ABSTRACT

There are widespread mineralized systems, occurrences, deposits that occurred in the South Gobi, Mongolia, where many of them already undergone mining activity. However, not all of them have a pre-mining environmental assessment. The Shuteen area is one of these highly prospective areas for mining; due to the porphyry copper system observed, prospecting and exploration projects have been carried out since 1980. Numerous prospecting and exploration works have been done during 1997–2007 and suspended last decade because of economic and political reasons. The area is located in a Gobi-desert environment and wind plays a main role in the transport and mobility of the elements. This research was conducted to assess the environmental condition of the area, based on soil, dry river sediment, and drinking water geochemistry. We are expecting the area has a naturally high concentration of some heavy metals in soil, concerning the geology and mineralization. The results show that the heavy metal content in the soil does not exceed the permissible limit of the Mongolian National standard on soil quality. Whereas, the water samples contain F above the permissible limit guided in the Mongolian National Standard on drinking water quality. The unusual chemical composition of the water is related to the soil composition characteristic of the Gobi region. They are characterized by low alkali, high salinity and mineral/water ratios are high. Environmental assessment surveys determine the characterization of an areal geochemical base prior the development of later exploration or mining project, might have affect it and establish the initial environmental status.

Keywords: Geoenvironment, Geology, Mineralization, Natural baseline

INTRODUCTION

Environmental assessment of mining area is a benefit to avoid the danger for human, animal, and natural environment from the heavy metal pollution. A few numbers of studies related to mining impact on the environment have been done at the Erdenet Mine including the preliminary result of previous research (Munkhtsengel, 2007; Namkhai, 2000; Bolor-Erdene et al., 2001; Jachek, 2005; Jachek et al., 2005; Batbold et al., 2014). Moreover, the pollution of river systems in Mongolia has been considered in several studies, which mentioned that there are several pollution sources including
mining sites (Altansukh, 2008; Byambaa and Todo, 2011; Batbold et al., 2014).
South Gobi is an important mining district in Mongolia, comprising several active explorations, such as the well-known Oyu Tolgoi, Tsagaan Suvarga and Kharmagtai porphyry copper deposits. However, there are no pre-mining environmental assessments of copper mineralized deposits in southern Mongolia, including the study area. Our study is based on geochemical analysis of soil and water at the pre-mining Shuteen copper porphyry mineralized area, in the South Gobi, aiming to assess the current environmental situation and compare to the adjacent areas information (Batkhishig et al., 2017a,b). During 2008–2012, the China

Fig. 1. (A) Geologic map of the Shuteen area. The main copper prospects are denoted by triangles: Shuteen Khanbogd lithocap, Khar Tolgoi, Bayan Khoshuu, and Dash Sum (Batkhishig et al., 2014). (B) Soil and water sampling points and their location for the environmental assessment (Batkhishig et al., 2017b).
Mongolian joint project conducted the 1:1 000 000 scale geochemical mapping along China–Mongolian Boundary. They have taken soil samples by 1:100 000 scale network (1:1000000 geochemical, 2012). Our soil data results are compared to the results of this project.

Shuteen has a semi-arid climate with average annual precipitation of 105.7 mm and wind 3.5-4.0 m/sec average wind speed (IRIMHE, 2008), without vegetation cover on the surface. A sampling campaign was carried out in May 2016, and a total of 25 rock samples, 57 soil samples and 9 water samples were taken from the Shuteen copper porphyry mineralized area to examine their geochemical composition concerning geological background and impact of mining activity on heavy metal accumulation (Fig 1).

MATERIALS AND METHODS

Samples

Soil samples were taken from the wide dry stream and downstream sediments (Fig. 1) and dried well bottom soil to investigate accumulation and transportation of the contaminants originated from the geological...
background. Besides, we selected 2 places to take soil samples by cross-section to check vertical evaluation. The cross-section ranges from 2–7 m and each different soil layer sampled separately, sample intervals are approximately 10–20 cm. Soil samples were taken from 10–20 cm depth and avoided the input of ground organic materials and placed in a clean plastic bag (MNS 3298:90). After complete drying, the soil samples were sieved by 2 mm mesh, then fine particles about 100 gr used for further sample processing. The prepared 100 gr samples grided using vibration sample mill Heiko Tl-100 for 20 minutes until the grain size suited for routine analysis. After that, without any additional binders, we prepared pellets with an inner diameter of 25 mm, under hydraulic pressure of up to 20 tons using Model N3124, NPa System Co., Ltd., Tokyo, Japan equipment. Water samples were taken from drinking water wells (Fig. 2A, B), livestock watering wells (Fig. 2C), and natural spring water (Fig. 2D) in the area. Physiochemical parameters of water were measured at the sites. Temperature, pH, and electric conductivity (EC) were measured in the field using a portable Horiba U-23 combined instrument. Water samples were collected by the two-step extraction method. 10 ml samples filtered by an inorganic paper filter and directly bottled in polyethylene bottles and the other 10 ml is filtered and acidified to 0.2% HNO₃ (0.03 ml HNO₃+9.97 ml water) for heavy metal analysis. All samples were stored at a temperature below +4°C until analysis.

