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Biogeochemical Orientation Exploration Surveys in Some Rare Metal Deposits in Korea: Case Histories

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ABSTRACT

Biogeochemical orientation exploration surveys were applied in the vicinity of some rare metal deposits in Korea: epithermal Au veins, Fe-Pb-Zn skarn, Mo skarn, U deposits in black shale and Sn-bearing pegmatite veins. The main objectives were, firstly, to study the geochemical characteristics of rocks, soils and plant organs in target (mineralized) and control areas, secondly, to investigate the spatial relationship between the main ore metals and associated elements in the soil–plant system, and finally, to evaluate the applicability of biogeochemical orientation prospecting for mineral occurrences. Composite samples of plant organs and soils were collected both along the traverse lines crossing the underlying orebodies of each target area and control barren locations, and were analyzed for ore metals and related trace elements by INAA and/or ICP-MS. Concentration levels of ore metals and related elements in soil and plant organs and their correlations were compared between target and control areas, and geochemical variations in soil and plants were investigated spatially crossing over the known orebodies in each case history. The BAC (biological absorption coefficient) of the associated elements in plants was calculated to denote the potential indicator plants, and the applicability of biogeochemical techniques was briefly summarized in five case histories.

INTRODUCTION

Biogeochemical exploration is a prospecting technique for subsurface ore deposits based on the interpretation of the growth of certain plants which reflects subsoil concentrations of some elements. Chemical analysis of plant tissues is to assess the presence and nature of underlying mineralization and bedrock composition. In Korea, preliminary vegetation geochemical studies on metallic ore deposits were started for the first time during 1965-1973 by Chung (e.g., Chung, 1971). After that, studies on the application of vegetation geochemistry to detection of metallic ores have been very few in Korea before Chon (2010, 2011) carried out the research projects on the application of biogeochemical orientation exploration techniques to rare metals, which were funded by Korea Resources Corporation (KORES).

The main purposes of this study were, firstly, to study the geochemical characteristics of rocks, soils and plant organs in target (mineralized) and control areas, secondly, to investigate the spatial relationship between the main ore metals and associated elements around orebodies, and finally to evaluate the applicability of the biogeochemical prospecting method for rare metal occurrences in study areas. Composite samples of plant organs and soils were collected both along the traverse lines crossing the underlying orebodies of each target area and from control barren locations, and were analyzed for ore metals and related trace elements by INAA and/or ICP-MS.

Five case histories of the author's projects will be summarized briefly as follows (Chon, 2010, 2011; Jeong et al., 2011; Jeon et al., 2012; Kim et al., 2013; Park et al., 2014; Chon et al., 2012).

CASE HISTORIES

Moisan Epithermal Au Veins, Haenam District

The Au-Ag bearing quartz veins of the mine occur as narrow open-space fillings within Cretaceous silicic pyroclastics. The vein minerals consist mainly of quartz, sericite, pyrite, chalcopyrite and galena with some electrum and argentite. Samples of rocks, soils and leaves of three plant species (Japanese red pine - *Pinus densiflora Siebold*-, oriental white oak - *Quercus aliena Blume*-, Japanese mallotus - *Mallotus japonicus (Thunb.) Muell. Arg*-) were collected from the vicinity of Au veins and the control areas. Sampling lines included one slope line which is almost parallel to the mineralized quartz-veins, and four transect lines spaced 100 m apart across the veins with sampling intervals of 20 m (Figure 1).

From the multi-element data of rock samples (n = 9), high values of Au (maximum 2,030 ppb) are spatially related to Au-quartz veins. Soil samples (n = 61) collected from five sampling lines show higher values of Au (range of 24–825 ppb) whereas soil samples from the control areas have lower values of Au (below 25 ppb). Many plant species collected from the vicinity of the veins yielded high Au contents compared to those in the control areas (Figure 2), but the ranges of Au values are variable among plant species. In a total of 128 samples of plant leaves, oriental white oak yields Au values of 0.4 ppb to 6.9 ppb, and Japanese mallotus 0.9 ppb to 4.1 ppb. Gold contents in Japanese red pine have a range from 0.1 ppb to 5.6 ppb. Plant leaves from the control areas contain less than 1.6 ppb Au.

