

Edaphic influences on a New Zealand ultramafic (“serpentine”) flora: a statistical approach

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Abstract

Ultramafic (“serpentine”) soils from and adjacent to the Dun Mountain Ophiolitic Belt, South Island, New Zealand were analysed for 11 elements in order to establish to what degree edaphic factors influenced the character of the overlying vegetation. Using principal components analysis with a mutual plot of the first two principal components, involving the total elemental concentrations in the soils, it was possible to divide the soils into 6 virtually non-overlapping fields, each of which represented a specific vegetation community. Component 1 was essentially an “ultramafic plot” with heavy loadings from the elements chromium, cobalt, iron, magnesium, manganese, and nickel. Component 2 was a “non ultramafic” plot with heavy loadings from aluminium, copper and zinc. For elements extracted from the soils at pH 5.9, discrimination was somewhat poorer but confirmed the great importance of magnesium and nickel as controlling elements for the serpentine vegetation. It was concluded that the results indicated the overriding importance of edaphic factors in controlling the serpentine vegetation.

Introduction

Ultramafic rocks cover a little less than 1% of the Earth and owe their origin to surface processes or metamorphism within the mantle far below the Earth’s surface (Coleman and Jove, 1992). Soils derived from these rocks are rich in iron and relatively so in chromium, nickel, and cobalt. They are also very rich in magnesium and relatively deficient in calcium. Nutrients such as potassium, phosphorus and nitrogen have very low concentrations.

There has been a long history of attempts to solve the “serpentine problem,” i.e. the infertility of serpentine soils (Brooks, 1987; Kinzel, 1982; Krause, 1958) but there appears to be no general agreement as to the causes of this infertility. Proctor and Nagy (1992) have however pointed out that whatever their variety, serpentine soils are always a major factor that controls the vegetation that they bear. Although physical and other

factors may control serpentine floras, possible edaphic influences can be summarised as follows:

(1) *Calcium and magnesium.* Calcium deficiency *per se* was emphasized as an important factor in controlling a serpentine flora (Kruckeberg, 1954). The prevailing view is however that calcium levels in serpentine soils should be considered in relation to those of other elements such as magnesium. The role of magnesium is still unclear because of its complex inter-relationships with other elements such as its ability to reduce uptake of potassium by plants (Epstein, 1972), and to ameliorate nickel toxicity (Proctor and McGowan, 1976).

(2) *Nickel.* Nickel was once thought to have a dominant role in the control of serpentine floras but later evidence tends to negate this supposition. For example, Lee (1992) in a study of New Zealand serpentine floras concluded that only nickel in serpentine soils from the southwest of South Island was likely to reduce plant growth critically.

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(3) *Chromium*. There is general agreement that chromium will have little effect on controlling a serpentine flora because of its lack of mobility. Elevated chromium levels in plant material are invariably associated with wind-borne surface contamination.

(4) *Cobalt*. Unlike chromium, cobalt is readily accumulated by plants. Indeed, the copper/cobalt deposits of Zaïre are host to nearly a score of species that are able to hyperaccumulate this element (Brooks et al., 1992). Despite this ability to accumulate cobalt, concentrations of this element in serpentine floras usually do not exceed $100 \mu\text{g g}^{-1}$ in dry tissue.

(5) *Low concentrations of nutrients*. The concentrations of plant-available nutrients in serpentine soils are probably one of the main contributors to the "serpentine problem." For example, in experiments on the Isle of Rhum (Scotland) and on the Keen of Hamar (Shetland), nutrient additions increased plant cover to a spectacular degree (Proctor and Nagy, 1992).

Some mention should also be made of physical factors such as water shortage due to the good drainage of serpentine soils. For example, Proctor and Craig (1978) found that drought was responsible for much of the lack of tree cover over The Great Dyke, Zimbabwe. They found well developed riverine forest over this body.

We have recently carried out an extensive ecological study of the flora of the Dun Mountain Serpentine Belt in the north of South Island, New Zealand, in the course of which soils were analysed and their composition related to plant communities growing over them. The purpose of the present paper is to report these findings in which statistical analysis of the data has enabled us to propose a model for edaphic factors that control the serpentine flora.

Site description

Geology

The Dun Mountain Ophiolitic Belt (Figure 1) extends southwards from d'Urville Island through Saddle Hill, and the Dun mountain, to Red Hill in the south. The Dun Mountain Massif where much of the work was carried out, is situated about 13 km east of Nelson and rises to an altitude of 1129 m. The ultramafic rocks intrude the older surrounding sediments and volcanic rocks. The main rock types are dunite and harzburgite with a little pyroxene. The ultramafic rocks of the Dun

Mountain Massif have a concentric form with serpentinization at the contacts.

