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# The Mineral Condition of Soils and Tree Species in Serpentine and Non-Serpentine Areas of Northern Hokkaido

by

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# 北海道北部の蛇紋岩地帯における土壌と樹木の無機成分

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## Abstract

Soils from a range of serpentine and non-serpentine sites in Teshio Experimental Forest, in the northern part of Hokkaido, were analyzed for the elements Ca, Mg, Na, K and trace elements Ni and Cr. Analysis for the same elements was also carried out on foliage ash from seventeen species of common plants growing in serpentine and non-serpentine sites.

The serpentine-derived soils were characterized by their high concentration of Mg and lower Ca content. Consequently, an imbalance of these minerals was observed.

Results of plant analysis showed that the levels of Ca and Mg found in trees growing in serpentine soils were significantly different among species, and most of the species did indeed maintain an excess of Mg over Ca in their leaf tissues. *Picea glehnii* appeared to be able to accumulate Ca preferentially to Mg. The species showed this particular mechanism of absorption of the available nutrients from the soil. It may be related to the ability of the roots to take up, selectively, the minerals needed by the plant. In addition, it can be also concluded that it is clear that the remaining species have adapted to low Ca levels in the substrate, since they are growing and regenerating in this serpentine environment.

The heavy metals Ni and Cr in the soils do not appear to have a marked influence (especially Cr) on plant cover because of their very low amounts in the form available to plants.

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**Key words :** Serpentine soil, Serpentine vegetation, Mineral composition, *Picea glehnii*, Teshio Experimental Forest.

## I. Introduction

The Teshio district of northern Hokkaido offers several places in which serpentine geology covers a considerable area. In these areas, the vegetation and soils show significant peculiarities presumably because of the unique physical and chemical properties of the parent rock (cf. NAKATA & KOJIMA, 1987). The occurrence of plant species is restricted to those of coniferous forests despite the climate, which would potentially support the establishment of a mixed forest of coniferous and deciduous trees. *Picea glehnii*, a tall species of forest tree of the genus Pinacea, having a shallow root system and tolerant to various impoverished soil types, appears to adapt itself to such particular soil conditions.

Studies of *Picea glehnii* forests in serpentine soils in the Teshio district have been carried out in detail (TATEWAKI & MORIMOTO, 1933 ; TATEWAKI, 1934 ; TATEWAKI & IGARASHI, 1971 and MATSUDA, 1989). The soils themselves in this area were also investigated (MATSUI, 1963 ; NARITA, 1967 and UJIIE & NISHI, 1975). However, the factors involving the tolerance or adaptation of some plant species and apparent intolerance of others to serpentine soils have not been well discussed.

It is the purpose of the present study to elucidate further the relationship between serpentine soils and the prevalence of certain species, particularly *Picea glehnii*, by comparing the chemical compositions of the soils and the tree species growing with those of non-serpentine areas in the same region. This paper presents the analysis of the elements calcium (Ca), magnesium (Mg), sodium (Na), potassium (K) and the trace elements nickel (Ni) and chromium (Cr) in species common to serpentine and non-serpentine substrates.

## II. Study area

The Teshio Experimental Forest (Fig. 1) is located at 45° north latitude, 142° east longitude. In terms of geology, the study areas are situated in two parts separated by the Toikanbetsu River, which is a tributary of the Teshio River. The east side is composed mainly of serpentine-derived soils, and was probably formed at the end of the Mesozoic era, while the west side is mostly composed of mudstone and sandy mudstone which belong to the fold zone of the Neogene system of the Tertiary period (MATSUI, 1963).

In order to compare the mineral conditions of the soils and the tree species growing in serpentine and non-serpentine sites, four different sites were selected from the Experimental Forest : two (Katou 52 compartment and Katou 51 compartment) were in a serpentine zone and others (Okuchi 18 compartment and Kasai 42 compartment) were in a non-serpentine zone.

As regards the climate, mean annual temperature is 5.7 °C, and the maximum and minimum temperatures are reported to be 35 °C and −35 °C, respectively. Annual precipitation is 1,000 mm, mainly snow which falls from November to April, for a maximum snow depth of 1.2 m.