LABORATORY ANALYSIS

Energy dispersive X-ray fluorescence spectrometry (EDXRF)

Major elements SiO₂, TiO₂, Al₂O₃, Fe₂O₃, MnO, MgO, CaO, Na₂O, K₂O, P₂O₅ and S and trace element V, Cr, Ni, Cu, Zn, As, Rb, Sr, Y, Zr, Nb, Sn, Cs, Ba, La, Ce, Pr, Nd, Pb and Th abundances in the sediments were determined by X-ray fluorescence in the Graduate School of Environmental Studies, Tohoku University using a PANalytical, Epsilon 5. The instrument was equipped with a Sc/W anode X-ray tube, with the goal of increased sensitivity for lighter as well as heavier elements. The instrument has a series of user-selectable secondary targets and is equipped with a liquid-nitrogen-cooled Ge solid-state high-resolution detector with a Be (8 μm) window. A three-dimensional design (or Cartesian geometry) was adopted for the instrument to eliminate the X-ray tube spectrum by polarization. Consequently, the background can be an order of magnitude lower than the traditional two-dimensional optics, resulting in much lower detection limits. The overlapping of the characteristic L lines of heavier elements with the K lines of lighter elements (a typical example is the overlap of Cd L lines on K lines) has been known as one of the major drawbacks in determining heavy elements with the EDXRF method. However, since the instrument used in this study is equipped with a 100 kV Sc/W tube, even heavy rare earth elements (from Eu to Lu) can be analyzed using the more sensitive K lines and hence is less susceptible to spectral overlapping with the K lines of lighter elements. The instrument was calibrated with 26 geological and environmental standard reference materials (Matsunami et al., 2010; Yamasaki et al., 2011; Yamasaki, 2018).

Inductively coupled plasma mass spectrometry (ICP-MS)

Trace and rare elements (Li, B, Al, Sc, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, Mo, Cd, Sb, Cs, Ba, Pb, and U) in water and soil samples were carried out using an ICP-MS PerkinElmer, ELAN 9000 equipment, in the laboratory of the Graduate School of Environmental Studies, Tohoku University. Sample preparation was performed by acid-leaching method. Half a gram of each finely ground soil sample was treated with 4 ml of perchloric acid (HClO₄) and hydrofluoric acid (HF) (1:1 mixture) in a closed polytetrafluoroethylene (PTFE) vial. The sample was dissolved with 6 ml of (HNO₃) and water (2:4 mixture) and then was treated with 8 ml of hydrochloric acid (HCl) and water (2:6 mixture). Each treatment for the sample was performed in the closed vials on a hot plate for 1 night at 140°C. After cooling, the vials were opened and then heated at 210°C until completely dry. Finally, the residue was heated with 25 ml of nitric acid (HNO₃) and water (1:10 mixture) and
dissolved by the addition of 25 ml of H$_2$O and made up to 50 ml. The final solutions were stored in plastic bottles until measurement. After a 100-fold dilution of the final solution, the acid digests were analyzed by ICP–MS for trace elements. Indium (In) was used as an internal standard (Yamasaki 1996; 2000). For the determination of In, however, rhodium (Rh) was used as an internal standard. The working standards were prepared from a series of SPEX Multi-Element Plasma Standards (XSTC-1, XSTC-7, XSTC-8, and XSTC-13 and XSTC-331) supplied by SPEX Industries (New Jersey, USA).

**Ion chromatography**

Major anions (F$^-$, Cl$^-$, Br$^-$, NO$_2^-$, NO$_3^-$, PO$_4^{3-}$, and SO$_4^{2-}$) were determined using an ion chromatography 881 Compact IC pro, Metrohm with 1% accuracy at the Graduate School of Environmental Studies, Tohoku University, Japan. The analytical error for the measurement of major ions was determined by calculating the ionic charge balance, which was within $\pm$ 5% for all samples.

**Data analysis**

Principal compound analysis (PCA) this method aid in reducing the complexity of large-scale data sets and are currently broadly used in environmental impact (Candeias et al., 2011) studies elucidate relations among variables by identifying common underlying processes (Davis, 1986; Webster and Oliver 1990; Wackernagel 1998). PCA, was performed, using JMP 12.0.1 statistical software.

