U-Pb ages and Hf isotope data from detrital zircons in the sedimentary rocks from the Undurkhaan island arc terrane, Eastern Mongolia: age of deposition, provenance and tectonic setting

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The territory of Mongolia lies in the central part of the Central Asian Orogenic Belt (CAOB), one of the largest provinces for Phanerozoic continental growth on Earth. Traditionally, the territory of Mongolia is subdivided into northern and southern domains which separated by the so-called Mid Mongolian Tectonic Line (Tomurtogoo, 2012).

Undurkhaan island arc terrane, belonging to the South Mongolian Domain is located in the Eastern Mongolia and bordered by the Ereendavaa active continental margin terrane in the northwest, whereas, its southeastern boundary is obscured by the Herlen fault separating Idermeg passive continental margin terrane (Tomurtogoo, 2002). The terrane is composed of mainly Neoproterozoic-Lower Cambrian island arc rocks of Tahilga formation and contains complete section of ophiolite (Agafonov and Stupakov., 1980; Sherbakov, 1996; Tomurtogoo, 2014). The Herlen ophiolite and island arc volcanic rocks have been interpreted as fragments of the Palaeoasian ocean and island arc systems (Tomurtogoo, 1989; Sherbakov, 1996; Tomurtogoo, 2014).The island arc rocks are represented by basalt, andesite, tuff, minor conglomerate, sandstone, siltstone and limestone and crosscut by Cambrian gabbro and Silurian granite. The Herlen ophiolite is unconformably overlain by the thin basal conglomerate, followed by undeformed sandstone.

Depositional ages of sedimentary rocks of Tahilga formation and sedimentary cover of Herlen ophiolite are not very well constrained, and they have been assigned variably to the Lower Cambrian (Agafonov and Stupakov, 1980), Middle Cambrian (Byamba, 2011) or Late Ordovician (Tomurtogoo, 2014) based only on the stratigraphic position and rock associations.

This paper reports new results from U-Pb geochronological, Hf isotopic and REE geochemical studies of detrital zircons from 2 representative samples of metasedimentary rocks in the Undurkhaan island arc terrane with the aim of constraining the depositional ages, provenances, and the implication for tectonic setting of terrane.

Totally, ninety five detrital zircons from two metasandstone samples (HN68; HN100) were analyzed successfully for U-Pb and Hf isotopic compositions.

The CL images show that detrital zircons from the two samples form 2 distinct groups: one large group (about 70-75%) consists of euhedral to slightly subhedral, stubby to mid-long prismatic crystals (60-210 μm) with concentric oscillatory zoning, typically igneous origin. The length to width ratios for zircons from the first group vary between 1.5 and 4.6. Zircons from the second group (about 25-30%) are mostly rounded and subrounded grains with complicated morphology. Some of them are oscillatory zoned and few display a metamorphic overgrowth rims. Th/U ratios of the zircons from the first and second group have no significant differences and vary between 0.2 and 1.3.

Most detrital zircons display LREE-depleted and HREE-enriched patterns with pronounced positive Ce (Ce/C*=1.0-310) and negative Eu-anomalies (Eu/Eu*=0.04-0.84), which are typical for magmatic zircons (Hoskin and Ireland, 2000; Belousova et al., 2002). High Th/U ratios together with REE data suggest that the detrital zircons were mainly derived from igneous rocks.

Analyses on the euhedral to subhedral zircon crystals with oscillatory zoning mostly give Late Neoproterozoic to Cambrian $^{206}Pb/^{238}U$ ages between 622±17 Ma and 510±6 Ma, with prominent peaks at 545 Ma and 553 Ma for sample HN68 and HN100, respectively. The youngest concordant ages are 480±8 Ma and 531±7 Ma, respectively. Dating results for zircons with complicated structures show Neoarchean to Mesoproterozoic $^{207}Pb/^{206}Pb$ ages with peaks at 2.7 Ga (n=4), 1.9-1.7 Ga (n=11) and 1.2 Ga (n=16).

In terms of Hf isotope compositions, all the Late Neoproterozoic to Ordovician zircons have negative $\varepsilon_{Hf}(t)$ values (-25.19 to -1.13) and mostly PaleoproterozoicT_{DM}^{c} model ages ranging between 2.3 Ga and 2.1 Ga. This suggests a crustal component may have contributed to the magma from which these zircons crystalized. The $\varepsilon_{Hf}(t)$ values of Neoarchean to Mesoproterozoic zircons vary widely from -21.27 to +10.60, which indicates a complex provenance for the zircons. The predominant Mesoproterozoic zircons have positive $\varepsilon_{Hf}(t)$ values (+0.87 to +7.38) and PaleoproterozoicT_{DM}^{c} model ages (1.9to 1.6 Ga) with a weighted average of 1.7 Ga. Paleoproterozoic zircons have mostly negative $\varepsilon_{Hf}(t)$ values ranging from -16.48 to -1.96

and MesoarcheanT_{DM}^{c} model ages between 2.7 Ga and 3.2 Ga. All Neoarchean zircons have negative $\varepsilon_{Hf}(t)$ values varying between -6.09 and -0.17 and mostly PaleoarcheanT_{DM}^{c} model ages (3.0 to 3.6 Ga).

New geochronological data indicate that sedimentary rocks of Tahilga formation from the Undurkhaan island arc terrane cannot be older than 531±7 Ma, the youngest concordant zircon age of the metasandstone sample HN100. This sedimentary rock probably deposited in Lower Cambrian. Detrital zircon ages from sedimentary strata overlying the Herlen ophiolite indicate that its deposition age is later than Lower Ordovician (480±8 Ma, the youngest concordant age from sample HN68).

The detrital zircons of the two sandstone samples from the Undurkhaan terrane all have a predominant population between ~620 to ~510 Ma, clearly indicating that their provenance was dominated by Late Neoproterozoic to Early Cambrian rocks. Zircon Hf isotopic compositions indicate that a significant amount of recycled ancient continental crustal material was involved in their sources, an idea also supported by their model ages of 2.3 and 2.1Ga. Besides, all of these zircons have euhedral to subhedral shapes, which may imply a short transporting distance from their provenance. Based on these lines of evidence, we suggest that materials from Late Neoproterozoic-Early Cambrian island arc terranes of Mongolia were the main provenance for the sedimentary rocks. In addition, the lack of zircon ages between ca. 1.0 and 0.7 Ga, i.e. the absence of early Neoproterozoic signature was clearly recorded in mica-quartz schist of the Ereendavaa terrane (Narantsetseg et al., 2015), suggesting that the Undurkhaan island arc terrane was developed during the Cambrian to Early Ordovician and isolated from present neighboring continental margin terranes.

The older zircons with Neoarchean to Mesoproterozic ages are usually rounded perhaps indicate a longer transport distance from their source. However, their age pattern is not comparable with the well-known zircon records from different cratons bordering the CAOB and North Eastern Gondwana except Tarim craton (Rogas-Agramonte et al., 2011). But, the major peak at 790 Ma for Tarim Craton is absent in Eastern Mongolian detrital zircon record. Nevertheless, the existence of 2.8-1.1 Ga zircons in the Lower Paleozoic strata of Undurkhaan island arc terrane, Eastern Mongolia allows us to make the following suggestions. The age peak between 1.1 and 1.4 Ga, culminating at 1.2 Ga may reflect a Grenville-aged magmatism in the source region. The predominant positive $\varepsilon_{Hf}(t)$ values of these zircons implying that juvenile crustal growth was happening at that time, corresponding to crustal model age of 1.7 Ga. Also, the Hf isotope data demonstrate the existence of Paleoarchean to Mesoarchean crust which was reworked during the Neoarchean and Paleoproterozoic at ~2.7 Ga, ~1.9-1.7 Ga, respectively.

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Metamorphic evolution of pelitic schists and eclogites in the Alag Khadny metamorphic complex, Lake Zone, SW Mongolia

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The Alag Khadny metamorphic complex in the Lake Zone, SW Mongolia, which is located in the central part of the Central Asian Orogenic Belt, and it consists mainly of orthogneisses and minor micaschists interleaving marbles including lenses of garnet-chloritoid schists of the Maykhan Tsakhir Formation. Eclogites occur as lenses and boudins in the matrix of orthogneisses and minor micaschists. The peak metamorphic conditions for the eclogites have been estimated as T=590-610 °C and P=20-22.5 kbar (Štípská et al, 2010). The eclogites were subsequently decompressed into the conditions of T=600-630 °C and P< 16 kbar (Štípská et al, 2010). In contrast the pressure conditions of the garnet-chloritoid schists (P=10-11 kbar) are distinctly lower than those of the eclogites, whereas temperature conditions (T=560-590 °C) are similar (Javkhlan et al., 2013).

We discovered thin garnet-phengite schist layers intercalated within the eclogites from the Alag Khadny metamorphic complex. Garnet-phengite schists consist mainly of garnet, phengite and quartz, with minor chlorite, turmaline, rutile, and paragonite. Preferred orientation of phengite, paragonite and quartz defines a schistosity, however there are randomly oriented grains of phengite, plagioclase (An=12-13) and chlorites.