Chrome and copper (mined at the turn of the century) are associated with a prominent fault near Wooded Peak. The surrounding rocks are predominantly spilites interspersed in a Permian sedimentary sequence composed of greywackes, argillites and calcareous rocks (Lauder, 1965).

The Cobb Valley asbestos mine is found in the Upper Takaka Valley. The deposits were mined from 1949 to 1963 (Williams, 1965). All the ultramafic rocks are hydrothermally altered and the peridotitic differentiate has been completely serpentinised to chrysotile, bastite, and to an antigorite-like serpentine. Serpentine from the asbestos workings averages only $650 \mu\text{g g}^{-1}$ nickel (low for ultramafics in this part of New Zealand), whereas the magnesium concentration averages 23%, and there is only a trace of calcium (Wellman, 1942). The magnesium/calcium quotient is therefore highly unfavourable for plant growth.

The Dun Mountain Belt is floristically one of the most important of the ultramafic zones of New Zealand. The Dun Mountain itself was the type locality for dunite (FeMgSiO_4) first described by Hochstetter in the first half of the 19th Century.

Soils

The soils derived from the rocks of the Dun Mountain Belt have all of the characteristics that typify serpentine soils: (1) they contain predominantly ferromagnesian minerals, the silica and magnesium content decreasing as the soils are weathered; (2) they contain relatively large amounts of nickel, chromium, manganese and cobalt; (3) they have relatively low concentrations of nitrogen, phosphorus and potassium; (4) they have a high magnesium/calcium quotient; (5) they have a low content of organic matter; (6) they are sandy, relatively homogeneous, and generally shallow with typically 15 cm of soil on top of the parent material.

The soils of the Dun Mountain Ophiolitic Belt are quite variable but a profile in the Lee Valley under stunted manuka (*Leptospermum scoparium*) and native grasses (15° slope) has been described as "Dun Steep-land" by Chittenden et al. (1966). Their description is as follows:

(1) 0–2.5 cm – dark brown sandy loam, friable, moderately developed fine soft crumb structure.

(2) 2.5–12 cm – dark brown silt loam with rock fragments, friable, strongly developed medium nutty structure.