The biological absorption coefficient (BAC) of Au in plants decreases in the order of oriental white oak > Japanese red pine

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> Japanese mallotus (Table 1). Accordingly, oriental white oak is potential indicator plant in study areas.

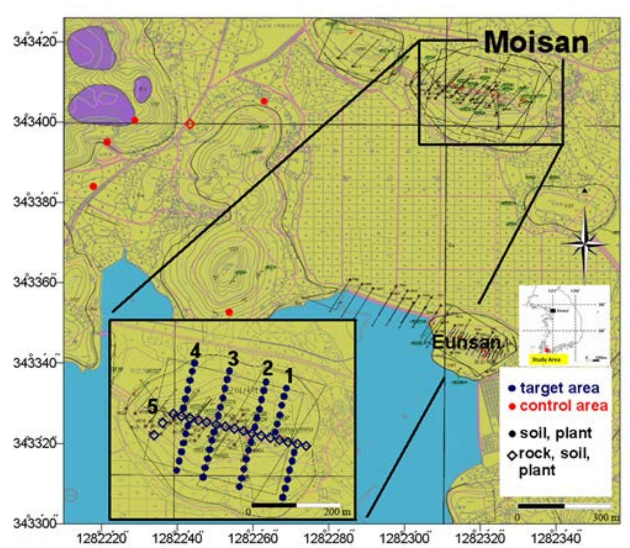


Figure 1: Location map and sample sites, Eunsan mine area, Haenam, Korea. Line 5 is a sampling line along the ridge slope on which Au-bearing quartz veins are localized almost parallel to the line. Lines 1–4 are transect sampling lines across the Moisan vein.

		Pine (n=61)[a]	White oak (n=71)	Mallotus (n=6)
Au	Range	0.000 – 0.303	0.011 – 0.997	0.024 – 0.070
	Mean	0.061	0.121	0.051
As	Range	0.010 – 1.170	0.010 – 0.220	0.100 – 0.380
	Mean	0.107	0.097	0.224

[a] n = number of samples.

Table 1: BAC values of each plant species.

Ildong Fe-Pb-Zn Skarn, Jeongseon District

The orebodies occur within skarn at contacts between limestone and diorite. Around the mine area, about seven orebodies are localized with their individual characteristics. Among them, A orebody, B orebody and Eungok orebody were targets in this study.

Sampling was conducted along four traverse lines over three orebodies and control areas (Figure 3). A total of 12 rock, 64 soil, and 320 plants samples (including three species such as Daimyo oak leaves/branches - *Quercus dentata*, Ash tree leaves/branches -*Fraxinus rhynchophylla Hance*, and Japanese red pine leaves -*Pinus densiflora Siebold & Zucc.*) were collected.