**GEOLOGY AND MINERALIZATION AT THE SHUTEEN AREA**

The Shuteen area contains intermediate volcanic rocks of the Dushiin-Ovoo Formation and plutonic rocks of Shuteen pluton (also called Shuteen Complex) were emplaced over and into the Lower Carboniferous Ikh Shankhai Formation, respectively (Fig. 1). Quaternary sediments are located in the topographic lower areas. The Shuteen Complex is approximately 15x13 km in size (Fig. 1) and is characterized by co-magmatic andesitic, dacitic, and rhyolitic volcanic rocks, diorite, and granodiorite (Batkhishig, 2005; Batkhishig et al., 2010). The Shuteen pluton has a well-defined isochron age of 321 ± 9 Ma, whereas the Shuteen andesites yielded a 336 ± 24 Ma Rb–Sr whole-rock isochron age (izumi and Batkhishig, 2000; Batkhishig et al., 2010). A 325.5 ± 1 Ma U-Pb zircon age was obtained from the Shuteen quartz monzonite, and microgranite dikes that crosscut the intrusion have been dated at 325.4 ± 1 Ma (Blight et al., 2010). The Shuteen Complex contains local silicic, potassic, advanced argillic, and propylitic alteration assemblages, and weakly developed porphyry-style copper mineralization is associated with small porphyritic intrusions. Gold-bearing quartz and quartz–tourmaline veins and domains of intense alunite alteration have been found on the periphery of the main Shuteen alteration zone. (Hovan et al., 1982, 1983; Batkhishig et al., 2014). Geologic, surface geochemical, and geophysical data have revealed intensely developed hydrothermal alteration zones and weak copper porphyry mineralization locally associated with porphyritic intrusions. Several prospects of copper mineralization are recognized within the complex, including Shuteen-Khanbogd, Khar Tolgoi, Bayan Khoshuu, and Dash Sum (Fig. 1). Currently, it is concluded that the Carboniferous Shuteen Complex hosts one or more fossil magmatic-hydrothermal systems. During the early stages of magmatic-hydrothermal fluid activity, weak copper porphyry mineralization associated with potassic and propylitic alteration formed in association with the emplacement of porphyry intrusions into the Shuteen Complex. Extensive exploration activity at Shuteen has not yet identified any economic resource, only large-scale geochemical anomalies and hydrothermal alteration zones have been identified. The copper porphyry style mineralization remains to be discovered in the Shuteen area and it is likely to be concealed beneath the Shuteen lithocap (Batkhishig, 2005; Batkhishig et al., 2014).

**RESULTS**

**Soil geochemistry**

Results of geochemical analysis of the soil samples are shown in Table 1. Average contents of heavy metals in the Shuteen soil are Cu $\sim$35
| Element | Shuteen A | Shuteen B | Shuteen C | Shuteen D | Shuteen E | Average |
|---------|-----------|-----------|-----------|-----------|-----------|---------|
| As      | 1.2 ± 0.4 | 2.5 ± 0.6 | 1.8 ± 0.7 | 2.6 ± 0.5 | 2.4 ± 0.8 | 2.0 ± 0.6 |
| Cu      | 0.4 ± 0.2 | 0.3 ± 0.1 | 0.4 ± 0.2 | 0.3 ± 0.1 | 0.4 ± 0.2 | 0.3 ± 0.2 |
| Fe      | 15.2 ± 1.6 | 16.8 ± 1.9 | 15.0 ± 1.3 | 16.5 ± 1.4 | 15.4 ± 1.7 | 15.8 ± 1.6 |
| Mg      | 0.09 ± 0.03 | 0.11 ± 0.04 | 0.09 ± 0.03 | 0.10 ± 0.03 | 0.09 ± 0.03 | 0.10 ± 0.03 |
| Sr      | 0.06 ± 0.02 | 0.04 ± 0.01 | 0.06 ± 0.02 | 0.05 ± 0.02 | 0.05 ± 0.02 | 0.05 ± 0.02 |

Table 1. Major and trace element composition of the soil samples from the Shuteen area.
Table 1. Major and trace element composition of the soil samples from the Shuteen area (continued)

| Element | Sr  | Ca  | Mg  | Na  | K  | Fe  | Zn  | Cu  | Co  | Cr  |
|---------|-----|-----|-----|-----|----|-----|-----|-----|-----|-----|
| Shuteen area |     |     |     |     |    |     |     |     |     |     |
| 1 | 21.3 | 14.9 | 10.6 | 7.9 | 6.5 | 3.9 | 2.5 | 1.9 | 1.3 | 0.7 |
| 2 | 19.6 | 14.2 | 10.2 | 7.5 | 6.2 | 3.7 | 2.3 | 1.8 | 1.2 | 0.6 |
| 3 | 18.9 | 13.9 | 10.0 | 7.3 | 6.0 | 3.5 | 2.2 | 1.7 | 1.1 | 0.5 |
| 4 | 18.2 | 13.6 | 9.8 | 7.1 | 5.8 | 3.3 | 2.0 | 1.6 | 1.0 | 0.4 |