Two different vegetations correspond to the two geological structures. The vegetation of main serpentine outcrops was described by TOYOKUNI (1957a, 1957b and 1960) and others. In the forest the most dominant tree is *Picea glehnii*, mixed with *Abies sachalinen-*

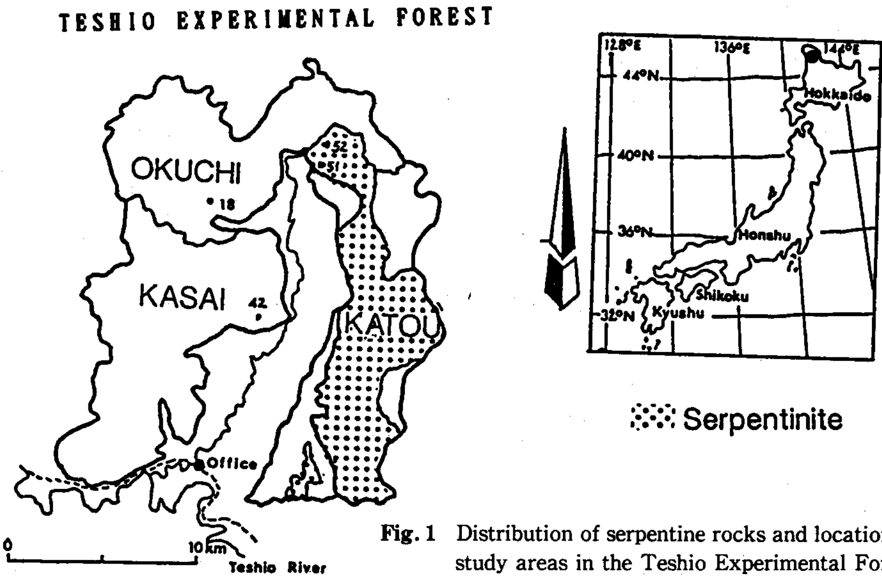


**Fig. 1** Distribution of serpentine rocks and location of study areas in the Teshio Experimental Forest

*sis, Taxus cuspidata,* and deciduous trees such as *Betula platyphylla* var. *japonica, B. ermanii, Alnus maximowiczii, Sorbus commixta, Quercus mongolica* var. *grosseserrata*, etc. The forest floor is mainly covered with *Sasa kurilensis* and/or *S. senanensis*. In the alpine region, the dominant tree species is *Pinus pumila* and all the plants growing there tend to be lower in height than those growing in non-serpentine areas of the same altitude.

The non-serpentine zone (mudstone area) consists of well-developed mixed forests of coniferous and broad-leaved (deciduous) species like *Abies sachalinensis, Picea jezoensis, Quercus mongolica* var. *grosseserrata, Kalopanax pictus, Ulmus davidiana* var. *japonica, Betula ermanii, B. maximowicziana*, etc. The forest floor is widely covered with Sasa species (TESHIO EXPERIMENTAL FOREST, 1987).

## III. Material and methods

Soil profiles were made by digging to about 1m depth, and some physical characteristics were observed and described (in situ) according to standard procedures. Furthermore, from each soil type, samples of two upper horizons were collected after surveying the soil profile for the laboratory analysis of chemical properties. The soil samples were then air -dried and sifted through a 2-mm sieve.

Chemical analysis was carried out by the following methods: 1) soil pH : glass electrode for soil suspension of 1 : 5 of soil : water and soil : KCl(1N) ratios ; 2) exchangeable cations : atomic absorption spectrophotometry (Ca, Mg) and flame emission photometry (K, Na) after an extraction with 1N-ammonium acetate ; 3) cation exchange capacity (CEC) : Schollenberger's method ; 4) trace elements (Ni and Cr) : atomic absorption spectrophotometry after decomposition with perchloric acid ($HClO_4$) and fluoric acid (HF).

A total of seventeen coniferous and broad-leaved species were selected for sampling. Owing to the heterogeneity in the distribution of serpentine vegetation, samples were collected randomly in the compartment in the areas nearest to where the soil was dug and soil samples were taken.

For each tree species, three samples were selected and leaves were picked out at random in September 1989. The fresh weight was determined and then the leaves were oven-dried at 85 °C for about 48 hours, after which the dry weight was determined. After dried, the foliage material was crushed and ashed at 500 °C for about 24 hours in a muffle furnace. The resulting ash was dissolved in 5ml of perchloric acid ($HClO_4$) and 5 ml of nitric acid ($HNO_3$). The solution was filtered and diluted with distilled water. Ca, Mg, K, Na and trace elements in the plant ash solutions were measured by the methods described in soil analysis.

Comparative analysis of the nutrient content was carried out on the stems (bark, sapwood and heartwood), branches and roots (primary and secondary) of *Picea glenii* and *Abies sachalinensis*. The analyses and procedures were the same as those for the leaves.