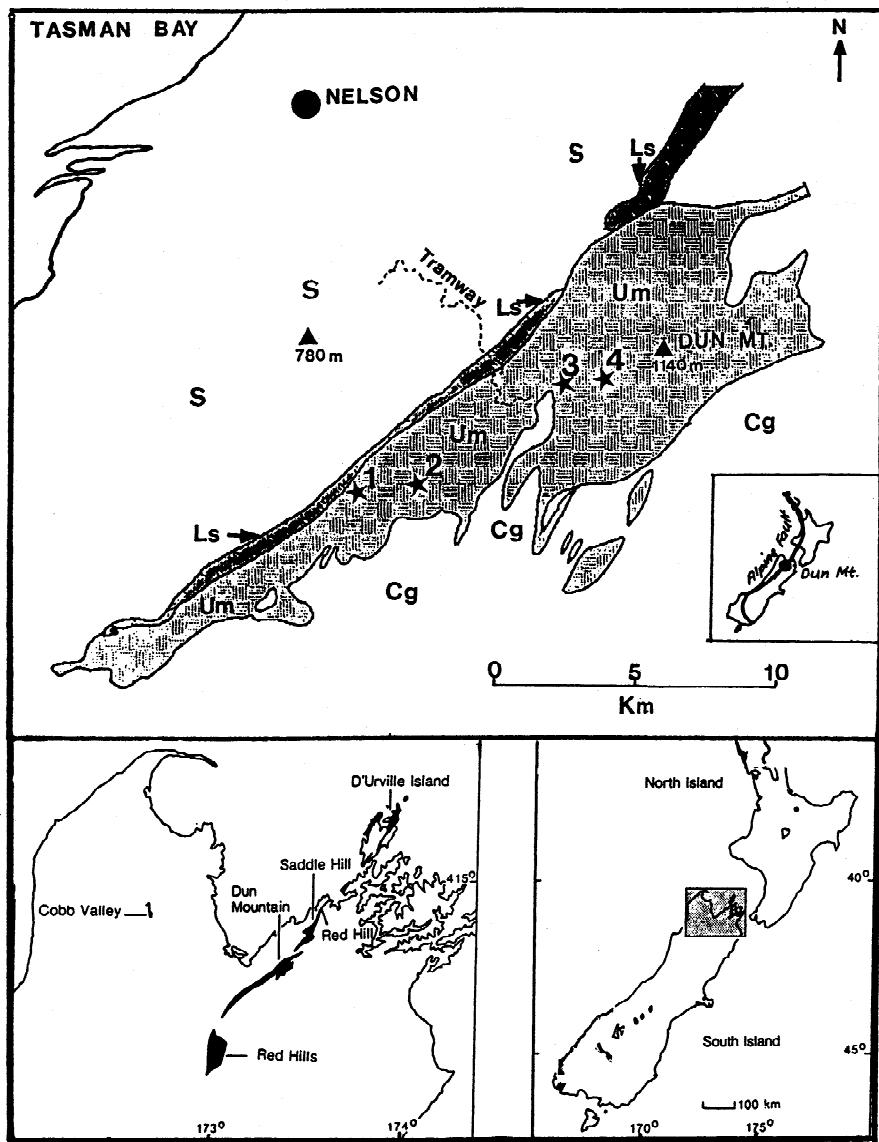


Figure 1. Map of the Dun Mountain Ophiolitic Belt. Cg – Patuki Melange of a conglomerate of sedimentary, volcanic and ultramafic rocks. Ls – Wooded Peak Limestone consisting of poorly bedded grey limestone with lenses of grey siltstone. S – Greville Formation of interbedded laminated grey sandstone, siltstone and mudstone. Um – Layered dunite, harzburgite and pyroxenite with widespread serpentinisation. * – sampling sites represented by: 1 – Hackett Creek chromite mine, 2 – United Mine, 3 – site of sedimentary/ultramafic ecotone, 4 – Dun Saddle.

(3) 12–22 cm – dark olive-brown silt loam with many rock fragments, friable, moderately developed medium granular structure.

(4) >22 cm – weathered serpentinite rock.

Elsewhere the soil cover consists of little more than weathered serpentine scree with little or no organic content. The modern nomenclature for this serpentine soil type is *magnesic mafic brown* (Anon, 1992) or *typic argiudoll (vermiculitic)* in the US taxonomy.

Vegetation

Ultramafic areas nearly always support a characteristic vegetation, distinct from adjacent areas. The vegetational boundary between ultramafic and non-ultramafic soils is often very sharp, occurring over only a few metres. The Dun Mountain Belt is a particularly good example of this sharp differentiation.

Table 1. Floristic composition of plant communities in the Dun Mountain Ophiolitic Belt

Community	Geology	Dominant species and relative abundance
A - Cobb Valley beech	Gabbro	<i>Nothofagus menziesii</i> (5), <i>Weinmannia racemosa</i> (3), <i>Pseudopanax crassifolium</i> (1), <i>Leucopogon fasciulatum</i> (1).
B - Dun Saddle beech	Sedimentary/ultramafic melange	<i>Nothofagus solandri</i> var. <i>cliffortioides</i> (5), <i>Phyllocladus trichomanoides</i> (3), <i>Podocarpus hallii</i> (2), <i>Blechnum procerum</i> (3).
C - Cobb Valley kanuka scrub	Sedimentary to ultramafic	<i>Nothofagus solandri</i> var. <i>cliffortioides</i> (5) forest
D - Dun Mt. <i>Chionochloa</i> grassland	Dunite	<i>Chionochloa diffusa</i> (5), <i>Dracophyllum uniflorum</i> (3), <i>Leptospermum scoparium</i> (3), <i>Phormium cookianum</i> (2), <i>Gentiana corymbifera</i> (2), <i>Melicytus alpina</i> (2), <i>Notothlaspi australe</i> (2), <i>Euphrasia monroi</i> (1), <i>Hebe odora</i> (2), <i>Cassinia vauvilliersii</i> (2).
E - Hackett Creek serpentinite	Serpentinite + chrome	<i>Leptospermum scoparium</i> (2), <i>Pteridium esculentum</i> (2), <i>Cyathodes juniperina</i> (1), <i>Melicytus alpina</i> (2), <i>Phormium cookianum</i> (2), <i>Gentiana corymbifera</i> (3), <i>Cassinia vauvilliersii</i> (1).
F - Cobb asbestos tailings	Talc-magnesite	<i>Colobanthus strictus</i> (2), <i>Poa picta</i> (2), <i>Hebe odora</i> (1), <i>Leptospermum scoparium</i> (1), <i>Coria arborea</i> (1).

The vegetation of the Dun Mountain Belt has been described by Lee (1980; 1992) who recognises several distinct communities many of which are separated from the surrounding sedimentary forest by exceedingly sharp boundaries. We have carried out plant mapping at 6 of these communities (see below and in Table 1 for species lists).

Materials and methods

Soil sampling

Visits were made to the Dun Mountain, Hackett chromite mine and Cobb Valley asbestos mine and to the ultramafic terrain surrounding these areas (Figure 1). Soils were collected from each site where samples were taken from the material immediately under the layer of humus and surface litter (which was usually sparse).