As | 10.4 | 12.2 | 13.2 | 13.2 | 13.2 | 13.2 | 13.2 | 13.2 | 13.2 | 13.2 |

Ba | 90.0 | 90.0 | 90.0 | 90.0 | 90.0 | 90.0 | 90.0 | 90.0 | 90.0 | 90.0 |

Table continues...
Fig. 4. Heavy metal contents vs SiO$_2$ diagram for the Shuteen area.
Fig. 4. Heavy metal contents vs SiO₂ diagram for the Shuteen area (continued).
The geochemical composition of the soil is uniform throughout the area (Fig. 5). Moreover, the Shuteen soil geochemical results are compared to the results of the 1:1000000 geochemical mapping project’s data (1:1000000 Geochemical, 2012). It is the geographically closest and comparable data in the South Gobi region; the Shuteen area is located in the northern edge of their study area. We have selected data from the geochemical mapping project which are the closest to our study area, but not completely covered the same area. Basically, results do not show much difference, but our data is higher in Cu, Mo, As, Ni and Sr, the same in Zn, Cd, Co, Cr and V contents and Pb and Sn are lower than Geochemical mapping data (Fig. 4; Batkhishig et al., 2017b; 1:1000000 Geochemical, 2012).

**Water geochemistry**

Table 2 shows the general characteristics of drinking and livestock water wells and natural springs located in the Shuteen area. The heavy
Table 2. General characteristics of river water in Shuteen area, 2016

| Sample numbers | Water temperature at sampling (°C) | Alkaline properties (pH) | Electrical conductivity (EC) | Note |
|----------------|-----------------------------------|--------------------------|----------------------------|------|
| SH01_ws        | 25.4                              | 9.05                     | 0.44                       | An old well for watering livestock. Not used for drinking water |
| SH20_ws        | 23.9                              | 9.02                     | 0.09                       | Old abandoned well. Not used for drinking water |
| SH49_ws        | 13.7                              | 9.17                     | 0.31                       | Motor well for drinking water |
| SH47_ws        | 9.07                              |                          |                            | Zuun Khujirtiin Shand well, depth is 1.5 m |
| SH48_ws        | 9.04                              |                          | 0.03                       | Livestock well, depth is 2 m |
| SH42_ws        | 9.85                              |                          | 0.05                       | Hand motor drinking well |
| SH16_ws        | 9.07                              |                          | 0.2                        | Small natural springs |
| SH14_ws        | 8.99                              |                          | 0.02                       | Newly developed drinking well |
| SH53_ws        | 17.8                              | 9.01                     | 0.01                       | Winter camp drinking well depth of the well is 1.5 m |
| **Average**    | **20.2**                          | **9.14**                 | **0.13**                   |      |

Table 3. Heavy metals (ug/L) and anion contents (ppm) of the water samples, Shuteen area

| 1 Elements | SH42_ws | SH47_ws | SH53_ws | SH49_ws | SH48_ws | SH16_ws | SH20_ws | SH14_ws | SH01_ws |
|------------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| Li         | 27.39   | 15.30   | 14.44   | 32.77   | 27.05   | 28.81   | 19.58   | 18.16   | 13.40   |
| Sc         | 5.23    | 6.25    | 9.09    | 14.20   | 6.82    | 6.23    | 8.31    | 6.96    | 5.71    |
| Cr         | 4.33    | 4.96    | 6.40    | 4.81    | 5.30    | 4.28    | 3.61    | 4.91    | 3.99    |
| Mn         | 25.77   | 3.91    | 204.73  | 3.88    | 4.68    | 41.82   | 41.64   | 3.39    | 97.39   |
| Co         | 0.33    | 0.22    | 1.80    | 0.13    | 0.23    | 0.77    | 0.22    | 0.16    | 0.32    |
| Ni         | 6.05    | 2.77    | 11.19   | 1.89    | 4.30    | 7.72    | 2.20    | 2.89    | 4.75    |
| Cu         | 4.02    | 5.98    | 43.99   | 5.14    | 6.21    | 7.54    | 3.09    | 6.16    | 2.51    |
| Hg         | 3.64    | 4.75    | 43.37   | 2.98    | 5.03    | 7.30    | 2.88    | 5.38    | 2.39    |
| Zn         | 3.75    | 5.93    | 11.51   | 5.79    | 11.04   | 5.63    | 3.56    | 7.74    | 3.94    |
| Ga         | 1.05    | 0.50    | 1.51    | 0.28    | 0.40    | 1.67    | 0.74    | 0.69    | 0.64    |
| As         | 7.87    | 12.34   | 22.16   | 536.84  | 24.42   | 7.70    | 9.26    | 15.92   | 1.91    |
| Rb         | 0.64    | 1.52    | 2.21    | 4.44    | 0.89    | 0.96    | 0.45    | 0.35    | 0.48    |
| Y          | 0.04    | 0.12    | 0.28    | 0.07    | 0.08    | 0.08    | 0.07    | 0.03    | 0.05    |
| Mo         | 24.58   | 106.04  | 188.58  | 19.76   | 51.82   | 63.98   | 45.21   | 45.54   | 10.09   |
| Cd         | 0.11    | 0.44    | 0.89    | 0.08    | 0.31    | 0.28    | 0.20    | 1.26    | 0.05    |
| Sb         | 0.09    | 0.13    | 0.24    | 0.46    | 0.39    | 0.26    | 0.12    | 0.15    | 0.09    |
| Cs         | 0.00    | 0.01    | 0.01    | 0.06    | 0.01    | 0.01    | 0.00    | 0.00    | 0.07    |
| Ba         | 49.66   | 19.60   | 74.05   | 8.34    | 13.78   | 84.34   | 36.60   | 31.32   | 29.19   |
| Pb         | 0.15    | 0.25    | 0.52    | 0.15    | 0.23    | 0.16    | 0.14    | 0.16    | 0.13    |
| U          | 18.25   | 34.88   | 33.68   | -       | 25.48   | 36.93   | 5.04    | 35.18   | 6.67    |