## IV. Mineral conditions of the soils and tree species

1) Soil profiles

The soil properties examined are summarized in Table 1. The soil horizon sequence of the Katou 52 compartment is $A_1/A_2g/B_2g/BCg/Cg$ and the occurrence of g horizon in the shallow part of the profile indicates that this soil has developed under wet conditions. This profile was affected by secondary deformation, and due to strong serpentinisation, original peridotite texture has almost disappeared. The solum (total thickness above the

**Table 1.** Soil profile description under natural conditions

| Location | Horizon | Depth(cm) | Texture | Nature * | Color |
|---|---|---|---|---|---|
| Katou 52 | $A_1$ | 0－ 2 | CL | S.W | 7.5YR2/2 |
| (serpentinite: | $A_2g$ | 2－ 5 | CL | S.W | 10YR5/2 |
| residual | $B_2g$ | 5－10 | SiC | S.W | 10YR5/4 |
| material) | BCg | 10－30 | L | W | 10YR6/5 |
| | Cg | 30－60＋ | L | W | 10BG4/1 |
| Katou 51 | A | 0－15 | CL | V.L.W | 7.5YR3/3 |
| (serpentinite | B | 15－23 | CL | L.W | 7.5YR4/5 |
| or terrace | BC | 23－42 | CL | W | 10YR4/6 |
| deposits) | C | 42－50＋ | CL | W | 10YR4/6 |
| Kasai 42 | $A_1$ | 0－15 | CL | L.W | 10YR3/4 |
| (alluvial | Bg | 15－45 | CL | L.W | 10YR4/6 |
| deposits) | Cg | 45－70 | CL | W | 10YR5/6 |
| | II Cg | 70－90＋ | SCL | W | 10YR6/8 |
| Okuchi 18 | $A_1/A_2$ | 0－10 | CL | W | 7.5YR3/5 |
| (tertiary | $B_1$ | 10－15 | SiC | W | 7.5YR4/6 |
| mudstone) | $B_2$ | 15－30 | SiC | W | 7.5YR4/4 |
| | C | 30－60＋ | SiC | V.W | 10YR6/4 |

* Nature
V.L.W＝Very Little Weathered
L.W＝Little weathered
W＝Weathered
V.W＝Very Weathered
S.W＝Strongly Weathered

C horizon excluding $A_0$ horizon) was relatively shallow (< 50 cm) and the gravel of serpentine, which had been well weathered and had become very brittle, was abundant in the lower subsoils.

The soil of the Katou 51 compartment was derived from terrace deposits and located in the margin of a serpentine area. It is probable that these soils had been slightly influenced by the intrusion of materials from the surrounding serpentine substrates. The thickness of solum was also shallow (< 50cm) but the content of gravel, which was strongly weathered, was low or very low in the topsoils and the consisitency was firm especially at the lower horizons.

Meanwhile, in the non-serpentine zone, the soil of the Okuchi 18 compartment, derived from Neogene strata in the Koetoi formation, was deeper than the soils of the serpentine areas and the horizons were gravel-free. The consistency was friable in the $A_1$ horizon and firm in the lower horizons. The soil of the Kasai 42 compartment is derived from the alluvial deposits of the Nuporo-Mapporo formation. This soil was the deepest one (< 90cm), gravel-free and firm in consistency.

2) Chemical properties of the soils

The chemical properties of the soils are shown in Table 2. The difference between the serpentine and non-serpentine areas was much more striking with regard to the chemical properties of the soils. The pHs($H_2O$) of the soils of the non-serpentine areas (Kasai 42 and Okuchi 18) and the margin of the serpentine area (Katou 51) ranged from 4.91 to 5.33 and were more acidic in the upper horizons than in the lower. On the other hand, the pHs of the soil derived from serpentine (Katou 52) were 6.6 in the upper horizon and 7.05 in the lower, which were very high compared with those of non-serpentine areas.

CEC ranged from 11.6 to 28.3 meq/100 g soil and generally was high in the soils of non -serpentine areas because of the heavy texture of the soil. With respect to the total amounts of exchangeable cations, it is obvious that the soils in serpentine substrates were much higher in total amounts than those in non-serpentine substrates due to the extremely high concentration of exchangeable Mg in the serpentine soils. The much higher amount was shown in the lower horizon of the Katou 52 compartment (8.93 meq/100 g soil) and the lowest was in the lower horizon of the Okuchi 18 compartment (1.01 meq/100 g soil). In terms of base saturation, serpentine-derived soils showed the highest values, with 55.9 and 58.5 % in the horizons of the Katou 52 compartment, the value increasing from top to

