Geochemical Investigation of the Distribution of *Arabis macdonaldiana* in the Josephine Ophiolite, Six Rivers National Forest, Del Norte County, California

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ABSTRACT

Arabis macdonaldiana, a federally listed endangered species, is now on the brink of extinction. The only known occurrences are in Del Norte, Siskiyou, and Mendocino Counties, California (Figure 1) where it grows in soils developed on mafic and ultramafic rocks. Within the Six Rivers National Forest, in Del Norte County, it exhibits very sparse and patchy distribution in areas where it appears to be well suited for growth. In order to assess the influence of local geochemistry on *Arabis macdonaldiana* distribution, this study compares the soil and rock chemistry and mineralogy of sites both occupied and unoccupied by the *Arabis macdonaldiana*. Study area sites are underlain by serpentinized mafic and ultramafic rocks of the Josephine ophiolite complex, which provides a suitable habitat for *Arabis macdonaldiana*. Soils developed from such bedrock are relatively enriched in various toxic metals, including nickel, magnesium, barium, and chromium; they are also lacking in important nutrients. The range of nickel concentration within soil samples range from 1850 to 5980 parts per million (ppm). Sites with low plant densities have high nickel, suggesting the likelihood of nickel being a growth inhibitor. In addition, barium range from 0.497 to 7.55 μg/g and is also a growth inhibitor.

Contents

Figure 1
Index map showing location of study area.

ACKNOWLEDGMENTS

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INTRODUCTION

This study is an assessment of anomalous growth patterns of *Arabis macdonaldiana* by the examination of possible geochemical effect on these growth patterns. High concentrations of specific elements or a combination of elements, in addition to low concentrations of nutrients needed for growth, are possible explanations. Soils developed from serpentinized mafic and ultramafic rock (Figure 2) may be relatively enriched in various toxic metals, including nickel, magnesium, barium, and chromium, and lacking in important nutrients, such as calcium. Nickel in serpentinized soil is toxic to most plant life. However, nickel accumulation by serpentine biota is essential for evolutionary adaptation. Extraordinary facilitation of serpentine taxa is called *hyperaccumulation,* (Robertson, 1985). This enables taxa to alter the toxicity of nickel, thus enabling toleration.