F⁻, Cl⁻, NO₂⁻, Br⁻, NO₃⁻, PO₄³⁻, SO₄²⁻

nd—not detected
metals and anion contents of the water samples are summarized in Table 3.
Fig. 6 shows a diagram comparing the content of F, Cl, NO$_2^-$, Br, NO$_3^-$, PO$_4^{3-}$, SO$_4^{2-}$ with the Mongolian drinking water quality and safety assessment standard (MNS 0900: 2005; MNS, 1992). Water samples from the Shuteen area show an average temperature of 20.2°C, pH 9.14, and electric conductivity 0.13. Generally, the water samples contain F above the permissible limit guided in Mongolian National Standard (MNS) on drinking water quality (MNS 5850:2008). However, Cl, NO$_2^-$, Br, NO$_3^-$, PO$_4^{3-}$, SO$_4^{2-}$ are within the permissible value (Batkhishig et al., 2017a,b).
Mongolia has a harsh continental climate, with four seasons that make differences in water quality. As well, the water compositions different due to geographic locality, especially in the Gobi region, low alkalinity and high saline water are due to the high carbonate content of the soil. Although only 2-3 wells of regularly used drinking water have been surveyed, the sample number SH49 ws from a
Fig. 7. Comparison of the drinking water standard of Mongolia with a heavy metal content of water samples from the wells in the Shuteen area. The red line shows the permissible limit of drinking water (Batkhishig et al., 2017b).
motor drinking water well show relatively standard composition.

Fig. 7 shows the content of some heavy metals in the drinking and livestock wells water in the Shuteen area. Heavy metal contents of Cu, Cr, Pb and Zn are much lower, and Mo and Ba are close to the permissible limit, whereas As and U are higher than the guided limit of Mongolian National standard (MNS 5850:2008). Those higher concentrations of U, As, and F in water samples may have related to the South and Eastern Mongolian U, Pb-Zn and CaF₂ metallogenic belts. The water quality concern is the salinity with the occasional occurrence of trace elements like As, and F (Batkhishig et al., 2017a,b).

DISCUSSION

Heavy metal concentration correlation between rock and soil

According to Hovan et al., lithogeochemical (rock chips) anomalies of <100–200 ppm Cu and <10-20 ppm Mo are considered at the Shuteen area (Hovan et al., 1982; 1983; Batkhishig et al., 2014), whereas ongoing project of 1:50000 scale geological mapping work used geochemical baseline limit of soil as Cu is ~70 ppm and V is ~95 ppm in the Manlai area, including Shuteen (unpublished data). The Cu content of the soil compared with the Cu content of the volcanic and plutonic rocks in the area, where yielded similar content between them (Fig. 8A). It indicates there is no late enrichment of heavy metals in soil associated with mineralization. The basic and intermediate composition rocks (diorite, granodiorite, and andesite) in the Shuteen area are mostly affected by hydrothermal alteration and associated with mineralization. Although vanadium (V) content is not directly related to the copper mineralization of the Shuteen, it is considered that the high content of V in the soil than guided standard limit, can be explained by basic and ultrabasic rocks in the Manlai region (Fig. 8B).