**Table 2.** Chemical properties of the soils investigated

| Location | Horizon | pH | | Ex. −Cations (meq/100g) | | | | C.E.C. | Base | Ca:Mg |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $H_2O$ | KCl | Ca | Mg | K | Na | (meq/100g) | Saturation(%) | Ratio |
| Katou 52 | $A_1+A_2$ | 6.60 | 5.23 | 1.01 | 5.14 | 0.10 | 0.11 | 11.6 | 55.9 | 0.22 |
| Katou 52 | $B_2$+BC | 7.05 | 5.51 | 1.00 | 7.74 | 0.12 | 0.07 | 15.3 | 58.5 | 0.13 |
| Katou 51 | A | 5.34 | 4.00 | 2.60 | 2.12 | 0.28 | 0.71 | 19.5 | 29.4 | 1.23 |
| Katou 51 | B | 5.43 | 3.95 | 0.98 | 0.98 | 0.16 | 0.22 | 18.1 | 12.6 | 1.03 |
| Kasai 42 | $A_1$ | 5.23 | 3.67 | 2.70 | 1.95 | 0.18 | 0.42 | 24.1 | 21.8 | 1.38 |
| Kasai 42 | Bg | 5.00 | 3.74 | 2.40 | 2.10 | 0.61 | 0.66 | 28.3 | 21.1 | 1.14 |
| Okuchi 18 | $A_1+A_2$ | 4.91 | 3.68 | 1.50 | 0.81 | 0.14 | 0.46 | 25.6 | 11.3 | 1.82 |
| Okuchi 18 | $B_1+B_2$ | 5.33 | 3.99 | 0.30 | 0.44 | 0.12 | 0.15 | 21.7 | 4.7 | 0.70 |

bottom in the profile. However, the relation was totally reversed in non-serpentine soils, where the highest value of base saturation was in the upper horizon of the profile, with the value decreasing with depth. The lowest range was in the soil of the Okuchi 18 compartment, which showed 11.3 % in the surface layer and only 4.7 % in the lower horizon.

With respect to exchangeable cations, the highest Mg concentration (7.74 meq/100g soil) was noted in the lower horizon of the Katou 52 compartment, in the serpentine area. However, the amount of Ca in the same horizon was as low as 1.0 meq/100g soil. The Ca : Mg ratio in serpentine soil, which is considered to be of particular importance in connection with soil fertility (WALKER, 1954), was less than 1.0, sometimes as low as 0.13 in the lower horizon of the Katou 52 compartment. On the other hand, in the non-serpentine substrate, the results showed a high Ca : Mg ratio, with the only exception being the lower horizon of the Okuchi 18 compartment. Other exchangeable cations, i.e. K and Na, showed the highest concentration in the upper horizon in almost all soils. Generally, they decrease with depth except for some cases (Kasai 42 compartment).

The concentrations of heavy metals (Ni and Cr) in the soils investigated are listed in Table 3. Serpentine soil, the Katou 52 compartment, contained higher amounts of total Ni and Cr than other soils examined. The content of Ni in the soil of the Katou 52 compartment was particularly high, about 35 times that of the Okuchi 18 compartment in the non-serpentine area.

3) Mineral contents in leaf ash of species growing in serpentine and non-serpentine substrate

A broad analytical study of the leaf ash of seventeen species growing in serpentine and non-serpentine soils was carried out for six elements: Ca, Mg, K, Na, Ni and Cr. Table 4 summarizes the content of major elements (Ca, Mg, K, Na) in the samples of the species collected at random from non-serpentine sites. The data show that the highest concentrations for Ca and Mg were in broad-leaved species, but in terms of Ca : Mg ratio, results varied from one species to another. In general, the Ca:Mg ratio was less than 1.0 with only few exceptions in which this ratio reached values higher than 2.0 (e.g. *Quercus mongolica* var. *grosseserrata*).

The content of the same elements in samples of the species collected from serpentine site is summarized in Table 5. Since serpentine derived soils generally have very high Mg levels and low Ca levels, it was expected that plants would reflect this feature. The Mg content of the broad-leaved species in the serpentine site, except for *Betula platyphylla* var. *japonica,* was higher than of those in the non-serpentine site. In contrast to broad-leaved species, many coniferous species did not show such a trend and their Mg content was relatively the same or even low compared with those in the non-serpentine site.

