unstable ore quality (Ukha-Gol, Kharnuur; Khövsgöl and Bürenkhaan deposits in Mongolia).

The 3rd group includes deposits of usually small nodular phosphorites and ores of weathering crusts, represented by deposits of complex irregular shapes with very variable thickness and uneven quality of ores (Kovdorskoye and Beloziminskoye). Often they are localized in karts' funnels (Seybinskoye, Oblajanskoye, Ashinskoye, etc.). A characteristic feature of these deposits is rather high contents of lemon-soluble P2O5.

2.2. The belonging of deposits to one or another complexity group is determined based on the nature of the geological settings of the main ore bodies, which contain at least 70% of the total reserves.

2.3. In order to more objectively assign deposits to the corresponding group of complexity of the geological structure, quantitative indicators of the variability of the main properties of mineralization can also be used: the coefficient of variation in the thickness of ore bodies and the contents of useful components in them, the indicator of the complexity of the structure of ore bodies (see Appendix).

3. Geological setting of ore deposits, study of ore mineral component

3.1. For an exploring deposit, it is recommended to choose a topographic base map, of which scale corresponds to its size and features of the geological structure. Topographic maps and plans for deposits of apatite and phosphorite ores are usually compiled at scale 1:2000 to 1:5000, and for large deposits - 1:10,000. In deposits that are small in area or with a highly delineated landscape, the scale of the topographic base map should not be smaller than 1:500 to 1:1000.

All exploration and operational workings (drill holes, trenches, dug pits, main trenches, adits/galleries, vertical mines/shafts, etc), detailed geophysical observation profiles, geochemical sampling profiles and points, and all types of natural outcrops are tied by geodetic measurements and plotted on contour maps. Using data of underground mining surveyor, the sites of underground excavation and underground boreholes are plotted to the Mining Horizon Maps. For bore holes, the coordinates of the points of intersection of roof and base of ore body and the extensions of their barrels/hollow space (estimating their curve or deviation) are plotted on exploration plan maps and sections. The exploration plan maps and mining horizon maps are usually produced at scales 1: 200 to 1: 500, unified underground surveyor maps – not less than 1: 1000 depending on the size of the deposit, geological settings and survey accuracy.

3.2. The geological structure of the deposit should be studied in detail and plotted on a geological map at scales 1:2000 to 1:10,000 (depending on the size and complexity of the deposit), geological sections, plan maps, underground horizons' maps and vertical (horizontal) projections.

The geological and geophysical survey materials of the deposit should give an idea of the size and shape of the phosphorite deposits, the conditions of their occurrence, reflecting their complexity including internal structure and continuity or discontinuity of beds, the characteristics of correlation between ore bodies and host rocks, influence of folded structures and tectonic faults to ore bodies in necessary and sufficient level of studies, become justified for the reserve estimation and resource evaluation. These data should also reflect the location of various types of ores, the structure of the top and base of ore bodies, changes of thickness along with strike and dipping direction, P_2O_5 contents and harmful impurities in the ore. It is recommended to define the geological boundaries of the deposit or mineralized zone based on the search criteria that determine the location of promising areas within which the determined resources (category P_1) are estimated.

3.3. Outcrops of ore bodies and subsurface parts of the deposit are recommended to be studied in detail, allowing determining the thickness and composition of the overburden, the position of ore bodies, degree of weathering, depth of the weathering zone development, and changes in the mineral composition and technological properties of ores. It has to be determined presence and degree of karsts development, tectonic faults and their nature. For this purpose, in addition to natural outcrops, it has to be conducted clearing works on ditches, digging pits and trenches, drilling shallow bore holes, as well as ground methods of geophysical survey.

3.4. Exploration of deposits of apatite and phosphorite ores to a depth is carried out mainly by rotary drilling using downhole logging and surface geophysics methods, and at a shallow depth poition of ore bodies – bore holes in combination with [surface] mine workings.

Exploration methodology - the ratio of drilling and mining volumes, types of mine workings and drilling methods, geometry and density of the exploration grid, methods and methodics of sampling - should provide the ability to calculate reserves at explored deposits in reserve categories corresponding to the complexity group of the geological structure of certain deposit. It is determined based on the geological features of the deposits, taking into account the capabilities of mining, drilling, geophysical tools for exploration, as well as the experience of exploration and development of deposits of a similar type.

When choosing the optimal exploration option, comparative technical and economic parameters and the timing of work on various exploration options are taken into account.

3.5. Exploring bore holes have to penetrate apatite or phosphorite beds in full thickness and deepening into the underlying rocks, depending on geological factors. In those cases where there are indications for identifying other horizons of phosphate-bearing rocks in the underlying rocks, a small part of exploration bore holes should cross the entire section of these rocks. In the exploration of steeply dipping ore bodies, to obtain their intersections at large angle, it will be useful inclined bore holes, artificially curved boreholes and drilling of multilateral holes.

The maximum possible yield of a well-preserved core should be obtained from rotary drill holes, which makes it possible to determine the bedding condition of ore bodies and host rocks, their thickness, the internal structure of ore bodies, the distribution of natural varieties of ores, their texture and structure, and to ensure the representativeness of the material for sampling. The practice of geological exploration has established that the core recovery from the ore body must be at least 80% for each drilling run. It is recommended to systematically control the reliability of the linear output of the core by other methods - by weight or by volume.

The representativeness of the core for determining the content of phosphorus pentoxide (P_2O_5) and the thickness of ore intervals is confirmed by studies of the possibility of its selective abrasion. To do this, it is necessary to compare the results of core sampling (if necessary, and slime) for the main types of ores by intervals with its different core recovery.

With a higher content of P_2O_5 in low core recovery classes, it is recommended to go through control boreholes by percussive, pneumatic percussion and cone drilling methods, as well as rotary bore holes using removable core tubes. When selective core abrasion is observed and (or) low core recovery is established, measures are taken to increase its recovery by using drilling tools with bottom-hole circulation of drilling fluid, ejector tools, etc. If it is impossible to eliminate the selective abrasion of the core in sufficient volume, control mine workings would be carried out to the site and using the data, the value of correction factor is substantiated to the results of core sampling. It is also possible to use the results of downhole logging survey, of which reliability is confirmed in the prescribed manner.

The diameter of the boreholes is taken by analogue with the explored deposits, the ores of which are similar to the data on physical and technical properties and textural and structural features. In deposits of phosphorites of the nodular typethe major part of phosphorus is concentrated in nodules about 5 cm in diameter or more, the diameter of the boreholes must be at least 168 mm.

It is allowed to use boreholes of smaller diameter, subject to the use of neutron activation and gamma ray logging to determine the P_2O_5 content and confirm the reliability of nuclear physics methods. In this case, large-diameter boreholes are drilled in the amount necessary to control the geophysical sampling data and take bulk samples for pilot test. When exploring ore bodies composed of loose ores, it is recommended to use a special drilling technology that increases the core yield (drilling without fluids, short runs, the use of special drilling fluids, etc.).

To increase the reliability and information content of drilling data, it is recommended to use methods of geophysical surveys in boreholes, the rational complex of which is determined based on the tasks set, the specific geological and geophysical conditions of the field and modern capabilities of geophysical methods. The downhole logging complex, effective for identifying ore intervals and establishing their parameters, is performed in all boreholes drilled on the deposit.

In vertical boreholes with a depth of more than 100 m and in all inclined ones, including underground ones, the azimuth and zenith angles of the boreholes are determined and confirmed by control measurements no more than every 20 m. The results of these measurements are taken into account when constructing geological sections, plan maps of horizons and calculating the thickness of ore intervals. If there are intersections of borehole's barrel to mine workings, the results of measurements are verified by the data of Underground mine surveying reference/tying data.

3.6. Mining workings on deposits with relatively consistent thickness and internal structure of ore bodies with a relatively uniform distribution of P_2O_5 are carried out mainly to control drilling data (in the presence of selective abrasion), study the near-surface parts of the deposit (certain area) and take bulk samples for pilot test. When underground mine workings are used as control for core sampling in the areas of their penetration, at first boreholes are drilled (in vertical and horizontal ways), and then mine workings are passed along the borehole barrels, in which sampling is carried out by method of channel samples of large cross-cuts or bulk samples. During the exploration on horizontally and gently stratified and lenticular deposits (or accumulation) of nodular and shell phosphorites, excavation of dug holes can be replaced by drilling large diameter boreholes (168 mm or more).

At deposits of complicated structures with high variability in morphology, internal structure of ore bodies, as well as the nature of mineralization, in addition to drilling, the main exploration method includes mine workings, which reveal the main ore bodies in representative areas. Their main goal is to establish the nature of the spatial variability of mineralization (continuity, discontinuity of ore bodies, patterns of distribution of useful components and harmful impurities), as well as to identify natural types and varieties of ores.

3.7. Types of exploration workings, their location and distances between them (grid density) are determined in each individual case, taking into account following geological features of the deposit: the conditions of occurrence, morphology and size of ore bodies, the variability of their thickness, the nature of the distribution of individual types of ores and the capabilities of geophysical method use, as well as the proposed method for developing the deposit in future. With complex tectonics and presence of erosion on the deposit, it has to be determined the nature, spatial position and amplitude of faults, and contoured the erosion zones, etc.