Soil natural geochemical baseline

A multivariable analysis and factor analysis are useful to understand the nature of the background of heavy metals. To understand a natural background of heavy metals, especially Cu and Mo (or V) related to mineralization of the area is described using principal compound analysis (PCA) of major and trace element composition of soil in Shuteen area is described below. There were 8 principal compounds obtained by PCA statistical analysis using the element concentrations of the soil samples (Table 4). Three principal compounds were considered for discussion (Fig. 9). Principal compound 1 (PC1), explaining 38.4% of the total variance, defines two groups of variables: Sn, Pb, Nb, As, positively related, in opposition to Al₂O₃, CaO, Cu and Sr variables, with high negative SiO₂ and Na₂O loadings. Principal compound 2 (PC2), explaining 15.1% of the total variance, defines variables: K₂O, Rb, Th Cs positively related, in opposition to As, MnO and Mo variables. Principal compound 3 (PC3), explaining 13% of the total variance, defines variables: positively related Pb, Zn, Sb, and Sn elements (Fig. 9).
Table 4. Result of correlation between major and trace elements in soil of the Shuteen area. Red color indicates positive and blue color indicates a negative correlation.

PC1 is representing the host rock composition of the Shuteen area. SiO₂ and Na₂O exhibit negative (unique characteristic), whereas other elements were positive (Fig 9; Table 4). There are two possibilities to explain the negative SiO₂ and Na₂O oxides. (1) High amount of SiO₂ and Na₂O oxides suggest the host rock weathering in the area. The host rocks in the Shuteen area
Fig. 9. Comparative diagram of the main three compounds described in the Shuteen soil geochemistry. Scatters of the representative elements contained in the soil of each Compound. Confidence coefficients: Compound 1 - 38.4%, Compound 2 - 15.1%, Compound 3 - 13%.

comprised intermediate to felsic (SiO$_2$ > 64%) volcano-plutonic rocks with adakitic affinity (mostly plagioclase porphyritic-Na feldspar), silica lithocap, quartz stockworks, and widespread quartz veins. Those rocks can be responsible for weathering soil surfaces with a high amount of SiO$_2$ and Na$_2$O. (2) The other possibility is concerning to a dry environment and climate characteristics of the Gobi region. An evaporation of NaCl and quartz vein or quartzite is unrestricted.

PC2 is may have represented hydrothermal alteration of the Shuteen area (Fig 9; Table 4). The high-temperature, magmatic alterations in the copper mineralized Shuteen Complex consist of mineral assemblages including plagioclase, biotite, and quartz. Besides, high-temperature, hydrothermal alterations are characterized by silicification, argillic, propylitic alteration, including quartz/chaledony, alunite, hematite and kaolinite. Besides, the temperature series matches field observation, for instance, at high-temperature hydrothermal alteration assemblages include quartz, alunite, andalusite, hematite and kaolinite, whilst at lower temperature chalcedony, kaolinite and pyrophyllite formed (Batkhishig, 2005). According to PC2, K, Ba and Rb and subsequent Cs and Th enriched in hydrothermal alteration may have indicated potassic alteration which is indicative of the porphyry type mineralization.

PC3 shows positive Mo, Pb, Zn, Sb and Sn elements, that are represented mineralization characteristics of the Shuteen area (Fig 9; Table 4). Mo and Sn are indicative of high-temperature mineralization, whereas Pb, Zn and Cu are for the moderate-temperature mineralization. The main mineralization type of the Shuteen is porphyry copper mineralization, however interesting that the Cu did not appear positive by the PCA. On the other hand, in Fig. 4, all data of Cu in Shuteen are higher than those of soil results of the 1:1000000 geochemical mapping project (1:1000000 Geochemical, 2012), and lithogeochemical anomalies of <100 – 200 ppm Cu are distinguished (Hovan et al., 1982; 1983). Therefore, in the general meaning, a positive Cu anomaly is demonstrated in this area. Mo is generally not positive and some points show very high concentration up to 4 ppm, and Pb and Zn are also negative and As is also high in the Shuteen Complex (Fig. 4). Those geochemical anomalies indicate the following: (1) Low Pb and Zn anomalies indicate that Shuteen is a porphyry copper deposit, not a hydrothermal (or epithermal) vein-type deposit. (2) Mo is a high-temperature element than Cu, but the Mo concentration anomaly is not so clear in Fig. 4, but in the PCA, Mo shows a high value which means there are some effects of Mo in Shuteen. (3) Cu concentration associated with As is obvious and it was caused by porphyry copper mineralization (high-temperature mineralization), not epithermal (low to middle temperature) mineralization. (4) The current surface shows some effects of Cu mineralization, but the main body may be in the subsurface (relatively high concentration but PCA is negative) and Mo is a much deeper zone than Cu.