On the other hand, many broad-leaved species in the serpentine site had a lower Ca content than those of non-serpentine sites. The Ca level of coniferous species, however,

**Table 3.** Ni and Cr concentration (ppm) in soils surveyed

| Location | Horizon | Ni | Cr |
|---|---|---|---|
| Katou 52 | $A_1+A_2$ | 14.0 | 4.8 |
| Katou 52 | $B_2$+BC | 15.0 | 5.0 |
| Katou 51 | A | 0.7 | 0.7 |
| Katou 51 | B | 1.2 | 1.3 |
| Kasai 42 | $A_1$ | 2.0 | 4.7 |
| Kasai 42 | Bg | 1.0 | 2.2 |
| Okuchi 18 | $A_1+A_2$ | 0.4 | 1.2 |
| Okuchi 18 | $B_1+B_2$ | 0.4 | 0.9 |

**Table 4.** Ca, Mg, Na, and K contents of leaf tissues of species in non-serpentine sites in the Teshio Experimental Forest

| Species | Cations in leaf tissue (dry matter basis) Ca(%) | Mg(%) | Na(%) | K(%) | Ca:Mg mol ratio |
|---|---|---|---|---|---|
| *Picea glehnii* | 1.08 | 0.90 | 4.94 | 3.60 | 0.73 |
| *Picea jezoensis* | 0.80 | 0.92 | 0.74 | 2.66 | 0.53 |
| *Abies sachalinensis* | 1.32 | 0.46 | 0.90 | 2.46 | 1.74 |
| *Larix kaempferi* | 1.04 | 0.73 | 0.85 | 4.11 | 0.87 |
| *L. gmelini* x *L. kaempferi* | 0.80 | 0.80 | 1.08 | 3.05 | 0.61 |
| *L. gmelini* | 0.96 | 0.85 | 1.10 | 4.30 | 0.69 |
| *Pinus pumila* | 0.40 | 0.46 | 0.60 | 4.18 | 0.53 |
| *Quercus mongolica* var. *grosseserrata* | 2.44 | 0.63 | 0.80 | 4.30 | 2.35 |
| *Alnus hirsuta* | 1.80 | 1.51 | 0.94 | 3.21 | 0.73 |
| *Betula platyhylla* var. *japonica* | 1.64 | 2.19 | 0.80 | 2.93 | 0.46 |
| *B. ermanii* | 2.24 | 1.22 | 0.99 | 4.85 | 1.12 |
| *B. maximowicziana* | 1.12 | 1.29 | 0.83 | 6.92 | 0.53 |
| *Sorbus commixta* | 3.12 | 1.85 | 1.17 | 6.65 | 1.03 |
| *Acanthopanax sciadophylloides* | 1.04 | 1.63 | 1.52 | 4.57 | 0.39 |
| *Acer mono* | 3.48 | 1.46 | 2.62 | 1.76 | 1.45 |
| *Sasa senanensis* | 0.24 | 0.39 | 0.48 | 3.32 | 0.38 |
| *Sasa kurilensis* | 0.56 | 0.41 | 0.53 | 3.36 | 0.82 |

**Table 5.** Ca, Mg, Na, and K contents of leaf tissues of species in serpentine sites in the Teshio Experimental forest

| Species | Cations in leaf tissue (dry matter basis) Ca(%) | Mg(%) | Na(%) | K(%) | Ca:Mg mol ratio |
|---|---|---|---|---|---|
| *Picea glehnii* | 0.92 | 0.10 | 1.70 | 1.80 | 5.75 |
| *Picea jezoensis* | 1.40 | 0.66 | 0.92 | 2.31 | 1.30 |
| *Abies sachalinensis* | 1.20 | 0.49 | 0.48 | 1.06 | 1.50 |
| *Larix kaempferi* | 0.72 | 0.51 | 0.83 | 2.11 | 0.86 |
| *L. gmelini* x *L. kaempferi* | 0.72 | 1.04 | 2.78 | 2.31 | 0.42 |
| *L. gmelini* | 0.88 | 0.95 | 1.24 | 3.30 | 0.56 |
| *Pinus pumila* | 0.36 | 0.61 | 0.57 | 2.03 | 0.36 |
| *Quercus mongolica* var. *grosseserrata* | 1.00 | 1.12 | 0.80 | 2.39 | 0.54 |
| *Alnus hirsuta* | 1.68 | 2.04 | 0.74 | 2.07 | 0.50 |
| *Betula platyhylla* var. *japonica* | 1.64 | 1.68 | 1.06 | 2.39 | 0.59 |
| *B. ermanii* | 0.72 | 2.19 | 0.99 | 1.84 | 0.20 |
| *B. maximowicziana* | 0.96 | 2.89 | 1.70 | 4.11 | 0.20 |
| *Sorbus commixta* | 2.12 | 2.07 | 4.12 | 5.90 | 0.62 |
| *Acanthopanax sciadophylloides* | 0.64 | 1.65 | 1.33 | 2.31 | 0.24 |
| *Acer mono* | 2.56 | 3.38 | 1.03 | 2.62 | 0.46 |
| *Sasa senanensis* | 0.32 | 0.56 | 0.51 | 2.82 | 0.35 |
| *Sasa kurilensis* | 0.24 | 0.70 | 0.48 | 2.85 | 0.21 |