Garnets occur as euhedral to subhedral porphyroblasts, and their maximum size is up to 4 mm across. Garnets in the garnet-phengite schists intercalating with eclogites bodies display a compositional zoning and divided as core and rim. The core of garnet is partially replaced by overgrown rim. This texture suggests the core of garnet is resorbed garnet. Sometimes the fracture of garnet is filled by albite, K-feldspar and chlorite. Garnets contain inclusions of phengite (Si=6.5-6.9), paragonite, and chlorite (X_{Mg} 0.71-0.75 in the core; X_{Mg} 0.49-0.55 in the rim of garnet).

Phengite has three modes of occurrence: inclusions of phengite (Ph1), discrete grains of phengite along schistosity (Ph2) and randomly oriented phengite (Ph3) in the matrix. Ph1 inclusions occur as anhedral, and their maximum size up to 0.03 mm across. Ph2 in matrix occur as subhedral, and their maximum size up to 0.2 mm across. Ph3 in matrix occur as subhedral, and their maximum size up to 0.4 mm across. Chlorite has two modes of occurrence, i.e. inclusions of chlorite (Chl1) in the garnet (anhedral, maximum size up to 0.01 mm), discrete grains of chlorite (Chl2) which are anhedral, up to 0.1 mm across, mostly they are intercalated with Ph2 and occur in the pressure shadows of garnet. Plagioclase in matrix are subhedral, up 1 mm across intercalating with Ph2. Paragonite occur as subhedral, up to 0.02 mm across, intercalating with Ph1. Tourmaline occur as euhedral to subhedral, yellow brown in one nicol, up to 0.3 mm across. Rutile occur as anhedral, up to 0.1 mm in across.

Garnets display a prograde compositional zoning, in which X_{Sps} decreases continuously from core and slightly fluctuated in the rims (0.06-0.01), whereas X_{Prp} increases from core (0.03-0.25), then decreases (0.13-0.16) and distinctly increases to rims (0.13-0.22). X_{Alm} increases slightly from the core (0.66-0.79), then decreases to rim (0.72-0.55) with fluctuations. X_{Grs} decreases slightly from core (0.26-0.12), then increases sharply to outer rim (0.06-0.25). Si contents of phengites (Ph2) in the main schistosity vary from 6.9 to 7.2 pfu, whereas Si contents of the randomly oriented grains of phengite (Ph3) vary from 6.5 to 6.4; distinctly lower Si content than Ph2.

Based on the compositional zoning of the garnet, the metamorphism of the garnet-phengite schist is devided into two events, i.e. high-P metamorphic event and medium-P metamorphic event. The high-P metamorphic event is defined by core of the garnet (X_{Prp}0.07-0.25) and its inclusions of chlorite (X_{Mg} 0.71-0.75) and the matrix phengite (Ph1; Si=6.9-7.2) and rutile. The temperatures of high-P metamorphic event are estimated using THERMOCALC program with average temperature (*AvT*) as T=585-640°C. The minimum pressure conditions are estimated by maximum Si content of phengite (Si=7.2) (Massone and Schreyer, 1987) as P>15 kbar. The medium-P metamorphic event is characterized by the rim of the garnet (X_{Prp} 0.13-0.22), discrete grains of chlorite (X_{Mg} 0.53-0.57), randomly oriented phengite (Si=6.5-6.4) and plagioclase (An_{13-14}) in the matrix of pelitic schists. The P-T conditions of the medium-P metamorphic event is estimated using THERMOCALC with average pressure-temperature (*AvPT*) mode; are given as T=600-610°C and 9-10 kbar. The geothermal gradient of the metamorphism of the garnet-phengite schists has been changed from high-P to the medium-P conditions, and therefore consistent with the eclogite and garnet-chloritoid schist metamorphism (Štípská et al, 2010; Javkhlan et al., 2013). This study suggests that both eclogites and pelitic schists were experienced the similar metamorphic history. And, they were once exhumed from the high-P conditions, juxtaposed with the garnet-chloritoid schists, and the amalgamated sequence of metamorphic rocks was then exhumed together to shallower levels.

Key words: garnet-phengite schist, eclogite, Alag Khadny metamorphic complex, Lake Zone

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Petrography of metamorphic rocks in the Bodonch block

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South Altai metamorphic belt occurs in the transition zone of Irtysh, along the south of East Kazakhstan and Chinese Altai, Mongolian Altai, and Gobi-Altai in Caledonian south edge of the Northern Asia.

Metamorphic complex of Bodonch block incorporated into the metamorphic belts of South Altai. This district is separated by the Caledonian, Hercynian junction zone and from Baruunkhuurai zone by Bulgan fault. There has widespread the common metamorphic rocks such as *greenschist* and *amphibolites*. The samples was collected about 40 samples along two sections in the Bodonch block. It summarized the different types of rocks. Petrographic description is following.

Quartz-mica schist and layered marble that a relatively low pressure and temperature conditions. Schist is transition type from greenschist to amphibolite facies. Temperature and pressure increases, rocks undergo metamorphism at quartz-amphibolite schist it is also identified the medium to high-temperature of amphibolite facies. It is depends on the type of amphibolite and mica gneiss.

However, the granulite facies are not been determined in the district. Lower age of Tseel block age 511 ± 4 Ma and of Bodonch block sedimentary is identified by detrital zircon age 458 ± 4.5 Ma and upper age metamorphic zircon 385±5Ma in the Tsogt block. Ergiin-Adag synmetamorphic granitoids at Bodonch block have identified metamorphic zircon age of 371 ± 2 Ma.

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Geochemistry and Mineralization of Rare earth element bearing Mushgai Khudag deposit, South Mongolia

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Introduction

The purpose of our research is to reveal REE mineralization and geochemical characteristics of apatite ore body in Mushgai Khudag REE bearing deposit in southern Mongolia. Apatite ore body occur in northern west of Mushgai Khudag deposit area. It is lenticular and big ore body. It contains high amount of REE which is ΣREE 3.5 wt% on average, determined by ICP-MS analyses. The $(La/Yb)_N$ values of REE bearing apatite rock is 490.

Regional Geology

The vast territory of Mongolia situated in the Central Asian Orogenic Belt, which is the largest province of Phanerozoic continental growth on Earth. The Precambrian Siberian Craton is the north, the Tarim and Sino Korean Cratons are located in south of the Central Asian Orogenic Belt. The geology of Mongolia is subdivided into 44 terranes (Fig.1). Mushgai Khudag deposit is located in the Mandalovoo terrane which consists of a deformed stratigraphic succession of Ordovician to Carboniferous volcanic and Sedimentary rocks (Badarch, 1997). It comprises Ordovician and Silurian sanstone, argillite, fossiliferouos limestone, Lower-Middle Devonian conglomerate, sandstone, shallow-marine fossil-rich limestone containing brachiopods, felsic tuff, Upper Devonian pillow basalt, andesite, tuff, volcaniclastic andstone, chert, Lower Carboniferous marine sedimentary roks and Devonian diorite and granodiorite plutons (Lamb el al., 2001).

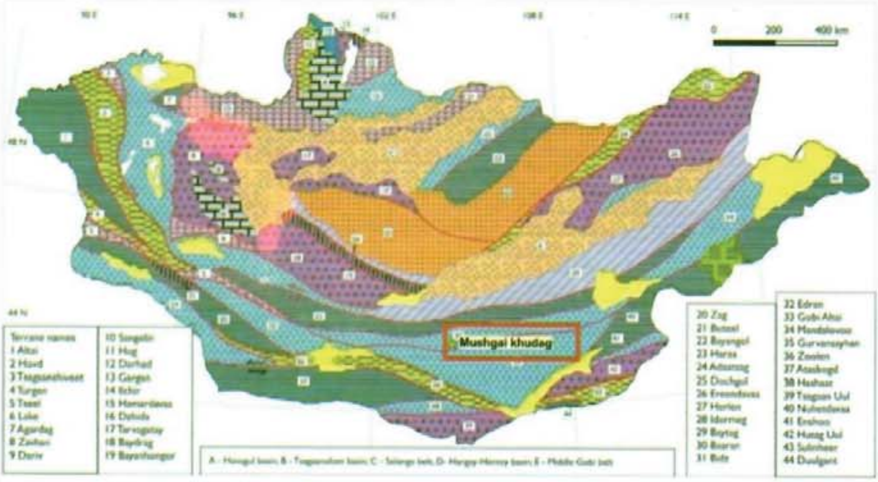

Fig.1. Tectonostratigraphic terrane map for Mongolia (Badarch et al., 2002). Red solid line is illustrating our study area.