Given in Table 2-1, the generalized data about the grid density used in Commonwealth of Independent States (GIS) for the exploration of deposits of apatite and phosphorite ores can be used in the design of geological prospecting works. For each deposit, based on the study of the features of the geological structure in the areas of detailing and a thorough analysis of all available geological, geophysical and exploitation data for this or similar fields, rational geometry and density of the grid of exploration workings are substantiated.

The Table 2.2 presents some data of the phosphorite deposits and ore bodies identified in Mongolia, their properties, abilities of ores for concentrating and processing activities, and some information about exploration that carried to them.

3.8. To confirm the reliability of the parameters for reserve estimation, certain areas of deposits are explored in more detail. These areas are being explored and sampled on a denser prospecting grid than is accepted in the rest of the deposit. At the deposits of the 1st group, reserves in such areas or horizons are considered in categories A and B, of the 2nd group - in category B. At the deposits belonging to the 3rd group, the reserve is estimated in category C, but it is advisable to use denser prospecting grid for the workings in detailing areas, as a rule, not less than 2 times compared with the accepted for category C reserves estimated on deposits belonging to the 2nd group.

When using interpolation methods for reserve estimation (geostatistics, method of inverse distances, etc.), it is recommended to ensure the prospecting grid density in the detailing areas, sufficient to justify the optimal interpolation formulas.

The areas that subjected to be prospected in details should reflect the features of geological setting of deposits and the shape of the ore bodies that contain the main reserves of the deposit, as well as the prevailing quality of the ores. If possible, they are located in the contour of reserves subject to priority development. In those cases when the areas scheduled for priority development are not typical for the entire deposit in terms of the geological settings, the quality of the ores and the mining and geological conditions, the areas have to be studied in detail up to levels fitting to the above mentioned requirements.

The number and size of areas that subjected to detailed exploration in the deposits are determined in each specific case by the subsoil user considering the specifics of each deposit/area.

The information that obtained from the detailing area is used to substantiate the group of geological complexity of the deposit, to establish the compliance of the adopted methodology and the selected exploration equipment with the features of its geological structure, to evaluate the sampling results and the calculation parameters adopted when calculating the reserves in the rest of the deposit, as well as the conditions for developing the field as a whole. And for these purposes, operational exploration data and development data would be used at those areas that are under development,

3.9. A rational complex of surface geophysical surveys, including geological information system, is used to trace and delineate ore bodies in area and depth, identify poor ore bodies, as well as to determine the thickness of weathered ore and overlying sediments, define the geological sections in details, determine the contents of P_2O_5, and study the hydrogeological and mining-geological conditions of the deposit. In cases of gas emissions, it is recommended to include gas logging complex in the geological information system (GIS?).

For phosphorite ores of most deposits, there is a direct correlation between the content of P_2O_5 and radioactivity, which ensures the effectiveness of the use of radiometric methods of sampling and downhole logging. Neutron activation methods have high efficiency due to they based on a close, almost linear relationship between the contents of Phosphorus and Fluorine (correlation coefficient up to 0.98). Downhole logging method based on nuclear physics is the most effective for a particular area or deposit, and have to be used all of boreholes.

It is recommended to confirm the reliability of downhole logging data by comparing to the borehole data, geological logging and sample results taken from boreholes with high core recovery and sample results from mine workings, if which are there. Reasons for significant discrepancies between geological and geophysical data should be identified and reported.

3.10. All of exploration and exploitation workings, boreholes, and outcrops of ore bodies are properly documented. The results of sampling are inserted to the primary documentation and compared with the geological description. The completeness and quality of the primary documentation, its compliance with the geological features of the deposit, the spatial correctness of determining the structural elements on core and mine faces, drawing up sketches and their descriptions are systematically controlled and corrected by comparison with nature by specially appointed commission.

Table 2.1: Information of exploration grid density used for phosphate ore exploration

Group of deposits	Characteristics of ore bodies	Type of workings	Distance between workings (m) for reserve categories $\frac{\text{along with straike}}{\text{along with dipping}}$		
			A	B	C
1	2	3	4	5	6
1st	Horizontally and gently sloping beds/seams or deposits of consistent thickness with relatively stable ore quality	Boreholes	$\frac{100\text{-}200}{-}$	$\frac{200\text{-}400}{-}$	$\frac{400\text{-}800}{-}$

	Steeply dipping layers, layered and large lenticular accumulations with relatively stable thickness and quality of ores	Boreholes	100-200 50-100	200-400 100-150	400-800 150-200
2nd	Complicated in shape accumulations of varying thickness with inconsistent quality of ores	Boreholes	-	75-150 50-75	150-300 75-100
	Steeply dipping layers, layered and large lenticular accumulations with varying thickness and quality of ores	Boreholes	-	75-150 50-75	150-300 75-100
	Massifs of igneous rocks with uneven impregnation of apatite	Boreholes	-	100-200 -	200-400 -
3rd	Complicated lenticular and dome-shaped accumulations of small sized nodular, weathering crusts and "karst" phosphorites	Boreholes and excavation workings	-	-	50-100 25-50

Footnotes:
1. When exploring nodular phosphorites in order to take representative samples, it is needed to dig mine workings or to drill large-diameter boreholes (168 mm or more).
2. At evaluated deposits, the exploration grid for category P_1 (Determined resource), compared to the grid for reserve category C, is sparse by 2-4 times, depending on the complexity of the geological structure of the deposit.

3.11. To study the quality of mineral resources, contouring the ore bodies and calculating the reserves, it has to be properly sampled all exploration and exploitation workings that have exposed mineralization, as well as outcrops, too. The choice of methods and ways of sampling is made on the basis of specific geological features of the deposit, providing the greatest reliability of results with sufficient performance and economy. In the case of using several sampling methods and ways, it is recommended to compare them in terms of the accuracy of the results and reliability, and to evaluate ability to replace / represent each other.

When choosing methods (geological, geophysical) and sampling ways (core, sludge, channel, bulk) for the exploration, determining the quality of sampling and processing, and evaluating the reliability of the results obtained, it is recommended to be guided by the relevant regulatory and methodological documents.

3.12. Sampling of exploration sections is carried out in compliance with the following necessary conditions:

- sample grid must be consistent, its density is determined by the geological features of the studied areas of the deposit; samples should be taken along with direction of maximum variability in the mineralization content; in the case of intersection of ore bodies by exploration workings (especially boreholes) at an sharp angle to the direction of maximum variability (if this raises doubts about the representativeness of sampling), it is proven the possibility of using sample results of the sections in reserve estimation by control work or comparisons;

- sampling must be carried out continuously, at full thickness of the ore body with access to the host rocks by a value exceeding the thickness of gangue rock or substandard interlayer, included in accordance with the requirements of the conditions in contour of productive ore; to trenches, dug holes and main trenches; in addition to the ore outcrops, it should be separately sampled the products of their weathering;

- natural ore varieties and mineralized rocks are sampled separately - in sections, of which length (routine sample) is determined by the internal structure of the ore body, variability of the elemental composition, textural and structural features, physical, mechanical and other properties, while in boreholes - also by the run length; at the same time, intervals with different core recovery are sampled separately; in the presence of selective abrasion of the core, both the core and the crushed drilling cuts are subjected to sampling; and small pieces are taken in an independent sample from the same interval as the core sample, they are processed and analyzed separately;
- the length of the sampling section (based on downhole logging interpretation intervals) should not exceed 1 m, in the case of large thicknesses and even mineralization - 2 m for study the irregularity (portion contrast) of ores;

- results of nuclear geophysical readings (at downhole logging) are interpreted differentially in intervals of 5–10 cm, equivalent to the size of a piece to determine the contrast of ore in natural occurrence, guided by the relevant regulatory and methodological documents.

Table 2-2: Exploration grid density boreholes and excavation working used for phosphorite deposits in Mongolia

Group of deposits	Name of deposits	Date of conducted exploration	Type of exploration, shape and size of ore body	Type of workings	Distance between dug workings and boreholes revealing ore body (m)		
					Proved (A)	Measured (B)	Indicated (C)
0	1	2	3	4	5	6	7
II	Bürenkhaa n	In 1981, Complex geophysical survey; for 1981-1983, prospecting-evaluating works, in 1983, preliminary and detailed exploration	Drilling, mapping, complex air-borne geophysical survey, hydro-geological survey, trenches, open pit and underground mining excavation such as trenches, adits\galleries, tunnels. Penetration length 60 to 9600 line m, cross section of excavations ~ 6 to 36 m^2. Ore bodies' shapes layers/beds or flat lenses.	At detailed exploration, Trenches Main trenches / Exploration boreholes	-	75(40)-100 40-140/50(80)-100	300-600x100-150
II	Ongolig Nuur	In 1965, 1968 and 1974, prospecting works, and prospecting-evaluating works; for 1984-1986, Prospecting--evaluating works and preliminary exploration works on Jankhai Area belonging to Ongolig nuur Deposit in Khövsgöl Basin	Drilling, trenches, channel and core sampling; geophysical gamma spectrometric mapping, magnetic and electrical survey, and complex caliper survey conducted to there.	Boreholes	-	-	300-600x100-150, 300 x 200-300, (P_1 1200 x 200-300)
II	Urandush	In 1987, basic prospecting works	Drilling (), excavating (trenching ~ 72 м^3) and dug holes~ 8 line m); channel and core sampling (12 samples); and geological traverse (9 line km).	Trenches Boreholes		-	Predicted resource (P-) (200-300 80-100)
I-?	Alagiin Davaa, Tsakhir uul	In 1997, prospecting-evaluating works and preliminary exploration	Trenching ~260.5 m^3, drilling~5 boreholes, 298.2 line m), and magnetic and radiometric survey at scale 1:25000.	Boreholes, Trenches	-	-	400-800

At deposits of nodular and shell phosphorite ores, the entire productive cores that picked up from the boreholes are taken into the samples. At deposits that composed of apatite and microgranular phosphorite ores, halves of the core are taken into the sample (mineralized core is divided along the axis), and in the case of a small diameter, the entire core is taken into sampling sections with the preservation of samples pieces in the boxes.