was of the same magnitude as those of non-serpentine sites. The Ca : Mg ratio of the trees in serpentine sites tended to be low compared with those of non-serpentine sites. Among the species collected from serpentine substrates, *Picea glehnii* showed the most notable and impressive feature in terms of Ca and Mg levels. The results obtained from the analysis of leaf ash showed that the Ca concentration was about six times higher than the Mg concentration, having the highest Ca : Mg ratio, such as 5.75. No other species showed such a characteristic.

An analysis of a range of plants growing in serpentine and non-serpentine soils was undertaken to assess how much Ni and Cr were taken up. Trace element analysis (Table 6) revealed that there are large differences between the species. For instance, *Betula platyphylla* var. *japonica* collected from serpentine substrates showed markedly high Ni concentration, as high as 44.71 ppm. On the other hand, *Acer mono* had the lowest concentration, 0.11 ppm. The two species of Sasa dwarf bamboo also showed high Ni content, as high as 19.31 ppm for *Sasa senanensis* and 12.76 ppm for *S. kurilensis*. However, the content of Cr was relatively low in almost all the species from serpentine and non-serpentine sites.

4) Mineral contents of stems, branches and roots of *Picea glehnii* and *Abies sachalinensis* collected from a serpentine area

Taking into account the results obtained from the leaf ash analysis, which showed that *Picea glehnii* appeared to be able to accumulate Ca in high quantities in preference to Mg,

**Table 6.** Ni and Cr contents of leaf tissue of species growing at serpentine and non-serpentine sites in the Teshio Experimental Forest

| Species | serpentine | | non-serpentine | |
|---|---|---|---|---|
| | Ni (ppm) | Cr (ppm) | Ni (ppm) | Cr (ppm) |
| *Picea glehnii* | 1.35 | 0.03 | 1.90 | 0.08 |
| *Picea jezoensis* | 1.12 | 0.05 | 2.40 | 0.07 |
| *Abies sachalinensis* | 8.03 | 0.09 | 1.40 | 0.08 |
| *Larix kaempferi* | 1.66 | 0.04 | 0.33 | 0.06 |
| *L. gmelini* x *L. kaempferi* | 2.30 | 0.04 | 0.33 | 0.07 |
| *L. gmelini* | 1.45 | 0.05 | 1.10 | 0.16 |
| *Pinus pumila* | 0.75 | 0.05 | 0.82 | 0.04 |
| *Quercus mongolica* var. *grosseserrata* | 1.86 | 0.04 | 1.80 | 0.03 |
| *Alnus hirsuta* | 2.60 | 0.06 | 2.70 | 0.05 |
| *Betula platyhylla* var. *japonica* | 44.71 | 0.06 | 0.89 | 0.04 |
| *B. ermanii* | 5.10 | 0.05 | 0.31 | 0.02 |
| *B. maximowicziana* | 0.78 | 0.05 | 1.60 | 0.04 |
| *Sorbus commixta* | 3.30 | trace | 0.16 | 0.03 |
| *Acanthopanax sciadophylloides* | 1.90 | 0.02 | 4.60 | 0.01 |
| *Acer mono* | 0.11 | trace | 6.00 | 0.02 |
| *Sasa senanensis* | 19.31 | 0.02 | 0.15 | 0.02 |
| *Sasa kurilensis* | 12.76 | 0.02 | 0.40 | 0.02 |

and consequently, had the highest Ca : Mg ratio, even though the soils where it was growing had an opposite relation, the need was seen for a more detailed analysis in order to elucidate the possible relationship between these species and the serpentine-derived soils.

Tables 7 and 8 summarize the Ca, Mg, K and Na concentrations in leaves, stems (bark, sapwood, and heartwood), branches and roots of *Picea glehnii* and *Abies sachalinensis*, respectively.

The data indicate that for both species the concentration of Mg was higher in the leaves and that of Ca higher in the bark. However, for *Picea glehnii*, the concentration of both elements in the roots was very low compared with that in the leaves, which in terms of the Ca : Mg ratio is of great importance. On the other hand, in the case of *Abies sachalinensis* there were no significant differences in the ratio values between leaves and roots.