Copper mineralization can occur with all three (high, moderate and low temperature) levels of hydrothermal events. In the case of copper mineralization is associated with low-temperature mineralization, the main ore body
may be weathered or in contrast, if the copper mineralization is associated with high and medium-temperature alteration, the ore body may be at significant depth. This suggestion is consistent with the previous study of the present-day erosion level at Shuteen is relatively shallow, implying that economic porphyry-style mineralization may exist at depth within or beneath the Shuteen lithocap (Batkhishig et al., 2014).

CONCLUSION

The environmental assessment results show that the heavy metal content of the soil in the Shuteen area does not exceed the permissible limit of the Mongolian National standard on soil quality. The Shuteen soil geochemistry reveals the geochemical characteristics related to the geology and mineralization of the host rocks, alteration, and mineralization widespread throughout the area, without mechanical contamination.

Whereas, the water samples contain F- above the permissible limit guided in Mongolian National Standard on drinking water quality. The chemical composition of the water (elevated content of Cl, F and As) is due to the Gobi region.

These environmental assessment surveys determine the characterization of an aerial geochemical base prior the development of later exploration or mining project, and establish the initial environmental status.

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REFERENCES

Altansukh, O. 2008. Surface Water Quality Assessment and Modelling: A case study in the Tuul River, Ulaanbaatar city, Mongolia. MSc thesis, International Institute for Geo-Information Science and Earth Observation, Enschede, the Netherlands, 87 p.

Batkhishig, B. 2005. Magmatic-Hydrothermal System of the Shuteen Mineralized Complex, South Gobi, Mongolia. PhD thesis, Tohoku University, Japan.

Batkhishig, B., Munkhtsengel, B., Manzshir, B. Soyolmaa, B., Otgonbayar, D. 2017a. Pre-mining environmental assessment of the Shuteen area, South Mongolia Goldschmidt Abstract

Batkhishig, B., Munkhtsengel, B., Manzshir, B., Soyolmaa, B., Otgonbayar, D. 2017b. Environmental geochemistry related to geological and mining activity 2016-2017. ADB funded research project, Ulaanbaatar, Mongolia, 71 p.

Batkhishig, B., Tsuchiya, N., Bignall, G. 2010. Magmatism of the Shuteen Complex and Carboniferous subduction of the Gurvansaikhan terrane, South Mongolia, Journal of Asian Earth Sciences, v. 37, 399-411. https://doi.org/10.1016/j.jseaes.2009.10.004

Batkhishig, B., Tsuchiya, N., Bignall, G. 2014. Magmatic-Hydrothermal Activity in the Shuteen Area, South Mongolia, Economic Geology, v. 109, 1929–1942. https://doi.org/10.2113/econgeo.109.7.1929

Battogtokh, B., Lee, J. M., Woo, N. 2014. Contamination of water and soil by the Erdenet copper-molybdenum mine in Mongolia. Environmental Earth Sciences. v. 71, p. 3363-3374. https://doi.org/10.1007/s12665-013-2727-y

Blight, J.H.S., Crowley, Q.G., Petterson, M.G., Gunningham, D. 2010. Granites of the Southern Mongolia Carboniferous Arc: New geochronological and geochemical constraints: Lithos, v. 116, p. 35-52. https://doi.org/10.1016/j.lithos.2010.01.001

Bolor-Erdene, D., Norjinbadam, S., and Davaasambuu, D. 2001. Chemical and bacteriological pollution of surface water in Khangal River basin. Mining journal of Mongolia, Erdenet city (in Mongolian).

Byamba, B., Todo, Y. 2011. Impact Of Placer Gold Mine Technology On Water Quality: A Case Study Of Tuul River Valley In The Zaamar Goldfield, Mongolia. WIT Transactions on Ecology and the Environment, v. 145, p. 308-318. https://doi.org/10.2495/WRM110261

Candeias, C., Ferreira da Silva, E., Salgueiro, A.R., Pereira, H.G., Reis, A.P., Patinha, C., Matos, J.X., A´vila, P.H. 2011. The use of
multivariate statistical analysis of geochemical data for assessing the spatial distribution of soil contamination by potentially toxic elements in the Aljustrel mining area (Iberian Pyrite Belt, Portugal) Environmental Earth Sciences, v. 62, p. 1461–1479. https://doi.org/10.1007/s12665-010-0631-2

Davis, J.C. 1986. Statistics and data analysis in geology, 2nd edn. Wiley, New York

Hovan, M., Gregush, Ya., Gladil, I., Moravek, R., Delgertsoogt, B., 1983. Result of geological prospecting work on the Shuteen volcano-plutonic structure in Alagbayan horst, South Gobi district. Geological Report 46, Geo-Information Center, Ulaanbaatar, Mongolia, 125 p. (in Russian).