From mine workings excavated during exploration, the ore bodies are sampled by channel sampling method with a cross section from 5×3 to 10×15 cm. If selective abrasion occurs, the cross sections of the channels are increased, in some cases the channel samples are replaced with scrape samples. Channel sampling of large cross-section (5×25 to 10×40 cm) and scrape sampling are recommended for shell phosphorites, while bulk sampling – from mine workings on nodular phosphorites. Typically, a bulk sample weight of 50 to 150 kg is representative, depending on the size of the nodules and the nature of their distribution.

The quality of sampling for each accepted method for the main varieties of ores and each stage of sampling (taking samples, sample processing, sample analysis, etc.) are recommended to be systematically monitored, assessing the accuracy and reliability of the results. It is recommended to check the position of the samples relative to the elements of the geological structure, the reliability of the contouring of ore bodies in terms of thickness, the consistency of the accepted parameters of ore samples and the compliance of the actual mass of the sample with the calculated one, based on the actual core diameter (deviations should not exceed ±10 to 20%, taking into account the variability of ore density). It is recommended to control the accuracy of core sampling by sampling from the second halves of the core.

During geophysical sampling on natural accumulation, the stability of equipment operation and the reproducibility of the method have to be controlled under the same conditions of ordinary and control measurements. In case of revealing deficiencies that affect the accuracy of sampling, it is recommended to resample (or re-log) the ore interval.

Reliability of core sampling is, if possible, verified by sampling of adjacent excavation workings or logging data. At deposits being under operation, ore reserves and grades of useful components calculated from borehole data are recommended to be compared with the same indicators determined from mine workings (within the same horizons or counting blocks), and also compared with the operational results. The reliability of the results of nuclear-physical methods of downhole logging in boreholes is certified by the results of core sampling at intervals with a core recovery of more than 90%. The reliability of the channel sampling is certified by bulk sampling or scrapes sampling ways.

The volume of controlling samples should be sufficient for statistical processing of the results and reasonable conclusions about the absence or presence of systematic errors, and, if necessary, for introducing correction factors.

At phosphate ore deposits, with proper justification, it is advisable to use nuclear geophysical methods as a routine sampling. It is recommended that nuclear geophysical sampling should include differential interpretation with determination of content in intervals of 5 to 10 cm and subsequent data processing to determine the contrast of ores in order to predict the radiometric concentration in accordance with regulatory and methodological documents.

The application of geophysical sampling methods and the use of their results in reserve estimation are regulated by the relevant regulatory and methodological documents. If such kinds of documents are not approved, other similar methods may be used as a reference.

3.13. Sample processing is carried out in accordance to the schemes developed for certain deposit or ore type, or the scheme used for similar deposits as an alternative. The correctness of the adopted sample processing scheme and the value of the coefficient ***K*** must correspond to those used in the same type of deposits or are confirmed by experimental work.

The main and control samples are processed along with the same scheme. The value of the coefficient ***K*** is usually in the range of 0.1 to 0.2 for apatite deposits and 0.05 to 0.1 for phosphorites.

The main control of the sample processing is performed on samples that formed collecting the waste from the sample reduction process via the analyses as the main sample, and use the same method as the main sample.

When exploring nodular and shell phosphorites using samples taken from individual dug holes or large-diameter boreholes that characterize the deposit evenly over the area, a study is carried out to the grain composition of the industrial (technological) types and varieties of ores identified at the deposit. Usually, sieving is done on classes +10; -10+5; –5+0.5; -0.5 mm. The need to distinguish other classes is established due to the specific features of the ores and the requirements arising from their purpose and method of processing.

Large bulk and technological samples are processed according to independent schemes.

3.14. The quality assessment of the mineral raw materials is carried out taking into account the possible directions of its use in agriculture and industry, in accordance to the requirements of the consumer or current state and industry standards, specifications and approved conditions. The chemical and elemental compositions of ores are studied with completeness, providing an assessment of the industrial value of the main and accompanying components, as well as the effect of harmful impurities on the processing technology and the use of raw materials. The contents of all components are determined in samples by chemical, nuclear, spectral or other methods in accordance with the approved norms and standards applicable to the analysis.

In all ordinary samples of apatite and phosphorite ores, the content of P_2O_5 is determined, and the content of insoluble residue is also determined in phosphorites.

For all samples, the content and forms of presence of harmful impurities are stipulated by the requirements of standards or conditions, which affect the technological processing of ores and the quality of raw materials are determined. The list of these components for phosphorites depends on their type and the planned method of processing and use, and for apatite ores it is determined by the material composition (for example, Al_2O_3 - in apatite-nepheline ores, TiO_2 - in titanomagnetite-apatite ores, Fe_2O_3 in apatite-magnetite ores, etc.). For nodular and shell phosphorites, the determination of the content of useful and harmful components is also carried out in samples of the selected ore granulometric classes.

The composite samples are used to determine the contents of SiO_2, Al_2O_3, Fe_2O_3, FeO, P_2O_5, CaO, MgO, MnO, Na_2O, K_2O, CO_2, S (total and sulfides), U and losses on ignition. In addition, for apatite-nepheline and complex apatite-containing ores, the contents of BaO, SiO_2, ZrO_2, TR_2O_3, Y_2O_3, F are additionally determined, and for phosphorites - F, and when they are used for the production of phosphate pulp - the content of lemon-soluble P_2O_5; for typical and composite samples, a complete spectral analysis is performed. The composite samples should characterize all industrial (technological) types and varieties of ores.

The procedure for combining ordinary samples into composite samples, their placement and total number should ensure regular sampling of ore bodies and varieties of ores for accompanying components and harmful impurities and clarify the patterns of changes in their contents along the strike and dip of ore bodies.

The study of accompanying components contained in apatite and phosphorite ore is carried out in accordance with the "Recommendation for the integrated study and reserve estimation of accompanying useful components". As such kind of recommendation has not yet been developed, therefore similar recommendations can be used, such as the Russian "Methodological recommendations for the comprehensive study of deposits and reserve estimation of accompanying mineral resources and components" developed in 2007.

To establish the balance of distribution of the main and accompanying components in the ores, as well as harmful impurities; the monomineral samples, concentrates and other products obtained during technological research are selected and analyzed. The phosphate raw materials intended for the production of animal feed additives and fertilizers are recommended to be passed a radiation-hygienic assessment.

3.15. There are two types of errors in assays: sporadic and systematic (persistent).

Geological control on sample analyzes has been carried out independently of laboratory control, during the entire period of exploration of the deposit. The results of analyzes for all main and accompanying components and harmful impurities are subject to control. All samples with extremely high content must be subjected to the internal control.

The control on random errors is carried out to encrypted duplicates of analytical samples dispatching to the same laboratory that conducted the main analyses within terms of a quarter. This kind of procedure is labeled as internal control.

The external control that completed to identify and evaluate possible systematic errors is carried out to a laboratory that has a control status. Duplicate analytical samples are sent for external control, stored in the main laboratory and passed internal control. For the systematic control of the work of the main and control laboratories, it is needed reference samples (composed of ores of deposits) and standard samples composition (SSC), which are included in encrypted form in batches of analyzed samples.

The volume of internal and external control on the sample analyzes should ensure the representativeness of the samples for each grade class from all varieties of ores of the deposit and periods of analysis. The standard requirements shall be taken into account in determining the grade class of useful mineral in the sample. With a large number of analyzed samples per year (more than 2000), 5% of their total number is sent for control analyzes, with small batches of samples for each distinguished grade class, at least 30 control analyzes are performed for the control analyzes in reference period.

3.16. The processing of internal and external control data for each grade class is carried out by periods (quarter, half year, year) separately for each method of analysis and the laboratory that performed the main analyzes. And based on the assessment of internal and external control data, the discrepancies and errors should be corrected.

The random standard deviation of a value of sample analyzes, determined by the results of internal control, should not exceed the values given in Table. 3.

Table 3: The allowable relative value of standard deviation for the analyses results on phosphate ore content

Component	Class of ore content, %,	allowable relative deviations *	Component	Class of ore content, %,	allowable relative deviations *
P_2O_5	30–40	1.3	Al_2O_3	>70	1.3
	20–30	2.0		50–70	1.5
	10–20	3.5		30–50	2.5
	5–10	4.0		25–30	3.5
CaO	>60	1.5		15–25	4.5
	40–60	2.0		10–15	5.0
	20–40	2.5		5–10	6.5
	7–20	6.0		1–5	12.0
	1–7	11.0	SiO_2	>50	1.3
	0.5–1	15.0		20–50	2.5
	0.2–0.5	20.0		5–20	5.5
	<0.2	30.0		1,5–5	11.0
MgO	>60	2.0	TiO_2	>15	2.5
	40–60	2.5		4–15	6.0
	20–40	3.0		1–4	8.5
	10–20	4.5		<1	17.0
	1–10	9.0	Lost of ignition	20–30	2.0
	0.5–1	16.0		5–20	4.0
	0.05–0.5	30.0		1–5	10.0
	<0.05	30.0		<1	25.0

* If the specified limits are exceeded, the basic analyzes results of a certain class and the times of their performance are rejected and it is subjected to re-analysis and control. At the same time, the main laboratory identifies the causes of defects and takes measures to eliminate them.