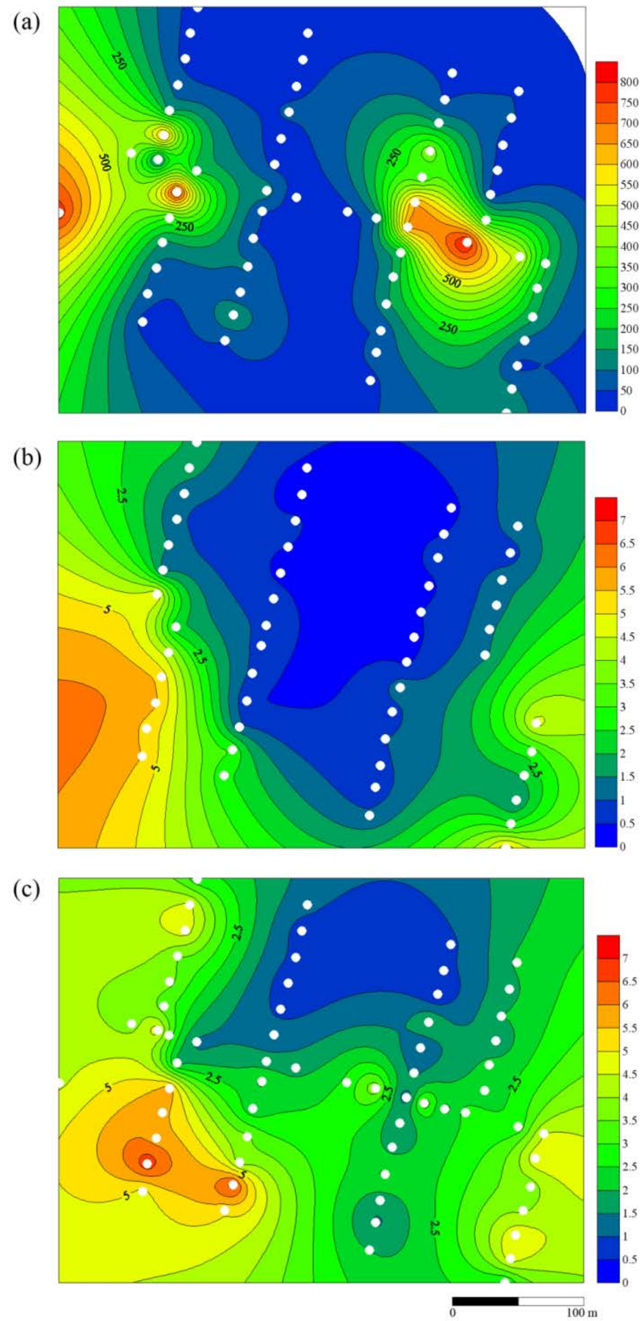


Figure 2: a) Contour map for Au (unit in ppb) in soil; b) Japanese red pine; c) and oriental white oak.

The contents of Cu, Pb, Zn, Mn, Cd, As and Mo in soil from target areas (n = 56) were 2–4.5 times higher than those from control areas (n = 8). However, there were no specific contrasts of element contents in plant samples (each n = 56) except for both Pb in *Q. dentata* leaves (0.45–54.93 mg/kg Pb) and branches (0.73–25.89 mg/kg Pb), and Cd in *P. densiflora* leaves (0.06–4.08 mg/kg Cd) as shown in Figure 4. BAC for each plant samples was low except for Cd and Mo which show 0.214 and 0.149 in *P. densiflora*, respectively. Also, element contents in soils and *P. densiflora* leaves are positively correlated and these geochemical variations of Cd and Mo show similar trends (Figure 5).

In summary, *P. densiflora* leaves showed the potential to be a Cd and Mo indicator in these types of deposits.

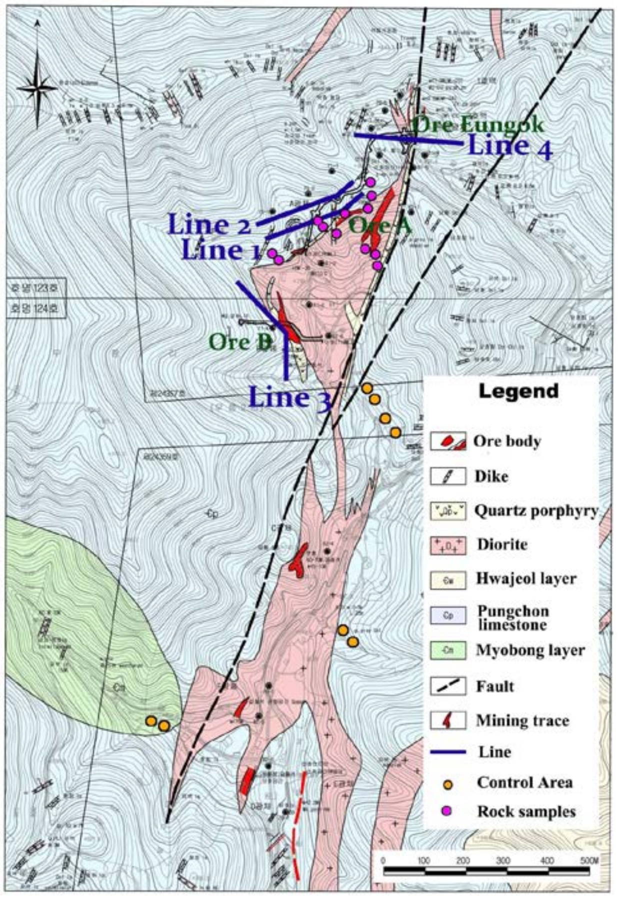


Figure 3: Geology and sampling location map in Ildong mine.