Geology of deposit

Mushgai khudag deposit is located along the Main Mongolian lineament and situated in the Mandalovoo terrane. Host rocks are represented by Paleozoic sedimentary-volcanic sequence which are limestone, alevrolite, siltstone and granitoid in Paleozoic age ((Baatar et al., 2013). The volcanic rocks are effusive and pyroclast extruded and cause of volcanic formation which is along the latitude (Samoylov et al., 1983). Mushgai khudag alkaline complex consists of Late-Mesozoic subvolcanic and intrusive rock such as trachyte, syenite and shonkinite etc., (Fig.2) It is associated with carbonatite dikes. There are several mineralized such as main area, apatite hill, fluorite vein and celestine which contain high grade REE minerals. Our research is focused on main area and apatite hill (Fig.2). It consists of apatite ore body, magnetite ore body, quartz-fluorite vein and rhyolite dike.

By apatite ore body syenite host is intruded, which is lenticular and trachitic. Apatite ore body contain high REE. The apatite is associated with gypsum.

Methodology

Apatite ore bearing rock, gypsum bearing apatite rock and gypsum samples were examined by microscopic analyses. Whole rock samples were analyzed for major elements by X-ray fluorescence spectrometry (XRF). A HNO3+HF seal dissolution method was used for REE elements analyses measured by ICP-MS.

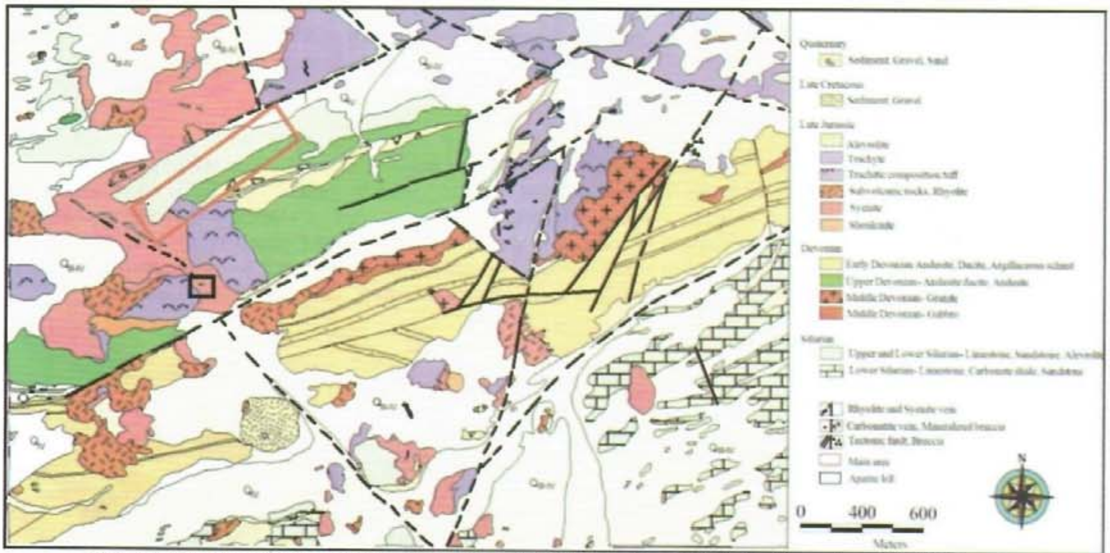

Fig 2. Geology map of the Mushgai Khudag deposit, South Mongolia, modified after Samoylov et al., (1983).

Mineralogy

Apatite ore bearing consist of apatite, iron oxide, celestine and strontium silicate. Apatite is abundant, which is very coarse grained in thin section. The apatite occurs as prismatic and detrital, sometimes broken crystals up to 2mm long (Fig.3A, 3B). It shows prismatic cleavage. Iron oxide is widespread as a secondary mineral which coatings along cleavages. Celestine and strontium silicate occur as accessory minerals in apatite ore bearing rock (Fig.3C.). Apatite ore bearing rock contained apatite and celestine is associated with gypsum. A gypsum only contains celestine.

The three crystals of apatite analysed by electron microprobe analyzer (Fig.4), all have a composition close to the theoretical formula Ca5(PO4)3(F,Cl,OH) of apatite with Ce_2O_3, La_2O_3, Nd_2O_3, SiO_2 and SO_3 (Table.1).

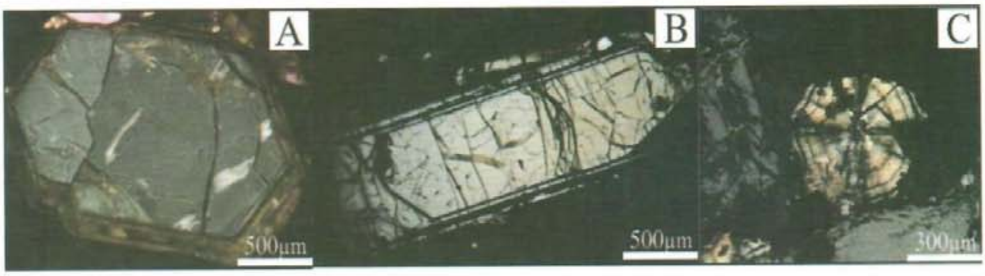

Fig 3. Photomicrograph of apatite. Abbreviation: Ap-apatite, Cls-celestine. (A) Prismatic texture of apatite in apatite ore bearing rock; (B) Elongated apatite ore bearing rock; (C) Strontium silicate in apatite ore bearing rock;

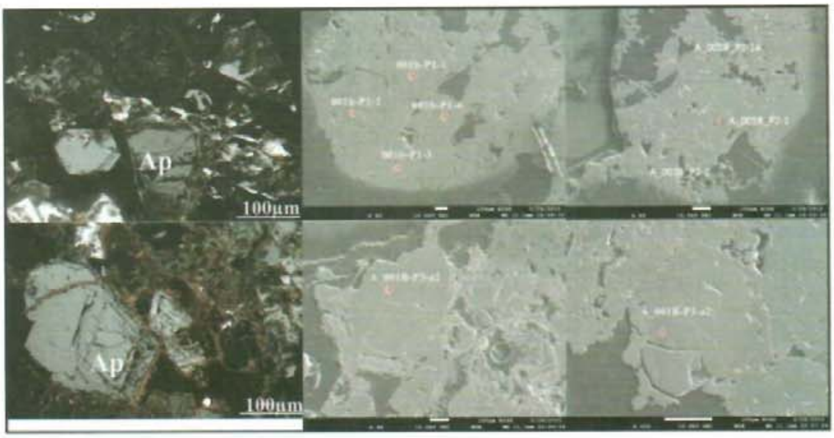

Fig 4. Backscattered electron images of apatite. In front of two image show that apatite crystals in thin section.

Table1. Microprobe analyses of apatite.

No	Points	Sample	SiO_2	F	P_2O_5	Ce_2O_3	CaO	Cl	La_2O_3	SO_3	Nd_2O_3	Total
1	001-P1-1	001b	5.183	3.393	31.134	3.287	50.964	0.121	2.682	2.785	0.814	98.907
	001-P1-2		5.984	3.482	29.545	4.023	49.85	0.134	3.257	2.946	0.96	98.685
	001-P1-3		5.833	3.496	29.839	3.911	49.97	0.135	3.266	2.902	0.89	98.74
	001-P1-4		5.43	3.739	30.444	3.673	50.366	0.095	3.129	2.966	0.868	99.114
2	A_001B_P2-1a		5.526	3.428	30.372	3.528	50.542	0.133	2.931	2.769	0.807	98.563
	A_001B_P2-1		5.907	3.196	29.807	3.834	49.746	0.128	3.273	2.799	0.963	98.278
	A_001B_P2-2		5.359	3.4	30.841	3.534	50.463	0.118	2.955	2.728	0.783	98.723
	A_001B_P3-a2		5.587	3.338	30.435	3.616	50.18	0.129	2.992	2.749	0.872	98.463
	A_001B_P5-a3		5.191	3.452	31.238	3.2	50.92	0.123	2.63	2.747	0.756	98.776
3	B_002_P2a	002	4.624	3.416	31.915	3.112	49.839	0.117	2.486	2.207	0.792	97.043
	B_002_P3a		4.072	3.352	28.738	2.631	41.346	0.093	1.919	1.86	0.72	83.299
	B_002_P4a		2.478	6.777	31.069	2.998	47.051	0.054	2.613	2.796	0.727	93.697
	B_002_P5a		5.554	3.427	29.076	3.604	47.342	0.123	2.956	2.686	0.888	94.185
	B_002_P6a		5.037	3.66	24.436	2.79	37.271	0.116	2.424	2.291	0.684	77.142

Geochemistry

Analysis of apatite ore bearing rock samples taken from apatite hill, main components are CaO (38.28 wt.%), $\sum Fe_2O_3$ (21.75 wt.%), P_2O_5 (25.18 wt.%) and SiO_2 (6.48 wt.%) which are determined by XRF analyses. There are also minor concentrations of F (2.54 wt.%), Sr (0.8 wt.%), S (2.47 wt.%) and Ba (0.01 wt.%). The concentrations of TiO_2, MnO and K_2O are quite low, ranging from 0.02 to 0.07 wt.%. ∑REE concentrations average 3.5 wt.% and range from 3 wt.% to 4 wt.%.