3.17. If systematic discrepancies are confirmed by the external control data between the analyzes results of the main and controlling laboratories, arbitration control should be dispatched about 30 to 40 samples from the each sample group, in which systematic discrepancies are revealed, into repeating analyzes. If an arbitration laboratory analyses reveal systematic / persistent errors, the issue of whether to use a correction coefficient to the results of basic analyses of the samples has to be resolved. At the same time, measures should be taken to identify and eliminate the cause of systemic / persistent errors in the laboratory where the main samples were analyzed.

If a systematic / persistent error is detected by analyzes involving standard sample content, 10 to 15 standard samples will be analyzed in an arbitration laboratory to determine the error and take action to correct it.

Without arbitrage analysis, the introduction of correction coefficient is not allowed.

3.18. The composition, structure, texture, and physical-mechanical properties of the ore mineralogy shall be studied using mineralogical-petrographic, physical, chemical, and other analytical methods in accordance with established methods and techniques.

Volume weight/density and moisture content of ore are representing important parameters for reserve estimation; therefore, they should be determined for each natural variety of ore, and layer / plies with substandard thickness or gangue rocks within the ore body.

The volume weight/density of massive ore is determined mainly from representative waxed samples via hydrostatic weighing method.

It is more reliable to determine the volume weight of loose, highly fractured and cavernous leached ore by comparing the weight of the excavated ore with the well-measured excavation volume.

Determination of the volume weight can also be completed by the method of absorption of scattered gamma radiation in the presence of the necessary amount of verification work. Simultaneously with the determination of the volume weight, the moisture content of the ore is determined on the same material. Samples and specimens that used for determination of volume weight and moisture are recommended to be characterized mineralogically and analyzed for the main components.

3.19. As a result of studying the chemical, mineral composition, textural and structural features and physical properties of ores, their natural varieties are determined and industrial (technological) types and varieties are preliminarily outlined. Finally, classification of industrial (technological) types and grades is based on results of pilot test defining enricheble capability of the ore samples

IV. Studies of ore technological properties

4.1. The quality of phosphate raw materials is determined by the amount of phosphorus contained in it, converted to P_2O_5, and the presence of harmful impurities, as well as its enrichment. In its natural form, the phosphate substance is practically not absorbed by plants and for this purpose is processed with the use of acids. It is processed into phosphorite powder using 2% citric acid, and several types of low-grade phosphorite ores are excluded.

Before processing into complex and concentrated fertilizers, all types of phosphate ores are enriched. The quality requirements for phosphate raw materials supplied in the form of apatite-nepheline ore, commodity phosphorites, phosphorite powder, apatite and phosphorite concentrates are regulated by the requirements of the consumer or (if available) relevant standards and specifications.

More than 60% of the apatite concentrate used to produce fertilizers is processed into a semi–product - extraction acid. Various phosphorus-containing fertilizers are produced on basis of the extraction acid. There are produced both single-component phosphorus fertilizers (double superphosphate, phosphorous powder) and complex fertilizers (ammophos, diammonium phosphate, diamophoska) in foreign countries.

4.2. Technological properties of ores, as a rule, are studied in laboratory and semi-industrial conditions on small technological, laboratory, enlarged laboratory and semi-industrial samples. If there is experience in processing ores in industrial conditions, it is allowed to use an analogy confirmed by the results of laboratory studies. Currently, the pilot tests are conducted on mainly laboratory and semi-industrial technology samples.

The samples for the pilot test have been taken from deposit in accordance with the recommendations for technological samples during exploration works. If this type of recommendation has not been developed, it can be applied a similar methodological recommendation, “Technologicheskoye oprobovanie v processe geologo-razvedochnykh Rabot, 1998”, Russian Federation.

4.3. Small technological samples are recommended to characterize all natural types and varieties of ores and to reveal the spatial variability of their technological properties. According to the test results, large-scale laboratory and semi-industrial technological samples are selected to refine the enrichment scheme and refine ore processing parameters. These samples should be representative, i.e. meet the requirements for chemical and mineral composition, textural and structural features, physical and other properties of the average composition of ores or deposit as a whole, taking into account possible dilution during operation.

4.4. Technological studies of ores are preceded by the study of the possibility of radiometric large-batch sorting of the extracted ore mass in transport tanks and fragmental separation. Preliminary prognostic technological parameters will have been obtained by calculation during processing the data of sampling or downhole logging within the technological contours of operational blocks. There have to be determined physical evidences that can be used to separate the ore mass, the contrast of the ore in relation to different volumes of portions of the ore mass, the granulometric composition of the extracted ore, and evaluated the radiometric sorting and separation parameters.

Further ore processing methods will be tested, taking into account economic efficiency.

4.5. In the study of the enrichment on phosphate ores, the following items are determined: chemical composition, insoluble residue in 3% hydrochloric acid (quartz, glauconite, aluminosilicates, sulfides, etc.), the balance of distribution of phosphoric anhydride by the main mineral components, structural and textural features of the ore, evaluation of the crushing, grinding and washing capacities using sieve, gravity and dispersion analyses.

It is established necessary grinding size, which ensures the optimal degree for freeing of mineral particles in the ore. It has to determine the density and magnetic susceptibility, to choose the technological scheme of enrichment, to define the bulk mass, moisture content of initial ore and enrichment products.

Apatite ores. The flotation is the main method for enrichment of apatite ore, using fatty acid collectors as collecting reagents, as well as organic products such as N-acylated amino acids (AAC-tallactam, IMR-25, etc.); and additives of liquid glass and OP-4 are added to increase the efficiency of the flotation process. The flotation is performed in alkaline environment (pH = 9.5–10.0) that created by soda or caustic soda.

Apatite concentrate is obtained with a content 38 to 40% P_2O_5 at extraction recovery 80 o 93% from initial ore containing 2.5 to 18% P_2O_5. Due to the most part of apatite ore is complex, therefore, the ore enrichment schemes include processes of magnetic separation, gravity and other process stages that ensure the accompanying yields of pyrochlore, ilmenite, magnetite, nepheline and other concentrates. The technological operation mode and its order are determined by the material composition of ores, the quantitative ratio of basic and rock-forming minerals, their physical-chemical and other properties.

Apatite-nepheline ores from Khibiny group deposits are easily enriched producing high-quality concentrates with 39.4% P_2O_5 content at extraction recovery 85 to 90%.

Apatite ores of the Oshurkovsky type and apatite-ilmenite-titanomagnetite ore are relatively easy to enrich, and for the second one, the magnetite and titanomagnetite are extracted in a weak magnetic field, while apatite and ilmenite are extracted by flotation.

Ores of apatite-carbonate type are difficult to enrich due to the proximity of the flotation properties of apatite and carbonates (calcite and dolomite). They require the use of more complex flowcharts and reagent modes. Carbonate-silicate ores, for example, of the Kovdorsky type, are difficult to enrich, a magnetic flotation scheme is used for their enrichment with the extraction of apatite, magnetite and baddeleyite.

Phosphorite ores are distinguished by a number of natural varieties, which affect the technology of their processing.

The enrichment of granular loose ores of Moroccan subtype is produced by hydraulic separation method or by scrubbing the pelitic fraction of carbonate minerals. For the enrichment of granular ores of the Kyzylkum subtype, in addition to gravity process, it is recommended to provide an energy-intensive process labeled calcinations firing the flotation sludge.

The enrichment of Unechsky phosphorite ore of sandy-granular type, beside the separation of the fraction +0.15 mm, also includes the process of acid dissolution of the phosphate shell on grains of other minerals.

Microgranular and aphanite ores of the Khövsgöl subtype are difficult to enrich due to the thin intergrowth of phosphate and carbonate minerals. Their enrichment by gravity without fine grinding ensures the extraction of 50%, and only subsequent grinding, flotation and firing (calcinations) can raise it to 65 to 80%.

The nodular phosphorites are not used to produce conditioned concentrates due to the low content of P_2O_5 and high one-and-a-half oxides. They are processed according to a flowchart involving disintegration, wet screening to obtain a lumpy product containing 20 to 21% P_2O_5, and phosphate flotation from the undersize product. Then joint grinding of both products gives phosphorous powder with a content 18 to 20% P_2O_5.

Shell phosphorites of the Kingiseppsky deposit are enriched by flotation. Phosphates are floated with fatty acid reagents in combination with apolar reagents in an alkaline environment (pH = 9.3 to 9.8) using liquid glass for suppression of quartz. Phosphorite concentrates with a content of more than 28% P_2O_5 are obtained from ores initially containing 8 to 12% P_2O_5 at 80 to 90% extraction recovery.

In recent years, methods of biotechnological (bacterial leaching of carbonates), radiometric and chemical enrichment, electrostatic and electromagnetic separation have been used to enrich phosphate raw materials; suspension hydrocyclones and heavy–medium separators have been used to separate phosphate and carbonate minerals.

In industry, three methods are used for processing concentrates and rich phosphate ores: decomposition by acids, electro-thermal reduction of phosphorus to elementary status and thermal processing with destruction of the apatite structure.