It might be argued that the surface organic layer should have been sampled rather than the lower inorganic fraction. However, in most cases there was virtu-

ally no surface organic material. In the non-ultramafic forested areas, there was indeed a shallow organic layer, but it would have been inappropriate to compare this organic layer with the rest of the soils where such a layer was lacking. Moreover, in the forested areas, the plant roots were located deep into the lower horizons and had little contact with the surface material.

Vegetation mapping

We carried out plant mapping of the plant species occurring over the various geological units as shown below. The mapping procedure consisted of dividing the terrain into 10 m × 10 m quadrats and counting the number of plant species within each quadrat.

(A) Gabbroic rocks adjacent to the Cobb Valley talc-magnesite workings carry a low forest dominated by species such as *Nothofagus menziesii* and *Weinmannia racemosa*. There is a relatively sharp transition to the adjacent *Leptospermum* shrubland over serpentinite.

(B) The low transition forest between ultramafics and sedimentary/ultramafic melange consists of a low

tree assemblage of variable composition depending on the predominance of one or more parent materials in the soil. The canopy is dominated by *Nothofagus solandri* var. *cliffortioides*.

(C) *Chionochloa* tussock grassland is very typical of the open vegetation of the dunites and peridotites of the Dun Mountain Massif and increases in importance with altitude.

(D) The vegetation of the Hackett Creek chrome mine closely resembles that of the *Leptospermum scoparium* shrubland (F) of the Dun Mt. Saddle except that the individual plants are more stunted. The only endemic plant found in this community is *Pimelea suteri*.

(E) *Leptospermum scoparium* shrubland forms a large part of the serpentine vegetation and is host to endemics such as *Pimelea suteri* and *Myosotis monroi*. The partially endemic *Notothlaspi australe* is often found in damper places. The small gentian *Gentiana corymbifera* is also very common and is often the only coloniser of serpentine scree. Larger shrubs include *Hebe odora* and *Cassinia vauvilliersii*.

(F) The talc- and quartz-magnesite tailings of the Cobb asbestos mine are an environment extremely hostile to vegetation. On the slopes of these tailings the only species are *Colobanthus strictus* and *Poa picta*. In the more level parts of these tailings are to be found, *Hebe odora* and the ubiquitous *Leptospermum scoparium*.

Chemical analysis

All soils were sieved to 210 µm size and the samples (0.5 g) were weighed into polypropylene cups. A mixture (12 mL) of 1:1 HF/HNO₃ was added to each cup and the solutions were evaporated to dryness on a water bath. Then 12 mL of 2 M HCl was added to each cup and the solutions warmed to redissolve the material. The chemical elements were determined in the solutions by flame atomic absorption spectrometry (FAAS). To measure the pH of the soils, 2.5 mL of water was added to 1 g of sieved soil and the mixture left overnight before measurement with a pH meter. A total elemental analysis by X-ray fluorescence spectrometry was also performed.

The extractable fraction of soil elements was determined by adding 10 mL of extractant (potassium hydrogen phthalate at pH 5.9) to 0.5 g of soil. The mixtures were shaken overnight and the supernatant decanted. The extracts were again analysed by FAAS.

The question of what extractant should be used to simulate the plant-available fraction of metals in soils received a great deal of attention by us. The pH of the soil in the rhizosphere of plants is often more acidic than the bulk soil, two pH units lower being typical (Salisbury and Ross, 1978). The pH values of the soil samples taken in this survey ranged from 4.9 under forest litter to 7.7 under serpentine scrub (the majority of the samples). It was decided that extraction at pH 5.9 would simulate conditions at the rhizosphere of most of the plants in these soils; the pH of 5.9 being about 2 units below the pH of serpentine soils.

There was a further rationale for selection of pH 5.9 as the one most likely to simulate uptake of elements from the soils. An experiment was carried out in which the serpentine-endemic Italian crucifer *Alyssum bertolonii* was grown for three months in serpentine soil from the Dun Mountain complex. This soil contained 6090 µg g⁻¹ Ni. The plants had been sown in a tray containing 3.46 kg of soil and extracted 0.019 g of nickel. This represented an extraction of 5.5 µg g⁻¹ of the original nickel content of the soils. The rhizosphere of plants is usually in contact with only 0.4–2.8% by volume) of the surrounding soil (Barber, 1984). If soil interception were the only factor, the total available nickel in the soil should therefore be in the range 196–1375 µg g⁻¹. This figure is however far too high because it does not take into account mass flow and diffusion (Barber, 1984) that together can amount to ten times the root interception factor. If this combined figure is taken (i.e. 4–28%), the plant experiments indicate a probable 20–138 µg g⁻¹ extractable nickel with a mean of 79 µg g⁻¹. Our experimental value using KH phthalate at pH 5.9 was 84 µg g⁻¹ Ni.