Even though the results showed the same trends for both species in all the organs examinated, the ability of *Picea glehnii* to absorb the element Ca, and at the same time, the possible inhibition of Mg (an element that in high levels can be harmful to the growth of the plant), were the most obvious and contrasting features found, as a common characteristic, in this study. The Ca : Mg ratio for all the organs of *Picea glehnii* examined was always higher than 2.0 (greater than the values in the soil extracts), and it is one of the convincing reasons to explain the abundance and favorable growth of *Picea glehnii* in most of the forests of Hokkaido whose substrate is serpentine.

HARADA (1976) proposed two reasons for this : the species' high tolerance to low calcium levels, and its shallow root system. Based on a chemical analysis of organs, UJIIE & NISHI (1976) recognized *P. glehnii* to have the ability to selectively absorb bases, absorbing Ca effectively while inhibiting the absorption of excessive Mg from soils with high contents of this element. WALKER et al. (1954), after detailed review of many works, also discussed the same point in question and confirmed that the ability to exclude Mg maybe a characteristic of tolerant species.

**Table 7.** Ca, Mg, Na and K contents of leaves, stems (bark, sapwood and heartwood), branches and roots of *Picea glehnii* (dry matter basis)

| | Ca(%) | Mg(%) | Na(%) | K(%) |
|---|---|---|---|---|
| Leaves | 0.932 | 0.107 | 1.713 | 1.810 |
| Bark | 1.692 | 0.087 | 0.237 | 0.387 |
| Sapwood | 0.184 | 0.024 | 0.138 | 0.356 |
| Heartwood | 0.204 | 0.032 | 0.097 | 0.246 |
| Branches | 0.176 | 0.039 | 0.039 | 0.016 |
| Roots | 0.172 | 0.039 | 0.055 | 0.039 |

**Table 8.** Ca, Mg, Na and K contents of leaves, stems (bark, sapwood and heartwood), branches and roots of *Abies sachalinensis* (dry matter basis)

| | Ca(%) | Mg(%) | Na(%) | K(%) |
|---|---|---|---|---|
| Leaves | 1.184 | 0.481 | 0.480 | 1.064 |
| Bark | 2.220 | 0.073 | 0.377 | 0.954 |
| Sapwood | 0.180 | 0.036 | 0.163 | 0.215 |
| Heartwood | 0.196 | 0.039 | 0.170 | 0.305 |
| Branches | 0.152 | 0.039 | 0.200 | 0.109 |
| Roots | 0.104 | 0.039 | 0.499 | 0.497 |

## V. General Conclusions

Although the physical properties of serpentine soils and, sometimes, restricted water supply are undoubtedly important factors in limiting plant growth, the peculiarities of serpentine soils are usually explained in terms of their chemical composition. Most serpentine soils are low in Ca, and only a few have high amounts. Occasionally there is so little that it cannot be measured by usual methods of analysis (e.g. samples from Scotland, PROCTOR & WOODELL, 1971). In contrast to most non-serpentine soils, in which Ca exceeds Mg, in serpentine soils Mg usually exceeds Ca, and the Ca : Mg ratio is very low (PROCTOR & WOODELL, 1971). GORDON & LIPMAN (1926) concluded that the infertility of serpentine soils is caused not by too high a content of soluble Mg, but by a high pH and a deficiency of certain ions, chiefly nitrate (N) and phosphate (P). Earlier workers recognized the necessity of a balanced content of Ca and Mg for the success of plants, and the Ca : Mg ratio was soon regarded as a prime factor in serpentine infertility.

Serpentine soils frequently show high concentrations of Ni and Cr, which occasionally may be considered resposible for the serpentine factor (BROOKS, 1987; SHEWRY & PETERSON, 1975 and LYON et al., 1970). However, there are a few serpentine soils in which these elements have not been show to exert an unsual influence. At the same time, serpentine soils tend to be low in N and P (MARTIN et al., 1953 ; PROCTOR & WOODELL, 1971 ; TURITZIN, 1982). Such chemical conditions seem to limit the occurrence and growth of plants, or alternatively force to them to alter their genetic nature to adapt themselves to the particular soil conditions.

Results of the chemical analysis carried out in the different soil types collected from the experiment area, in particular from the serpentine substrates, suggested that serpentine -derived soils of northern Hokkaido forests were not the exception in terms of chemical properties compared with other serpentine outcrops of the world.