Chondrite-normalized REE pattern of apatite ore bearing rock and gypsum are illustrating as Figure.5. However, the REE pattern of gypsum bearing apatite ore are similar to the apatite ore bearing rock, the REE content of the gypsum bearing apatite rock is slightly lower. The $(La/Yb)_N$ values of REE apatite ore bearing rock is 500 on average. Although the gypsum of REE concentrations are low, the ratios $(La/Yb)_N$ of the gypsum has higher (555) than the apatite ore bearing rock. The REE patterns for apatite ore bearing rock and gypsum are shown as enriched in REE.

Discussion

The REE distribution of the pattern shows apatite ore body strong LREE enrichment (Fig.5). The $(La/Yb)_N$ value of 500 in the apatite ore contained $\sum Fe_2O_3$ (18-20 wt.%). In contrast to the $(La/Yb)_N$ value 400 of the another sample (apatite ore) contain low concentration of $\sum Fe_2O_3$ (6.28 wt.%).

Conclusion

Apatite ore body outcrop consists of apatite, gypsum bearing apatite ore and gypsum. The REE mineral is apatite in apatite ore as primary mineral and gypsum bearing apatite ore. The apatite ore bearing rock is enriched in LREE and has a 500 average value of $(La/Yb)_N$. The similarity of the REE pattern in gypsum bearing apatite ore (Fig.5).

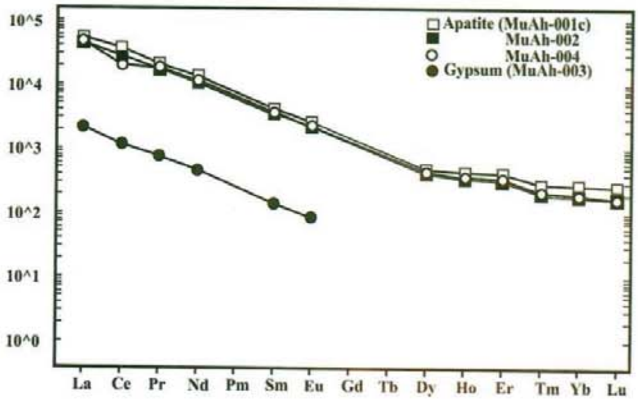

Fig 5. Chondrite normalized REE pattern of apatite ore body. The chondrite values were taken from Sun and McDonough (1989).

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Geochemical characteristics of the Tagaan Suvarga porphyry Cu-Mo deposit, South Mongolia

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The Tsagaan Suvarga porphyry Cu-Mo deposit is one of the largest deposit in the easternmost part the Central Asian Orogenic Belt. The deposit is located in the South Gobi Desert, approximately 650 km south east of Ulaanbaatar. The Tsagaan Suvarga deposit is hosted by late Devonian pluton, named the Tsagaan-Suvarga massive, which is covered by Carboniferous volcanic and sedimentary strata at it is western and northwestern part. The ore body consists of stockwork veinlets and veins of quartz, chalcopyrite, and molybdenite formed around the porphyritic intrusions. Three alteration zones have been recognized: quartz-sericite alteration zone, K-silicate alteration zone, and propylitization zone. The Rb-Sr and Sm-Nd isochron indicates a 338±14Ma and 364Ma age for deposit. Geochemical data indicate that the rocks are monzonite to granodioritic in composition, metaluminous with ASI values ranging from 0.97 to 1.14 and have I-type characteristics. The major element compositions reveal the Al_2O_3, Fe_2O_3(total), MgO, CaO, TiO_2 and P_2O_5 apparently decrease with increasing SiO_2 content, whereas K_2O and Na_2O increase with SiO_2. Trace element composition of granitic rocks: Sr=239-840 ppm; Y=15.94-7.99 ppm; Yb=0.8-1.78 ppm; Sr /Y wide range from 14 to 93.2; rare earth element composition are (ΣHREE) 3.09-6.68, (LREE/HREE) 5.5-13.5, $(La/Yb)_N$ 6.34-8.80. The primitive mantle normalized trace element diagram, all granitic rocks characterized by enrichment of large ion lithophile elements (LILE: Rb, Ba, Sr and U) and relative to high field strenght elements (HFSE: Nb, Ta, Ce and Ti) coupled with significantly negative Nb, Ta, and Ti anomalies. Chondrite-normalized rare earth elements (REE) patterns are fractionated with LREE enrichment and HREE depletion without Eu anomalies. Granitic rocks distributed at the Tsagaan Suvarga porphyry Cu-Mo deposit are characterized by a typical subduction related geochemical signature. The ore bearing granitic porphyry show depletion in heavy rare-earth elements, with average value of Yb and Y of 1.60 and 12.6 ppm respectively, this being a characteristic geochemical signature for adakitic magma. Negative anomaly of Nb and Ta on Primitive mantle normalized spider diagram implies that the granitic rocks are formed at a typical subduction related setting that means Cu-Mo mineralization is arc related porphyry type deposit. The initial $^{87}Sr/^{86}Sr$ ratios of the Tsagaan Suvarga ore-bearing granitic rocks range from 0.7027 to 0.7038, implying an upper mantle source for the magma. Homogenization temperatures of fluid inclusions are relatively low, between120 and 340 ^{0}C. Salinities exhibit range from 3.2 to 6.9 wt% NaCl equiv., with a mean of 5.8 wt % NaCl equiv., suggesting that ore fluids have low salinity. $\delta^{18}O$ values of quartz in the ores range from 9.5‰ to 11.8‰, 10.6‰ on average. Calculated $\delta^{18}O_{water}$ values of quart 3.25‰ to 5.9‰, suggesting that the ore fluids were mainly magma derived.

Keywords: Tsagaan Suvarga deposit, Porphyry copper, Genesis, Stable isotope, Hydrothermal alteration

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Stable isotope study of ore minerals in Erdenetiin-Ovoo copper-molybdenum porphyry deposit, Northern Mongolia

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The Erdenetiin-Ovoo Cu and Mo deposit is located in the central part of the Orkhon Province in Northern Mongolia 330km away from Ulaanbaatar to northwest. Rock samples collected for this study are composed of granodiorite, diorite porphyry and granodiorite porphyry complexes. QSP (Quartz-Sericite-Pyrite) alteration is well developed and ore-bearing quartz veins occur pervasively in this QSP zone. The observed main ore minerals are pyrite, chalcopyrite, molybdenite and chalcocite. Sphalerite, covellite, malachite, azurite and chrysocolla are also identified as minor ore minerals. Under microscope observation, chalcocite looks to fill the space between other primary sulfide minerals such as pyrite, chalcopyrite and sphalerite, indicating that precipitation of chalcocite occurred after other sulfide minerals had already formed. Sphalerite and chalcocite grains show relatively higher gold concentration than others by EPMA analyses.

The sulfur isotope compositions (^{32}S and ^{34}S) of major sulfide minerals are measured to trace the origin of sulfur and the formation process by EA-CF-IRMS (Elemental Analyzer-Continuous Flow-Isotope Ratio Mass Spectrometer) in NCIRF, Seoul National University. The average $\delta^{34}S_{V\text{-}CDT}$ value is -1.1‰ with difference between chalcocite and other sulfide minerals. The $\delta^{34}S_{V\text{-}CDT}$ values are ranging from -2.6 to -1.4‰, whereas other sulfide minerals such as pyrite, chalcopyrite and molybdenite range from -0.9 to 0.8‰ with no distinct variation among these three minerals. This suggests that sulfur were derived from deep source and sulfur isotope composition seems to preserve magmatic signature of sulfur. And lower sulfur isotope values of chalcocite indicates the sulfur isotope fractionation during its precipitation. To discuss it more, copper isotope will be conducted by MC-ICPMS in KBSI located in Ochang, South Korea.

Keywords: Sulfur isotope, Copper isotope, Erdenetiin-Ovoo, Mongolia

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Zircon crystal morphology and internal texture studies of magmatic rocks from the various plutonic complexes of Mongolia

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Zircon has to become one of the most widely used minerals for the extraction of information on the prehistory and the genesis of magmatic, metamorphic and sedimentary rocks.

The mineral zircon is extremely variable both in terms of external morphology and internal textures. These features reflect the geologic history of the mineral, especially the relevant episodes of magmatic or metamorphic crystallization (and recrystallization).

Often zircon crystals are faceted with combinations of prism ({100} and {110}) and pyramid forms ({211}, {101} and {301}).

A long experience and modern instrumentation and techniques have provided the "zircon community" the means to image and interpret preserved textures, and hence to decipher the history and evolution of a rock. The zircon pictures and images are categorized according to their inferred genetic context. A large number of internal textures are now described for igneous zircon as a result of the application of cathodoluminescence (CL) and backscattered (BSE) imaging.