Statistical treatment

Principal components analysis (PCA) (SAS Institute, 1987) was used to relate soil composition to the floristic composition of vegetation overlying the ultramafic substrate. The procedure involves finding one or more new variables (principal components) that condense as much as possible of the original data into a smaller set of uncorrelated variables. The variation in the first principal component accounts for as much as possible of the total variance in the original data set. The second principal component, at right angles to the first, expresses the next highest possible variance, and so forth. The main aim of PCA is to simplify the data. All data were transformed logarithmically because they

Table 2. Elemental concentrations (%) in a typical serpentine soil of the Nelson region

Al	1.53	Ca	0.262	Co	0.054	Cl	0.013	Cr	0.785
Cu	0.010	Fe	23.42	K	0.017	Mg	15.92	Mn	0.278
Na	0.009	Ni	0.609	O	41.5	P	0.034	S	0.052
Si	15.7	Ti	0.013	V	0.002	Zn	0.014	Total	100.2

Notes: (1) analyses performed by X-ray fluorescence spectrometry; (2) soil from Serpentine Rd between Rai Valley and Nelson.

represented *lognormal*, rather than *normal* distributions.

Results and discussion

Abundance data for heavy metals in soils and their extracts

The elemental content of a typical serpentine soil from the Dun Mountain Ophiolitic Belt is given in Table 2. The mg/Ca quotient (61) is within the range of 16–845 for all other sites in the region. This is lower than values reported by Brooks (1987) for 230 New Caledonian serpentine soils (however both elements had extremely low abundances in these soils) and higher than the quotient of 9.9 reported by the same source for Spanish ultramafics.

Table 3 summarises abundance data for 11 elements in the soils analysed in the course of this work. Table 4 lists abundances of 5 elements in soils extracts conducted at pH 5.9.

From the magnesium, nickel and chromium values in Table 3, it is clear that the soils supporting vegetation communities D, E, and F are ultramafic in character.

Correlation analysis

Correlation analysis of the total concentrations (transformed logarithmically because distributions were log-normal) of elements in the soils is shown in Table 5. Aluminium is negatively correlated with all other elements except calcium, copper and zinc. This reflects the low proportion of clays in the soils tested. Copper and zinc are typical chalcophile elements usually associated with sulphide mineralization which was virtually absent in all samples. Elements associated with serpentine soils (Co, Cr, Fe, mg, and Mn) were invariably mutually correlated.

In the case of elements extracted from soils at pH 5.9, there were no significant correlations since the

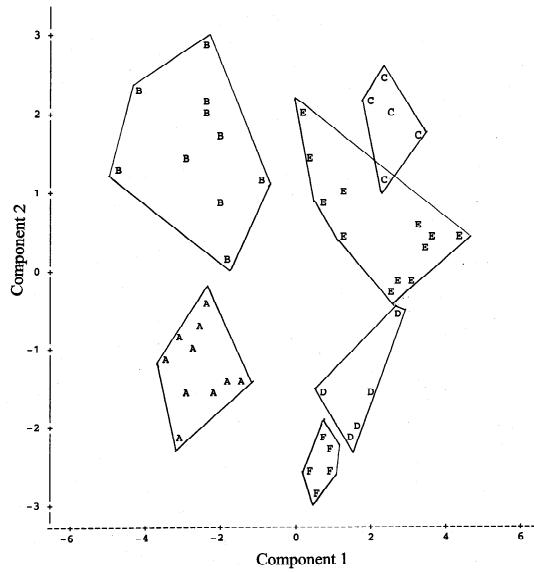


Figure 2. Plot of component 2 vs. component 1 for logarithmically transformed total elemental concentrations in soils. Symbols as in Table 1.

geochemical associations of the whole elemental concentrations were not reflected in the extracts. It will be noted that the extractabilities of only 5 of the original 11 elements has been reported because the concentrations of the other 6 (poorly extractable) were below the limit of detection (usually $< 1 \mu\text{g g}^{-1}$) of the analytical method.