By sulfuric acid decomposition, a simple superphosphate and extraction phosphoric acid are obtained, i.e. phosphoric acid with impurities Ca, Mg, Fe, Al, Na, K, F, SiO_2, etc.

Nitric acid decomposition provides the production of nitro-phosphates with a complete transfer of calcium from apatite into solution, while nitric acid itself is being a component of fertilizer.

Acid decomposition of apatite ensures the dissolution of the phosphate part of complex and concentrated fertilizers in water by 90 to 95%.

By electro-thermal processing, elemental phosphorus has been obtained by carbon reduction in electric furnaces at a temperature of 1450 to 1600°C during the melting of a mixture of phosphate ore, coke and SiO_2; the process is energy-intensive. When obtaining yellow phosphorus via electro-thermal process, it is necessary that the value of the acid modulus [(SiO_2 + Al_2O_3) / (CaO+MgO)] of the charge/mixture loaded in the furnace be close to 0.8. The yellow phosphorus is used to produce red phosphorus, phosphoric acid, phosphoric anhydride, and chloride-, sulfuric-, organic- and other phosphorus compounds.

4.6. Semi-industrial pilot test is conducted in accordance to the program agreed by the subsoil user with the project organization and the team performing geological exploration.

As a result of the pilot test, sufficient data should be obtained to design a rational technology for the enrichment and processing of ores with complex extraction of useful components of industrial importance and to determine the direction of use of production waste. Optimal measures are proposed for the storage, burial or disposal of enrichment tailings, the use of recycled water and the neutralization of industrial wastewater during discharge.

4.7. The technical requirements imposed by industry on phosphate raw materials are determined by the technical possibility and economic feasibility of chemical (acid, electro-thermal, hydrothermal) or mechanical (grinding) processing.

The content of P_2O_5 bears the greatest importance in phosphate raw materials. The contents of one and a half oxides of iron and aluminum, magnesium oxide, carbonates, and silicon oxide also play an important role. In addition to the chemical composition, the granular composition of the raw material is important.

A simple superphosphate is produced by treating the raw material with sulfuric acid, a double superphosphate with phosphoric acid, a complex fertilizer (ammophos, diammonium phosphate and diammophoska) with nitric acid or a mixture of nitric-, sulfuric- and phosphoric acids, and potassium- and ammonium sulfate or potassium chloride. An exception is some low-grade phosphate ores processed into phosphate powder.

Production of superphosphate and complex fertilizers require ores or concentrates containing at least 28% P_2O_5. Harmful impurities of ores and concentrates that complicate the processing works include one and a half oxides of iron and aluminum, magnesium oxides, dioxides of carbon and silicon, and toxic element oxides. The permissible content of harmful impurities depends on the processing method. And its evaluation shall be determined with ratios $100R_2O_3/P_2O_5$ and 100Mg/ P_2O_5. The first ration shall not exceed 8 to 12, the second one - 5 to 8. If CO_2 content occurs more than 6%, preliminary decarbonization is necessary. The content of CaO and the calcium module $100Ca/P_2O_5$ in the nodular phosphate is 47 to 48% and 1.55, in the shell phosphate – 50 to 52% and 1.40, in the Khibiny apatite - 52.0% and 1.25; i.e. the lowest module, which significantly (10 to 20%) reduces the consumption of sulfuric acid.

During nitric acid processing, the minimum content of P_2O_5 has to be 24% and iron module $100Fe_2O_3/P_2O_5$ in phosphate raw materials is allowed to be no more than 15%.

For the production of yellow phosphorus, phosphate raw materials of P_2O_5 content is at least 21% and a grain size of them greater than 10 mm are used, small classes are subjected to preliminary agglomeration or pellets.

The requirements for the granular composition of raw materials are in following: not less than 3 to 5 mm and not more than 50 to 70 mm. Small fractions are subjected to agglomeration.

The quality of phosphate raw materials supplied in the form of apatite-nepheline ore, commercial phosphate, phosphate powder, apatite and phosphate concentrates is regulated in each case by a contract between the supplier and the consumer.

Standards and technical specifications for phosphate raw materials currently in force in Russia are shown in Table 4.

Table 4: List of phosphate raw materials, concentrates, technical specifications of final products and basic standards

GOST 22275–90	Apatite concentrate
GOST 5716–74	Phophorite powder
TU 113-12-93–90	Apatite concentrate from Kovdorsky mining enrichment industry
TU 113-12-96–88	Phosphorite powder produced by industrial processing
TU 113-12-83–85	Phosphorite dry powder
TU 113-12-57–87	Phosphorite fine powder produced from Chilean ore
TU 113-12-141–90, TU 113-12-140–89	Suspension phosphorite agglomerate for electro-thermal treatment

Researchers at the Mongolian Academy of Sciences (MAS) have conducted a number of experiments using mechanical-chemical methods in ore samples from Tsakhir Uul and Alagiin Davaa phosphorite deposits in Zavkhan.Aimag, Mongolia.

Furthermore, in 2021, samples were prepared and processed at the Erdenet Plant, Mongolia, in accordance with relevant methods and techniques conducting processes using tallol, pine oil, and liquid glass that commonly used in the flotation of phosphorite ores, were used as the main flotation reagents.

Mineral analyses and chemical analyses were conducted to ore samples and test products using TESCAN-TIMA mineral analyzer and Bruker XRD D8 Endeavor X-ray diffractometer. There were used Mineral Stats' ESSA flotation equipment and laboratory rod mill in the test, determining the optimal ore grinding mode, flotation duration, ambient temperature and pH, and flotation reagent regime. Depending on the ore properties and the characteristics of the flotation reagent used, for the pulverized ore sample was preliminarily reducing sludge.

The test was carried out in a temperature of 65-70°C and a simple single-stage purification scheme was used producing the required phosphate concentrate. The basic flowchart of the experiment is shown in Appendix 3.

According to the results of equipment XRD DIFFRA info analysis taken on two samples, in terms of basic content, the sample from Tsakhir Uul Deposit has got fluoroapatite content almost twice as ore sample from Alagiin Davaa Deposit (See Table 5).

Table 5: Mineral composition of phosphorite ore samples

№	Minerals	Chemical formula	Tsakhir Uul Deposit	Alagiin Davaa Deposit
1	Quartz	SiO_2	54.7	67.7
2	Fluor apatite	$Ca_{10}(PO_4)_6(F)_2$	43.8	25.8
3	Dolomite	$CaMg[CO_3]_2$	-	2.8
4	Calcite	$CaCO_3$	0.5	0.5
5	Muscovite	$KAl_2(AlSi_3O_{10})(OH)_2$	1	1.6
6	Goethite	$FeO(OH)$	-	1.6
	Total		100	100

According to silicate analysis conducted on the ore samples, the P2O5 content is 10.81% for Alagiin Davaa Deposit and 18.33% for Tsakhir Uul Deposit. For the Alagiin Davaa and Tsakhir Uul deposits, the optimum aggregate size of ores at the highest flotation efficiency was determined to be P80 = 131 µm and P80 = 137 µm, respectively. Beside of the grind size, the optimal test mode, for both the deposits included following parameters: suspension pH ~ 8.2, suspension temperature ~ 65 to 70°C for basic flotation and cleaning flotation; collecting reagents are in following: tall oil in basic flotation - 1000 g / t, in control flotation - 900 g / t and in cleaning flotation - 500 g / t; pine oil is as froth reagent -100g / t; liquid glass as suppressant reagent for basic flotation - 50 g / t; for control flotation - 50 g / t, for cleaning flotation - 400 g / t; flotation time is for main flotation - 4 min, for control flotation - 4 min and for cleaning flotation -2.30 to + 2.30 minutes.

In Tsakhir Uul Deposit, the yield of ore cleaning concentrate was 22.2%, phosphate content was 32.9% and recovery was 38.34%, while total concentrate yield was 54.19%, the grade - 26.64% and recovery - 75.75%. In Alagiin Davaa Deposit, at ore purification-1, yield of concentrate was 28.67%, phosphate content was 25.67% and recovery was 66.16%, while total concentrate yield - 42.23%, the grade - 20.39% and the recovery - 77.39%. Due to the phosphate content in ore of Tsakhir Uul is 7.52% higher than that of Alagiin Davaa, requiring more kinetics to completely float the minerals.

The technology for production of phosphorus fertilizers depends on the nature of the phosphate concentrate. Therefore, there were determined in details following items: particle size, mineral freeing state, and mineral intergrowth of the concentrate obtained by laboratory tests.

A fully automated mineral analysis system based on the TIMA electron microscope of the TESCAN Company, Czech Republic, has determined the amount and attenuation of apatite particles in a concentrate with a phosphate content of 32.96%. In the concentrate, +45 µm class of lumpy agglomerate is characterized by 31.8% of the apatite grains belong to size of 106 to 150 µm, 56.3% of apatite grains ~ 45 to 106 µm, and 11.9% of apatite grains ~ less than 45 μm, while in the lumps of -45 μm class, 61.4% of the apatite grains ~ 20 to 45 μm, 26.3% ~ 10 to 20 μm, and 12.3% of apatite grains ~ less than 10 μm.

Apatite grains are usually forming open growth with quartz, while forming complicated intergrowth growth with grains of siderite, dolomite and clay minerals, i.e., according to electron microscopy, the intergrowths of crystals are from 11.9% quartz, 5.3% calcite and 3.6% other minerals. It is assumed that the phosphate concentrate produced in the laboratory meets all the requirements for raw materials for the production of phosphorus fertilizers.