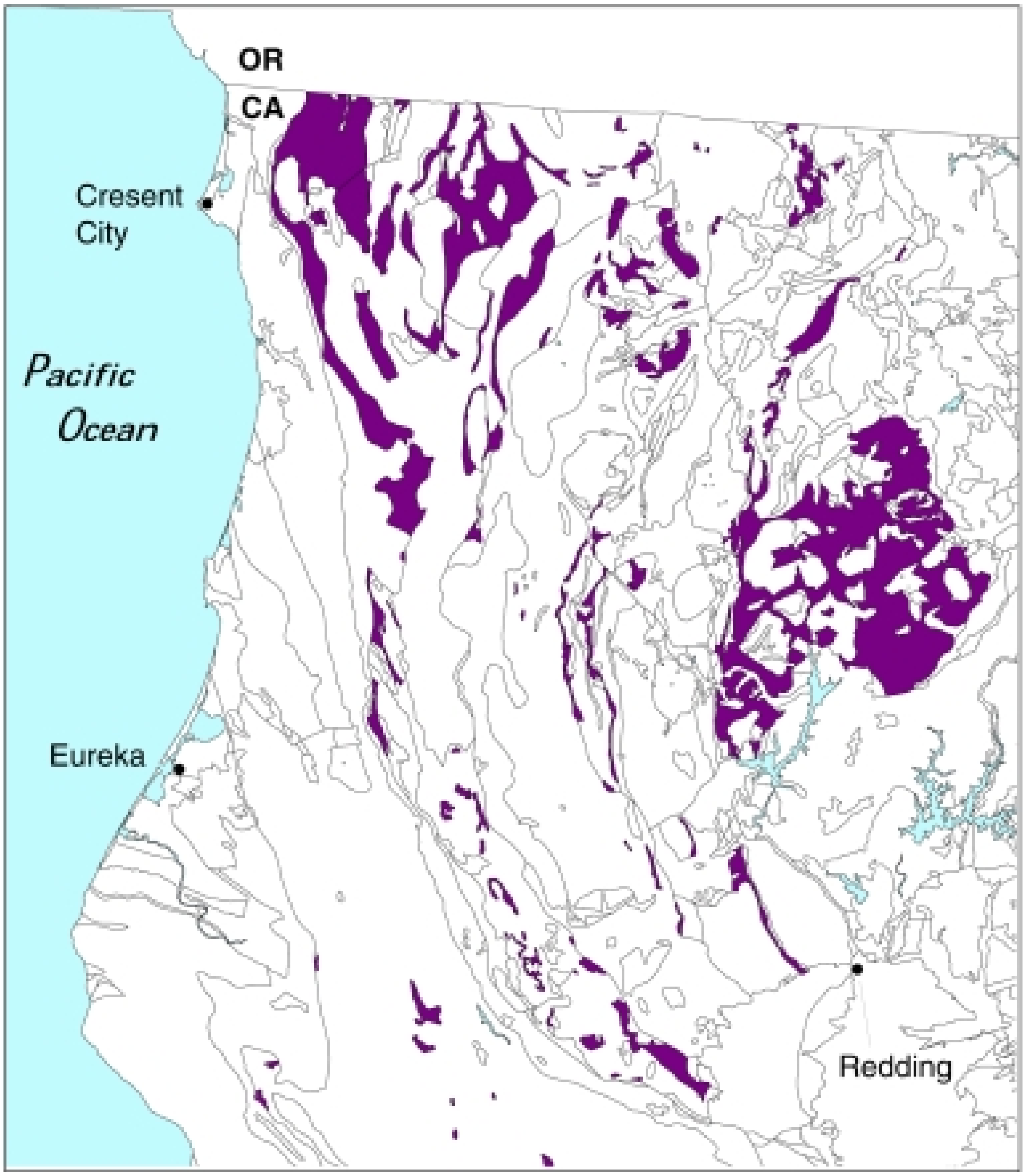

Figure 2
Map showing ultramafic rock in northern California including the Josephine Peridotite.

Geographical Setting

This study area is situated in two different areas within the Klamath Mountains. Sample collection sites are shown on Figure 3 and their coordinates are given in Table 1. The first is along County Route 305 (Rowdy Creek Road), and the second is along the Gasquet Toll Road, Gasquet, California. Rowdy Creek Road intersects Highway 101 at Smith River, California, near the Oregon border. It winds in a northeast direction along rugged terrain of dense redwood forests. The ecological system changes abruptly to a serpentine chaparral forest approximately five miles inland, as Rowdy Creek crosses the Great Valley fault. This abruptness represents a tectonostratigraphic terrane boundary between the Franciscan complex and the Josephine Peridotite (Irwin and Mankinen, 1998). The serpentine chaparral ecological system is the desired habitat of *Arabis macdonaldiana*. It coexists with a mosaic of vegetation, including Jeffrey pine, several grasses, various shrubs, a host of wildflowers, and other rock-crest species. These other species include *Claytoia sp.* and *Saxifragopsis fragarioides*. However, very few sites are found where *Arabis macdonaldiana* actually grows. Where it is found, the terrain commonly consists of steep debris slopes within drainage systems between approximately 525 m and 800 m.

The second study area is along County Route 314 (Gasquet Toll Road). The Gasquet Toll Road intersects Highway 199 in Gasquet, California. This logging road winds its way up the steep hillside above Highway 199 and the Smith River. Like Rowdy Creek Road, this steep drainage area's predominant features are landslides, and in areas with dense vegetation. Exposed outcrops are not easily accessible. Although this area is said to host *Arabis macdonaldiana,* growth sites were not found (Figure 4).