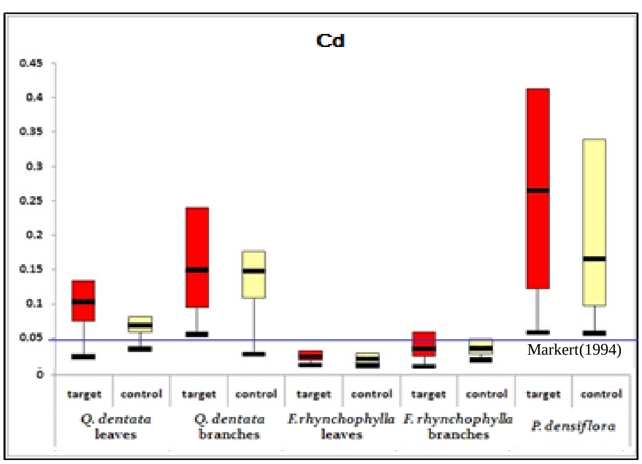
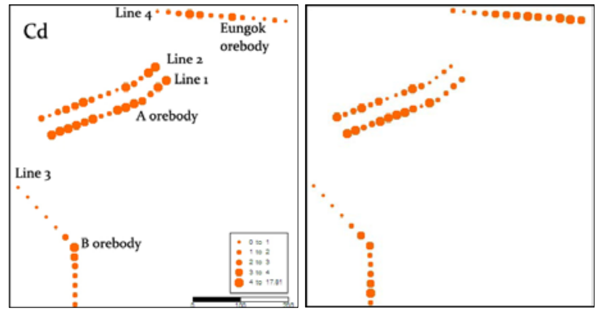


Figure 4: Concentration level of Cd in plants collected from target and control areas.



(a) (b)

Figure 5: a) Spatial distribution of Cd in soil; and b) *P. densiflora* leaves.

Low-Grade U Ores in Black Shale, Goesan District

Low-grade U deposits occur in black shale, which occurs within metasediments of the Guryongsan formation. The black shale member is impregnated with U minerals typical of black shale-type of mineralization. The orebodies extend for about 6.2 km, with an average thickness of 6.21 m and an average grade of 0.044% U_3O_8 (Kim et al., 2013).

Sampling was performed two times along three survey lines, each comprising 15 sampling points at 30 m intervals (Figure 6). Daimyo oak (*Quercus dentata*) leaves and twigs, Japanese red pine (*Pinus densiflora*) twigs and soils were collected at each sampling site, and the same kinds of samples from five points were taken in the control area.

Uranium concentration levels in soils vary from 2.7 to 694 ppm (mean 91.8 ppm). In plant samples, U concentrations in *Quercus dentata* leaves and twigs and in *Pinus densiflora* twigs range from 0.007 ppm to 2.687 ppm (mean 0.160 ppm), from 0.002 ppm to 0.53 ppm (mean 0.037 ppm) and from 0.002 to 0.2 ppm (mean 0.014 ppm), respectively.

In general, elevated values along profiles of uranium concentrations in soil and plant samples coincide relatively well with the uranium mineralized zone, although they do not coincide so well with the mineralized zone at some points, possibly due to downward displacement of soil (Figure 7). *Quercus dentata* twigs are thought to be useful as biogeochemical media in low-grade uranium exploration in the study area.