The interpretation of age and isotopic relations is affected, on the one hand, by the particular megascopic and petrologic relationships of a rock unit and, on the other hand, by the characteristics of the minerals analyzed, most commonly the external and internal characteristics of the accessory mineral zircon.

We investigated the external zircon morphology and their internal textures from more than 40 intrusive rocks which are collected from different intrusive complexes of Mongolia for the SHRIMP zircon U-Pb age dating. The all these zircon samples were photographed in backscattered (BSE) and cathodoluminescence (CL) images that are used to examine the internal texture of the analyzed zircons and with petrographic observations guided the selection of analytical spots, using a JEOL JSM-6610LV scanning electron microscope at Korea Basic Science Institute (KBSI).

Keywords: Zircon Crystal Morphology, Internal Texture, Mongolia

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Metallogeny of Mongolia

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According to Metallogenic Map of Central Asia and Adjacent Areas (Shatkov, Petrov, Dejidmaa et al., 2012) whole territory of Mongolia located in the Central Asian Planetary Metallogenic Belt (CAPMB) and at the same time Mongolia has a very key position of the Central Asian Mobile Belt. The Mongolian portion of CAPMB consist of mainly next three metallogenic superprovinces – Mongol Altay – Sayan superprovince (**MAS**), Mongol – Okhotsk superprovince (**MO**), and Irtysh – Great Hinggan superprovince (**IGH**). These superprovinces are themselves subdivided into smaller metallogenic units – provinces, districts, etc. Detailed divisions of superprovinces are shown below.

1. Mongol Altay –Sayan superprovince (MAS)
1.1 Altay – Salair province (AS)
  1.1.1 Mongolian Altay district (AS-3)
1.2 Lake – West Sayan Province (LWS)
  1.2.1 Upper Yenisei (East Tuva) district (LWS-2)
  1.2.3 Lake district (LWS-3)
1.3 Tuva – Mongol province (TM)
  1.3.1 Sangilen district (TM-1)
  1.3.2 Khubsugul – Gargan district (TM-2)
1.4 Selenge – Oldoy province (SO)
  1.4.1 Selenge – Yablonovaya district (SO-1)

2. Mongol- Okhotsk superprovince (MO)
2.1 Central Mongolian province (CM)
  2.1.1Central Mongolian district (CM-1)
2.2 Mongol – Transbaikalia province (MTB)
  2.2.1 Khentey – Dauria district (MTB-1)
  2.2.2 Aga – Shilka district (MTB-2)
  2.2.3 Hangay district (MTB-3)
2.3 Kherulen – Argyn province (KA)
  2.3.1 Argyn district (KA-1)
    Just small portion of this district entered into the Mongolian territory from the NE direction.
  2.3.2 Kerulen district (KA-2)

3. Irtysh – Great Hinggan superprovince (IGH)
3.1 South Mongol province (SM)
  3.1.2 South Mongolian district (SM-1)
3.2 South Gobi province (SG)
  3.2.1 South Gobi district (SG-1)
3. 3 Great Hinggan province (GH)
  3.3.1 East Hinggan district (GH-3)
  3.3.2 South Hinggan district (GH-4)
3.4 Ondor Sum province (OS)
  3.4.1 Ondor Sum district (OS-1)
    Great Hinggan and Ondor Sum provinces are locally distributed in the most NE part of Mongolian territory.

4. Central Kazakhstan – Junggar superprovince (CKJ)
4.1 Junggar province (JU)
  4.1.1 East Junggar district (JU-3)
    Central Kazakhstan – Junggar superprovince (CKJ) entered into the Mongolian territory from the SW direction just a small portion as a NE part of East Junggar district (JU-3)

Our recent study (Delgertsogt, 2015) reveals the Mongolian territory rich by next genetic types of mineral deposits.

Iron deposits belonging to BIF distributed within the passive margin of Central Mongolian ancient microcontinent of Paleoproterozoic time and are represented by few deposits, such as Tumur Chuluut, Navchitiin gol, Baidrag and several other occurrences.

On the territory of Mongolia also established two relatively big phosphorite-bearing basins, one of them is Hubsugul basin located in Northern Mongolia to the west of famous Hubsugul lake. This basin consists of nearly 50 phosphorite deposits and occurrences, phosphorite-bearing ore bodies occurred in Lower Cambrian Heseen formation. The another is Zavhan basin located in NW Mongolia in the Zavhan Gol river area. The Zavhan basin is relatively smaller than mentioned above Hubsugul basin and consist of 3 – 4 medium-sized deposits and some other occurrences. Phosphorite ore is located in Tsagaan-Olom formation of Neoproterozoic age. Phosphorite-bearing basins of Mongolia formed in passive continental margin shelves (or, shelf) environment of ancient Tuva – Mongolian and Central Mongolian microcontinents.

Metallogeny of suture zones of Mongolia is not famous so far, but some VMS type deposits of copper, lead, zinc might be of economic interests in coming years.

Sedimentary iron and manganese mainly small deposits and occurrences of Early and Middle Paleozoic age are predominantly distributed in the Central Mongolia, Hangay and Hentey basins. Genetically they related to small lenses-shaped inter-formational chert bodies.

Aluminum deposits and occurrences are few in Mongolia and has no economic significance at present. Genetically they belong to magmatic – iolite, urtite, nepheline syenite related type, and metamorphic – disten, sillimanite, kianite schist related types. These deposits distributed in Hubsugul and Buteel range areas of Northern Mongolia. One single laterite type deposit – Alag Uul located in Dariv Mt. range in Western Mongolia.

Porphyry copper deposits widely distributed in Mongolia, especially in its southern part. About 20 porphyry copper deposits discovered in this area, including world-class Ouy Tolgoi porphyry copper clusters, Zuunmod porphyry Molybdenum deposit, Harmagtai, Tsagaansuvarga porphyry copper deposits and others. In the North Mongolian porphyry copper belt located one of biggest deposit – Erdenetiin Ovoo. Several years ago in the SW part of Mongolia discovered Shirt VMS deposit and some other promising occurrences. Within Mongol Altay and Lake tectonic belts of Western Mongolia and in their adjacent areas located several VMS deposits, namely Huh Adar, Ulaan Hatuu, Dulaan Har uul, Bayan-Airag, etc. Porphyry copper and VMS deposits of Mongolia developed mainly in the subduction – accretional stage of Paleo-Asian Ocean of Neoproterozoic – Early Paleozoic time. Some porphyry copper deposits belong to Mesozoic era.

Gold, silver deposits are relatively wide distribution in Mongolia. Most significant metallogenic units are North and South Hentey district, South and West Mongolia. All gold (silver, mercury) deposits of Mongolia belong to next genetic types - granite-related deposits, epithermal deposits and orogenic gold deposits. Mineralization age of gold deposits depends on geodynamic condition of each specified area, however most significant genetic type among them is orogenic gold deposits

Rare metal (W, Mo, Sn, Be) deposits distributed mainly in Central, Eastern Mongolia and also in Western Mongolia regions. Mineralization age of these deposits is mainly Early Mesozoic in Central and Eastern part of country, but Devonian in western Mongolia. Geodynamically, they formed in anorogenic, post-collisional environment as a greisen, vein and stockwork type deposits. Rare Earth metal (REE) deposits of Mongolia belong to Devonian, Permian, and Jurassic age groups and they genetically related to continental rift settings.

Skarn type deposits are one of very interesting and complicated group in Mongolia and at the same time they have a wide distribution. They consist of next metals – Pb, Zn, Fe, Au, W, Mo, Sn, Cu. Spatially they occur mainly to the regions where the Proterozoic and Early Paleozoic carbonate formations have a wide distribution. Young intrusions of Devonian, Carboniferous, Permian and Mesozoic ages intruded into the mentioned above carbonate formations and formed contact-metasomatic skarn ores of different composition.

Lead, zinc, silver-bearing epithermal, mainly breccia-type deposits are widely distributed in most NE part of Mongolia and belong to late Mesozoic continental riftogenic stage.

Fluorspar deposits have a very wide distribution exclusively in Central, East and North Eastern Mongolia. They have strong genetic relation to late Mesozoic continental riftogenic stage, and especially to bimodal volcanogenic activity so called Tsagaantsav formation of Upper Jurassic and Lower Cretaceous time.

Uranium ores of Mongolia belong to two different genetic types. Volcanic-related deposits distributed exclusively in NE Mongolia and are represented by Gurvanbulag, Dornod, Mardai deposits of Cretaceous age. Another type is sandstone-hosted deposits and the main deposits of this type are concentrated in Mesozoic Zuunbayan basin of SE Mongolia. Recently discovered two important deposits within this basin, one of them is Zoovch Ovoo deposit which belong one of biggest deposit in the world by ore reserve. Another important deposit is Dulaan Uul deposit which located close to Zoovch Ovoo deposit. These uranium deposits located in sandstone horizons of Lower Cretaceous Sainshand formation.