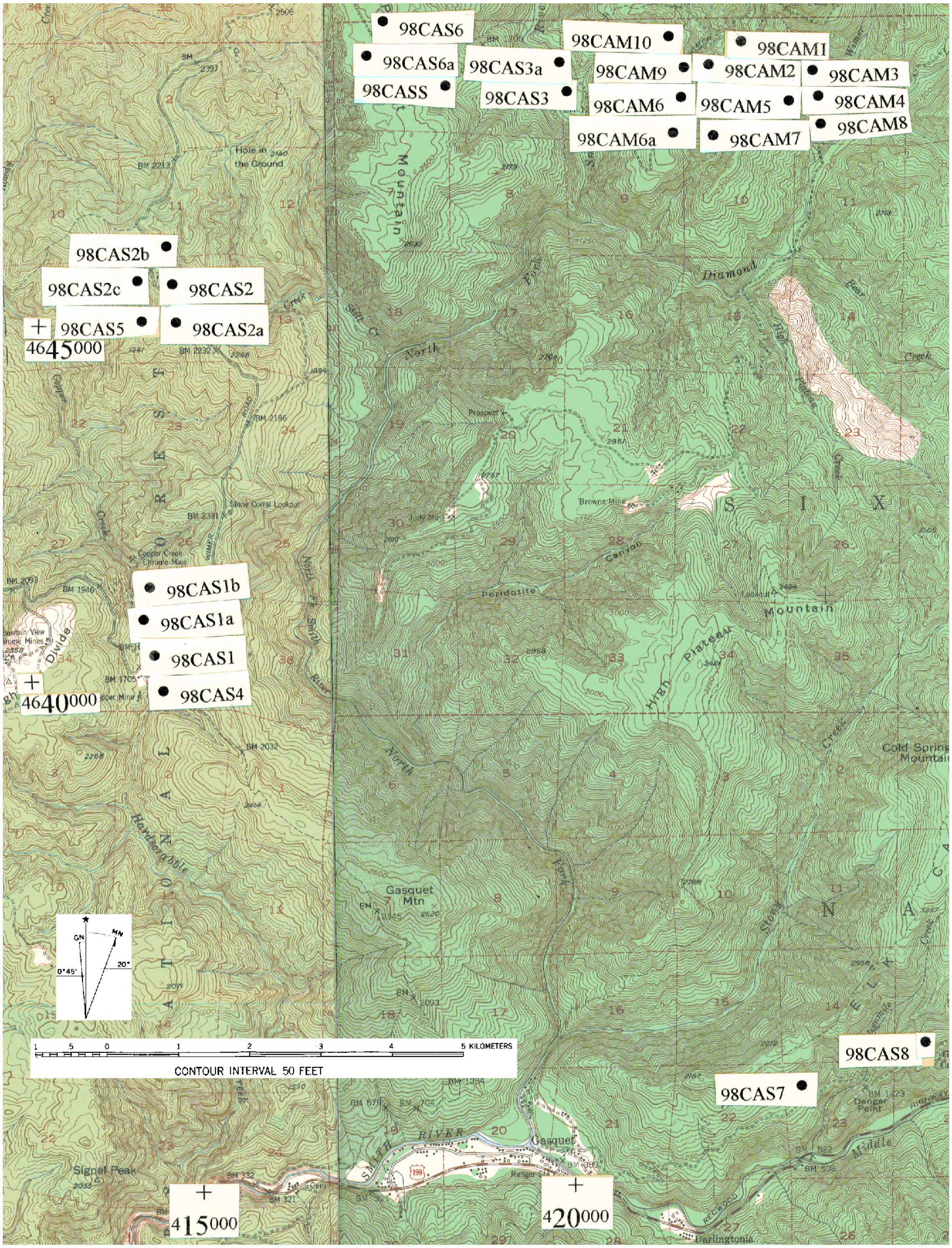

Figure 3
Map showing site locations.
[base from U.S. Geological Survey Crescent City (1952) and Gasquet (1951) 15' quadrangles]

Table 1
Site locations
[Coordinates given in UTMs; easting is in Zone 10. As GPS signals for civilian use are scrambled and only accurate to within 15 to 100 meters, data are rounded off to the nearest 50 meters]

Sample no.	**Easting**	**Northing**
98CAM1	4 228 00	46 486 00
98CAM10	4 223 00	46 490 50
98CAM2	4 224 00	46 482 50
98CAM3	4 227 00	46 482 00
98CAM4	4 227 00	46 483 00
98CAM5	4 227 00	46 483 00
98CAM6	4 227 50	46 479 00
98CAM6a	4 227 50	46 479 00
98CAM7	4 227 50	46 478 50
98CAM8	4 229 50	46 473 00
98CAM9	4 227 00	46 483 00
98CAS1	4 142 00	46 402 00
98CAS1a	4 153 00	46 448 00
98CAS1b	4 141 00	46 400 00
98CAS2	4 153 00	46 448 00
98CAS2c	4 151 00	46 445 00
98CAS3	4 211 50	46 476 00
98CAS3a	4 210 50	46 470 00
98CAS4	4 142 00	46 403 00
98CAS5	4 144 00	46 450 00
98CAS6	4 174 00	46 494 50
98CAS6a	4 174 00	46 494 00
98CAS7	4 232 50	46 335 00
98CAS8	4 280 50	46 360 00
98CASb	4 152 00	46 445 50
98CASS	4 188 00	46 435 00

Figure 4
Photograph showing overview of typical terrain in the Six Rivers National Forest in which *Arabis macdonaldiana* is found.