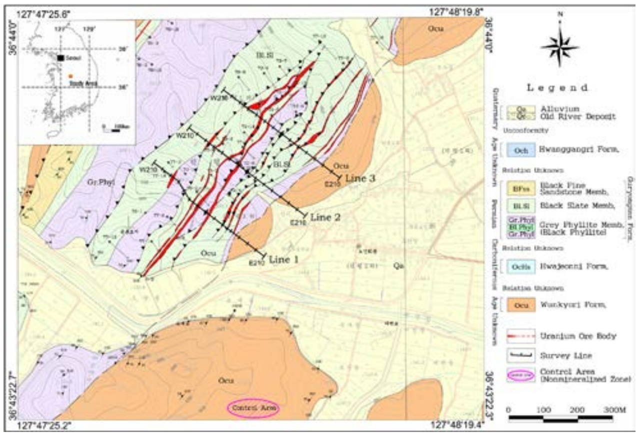


Figure 6: Regional geological map of the Goesan District study area.

NMC Moland Mo Skarn, Jecheon District

The main lithologies of the study area are Ordovician dolostone, limestone and calc-silicate rocks intruded by 'Jurassic Jecheon biotite granite'. The skarn zones occur at the contacts of granite and limestone. Molybdenum mineralization occurs in fracture zones in skarns within the screen and in disseminated form. The skarn ore minerals are mainly molybdenite, scheelite, galena and chalcopyrite. The control area is Gwanak Mountain where the Seoul National University is located, and the geology is mainly Jurassic granite with no Mo mineralization. The samples of soils and two plant species (Daimyo oak leaves/branches - *Q. dentata*, and Sargent cherry leaves - *P. sargentii*) were collected from the target area and control area (Figure 8).