5. Studies of hydrogeological, engineering-geological (geotechnical), geo-ecological and other natural conditions of deposit

5.1. Studies on hydrogeological condition of the deposit should be conducted in accordance to “Guidelines for hydrogeological survey on thematic studies, hydrogeological mapping at medium-large, scales and of hydro-geological survey during mineral deposit exploration and the requirements to them” approved by the Order No. A / 237 of the Minister of Mining and Heavy Industry of Mongolia dated December 12, 2017.

5.2. Hydrogeological study should determine the main aquifers that can participate in the watering of the deposit identify the most waterlogged areas, zones and resolve the issues of collecting or using mine waters. For each aquifer (water-bearing horizon), its thickness, lithological composition, types of reservoirs, recharge conditions, relationship with other aquifers and surface waters, position of groundwater levels and other parameters should be established; to identify possible water inlet (debt) into the exploiting of mines, which are included in the feasibility study of conditions, and to develop recommendations for their protection from groundwater. Furthermore, it is also necessary to define following items:

- to evaluate the chemical composition and quality of underground water that would possibly inflow into mine, determining their aggressiveness toward equipments made by concrete, metals, polymers, and other materials, the content of useful and harmful impurities in them; for the developing deposits - clarifying the chemical composition of mine water both of collected and discharged;

- to assess the possibility of using drainage water for the water supply or extracting valuable components from it, and possible impact of drainage on groundwater intakes in the surrounding area;

- to make recommendations for carrying out the necessary special prospecting work in the future, and to assess the impact of the discharge of mining waters on the environment, and necessary measurements;

- to assess possible sources for supplies of drinking water and technical water to meet the needs of future mineral extracting and ore processing plants.

- in case of utilization of drainage water, it should be calculated its exploitation reserves in accordance to the relevant regulations and methodological documents.

The result of hydrogeological studies should provide recommendations for the design of the mine on dewatering the mineable ore body, drainage water and its utilization, water supply sources and environmental protection measures.

5.3. The engineering-geological survey that has been carried out during the exploration of the deposit, will determine the main parameters of the open pit, underground excavation and protective pillars, completing required data for authorization of processing the drilling and blasting work passport and fastening work passport, allowing conditions for safety and healthy work in mining operations.

The studies of on engineering-geological (geotechnical) condition of the deposit shall be carried out in accordance with the methodological recommendations for conducting engineering geological condition study, i.e., "General principles for construction engineering research" of Mongolia (BNbD 11-07-19), Order No. 138 of 2019 of the Minister of Construction and Urban Development. In the absence of such kind of recommendations, similar recommendations can be used like as Russian "Methodological guidelines for the study of engineering and geological conditions of ore deposits during exploration. 2000" and "Engineering-geological, hydrogeological and geo-ecological studies in the exploration and operation of ore deposits. M., 2002".

The following issues will be identified by the engineering-geological survey of the deposit. These include:

- physical-mechanical properties of the ores, host rocks and overburden, determining their strength in natural condition and water-saturated states;
- engineering-geological features of the host rock that forming the deposit and its anisotropy, rock composition, texture specification, suffering fractures and tectonic faults, and
- physical-mechanical properties and state of the rocks in the weathering zone;
- possibility of landslides, mudflows, avalanches and other physical and geological phenomena that can complicate the mine development and others.

In areas with the development of perennial frozen rocks, it is necessary to establish their temperature regime, the position of the upper and lower boundaries of the permafrost sequence, the contours and depth of talik (layer of year-round unfrozen ground that lies in permafrost area), the nature of changes in the physical properties of the rocks during thawing, depths of seasonal defrosting and freezing.

In results of the engineering-geological studies, it should provide data related to predictive assessment of rock stability in the roof of underground mines and the sides of open pit and to obtain main preliminary information selecting excavation parameters for further calculation for future mining excavation.

If there are operating active mines or open pits in the region under similar hydrogeological and engineering-geological conditions, their parameters of hydrogeological and geo-technical conditions can be used for the assessment in the current ore deposit on correlation way.

5.4. Deposits of phosphate raw materials are extremely diverse in terms of conditions and depths of occurrence, size and morphology of ore bodies, physical and mechanical properties of ores and their host rocks. Depending on the volume of reserves, depth intervals of ore bodies, hydrogeological conditions and other factors, feasibility studies substantiate a rational system for mining the deposit by open (quarry), underground methods or a combination of them. A promising direction in the operation on phosphate ore deposits is being hydraulic borehole mining (HBM technology).

A promising way of managing the quality of mined ore, if there is a stable correlation between P_2O_5 content and natural radioactivity or with the content of associated components is by rapid analysis at mining stations (OCS-Ore control station) of the extracted mining mass in transport containers or on conveyor belts with large portions sorted for conditioned, substandard ore and refuse (spoil bank) rock.

5.5. Environmental studies should establish environmental background parameters (level of radiation, composition of surface water and groundwater, determination of soil cover, vegetation and wildlife, etc.), to define the expected chemical and physical impacts of the proposed facility on the natural environment (dust of adjacent areas, pollution of surface water, groundwater and soil with drainage water from mine and liquid industrial waste, pollution via air emissions to the atmosphere, etc.), to determine withdrawals for the production of natural resources (forest, technical water, local construction materials, land for main and auxiliary production, mine village, pile of stripped soil and produced waste rock, and substandard ores, etc.), and to assess the nature, intensity, degree and risk of impact, and the duration and dynamics of the sources of pollution and their impact zones.

During exploration, an environmental assessment of phosphate raw materials is given, including the determination of the contents of environmentally controlled elements and the nature of their changes in the ores of productive beds and processed products, including concentrates, fertilizer samples and production waste. It is necessarily established an ecological indicator (EI), on which based compiling ecological - geochemical distribution maps of main toxicants (F, As, Sr, Hg, Cd, U), showing the allocation and rejection of environmentally hazardous zones or parts of the section are carried out according to the EP, taking into account the excess of the MAC (Maximum allowable concentration).

Production of all kind of phosphorus mineral fertilizers is subject to ecological control, regardless of the type of phosphate raw material from which they are derived.

In order carry out biological rehabilitation of stripped soil, it is recommended to determine thickness of cover seam and to conduct agrochemical studies on loose sediments, as well as to find out the degree of toxicity of the stripped rocks and the possibility of formation of vegetation cover on them.

5.6. For areas that characterized by exceptionally complicated and special hydrogeological, engineering-geological, environmental and other natural conditions in exploitation activities, it is required special studies, of which the scope, timing and procedure for conducting studies shall be carried out in accordance with agreement of project organizations and license holders.

5.7. Areas with no mineral deposits for industrial and residential purposes, tailings ponds and spoil bank should be identified for new mining areas. It has to conduct a study on local construction materials and determine the direction and possibility of using stripped overburden.

5.8. For deposits where the natural gas-bearing (i.e. methane, hydrogen sulfide, etc.) sediment is observed, it has to be studied the regularity of changes in the content and composition of gases by area and depth.

5.9. Factors affecting human health (pneumoconiosis, increased radioactivity, geothermal conditions, etc.) should be identified.

5.10. Other mineral resources that are contained in form of separate accumulations within the host rocks and overburden of the deposit should be explored to the extent possible to determine their commercial value and area of possible use in accordance with requirements of established methodical guideline. In the absence of such kind of guidelines, a similar recommendation can be used, i.e., Russian "Recommendations on complex studies of deposits and reserve estimation of accompanying minerals and components, 2007".

6. Reserve estimation and Resource evaluation

6.1. Reserve estimation and resource evaluation of phosphorite deposit are completed in accordance with the Mongolian "Classification and Guidelines of Mineral Resources and Reserve estimation of Deposit, 2015".

6.2. Reserves of certain deposit are calculated on blocks, whose ore reserves should not normally exceed the annual production capacity of a future mine. The ore bodies allocated to the reserve estimation blocks shall be characterized by:

- the same level of exploration and study of the parameters determining the quantity and quality of ores;
- the homogeneity of the geological structure, approximately the same or similar degree of variability in thickness, the internal structure of ore bodies, the material composition, the basic quality and technological properties of the ore;
- stable bedding conditions for the ore bodies, defined by block location with a single structural element (on single limbs, core part of fold axis, tectonic block, limited by disrupting faults); and
- common condition for mining-geological development.

The reserve blocks will be limited to the mining horizon along with the ore body dipping direction or to boreholes, considering on the sequence of future mining operation.

6.3. The reserve estimation of the deposit has to consider following additional conditions, reflecting the specifics of phosphate ore deposits.

The proved (A) class/category reserve for exploration is calculated at Group I deposit subjected to its detailed study area. Boundaries of reserve blocks shall be restricted to only excavation workings and exploration boreholes.

In the deposits under development, A class reserves are calculated from the data of mining exploration and preparing excavation works for mining operations. This includes reserves of prepared or ready-to-extract blocks that meet the exploration requirements of the classification in this category.

The measured (B) class reserve for exploration is calculated at Group I and Group II deposits. This includes reserves that have been allocated in detail areas or within other parts of deposits that meet the requirements for estimating reserves by the objective class of the ore body. The main parameters of the geological structure of the blocks and the assessment of the quality of the minerals, which are classified as objective class reserve, shall be determined by sufficient representative data, contouring industrial (technologic) ore types.

In the deposit under development, the class B reserves are calculated from data resulted by additional exploration, operational exploration and preparing mining operations in accordance with the requirements of the reserve classification.