Coal deposits of Mongolia belong to four different age groups – Carboniferous (mainly in Western Mongolia), Permian (Western, SW and Southern Mongolia), Jurassic (Central, Eastern, NE Mongolia) and Cretaceous (very wide distribution in Central, Southern and NE Mongolia). Among them included world-class Tavan Tolgoi coal deposit Permian age. Oil, oil-shale deposits has a relatively wide distribution within

the Meso – Cenozoic sedimentary post-collisional, intermountain basins of Southern, SE and Eastern Mongolia. Oil-shale and oil-bearing horizons belong to Lower Cretaceous time.

Main Metallogenic profile of Mongolian territory has a very close genetic link to accretional – collisional events of Paleo – Asian and Mongol – Okhotsk Oceans since Neoproterozoic up to Triassic. Continental Riftogenesis and related Metallogeny played important role for Post-triassic time, mainly in Eastern Mongolian regions.

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Preliminary results of the Korea- Mongolia joint research project " Geological, geochemical and ore genetic studies of the Dzuun mod area gold deposits in the North Khentii gold belt located in North- Central Mongolia

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The project is a joint research project between Mongolian and Korean government, focusing on the Dzuun mod area gold deposits, and the duration of the project is 2015-2017. The primary objectives of the project are to: a) characterize types and age of the host rocks b) characterize the nature of gold mineralization and its structure c) contribute to the understanding the genetic models of the gold deposits in this area.

A first stage of the field work was carried out in 2015. During the field session, historical database of the project area were obtained and reviewed, and the site investigation and sampling were conducted. As a collaboration with the Seoul National University, the laboratory analyses will be conducted at the Seoul National University, and the samples delivered to the university. Petrographic and lithogeochemical analysis were performed on the all samples, and the ore mineral composition of the area has been described. The sedimentary units of the area were analyzed by the counting analysis, in order to characterize the nature of genetic source of the sandstone. Preliminary results of the project will be presented in this report.

The following laboratory analyses will be carried out in 2016 and 2017. The U-Pb geochronology of zircons will be performed at KBSI using SHRIMP lle. The gold grains will be analyzed by EPMA and SEM-EDS and fluid inclusion assemblages will be investigated by an optical microscope and using the fluid inclusion analysis techniques. Sulfur isotopic values will be measured by EA-CF-SIRMS located at Seoul National University. Sulfur isotope analysis can offer the information about the origins of sulfur and processes experienced during deposit formation. Rb and Sr isotopes are helpful to understand the petrology and tectonic histories of this area. The Rb and Sr isotope analyses will be conducted by a Thermal Ionization Mass Spectrometer (TIMS) housed at KBSI.

The Dzuun mod area is located in north-central part of the North Khentii gold belt. The Dzuun mod area is widely distributed the Middle Cambrian-Early Ordovician flysch terrigenous sediments Shiguu formation of Kharaa Series and Middle-Late Ordovician Boroo Complex granite rocks which intrude Kharaa Series rocks and in the central part along the Sujegtei fault occurred Late Ordovician subvolcanic rocks of Dzuun Mod, it is overlapped by Early Devonian volcanic sediments Ulaan-undur formation and Early-Middle terrigenous sediments Artsat formation.

The research area has a more potential for lode gold deposition, and significant numbers of placer and lode gold deposits and occurrences are hosted in the Dzuun Mod area, including Gatsuurt, Ulaanbulag, Kharganat, Sujigtei, Ereen, Baavgait, Urt and Biluut etc.

Keywords: North Khentii gold belt, Dzuun Mod area

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Geoscience Education in Mongolia focused in Environmental and Geoethical Literacy

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Geoethical literacy is the most important part of Geoscience education for university and secondary school students for understanding and protection our Earth.

Throughout Mongolia intensive mining operation, both large and small scale, has contributed to land degradation and a number of other environmental and health concerns. While legislation for environmental protection is already in place in Mongolia, there remains a real need to strengthen local capacity to put existing policies into practice. In particular, increased competence to recognize and deal with environmental issues is needed, as is the development of standards and experience for reclamation, mine closure and monitoring to provide environmentally sound practice. All these processes require the involvement of the mining industry (both large and small), government (both national and local), and the local communities (including herders and youth). EU projects developed in the Mongolian University of Science & Technology (MUST) have worked to strengthen the technical and managerial capacity of those engaged in the mining industry in Mongolia to carry out mining activities in an environmentally, ethically and economically sustainable manner. The project has worked towards building the capacity of MUST to train future geologists, government officials and other professionals working in the industry in the skills necessary to implement environmentally sustainable mining practices. During last 20 years MUST successfully implemented in Earth sciences education number of new courses in undergraduate and graduate educational programs including a revised pedagogical approach in the teaching: one that moves away from didactic learning towards a strategy that is focused increasingly on experiential and practice based learning (Gerel, Munkhtsengel, 2008)

One of the major challenges to arise during the project, was the revision of pedagogy and development of a new geology curriculum, which improved the environmental and geoethical literacy of the student body, implementation of a refocused applied research agenda centered on the environmental impacts of mining in Mongolia as well as other social and sustainable issues, development a public engagement and outreach strategy to build awareness and knowledge of environmental and geoethical issues related to mining within community and youth populations (Gerel, 2012).

Students have benefit from this new focus on environmental research with institution around the world. MUST has developed a successful outreach and public engagement strategy by Museum of Geology and Mineral Resources which has reached out a great number of key governmental officials, secondary school-students, and thousands of participants through general exhibitions in the city centre.

Geology students and faculty are increasingly pushed to consider other dynamics which may impact profitability including damages to the environment, gender, geoethics, and other social factors. In terms of research, this has resulted in a number of findings which have informed practical land use and strategies for locals living in polluted areas as well as soil remediation strategies in areas affected by ground and water pollution. We developed a multi-pronged approach to community outreach; one which includes training students to deliver outreach activities to the peers in secondary schools.

Key words: Geoethical literacy, education, Mongolia

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Effect of natural weathering on Tavantolgoi coking coal

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Coal oxidation takes place as soon as a coal comes into contact with oxygen in air. When this process occurs in nature, it is called coal weathering. Weathering has an impact on coal properties. In bulk chemistry, the content of oxygen, moisture, and volatile matter increases, while the sulfur content decreases. Moreover, weathering in coking coals can destroy their fluid properties. The Free swelling index and the Gieseler fluidity decrease dramatically as weathering increases.

In this study, the effect of natural weathering on Upper Permian Tavantolgoi coking coal is studied. 500 kg sample, collected from open pit, was pulverized and screened through 5 mm. Then the sample was divided into 20 equal parts (cones) and stored in open area at the mine site for a period of 20 months. Each month, the half of the each part was taken for lab assays. Proximate analysis involves determination of ash, moisture, volatile matter, total sulfur, fixed carbon and calorific value. In addition, Free swelling index and G index were determined to monitor changes in coking properties of the samples.

During the first 4 months, volatile matter (dry, ash free basis) reduced from 27.7% to 27.0% and then increased to 28.2%. Calorific value (as received basis) decreased from 6780 kcal/g to 5742 kcal/g, whereas ash content (as received basis) increased from 19.8% to 32.3%. The rate of the changes of these two indices intensified significantly after 12 month storage. Free swelling index and G index decreased from 7.5 to 6 and from 80 to 63, respectively. In the first 6 months, not much change was observed, but after that, the both indices decrease dramatically.

According to the results of this study, it can be concluded that (i) there will be not much changes, if mined Tavantolgoi coal is stockpiled up to 6 months, (ii) 6 to 12 month stockpiling influences some negative impact on coal quality, and (iii) stockpiling should not be exceed more than 12 months, because the caking properties of coal will be severely damaged due to weathering.

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The estimation results of earthquake hazard at Bulgan and Erdenet city due to the Mogod fault zone using the probabilistic approach

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Mongolia is considered to be located at the seismic active region and is divided into several tectonic zones. The Mogod earthquake (M=7.5, January 1967) which occurred at east of Hangai dome was one of the strongest earthquakes that occurred in the past century in Mongolia. The seismic event was closely studied by several researchers because seismicity of the Central Mongolian region was previously regarded as moderate.

In this study, we have determined the seismic hazard at Bulgan city (N48^{0}48'43", E103^{0}32'1") and Erdenet city (N49^{0}1'59", E104^{0}4'59") due to the Mogod fault zone using the probabilistic approach. The distributions of catalogued earthquakes, together with available geological and tectonic information of the Mogod fault region were used to calculate probabilistic seismic hazard parameters.

From the analysis, mean annual rate of exceedance, return period and cumulative probability hazard curve for peak ground acceleration (PGA) have been estimated at Bulgan city and Erdenet city.

Key words: seismic attenuation, peak ground acceleration, probabilistic seismic hazard analysis

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Research on Application of Highwall Mining Technology in Mongolia

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ABSTRACT

The pit boundary at the most of thermal coal mines located in central region of Mongolia such as Sharyngol, Baganuur and Shivee-Ovoo will be reached to the economic pit limit in the near future. Due to the approaching economic pit limit, high stripping ratio, decreasing of economic benefits and increasing mine depth, those mines' geotechnical and operational condition is dramatically getting worse year by year. Therefore, the geotechnical investigation and data are insufficient in most of coal mines, especially state-owned ones. In order to increase mineable reserves and operational lifetime, we present the potential utility of highwall mining method that extract remaining coal around highwall after economic pit limit is reached by surface mining operation.