Principal components analysis (PCA)

Table 6 shows eigenvectors and cumulative eigenvalues for logarithmically transformed total elemental concentrations in the soils. The first three principal components altogether accounted for 90.1% of the total variance of the system. A plot of component 2 vs. component 1 is given in Figure 2. From the plot it is clear that the soils of the 6 plant communities are almost completely separated from each other with very little

Table 3. Elemental concentrations ($\mu\text{g g}^{-1}$ except where otherwise stated) in serpentine soils

Element	A ^b (n = 10)	B (n = 10)	C (n = 5)	D (n = 5)	E (n = 12)	F (n = 5)
pH	4.9	4.9	6.9	6.6	7.4	7.7
Al (%)						
g.m. ^a	0.93	4.10	0.53	0.10	0.22	0.05
s.d.r.	0.45–1.94	2.51–6.69	0.30–0.95	0.06–0.16	0.06–0.78	0.04–0.08
Ca (%)						
g.m.	1.60	0.16	0.15	0.39	0.58	0.01
s.d.r.	1.10–2.33	0.06–0.39	0.09–0.22	0.24–0.65	0.16–2.11	0.009–0.018
Co						
g.m.	35	33	217	214	176	121
s.d.r.	29–43	23–48	173–272	180–254	112–278	105–138
Cr						
g.m.	373	146	887	936	1889	532
s.d.r.	247–565	43–495	790–996	660–1328	1170–3048	470–603
Cu						
g.m.	10	35	57	10	34	10
s.d.r.	5–20	19–65	45–73	6–16	22–53	6–17
Fe (%)						
g.m.	2.2	4.0	22.3	7.1	11.5	5.1
s.d.r.	1.7–2.7	3.0–5.0	18.3–27.1	5.2–9.6	0.2–18.3	4.0–6.1
K						
g.m.	247	302	1681	694	1078	757
s.d.r.	183–333	218–418	1614–1751	282–1707	608–1911	600–955
Mg (%)						
g.m.	9.6	4.0	7.2	19.2	12.4	19.0
s.d.r.	7.3–12.5	2.3–5.2	5.5–9.2	17.2–21.58	0.8–17.5	17.7–21.0
Mn						
g.m.	474	592	1801	1565	2318	382
s.d.r.	368–612	426–823	1421–2282	1250–1960	1335–4014	287–509
Ni						
g.m.	221	164	57	2418	1478	2674
s.d.r.	173–281	55–484	45–73	2210–2646	774–2823	2449–2919
Zn						
g.m.	14	46	106	25	67	14
s.d.r.	10–20	30–71	88–129	16–37	53–84	11–17

^ag.m. – geometric mean, s.d.r. – standard deviation range.^bA – Cobb Valley beech forest, B – Dun Saddle beech forest, C – Cobb Valley Kanuka Scrub, D – Dun Mt grassland, E – Serpentine scrub over Hackett Creek chromite mine, F – Cobb asbestos mine.

overlap of the fields. Plots of other combinations of the first three components were not as successful at separating the fields and are not discussed further. Other statistical techniques exist (e.g. discriminant analysis) which would maximise separation of plant communities, but PCA is sufficient in this case.

From Table 6 it can be noted that the most important positive eigenvector coefficients in component 1 are those involving chromium, cobalt, iron, manganese, nickel and potassium in total soil analyses.

It is appropriate at this stage to explain in greater detail the significance of these eigenvectors. The magnitude of the coefficients in these vectors and their sign, determine where a given plant community will appear in the plot. In Table 6, there are negative coefficients in the first principal component. These are for aluminium and calcium. There are positive values for chromium to zinc. This implies that in a plot of Component 2 vs. Component 1 (Figure 2), groupings along the right-hand side of the x-axis will generally correspond to low concentrations of aluminium and calcium, and

Table 4. Concentrations ($\mu\text{g g}^{-1}$) of elements extractable from serpentine soils at pH 5.9

Element	A (n = 10)	B (n = 7)	C (n = 4)	D (n = 5)	E (n = 7)	F (n = 3)
Ca						
g.m.	80	138	198	131	274	14.6
s.d.r.	39–165	68–280	160–246	99–172	134–558	11.4–18.7
Fe						
g.m.	66	48	23	7.5	1.0	4.7
s.d.r.	30–145	29–80	15–23	3.7–15	0.03–25	2.7–8.1
Mg						
g.m.	70	278	900	1622	1589	407
s.d.r.	33–147	127–608	825–981	1304–2018	1110–2275	376–440
Mn						
g.m.	32	50	24	12	21	2.9
s.d.r.	16–62	23–106	16–36	7.6–18	9.5–44	1.7–4.8
Ni						
g.m.	1.2	2.8	27	26	42	6.7
s.d.r.	0.18–7.7	0.83–9.3	25–29	20–35	27–66	3.7–12

Symbols as in Table 3

Table 5. Correlation analysis of total elemental concentrations in soils (n = 50)