The indicated (C) class reserve for exploration is calculated on deposit or its part (area) within which the grid density of exploration adopted for this reserve class is maintained, and the reliability of the obtained information is confirmed by the results by exploration at the detail areas, or data obtained during operational exploration or operational procedures from mine site under exploitation.

The contours of a class C reserve are generally determined by exploration boreholes, depending on complexity of geological setting of certain deposit, or/and for large deposits or ore bodies with stable geological settings, by limited extrapolation taking into account changes in morphostructure, thickness of ore bodies and ore quality.

Identified (P_1) class resource is evaluated for the deposit under exploration on a marginal area and deeply located parts in adjacent to the reserve estimated areas in C-class; and for the area under prospecting-evaluating works, the resource is estimated verifying geological-structural features of the deposit, as well as the results of geological, geophysical and geochemical surveys by data of few excavation workings and boreholes. The boundaries of the area being assessed for the determined (P1) resources will be determined by extrapolation based on the results of the study of changes in the thickness and content of the ore body, the regularity in changes of accumulation and location of the phosphate ore deposits, and geophysical and geochemical data.

Based on the geological reserves of the deposit, it will be developed a Feasibility Study for the mining of the deposit. According to the Feasibility Study, substandard ores, mining losses and contaminants are excluded from the geological reserves within the boundaries of the future mine, and the remaining part is classified as **Proved mineable** (A') and **Probable mineable** (B') reserves, which are determined in accordance to requirements that demonstrated in "Methodological Recommendation for applying of the Classification of Deposit Reserves and Mineral Resources of certain solid minerals, Mongolia".

Proved mineable *(A') reserve* is estimated on the basis of the certified (A) and objective (B) class geological reserves identified by the exploration work. And the technical and technological selection, reserve calculation and ore technology characteristics of the mining plant will be studied at the industrial pilot test level, the engineering solutions, environmental protection, labor safety, hygiene and legal, human resource, management, infrastructure and supply, social and household services, economic efficiency calculation, and related factors are determined in detail in the "Feasibility Study for the Development of a Mineral Deposit".

Probable mineable (B') reserves are estimated on the basis of the objective (B) and available (C) class geological reserves identified by the exploration work. And the technical and technological selection, reserve calculation and ore technology characteristics of the mining plant will be studied at the industrial pilot test level, the engineering solutions, environmental protection, labor safety, hygiene and legal, human resource, management, infrastructure and supply, social and household services, economic efficiency calculation, and related factors are determined in detail in the "Feasibility Study for the Development of a Mineral Deposit".

In use of extrapolation line, the width of the extrapolation zone in each case for categories/classes B and C reserves needs to be supported by factual data. Extrapolation should not permitted towards faults, the pinching out and splitting of ore bodies, the degradation of ore quality and deterioration of the mining and geological conditions for their exploitation.

6.4. Reserves are calculated separately by reserve classification, mode of operation (open pits, adit horizons, mines etc.), industrial (technological) types and their mineable productive reserve that determined by preliminary Feasibility Study.

if it is not possible to distinguish the boundaries of the production types and brands of ores, statistical assessment will be made of the quantitative ratio of ore technology types and brands. The ore reserves are estimated without moisture (on dry basis) indicating moisture in ore of dry basis. For water-bearing porous ores, it should be calculated the phosphate ore reserves on dry basis, too.

6.5. At the deposits being under mining operation, the ore reserves that stripped, prepared and ready-to-mine, as well as those located in the shaft pillars of mining and mining preparatory workings, are calculated separately with a division by reserve classification in accordance with the degree of their study.

6.6. Reserves of the ores enclosed in protected areas of large water reservoirs and streams, settlements, buildings and agricultural facilities, nature reservatums and monuments, historical and cultural sites, forest reserves and part of the river basin under special protection should be estimated in accordance to referring reserve classification and turning them to non-productive reserves (off-balance reserves).

6.7. For the deposits being under operation, in order to control the completeness of the development of previously approved reserves and substantiate the reliability of the calculated new reserves; it is necessary to compare the exploration and operation data on reserves, conditions of occurrence, morphology, thickness and internal structure of ore deposits, and the content of useful components. In the absence of such kind of guidelines, the same qualitative recommendations can be followed such as the Russian "Methodological Recommendations for the Comparison of Data on Exploration and Development of Solid Mineral Resources, 2007".

If the reserves that calculated by exploration data, are generally confirmed by the exploitation data or reflecting minor discrepancies, they do not affect the technical and economic performance of the mining enterprise, the results of geological and mining surveyor measuring data can be used to compare the exploration and exploitation data.

For a deposit, where, in the joint conclusion of the subsoil user and mining inspection organization considering the reserves or quality of the ores approved by Minerals Professional Council of Mongolia have not been confirmed at the time of mine development or adjustment factors needed into previously approved parameters or reserves, it is possible to calculate and use the correction factor for unsubstantiated reserves.

In the comparative study of the deposit exploration and mining results, it is necessary to compare the distribution area, size, thickness and content of the ore bodies used in the reserve calculation, their spatial variation characteristics, patterns, and ore volume weight, determining the reasons for discrepancies, and evaluating the quantity of the discrepancies.

6.8. In recent years, the geo-statistical modeling method using special soft ware has been widely used in the calculation defining regularity of spatial distribution and data variety evaluation of any key parameters such as useful mineral content, crossing thickness, metro-percent of the ore bodies in deposits.

The efficiency of the application of the geostatistical method is largely depending on quantity and quality of the initial exploration data, the methodology for the analysis of the primary data and the modeling corresponding to the individual geology of the structure of the explored field (distribution laws of calculating parameters, nature of trend and anisotropy, influence of deposit structural boundaries on structural and qualitative evaluation of experimental variograms and determination of parameters of search ellipsoids, etc.). The number and density of exploration crossings (grid) or initial sampling number should be sufficient to justify optimal interpolation formulae (krieging procedure, inverse distance weighting, nearest-neighbor interpolation) to determination of reliable data (for two-dimensional modeling- at least a few dozen data of prospecting crossings, for three-dimensional - at least the couple hundred sampling data) for subdivision of reserve contour space into sub-blocks/ micro blocks with reliable data (eg., grade of useful mineral resources etc.). And it is recommended to study the properties of spatial variables correlating to basic parameters of the deposit and ore bodies in the areas of detail.

The variograms are computed on the basis of sampling data that obtained from boreholes fully penetrating ore-sections or composite samples whose length corresponds to benches that cut into the side of an open-pit mine and the sample intervals.

When constructing a block geo-statistical model of the deposit, the maximum possible size of the elementary/sub block is chosen on the basis of the planned mining technology, the minimum size being determined by the density of the exploration grid established on the deposit (It is not recommended to take the size of the sides of an elementary block less than 1/4 of average grid density).

The results of geostatistical reserve estimation can be reported in the form of a table containing the main data for each elementary segment of the same size and direction, or in one of the combined forms of the estimated data, classified into large parts of the deposit.

All digital data sets (sampling data, coordinates of samples or ore crossings, rock information, analytical expressions of structural variograms, etc.) should be provided in formats accessible for users and expertise using the most common software packages (for example, as DBF files with a separate way of encoding missing values or as ASCII files of standard GEOEAS format). Models of symmetrical (or theoretical) transformations, trends and variograms, other parameters are presented in analytical and descriptive forms.

The geostatistical way of calculating reserves is considered to be the best way to establish estimates of the average content of the utility component in blocks, ore bodies and the deposit as a whole, allowing reducing the delineation errors of ore bodies with a very complex morphology. However, geostatistical methods of reserve estimation should be controlled in their application and subject to the geological features of the deposit. The results of geo-statistical modelling and estimation should be verified and concluded by comparison with the results of traditional methods of reserve estimation at representative sites/areas, which have been studied in details.

6.9. During the computer calculation of reserves, it shall be possible to view, verify and correct the raw data base (coordinates of exploration workings and boreholes, data of inclinometer, contact marks, results of sampling, etc.), the results of intermediate calculations and compilations (Catalogue of ore crossings that identified according to ore standards/conditions; geological sections or maps with contours of industrial standard mineralization; projection of occurrences to horizontal or vertical planes; catalogue of calculation parameters by blocks, benches and pit sectiions) and summary results of reserve estimations. Output documents and computer graphics shall meet the existing requirements for these documents in terms of composition, structure, form, etc.

6.10. The Report of Exploration works including Reserve Estimations is compiled in accordance with the Rules on Prospecting, Exploration Works and Exploitation Procedures on Mineral Resources in Mongolia, and submitted to discussion by the Minerals Professional Council of Mongolia following the Methodical Recommendation for applying of the

Classification of Deposit Reserves and Mineral Resources of certain solid minerals, and a copy of the report should be handed over to Authorized Central Archive of Geology and Mining in accordance to required procedures of relevant documents must be submitted in full as required.

7. Study degree of deposit

In terms of the degree of studies of the phosphate deposit (area of larger deposit) may be classified in following way: assessed mineral deposit (area) and explored deposit (area).

The study degree for the assessed deposits determines the advisability of continuation of exploration work at the deposit/site, for the explored - the preparation of the deposit for industrial development.

7.1. In the case of an assessed phosphate deposit, it is necessary to determine the overall size of the deposit and the quality of the mineral resources, and the most promising sites of deposit have to be identified to support the next stage's exploration sequence and subsequent operation.