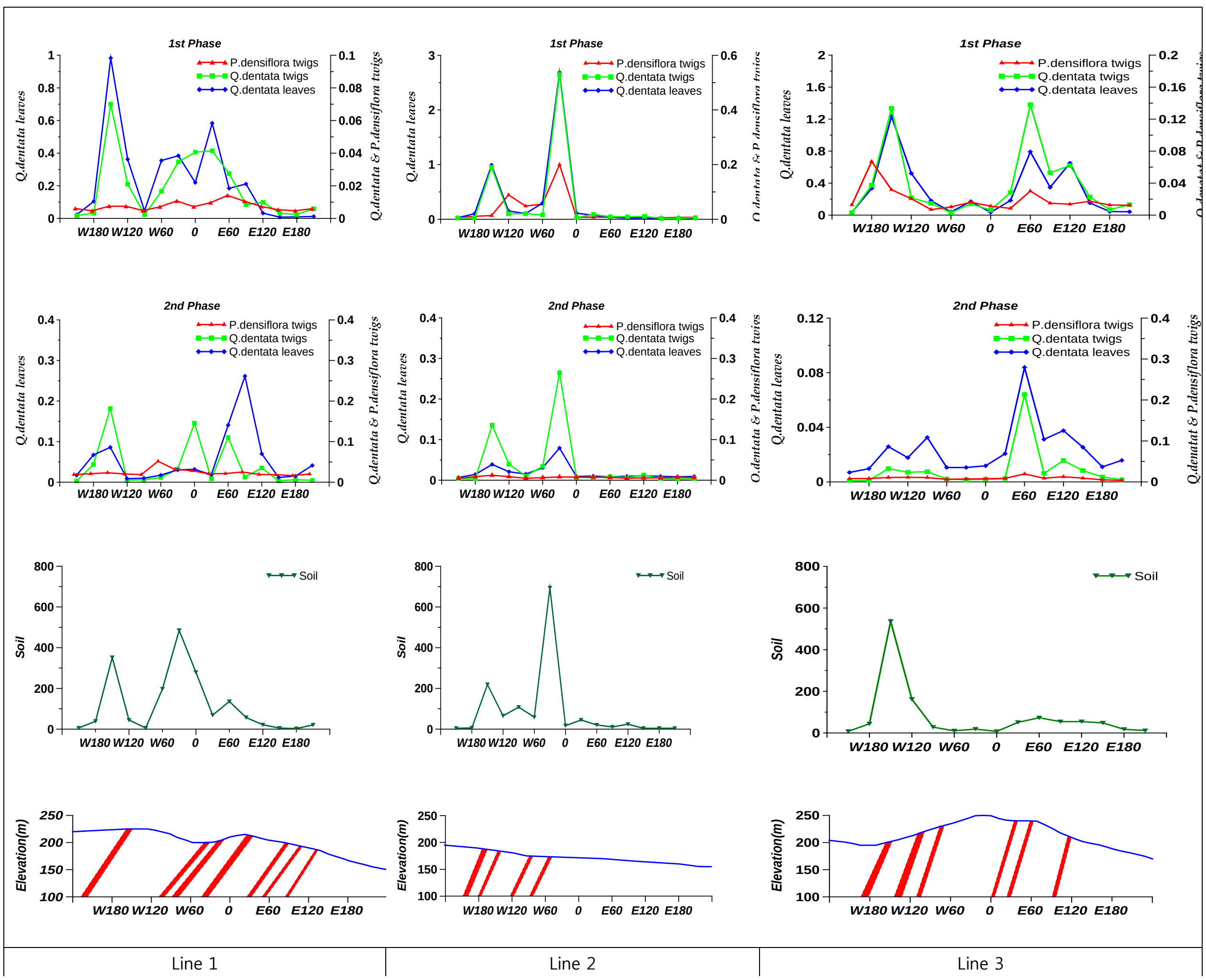


Figure 7: Profiles of U for each line. a) Line 1, b) Line 2, and c) Line 3. i) Plant samples (1st phase), ii) Plant samples (2nd phase), iii) Soil samples and iv) Geologic section (red striped band: U mineralized zone).

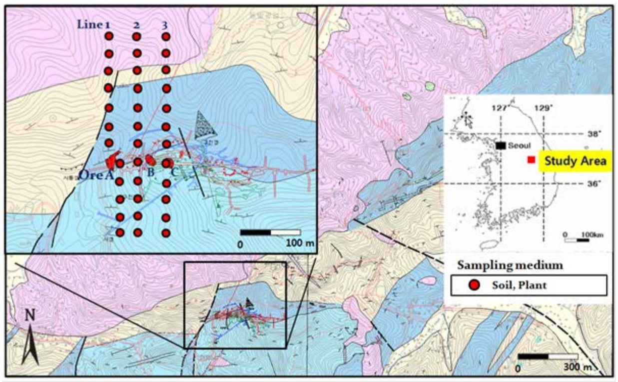


Figure 8: Sampling location map of the study area, NMC Moland mine, Jecheon, Korea.

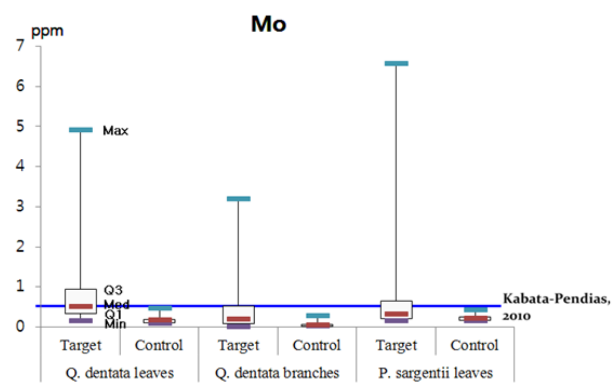


Figure 9: Box plot of Mo concentration in plant samples.

Each of three sampling lines was designed to cross over each underlying orebody at 30 m spacing in the study area, and 10 sampling points were chosen randomly in the control area. The soil samples (n = 36/10, target/control) collected from the target area show higher values of Mo (<0.1–38.7, median: 1.5 ppm) than those from the control area (<0.1–3.2, median: 0.9 ppm Mo). The concentration of Mo in plants (n = 108/30, target/control) from the target area (0.51 ppm in *Q. dentata* leaves, 0.19 ppm in *Q. dentata* branches and 0.31 ppm in *P. sargentii* leaves) is 1.5–5 times higher than that from the control area (0.16 ppm in *Q. dentata* leaves, 0.04 ppm in *Q. dentata* branches and 0.21 ppm in *P. sargentii* leaves) as shown in Figure 9.

The BAC of Mo is generally high (*Q. dentata* leaves = 1.4, *Q. dentata* branches = 0.4 and *P. sargentii* leaves = 1.2), and Mo content in soils and plants is strongly correlated. The geochemical variation patterns of Mo in plants are similar to those in soils, which suggest a corresponding Mo anomaly and enhanced contrast near the Mo orebodies (Figure 10). The three plant organs (*Q. dentata* leaves, branches and *P. sargentii* leaves) have high possibilities to be used as indicators for the biogeochemical prospecting of Mo.