The serpentine-derived soils of the study areas obviously show unique chemical characteristics in contrast with those of adjacent non-serpentine substrates. In general, they are characterized by : an extremely high content of Mg versus Ca, which results in a low Ca : Mg ratio and high pH ; high total exchangeable cations due to an extremely high concentration of Mg ; and high base saturation.

Soil analysis also showed that only small amounts of Ni and Cr were present in the serpentine soils studied. Nevertheless, plant analysis showed that concentration of Ni in the leaves varied greatly among species, and there was the possibility that at least Ni was likely to be of importance. On the other hand, even when soils contained Cr at relatively low concentrations ($<5$ ppm) compared with other serpentine soils, Cr concentrations in the plant-available form were extremely low, and in some cases null for all the plants examined ($< 0.1$ ppm). It can be concluded that, at least in the soils studied, Cr has little or no influence on plant cover because of its very low in a form available to plants.

On the other hand, the results obtained from analysis of foliage ash found the levels of Ca and Mg in trees growing on serpentine soil significantly different among species. The data indicate that most of the broad-leaved species growing on these serpentine soils do indeed maintain an excess of Mg versus Ca in their leaf tissues. However, this contrast with some coniferous species, which have relatively low Mg contents and some of which show high Ca : Mg ratio ($>1.0$). This tendency is typically revealed in case of *Picea glehnii*, which appeared to be able to accumulate Ca to a great extent, for it had the highest Ca content of the species examinated, yet the Mg content was comparatively very low. Consequently, it had the highest Ca : Mg ratio of about 5.3.

Recent analysis (SHEWRY & PETERSON, 1975) of plants and soils from European serpentine sites has shown that species differ in the amounts of Mg and Ca taken up from the soil. This may indicate that different tolerance or exclusion mechanisms occur in different species.

The results obtained from the analysis of leaves, stems (bark, sapwood and heartwood), branches and roots of *Picea glehnii* and *Abies sachalinensis* (Table 7 and 8) imply that these species, especially the former, have a particular mechanism of absorption of the available nutrients from the soil, possibly related to the ability of the roots to take up, effectively, the minerals needed by the plant, and retain them in the root surface, or to reduce the absorption of the other minerals that can be harmful to their growth. Even though the concentration of Mg in the soil is high and Ca is relatively low, it appears that the roots are absorbing Ca preferentially, but there is a possibility that the absorption of Mg is still undertaken by the roots. Meanwhile, it is possible that after the absorption the element Mg is accumulated by the roots' surface, and that the presence of Ca ameliorates its apparent toxicity, permiting the free movement of Ca to the xylem and finally to the leaves. Ca per se appears to play a key role in reduction or elimination of the toxic effects of Mg and Ni upon vegetation in serpentine areas.

With regard to the other species examined, although they do not show the mechanism of preferential absorption of nutrients seen in *Picea glehnii*, it is clear that they are adapted to low Ca levels in the substrate, seeing that they grow and regenerate in serpentine substrates.

All the species studied showed, as a direct response to the limiting factors of the serpentine environment, differences in elemental composition. However, the species have in many cases behaved differently to the same particular mineral concentrations in the soil.

We agree with BROOKS (1987) that no single factor is responsible for the fertility of serpentine soils but rather that a combination of factors, varying from region to region, is in the main responsible.

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## 要　　約

北海道北部における蛇紋岩地帯とそれに隣接する非蛇紋岩地帯より土壌サンプルを採取し、無機成分（交換態 Ca・Mg・K・Na および全 Ni・Cr）を分析した。また，両地帯に生育している樹木およびササ(合計17種類)についても土壌と同じ成分について分析をおこなった。

非蛇紋岩土壌に比較して蛇紋岩土壌では Mg イオンは Ca イオンより多く含まれており，Mg イオンと Ca イオンの割合が不均衡になっていることが推定され，このことは蛇紋岩土壌の肥沃度に関して重要だと思われる。

葉の分析では Ca イオンと Mg イオン含有量は樹木により異なっていたが，多くの樹種では Mg イオンの量が Ca イオンより多かった。ただし，いくつかの針葉樹(アカエゾマツ・エゾマツ）では Ca イオンの方が多く，特にアカエゾマツではその傾向が顕著であった。

分析結果からみると，アカエゾマツには Ca イオンを選択的に吸収する機構が存在する可能性が考えられ，それは根が必要な養分を効果的に吸い上げる能力と関連性があると考えられた。

重金属（Ni・Cr）については，土壌中には可給態のもの（特に Cr）が少なく，樹木の生育に与える影響ははっきりとは認められなかった。