This study based on results of numerical analysis which was carried out by using two-dimensional finite element method and Phase^2 software by Rocscience to discuss an application of highwall mining method at several coal mines in Mongolia. Baganuur coal mine is selected as a research object to examine possibility that whether we can adopt this technology after ultimate pit limit will reach and prior to apply underground mining method.

On the other hand, we expect that underground water problem that affects stability of slope and extraction is not serious at shallow mining depth in Mongolia.

Key words: stability of coal pillars/openings, mining depth, highwall mining method, numerical analysis

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1. Introduction

Surface coal mining has recently been played as a role mining method in rest of the world. But, however, stripping ratio related economic concerns has still been the biggest problem in surface mining development. Even though surface mining technology and techniques are getting more advanced and can give variety of advantages to the mining companies, geological and environmental issues are still existed in Mongolia such as ground control issues, underground water issues and rehabilitation concern as well as legal barrier and political issue are main problems in Mongolia.

In recent years, coal production has rapidly been increased with a lot of coal mines developed and extract to export much amount of high quality bituminous and coking coal to China as a raw coal without handling and processing. Moreover, domestic coal consumption is increasing year by year with respect to the demand of power generation.

Although demand on coal and energy will increase dramatically in the future, domestic thermal coal mines cannot overcome the economic challenges and operational problems that they will face further on. But, anyway, mining engineers hope that they are able to solve these problems based on academic research and experience obtained in actual mining field.

Due to high operational cost, low price and lack of experience of underground coal mining technologies, mining engineers are not interested in to study it. To define economic pit limit of open pit mine, engineers usually prefer to use empirical methods and calculation based on some universal formulas.

Our study will direct chances that we have, to increase economic efficiency and meet demand on thermal coal steadily. Moreover, despite of hard economic challenges, we need to apply an optional mining method such as highwall mining method, underground mining method and underground coal gasification with CO^2 issues are being risen up in the rest of the world.

2. Highwall mining method

It is a mining method to extract coal from highwall in open pit mining, its fatality rate is essentially the same as surface coal mining, thus highwall mining appears to be a very safe modern mining method (R.Karl Zipf, Suresh Bhatt, 2010). Open pit limit has been reach because of two kind of reason: economic restriction or geographical constraints.

Fig. 1. General scheme of highwall mining system

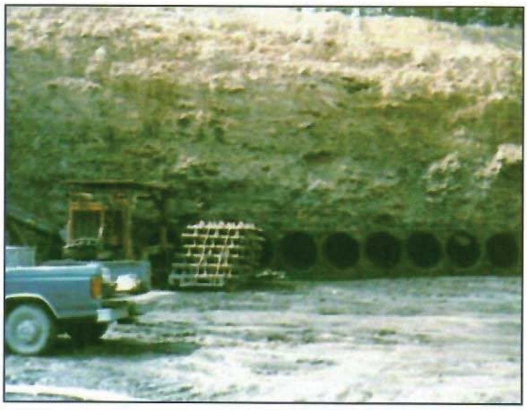

Fig. 2. Circular holes by Auger machine

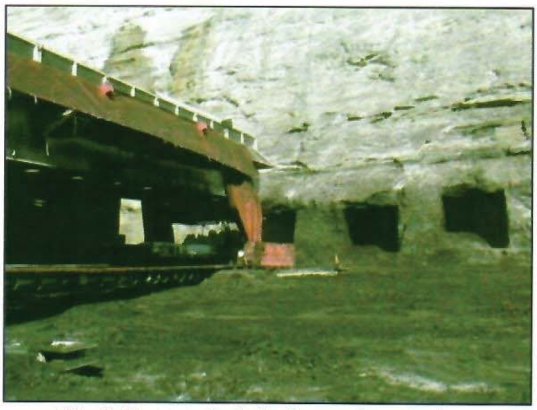

Fig. 3. Rectangular holes by continuous miner

There are three types of machines used in highwall mining method; one is Auger machine that extracts through circular shape hole, second one is continuous miner that exploits through rectangular shape hole and third one is metech highwall miner (see Fig 2-4.).

3. Brief of research site

Baganuur coal mine is one of the biggest domestic surface coal mines and is selected as a research object of case study in order to investigate the probability of application of highwall mining method. It is located in SE 130km from Ulaanbaatar capital city and is owned by 75% of state and 25% of other shareholders.

The total resource is 600.0 million metric tons of lignite estimated in 1978. In 1998, estimation of resources was updated up to 708.2 million metric tons of coal based on results of additional exploration and several boreholes drilled in the field.

It is connected to railway network and annual production is 3.5 million metric tons of coal that is around 50% of total domestic coal consumption produced by surface mining is shipped to the power plant for power generation.

4. Case study:

In order to conduct numerical simulation, properties of sandstone and coal are selected to use in numerical analysis. Sandstone is dominantly situated in overburden rather than another type of rock masses.

In the first case, the lateral stress ratio is equal to 1 which means horizontal and vertical stresses are same and analysis carried out at 100m, 150m and 200m depth.

In the second case, the lateral stress ratio was changed to 0.5 that means the value of vertical stress is twice as that of horizontal one.

Fig. 4. Top view of Baganuur coal mine.

Modelling

The overall view of simplified model is shown in Figure 4 in which was constructed in accordance with geological data and mining plan reviewed by mining engineers of Baganuur company such as: (1) the overburden thicknesses are ranging from 100m to 200m in three models, (2) thickness of coal seam is 18m, (3) a dip of coal seam is almost horizontal as 4-6°, (4) quite strong rock properties (see Table 1.), (5) the lateral in-situ stress ratio is equal to 1 and 0.5, overall slope angle is around 19° (see Fig 5).

The shape of openings by continuous miner is rectangular with dimension of 3m × 3m. The distance from extraction area to left, right and bottom boundaries are taken as 100m, 100m and 100m respectively.

5. Results and discussions

Basically, mining holes are drilled from right to left and from top to down in sequence as described in figure 5. As mentioned in previous section, it can clearly show that when the lateral stress ratio is different as 1 and 0.5, failure zone and surface subsidence are different in each cases.

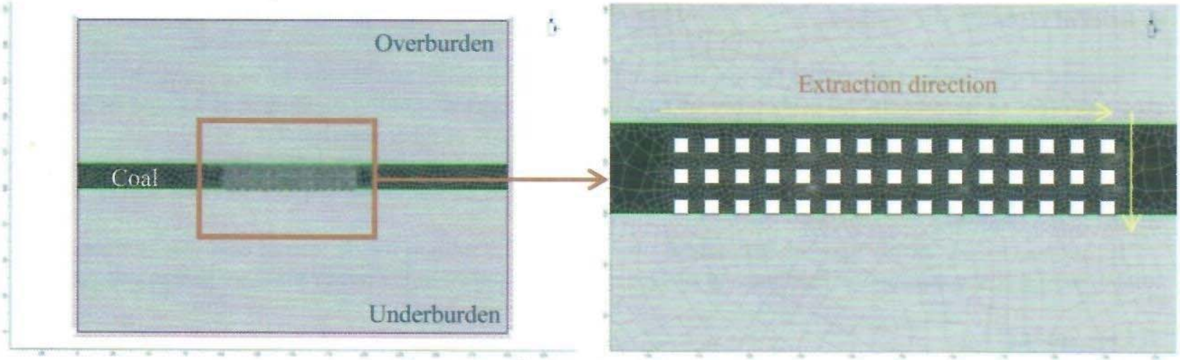

Fig. 5. Overall view of analyzing model

Table 1.
Mechanical properties of rock and coal

Rock materials	Unit weight, MN/m^3	Young's modulus, MPa	Poisson's ratio	Tensile strength (MPa)	Cohesion, MPa	Friction angle, °
Sandstone	0.020	7400	0.34	2.1	5.39	31
Coal	0.013	2000	0.15	1.1	2.1	24

The results show the failure zone around the openings/pillars after all rectangular shape holes extracted by continuous miner. (Fig 9-11) In order to present surface subsidence behavior of Baganuur coal mine after all holes were extracted completely, we have put such number of measurement points on ground surface of model.

Using those measurement points, we can examine the amount of surface subsidence and environmental impacts due to the highwall mining operation. In figure 9, although stress ratio is assumed as 1 and 0.5 differently in two cases, failure zone has not been developed around openings and pillars. Very small failure zone is generated around some corners of openings even though different lateral stress ratios have been applied.