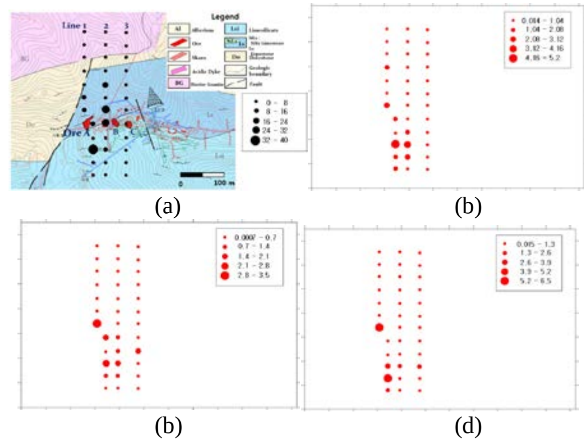


Figure 10: Spatial distribution of Mo by sampling medium. a) Soil; b) *Q. dentata* leaves; c) *Q. dentata* branches; d) *P. sargentii* leaves.

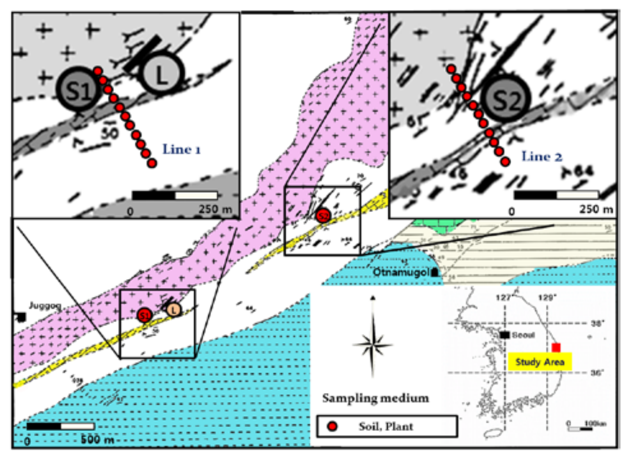


Figure 11: Two traverse sampling lines in target areas. Line 1 at Dongseog Sn mine (S1), and Line 2 at Yuchang Sn mine (S2).

Sn-Bearing Pegmatite Veins, Ulchin District

Tin deposits occur in cassiterite-bearing greisen pegmatite veins which intruded into the Yuli formation and Buncheon granite gneiss of Precambrian age. A total of 22 soil and 66 plant samples were collected with sampling intervals of 30 m along two traverse lines in target areas (Figure 11). Concentration levels of Sn and Li in soil from the target area were higher than those in soil from the control area.

However, contents of Sn and Li in plants (*C. controversa*, *P. sargentii and P. densiflora*) from target area were lower than those in plants from control area (Figure 12). The BACs of Sn and Li were very low. Element couples of Sn, Li, Be, Rb, Cs, and As showed highly positive correlation in soil but not in plants. The variation patterns of Sn and Li in plants are not similar to those in soil. In summary, there is no indicator plant in this area.

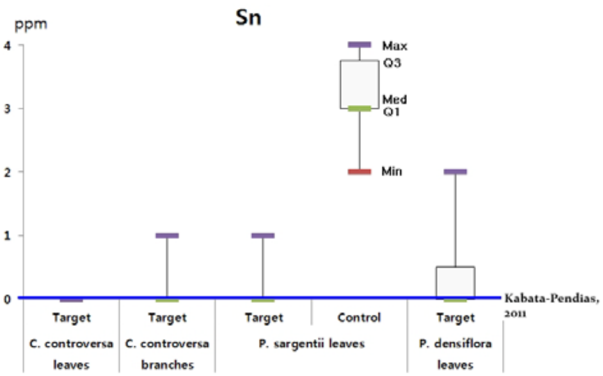


Figure 12: Content of Sn in plant species in target and control areas.

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