Al	Ca	Co	Cr	Cu	Fe	K	Mg	Mn	Ni
Ca	NS								
Co	-S**NS								
Cr	-S**	NS	S**						
Cu	S	NS	NS	NS					
Fe	-S**	NS	S**S**	S*					
K	-S**	-S	S**	S**	S	S**			
Mg	-S**	NS	S**	S**	-S*	S	S*		
Mn	-S	NS	S**	S**	S*	S**	S**	NS	
Ni	-S**	-S	S**	S**	NS	S**	S**	S**	S**
Zn	NS	NS	S**	S	S**	S**	S**	NS	S** S

S** = very highly significant ($p < 0.001$), S* = highly significant ($0.01 > p > 0.001$), S = significant ($0.05 > p > 0.01$), NS = not significant ($p > 0.05$). Negative sign implies inverse relationship.

high concentrations of the other elements (i.e. a strongly ultramafic grouping) in the soils. Thus community E (Hackett Creek) is a typical ultramafic grouping. To the left of the x axis we have communities A (Cobb Valley beech forest) and B (Dun Saddle beech forest) whose sedimentary substrates are high in aluminium and calcium but low in the other (ultramafic) elements.

Further discrimination of the vegetation communities is shown in Figure 2 where at the bottom of the y-axis (principal component 2) the Cobb Asbestos Mine community (F) grows over soils rich in the “ultramafic” elements chromium, cobalt, magnesium and nickel (large negative coefficients) and where at the top of the plot, the positive eigenvector coefficients indicate ele-

vated levels of the other elements aluminium, copper, iron, manganese, potassium and zinc in the soils.

The correlation coefficients of Table 5 are further evidence of the inverse relationship between aluminium and the typical “ultramafic” magnesium and heavy metals. The respective contributions of components 1 and 2 to the total variance of the system are 54.56% and 24.00%. The third component, a further 11.56% of the variance, is weighted very heavily to “non-ultramafic” calcium (eigenvector coefficient of 0.85 in principal component 3).

When PCA was applied to a number of extractable metals (calcium, iron, magnesium, manganese and nickel), the cumulative percentage of the first three components was 89.99%. Considering ultramafic and

Table 6. Eigenvectors and eigenvalues of the first three principal components of the soil system

Variable	Component 1	Component 2	Component 3
<i>Total elemental content in soils</i>			
Eigenvectors			
Aluminium	-0.30	0.37	0.11
Calcium	-0.08	-0.02	0.85
Chromium	0.34	-0.12	0.36
Cobalt	0.39	-0.03	-0.04
Copper	0.08	0.53	-0.01
Iron	0.37	0.20	-0.04
Magnesium	0.25	-0.45	0.11
Manganese	0.33	0.21	0.24
Nickel	0.37	-0.14	-0.13
Potassium	0.36	0.09	-0.17
Zinc	0.21	0.50	0.06
Eigenvalues	6.00	2.64	1.27
Cumulative percentage	54.56	78.56	90.12
<i>Elemental content of extracts at pH 5.9</i>			
Eigenvectors			
Calcium	0.23	0.70	-0.03
Iron	-0.45	0.01	0.87
Magnesium	0.60	0.03	0.30
Manganese	-0.21	0.71	0.02
Nickel	0.58	-0.03	0.38
Eigenvalues	2.22	1.56	0.71
Cumulative percentage	44.44	75.72	89.99

non-ultramafic soils as separate populations, the spatial separation of the fields was better than in the case of the whole-element analyses (Figure 3) but there was some overlap of the individual fields. The major loadings of the eigenvector coefficients for component 1 were from nickel and magnesium (0.58 and 0.60 respectively) though there was a surprisingly high negative loading for iron (-0.45). Component 2 was dominated by calcium (0.70) and manganese (0.71). Even after making allowance for the smaller number of elements used for the extracts (poor detection limits rendered impractical the determination of the other elements), it is clear that PCA using extractable fractions of the elemental content of the soils would also allow for a satisfactory discrimination of the different groups of soils and the vegetation communities that they supported.

It was concluded that the vegetation groupings are strongly dependent on the chemical composition of

the soils. Since both magnesium and nickel have a dominant role (high eigenvalues) in the major PCA component of both the total and extractable elemental concentrations in soils, these two elements are clearly important in defining the character of the overlying vegetation. This role is likely to be more important than in the case of elements of lower mobility such as chromium.

One problem that has to be addressed in making conclusions from this study, is the degree to which other "serpentine factors" such as lack of nutrients and drainage control the nature of the overlying flora. Such factors are however dependent on the chemical composition of the soils or the rocks from which they are derived. They are adjuncts to the edaphic factors rather than separate causative effects and cannot be considered in isolation.