Hovan, M., Gregush, Ya., Moravek, R., Delgertsoogt, B., Lukaya, P. 1982. Result of geological prospecting work on the Hunguit-Shuteen ore district, Tsohiot, Alagbayan, Narangijn Hudag ore mineralization area. Geological Report 35, Geo-Information Center, Ulaanbaatar, Mongolia, 152 p (in Russian).

Iizumi, S., Batkhishig, B. 2000. Petrology of Carboniferous Shuteen Pluton in the South Gobi Fold Belt, South Mongolia. Abstracts, The 107th Annual Meeting of the Geological Society of Japan, 319.

IRIMHE, 2008. Information and Research Institute of Meteorology, Hydrology and Environment, http://irimhe.namem.gov.mn/

Jachek, M. 2005. Ecological study of Erdenetiin Ovoo Cu-Mo deposit. Geology, journal of School of geology, Mongolian University of Science and Technology. No13, p. 200-205.

Jachek, M., Furih, V., Koprshiva, A., Orlitova, M., Kominek, E. 2005. Ecological assessment of mining of the Erdenet Cu-Mo deposit, Mongolia, Report by GEOMIN Cooperation, Iglava, Czech Republic (in Russian).

Matsunami, H., Matsuda, K., Yamasaki, S. I., Kimura, K., Ogawa, Y., Miura, Y., Tsuchiya, N. 2010. Rapid simultaneous multi-element determination of soils and environmental samples with polarizing energy dispersive X-ray fluorescence (EDXRF) spectrometry using pressed powder pellets. Soil Science and Plant Nutrition, 56(4), p. 530-540. https://doi.org/10.1111/j.1747-0765.2010.00489.x

Mongolian National Standard of drinking water quality. 1992. The National Authority of Mongolian Standard and Metrology (in Mongolian).

Mongolian National Standard, MNS 3298:90. 1991. Environmental protection and soil. Requirements for sampling. Ulaanbaatar, Mongolia, 1991. 5 p. (in Mongolian).

Mongolian National Standard, MNS 5850:2008. Soil quality: soil pollutant elements and substance. Ulaanbaatar, Mongolia, 2008. 6 p. (in Mongolian).

Mongolian National Standard, MNS-0900:2005. Drinking Water quality. Hygienic requirements, and assessment of quality and safety, Ulaanbaatar, Mongolia, 2005. 11 p. (in Mongolian)

Munkhtsengel, B., 2007, Magmatic and mineralization processes of the Erdenetiin Ovoo porphyry copper-molybdenum deposit and environmental assessment, Northern Mongolia: Japan, Tohoku University, Unpublished Ph.D. thesis, 195 p. https://doi.org/10.1111/j.1747-0765.2010.00489.x

Munkhtsengel, B., Ohara, M., Gerel, O., Dandar, S., Tsuchiya, N. 2006. Preliminary Study of Formation Mechanism of the Erdenetiin Ovoo Porphyry Copper-Molybdenum Deposit and Environmental Effects of Erdenet Mine, Northern Mongolia AIP Conference Proceedings 833, p. 204. https://doi.org/10.1063/1.2207106

Namkhai D. 2000. Report of detailed environmental assessment of the Erdenet mining activity, V.1-3. ENKO, Ulaanbaatar (in Russian)

Wackernagel, H. 1998. Multivariate geostatistics: an introduction with applications, 2nd edn. Springer, Berlin https://doi.org/10.1007/978-3-662-03550-4

Webster, R., Oliver, M.A. 1990. Statistical methods in soil and land resource survey. Oxford University Press, Oxford

Yamasaki S.I. 1996. Mass Spectrometry of Soils (edited by Thomas W. Boutton), Dekker, Inc. New York, Marcel, p. 459-491.

Yamasaki, S. 2018. Simultaneous Determination of Trace Elements in Environmental and
Geological Samples by Polarizing Energy Dispersive X-ray Fluorescence Spectrometry. In X-ray Fluorescence: Technology, Performance and Applications (Fonseca, R. Ed.), p. 1-46, Nova Science Publishers, USA.

Yamasaki, S.I. 2000. Soil analysis by ICP-MS (review) Bunseki Kagaku, v. 49(4), p. 217-224. https://doi.org/10.2116/bunsekikagaku.49.217

Yamasaki, S.I., Matsunami, H., Takeda A., Kimura, K., Yamaji, I., Ogawa, Y., Tsuchiya, N. 2011. Simultaneous Determination of Trace Elements in Soils and Sediments by Polarizing Energy Dispersive X-ray Fluorescence Spectrometry Bunseki Kagaku, v. 60(4), p. 323. https://doi.org/10.2116/bunsekikagaku.60.315

1:1 000 000 Geochemical mapping project the China-Mongolian Boundary Area, 2012.