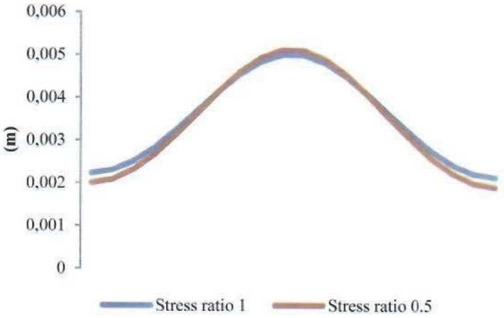

Fig. 6. Surface subsidence at 100m mining depth

The amount of surface subsidence at 100m mining depth after 45 holes excavated sequentially by continuous miner is ranging from 2mm to 5mm (see Fig. 6). It is relatively small and it can be said that the ground subsidence problems will not be serious in this area.

In figure 10, we have also got some similar results from numerical analysis, failure zones around the openings and coal pillars are very small, because of strong rock properties at shallow depth. Therefore, it can clearly be seen that highwall mining technology can be directly applied at shallow depth in Baganuur coal mine.

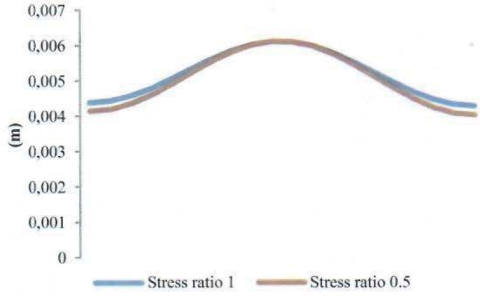

Fig. 7. Surface subsidence at 150m mining depth

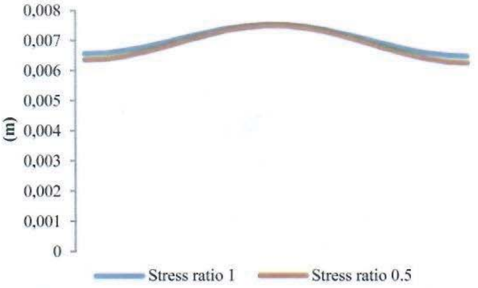

Fig. 8. Surface subsidence at 200m mining depth

The amount of surface subsidence at 150m mining depth is ranging from 4mm to 6mm (see figure 7). It is still being small, although mining depth is increased by 50m than previous one. It is also found that either stress ratio 1 or 0.5 is applied on analyzing model, the difference of subsidence has not clearly seen in the results. Probably, it means that stress ratio changing does not affect results of numerical analysis significantly, even it is observed on failure zone manners (see Fig 9-11).

In figure 11, the failure zones around the openings are changed dramatically with increasing mining depth. Usually, shear failure zone is being developed on the left and right side of openings. It can be observed from this results that the stability of openings/pillars at the stress ratio is 0.5 is worse than that the stress ratio is 1.

Subsidence at 200m mining depth is ranging from 6mm to over 7mm (see Fig. 8). It is becoming larger than those of previous two results, but, not so much difference are still being occurred.

However, failure zone has slightly been connected each other through pillars horizontally. It may cause of highwall mining equipment will be trapped hole inside and cost of purchasing equipment due to the collapsing holes and pillars. Since mining depth exceeds 200m, we need to consider the application of backfilling technology and changing the pillar width necessarily to maintain the ground control concerns.

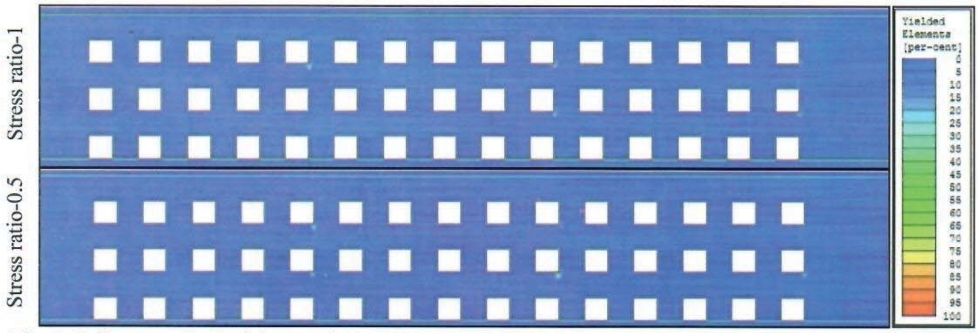

Fig. 9. Failure zone around the openings at 100m depth (Openings dimension – height-3m, width-3m and pillar width-3m)

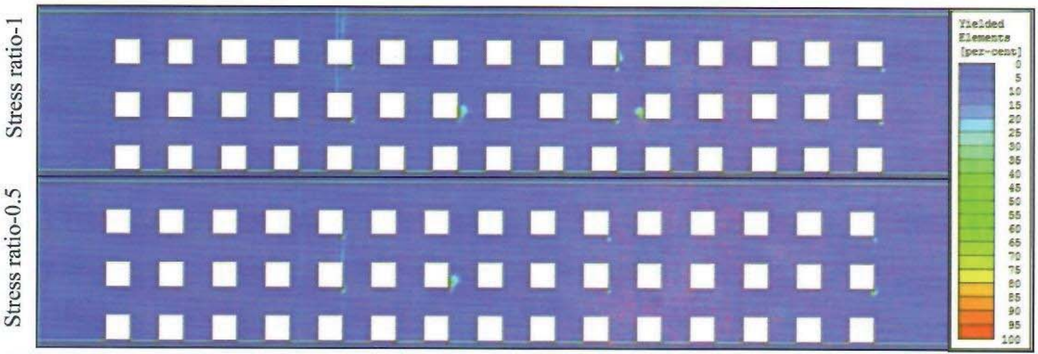

Fig. 10. Failure zone around the openings at 150m depth (Openings dimension – height-3m, width-3m and pillar width-3m)

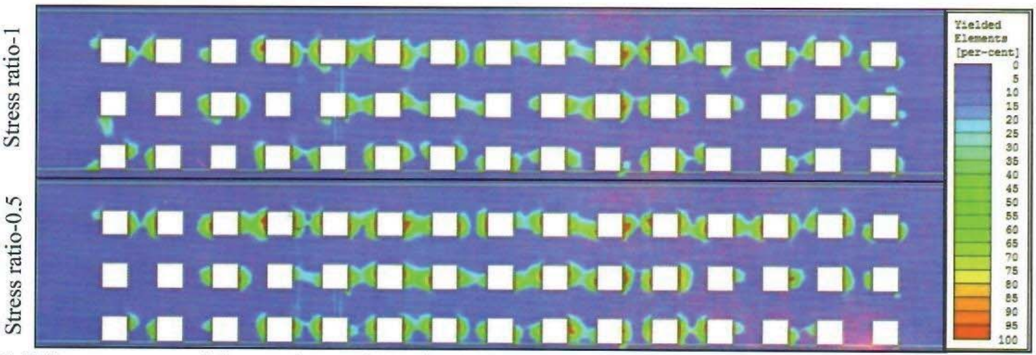

Fig. 11. Failure zone around the openings at 200m depth (Openings dimension – height-3m, width-3m and pillar width-3m)

6. Conclusion

Highwall mining method has many advantages in transition area from surface mining to underground mining, because it is low cost-effective, requires fewer personnel and very safe. Regarding to its advantages, it can be adopted at several mines in Mongolia.

According to a series of the results of numerical analyses, it can be concluded that the applicability of highwall mining method at shallow depth could be applied in future. Furthermore, strong rock properties can improve stability of openings and coal pillars and hence, more coal could be extracted with highwall mining method under highwall pit slope.

In order to increase coal recovery and to determine more appropriate design of highwall mining operation, study of adequate coal pillar and dimension of opening should be conducted further on.

7. Acnowledgement

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Problems and cooperation between key stakeholders in geological sector

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As of 2014, Mongolia attracted $6 billion in foreign investments from more than 100 countries as a result of striving to create a favorable and stable legal environment in order to attract foreign investment ever since the transition to free market economy. Two thirds of the total investment was stent on mining sector, and the leftover investment was spent on others. It shows that foreign investors are keenly interested in Mongolian mining sector.

On the other hand, mining sector cannot go forward without geological survey. For Mongolia, geological survey is vital, once economic development of Mongolia is directly related to mining. Unfortunately, Mongolian government allocates very limited budget for geological basic survey, and geological mapping, which causes negative impact on further development of geological and mining sector of Mongolia. Moreover, the number of problems occurs during the exploration and mining operation of private companies. It is mainly due to misunderstanding between state agencies, companies and citizens, who do not have proper information and do not realize the sector relevance.

In order to solve the problems mentioned above, it is necessary to (i) identify and systematically analyze the issues on professional level; (ii) increase the amount of state budget for geological research that is sufficient enough to conduct survey according to international standard as well as to create centralized geological data base, and (iii) educate social community by intensifying cooperation between media and entities of geological sector that will help companies to get social license easily.

Eventually mechanisms of cooperation between citizens, companies and government are important to signify geological sector. In other words, decision of government is fulfilled by local and state administration and citizens and civil society organizations control its result. When fulfill the idea mentioned above, the speed of geology sector development will improve.

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