The parameters of standard/condition for reserve estimations and resource assessments will be determined based on feasibility studies that calculated from the results of prospecting-evaluating work on the whole deposit or its well-represented area, as well as by comparing condition parameters with deposit data of similar geological formations and mining and economic conditions.

In the area that subjected to detailed study within the assessed deposit, the mass of mineral is estimated at an available (C) classification and the rest of them is assessed as determined resource (P_1).

Considerations of the methods and systems of exploitation of the deposit and the possible scale of production are justified on the basis of analogue mine projects; and enrichment technology schemes taking into account the complex use of raw materials including accompanying minerals, the possible yield and quality of the products are determined on the basis of laboratory-technological studies on samples; and capital costs for the mine development (mine construction), the cost of the products and other economic indicators are determined on the basis of aggregated calculations correlated to analogue mine-projects.

Issues of household-drinking and industrial water supply for future mining enterprises are evaluated on the basis of hydrogeological conditions, water point information, and hydrogeological surveys that conducted to the region for agricultural and other purposes.

The possible impacts of the exploration and future mining operation to the environment should be considered and evaluated.

In order to study in detail the morphology of ore body, material composition of ores and the development of technological schemes for the enrichment and processing of ores, pilot-industrial development (PID) can be carried out to the assessed deposit (sites/areas). The PID is carried out within the framework of the exploration phase project that prepared by mineral deposit explorers and mining operators and reviewed and approved by the relevant state mining authority of Mongolia. The PID project is conducted within the framework for less than 3 years on the most characteristic, representative sites of the majority of the deposit, including typical ores of the deposit.

PID is appropriated for the introduction of new mining method/techniques on ore deposit or new non-traditional types of ores, as well as for large and giant deposits, where developing technological design is going to be tested and improved in small enrichment factories before starting to build large plants.

7.2. On explored deposits, the quality and quantity of reserves, their technological properties, hydrogeological, mining and ecological conditions of exploitation should be studied by boreholes and excavation workings with completeness and sufficient level to develop a feasibility study, which will be involved constructing or reconstructing mining operation and ore-processing plants.

In terms of knowledge degree, explored deposits shall meet the following requirements:

- the possibility of qualification of reserves according to categories corresponding to the group of complexity of the geological structure of the deposit;
- the physical composition and technological types of industrial procedures and mineral grades have been studied in detail to provide basic data sufficient for the design with the complex extraction of all useful components, industrial waste management and identification of the utility direction of the waste formed or the optimal option for its storage or disposal;
- study the use of industrial waste and its storage and protection;
- study other minerals that can be used in addition to the main minerals (rock from stripped overburden, groundwater, etc.), investigating the minerals are contained in them, and to determine the quantities that can be used;
- hydrogeological, engineering-geological (geotechnical), geocryological, mining-geological, ecological and other natural conditions have been studied in detail, providing input data, the necessary conditions for the development of the deposit, taking into account the requirements of the environmental protection legislation and the safety of mining operations;
- The data on the geological structure, conditions, morphology and location of deposits, the quality and quantity of reserves is confirmed in the detail areas representative of the entire deposit, the size and position of which are determined by the subsoil user on a case-by-case basis, depending on their geological characteristics;
- Consideration was given to the possible impact of the development of the deposit on the environment and recommendations were made to prevent or reduce the projected level of negative environmental effects; the calculation of the parameters of the condition is based on technical and economic calculations that make it possible to determine the size and industrial value of the deposit with the necessary degree of confidence.

- The ratios of reserves between the various classes are determined by the subsoil user and experts of Mineral Professional Council taking into account acceptable business risk.

Based on the geological structure of the deposit, mining methods, system selection, and experience used in similar projects, the project implementers in consultation with experts of MRPC will make decision on full or partial involvement of available (C) class reserves that estimated in ore deposits belonging to Complexity Group I and II; and the related decision can be made on basis of the recommendations of Mineral Professional Council.

A deposit is considered to be ready for mining operation following it has been explored and the mineral reserves have been discussed and registered by the Mineral Professional Council by complying with the above requirements.

8. Re-estimation and registration of deposit reserves

Recalculation and reallocation of reserves in accordance with the established procedure shall be initiated by the license holders, State authorities and Occupational inspection authorities in case of a significant change in the quality of the ore and quantity of the geological reserve, economic assessment resulting from additional exploration and mining activities.

At the initiative of the license holder, the reserves are recalculated and reapproved at the deposit under operation due to events that significantly degrade the enterprise’s economy:

- substantial lack of confirmation of proven and previously approved reserves and/or quality of the ore decreasing more than 20%;
- objective, substantial (more than 20%) and stable fall in the price of production while maintaining the production cost level;
- changing the industry requirements for the quality of mineral raw material;
- when the total quantity of balance reserves written off and intended to be written off as unsubstantiated (in the process of completing exploration, exploitation exploration and exploitation of the deposit) and also those reserves not subject to processing for technical-economic feasibility reasons, exceeding the existing mining decommissioning regulations (i.e. more than 20%).

At the initiative of the control and oversight organizations, reserves are recalculated and re-declared in the event of instances that infringe on the rights of the subsoil mineral resource owner (State) to unreasonably reduce the taxable base:

- an increase of more than 50% balance reserves over those previously approved;
- a substantial and steady increase in the world prices of the enterprise’s products (more than 50% on the prices included in the justification);
- the development and introduction of new technologies that significantly improve the economy of production;

- the identification of valuable components or harmful impurities in ores and host rocks that have not been previously taken into account in the assessment of the deposit and the design of the enterprise.

Economic problems of the enterprise caused by temporary causes (geological, technological, hydrogeological and mining-related complications, temporary fall of world prices of products) will be solved through the use of reference operational standard mechanisms, and the reserves are not need to be recalculated or re-registered.

9. Reference materials

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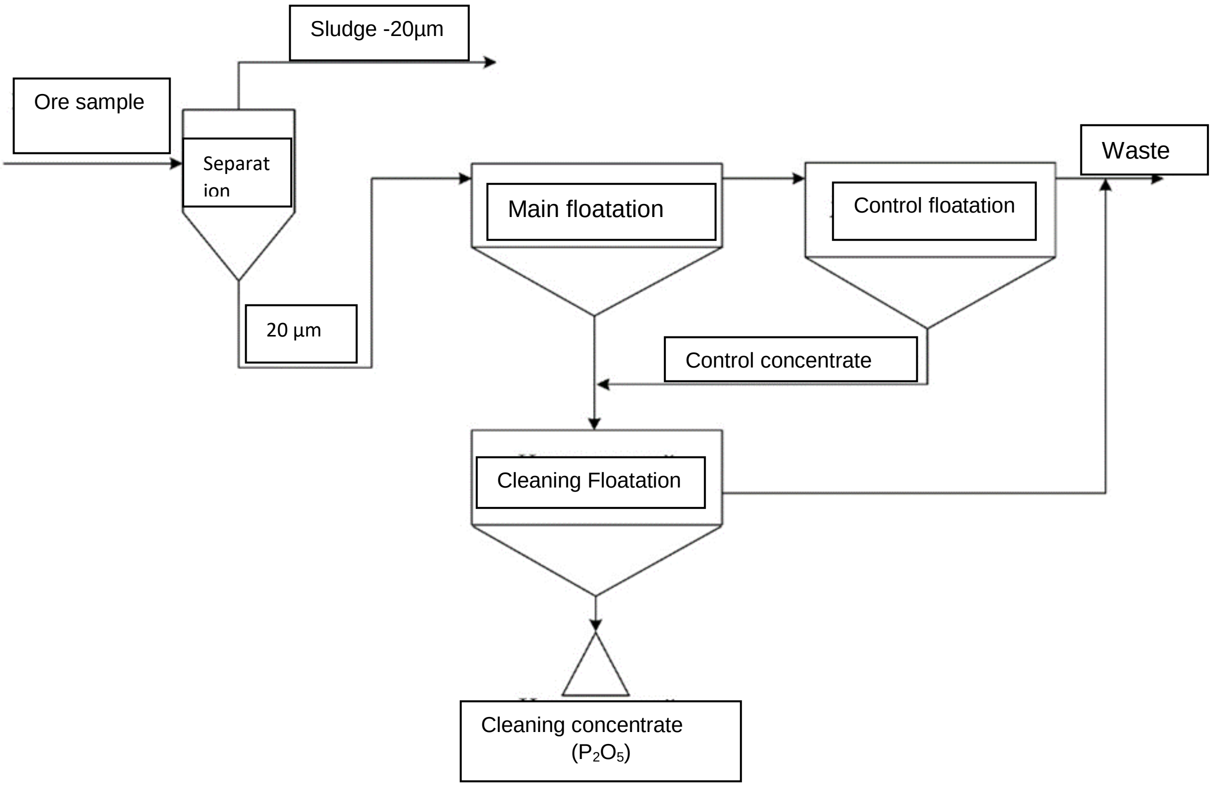
19. Aphanite genetic type of industrial phosphorites: Geological features, types of ores, promising technologies for enrichment and usage of disposal (on the example of the Okino-Hubsgul Basin). 2016. G.A.Fedorovich. Dissertation for the degree of Doctor of Geological and Mineralogical Sciences. Moscow.

20. Late Proteorzoic-Early Paleozoic structure and phosphorite in Mongolia. 2012. J.Byamba, Ulaanbaatar, Soyombo printing. Page 274, picture 91.

Appendix



Appendix Figure 3: Test flowchart with single stage cleaning flotation