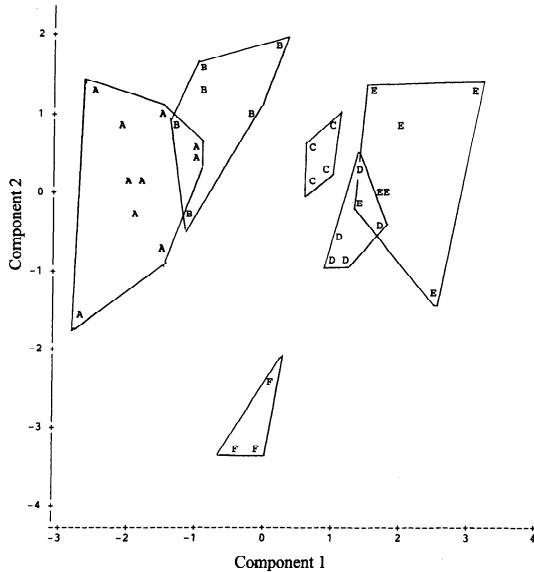


Figure 3. Plot of component 2 vs. component 1 for logarithmically transformed extractable concentrations of 5 elements in soils. Symbols as in Table 1.

It is proposed that PCA applied to the elemental content of soils has proved to be a useful tool to establish perhaps the most important of the causes of the plant communities found over soils of the Dun Mountain Ophiolitic Belt and its immediate surroundings. In this example edaphic factors such as the elemental content of the soil have predominant influence on the development of vegetation. Our findings may not represent a final solution of the "serpentine problem" but we believe that they have highlighted the fact that it is likely that the solution to the problem will be found in these edaphic factors.

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References

- Anonymous 1992 New Zealand soil classification. DSIR Land Resources Sci. Rep. 19, 1–133.
- Barber S A 1984 Soil Nutrient Bioavailability. Wiley and Sons, New York.
- Brooks R R 1987 Serpentine and its Vegetation. Dioscorides Press, Portland.
- Brooks R R, Baker A J M and Malaisse F 1992 Copper flowers. Nat. Geogr. Res. Explor. 8, 338–351.
- Coleman R G and Jove C 1992 Geological origin of serpentinites. *In* The Vegetation of Ultramafic (Serpentine) Soils. Eds. A J M Baker, J Proctor and R D Reeves. pp 1–18. Intercept, Andover.
- Chittenden E T, Hodgson L and Dodson K J 1966 Soils and agriculture of Waimea County, New Zealand. N.Z. Soil Bur. Bull. 30, 1–66.
- Epstein E E 1972 Mineral Nutrition of Plants: Principles and Perspectives. John Wiley and Sons, New York.
- Kinzel H 1982 Serpentinpflanzen. *In* Pflanzenphysiologie und Mineralstoffwechsel. pp 381–410. Ulmer, Stuttgart.
- Krause W 1958 Andere Bodenspezialisten. *In* Handbuch der Pflanzenphysiologie. pp 755–806. Springer Verlag, Berlin.
- Kruckeberg A R 1954 The ecology of serpentine soils. III. Plant species in relation to serpentine soils. Ecology 35, 267–274.
- Lauder W R 1965 The geology of the Dun Mountain, Nelson, New Zealand. N.Z. J. Geol. Geophys. 8, 475–504.
- Lee W G 1980 Ultramafic Plant Ecology of the South Island, New Zealand. PhD Thesis, Univ. Otago, Dunedin. 285 p.
- Lee W G 1992 New Zealand ultramafics. The Ecology of Areas with Serpentinized Rocks. A World View. Eds. B A Roberts and J Proctor. pp 375–417. Kluwer Academic Publishers, Dordrecht.
- Proctor J and Craig G C 1978 The occurrence of woodland and riverine forest on the serpentine of the Great Dyke. Kirkia 11, 129–132.
- Proctor J and McGowan I 1976 Influence of magnesium on nickel toxicity. Nature 176, 234.
- Proctor J and Nagy L 1992 Ultramafic rocks and their vegetation: an overview. *In* The Ecology of Areas with Serpentinized Rocks. A World View. Eds. B A Roberts and J Proctor. pp 469–494. Kluwer Academic Publishers, Dordrecht.
- Salisbury F B and Ross C W 1978 Plant Physiology. Wadsworth Publishing Co., Belmont, CA.
- SAS Institute Inc. 1988 SAS/STAT Guide for Personal Computers. SAS, Cary, NC. 705 p.
- Wellman H W 1942 Talc-magnesite and quartz-magnesite rock, Cobb-Takaka District. N.Z. J. Sci. Technol. 24, 227–235.
- Williams G J 1965 The Economic Geology of New Zealand. Australas. Inst. Mining Metall., Melbourne.

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