BOTANY

The following summary of the characteristics of *Arabis macdonaldiana* is excerpted from Jimmerson (1995).

Family: Brassicaceae

Species: *Arabis macdonaldiana*

Common name: Mcdonald's rock cress

Flower: pale rose to purple, with five spoon-shaped pedals.

Habit: Perennial Herb, 1-3 dm

Leaves: Basal rosette, glabrous, 1-2 cm, with few toothed

Blooms: April to June

Habitat: Talus hillslope (Figure 5), trending southwest, steeply to moderately sloping. Macrosites are associated with Jeffrey Pine woodlands. Serpentine soils, within rock crevices (Figure 6).

Status: Endangered

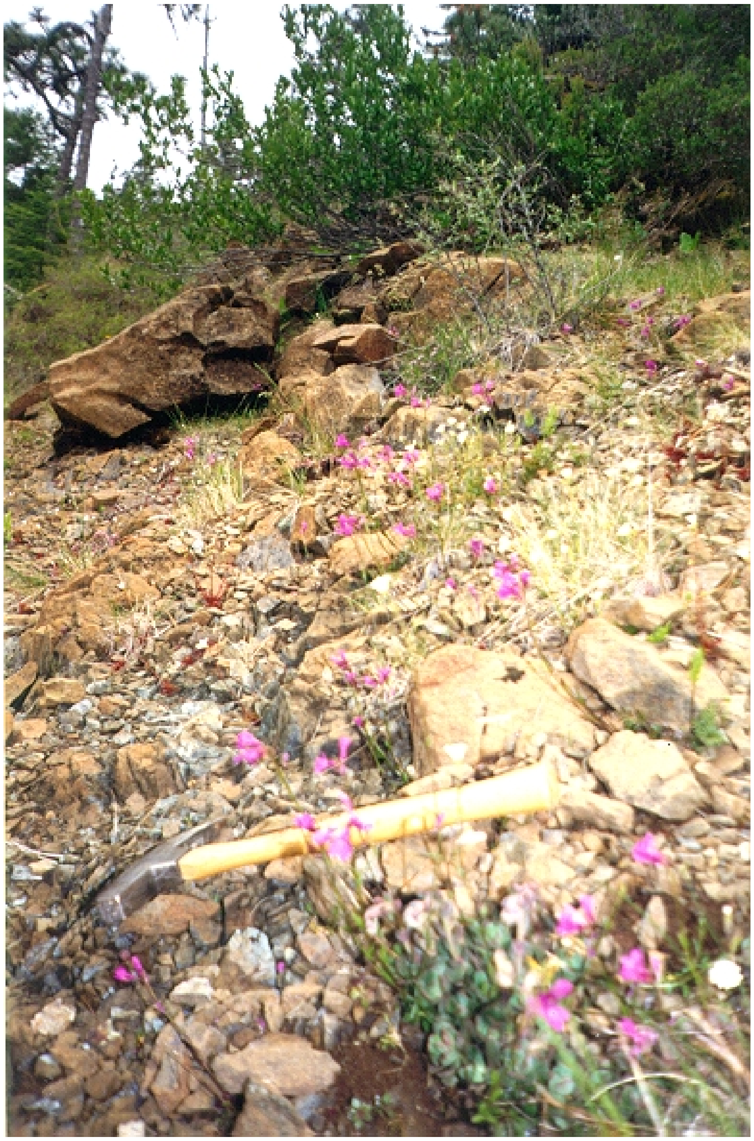

Figure 5

Photograph showing typical habitat of *Arabis macdonaldiana* (purple flower). It grows on talus hillslopes, steeply to moderately sloping, trending southwest.

Figure 6
Arabis macdonaldiana (purple flower) habitat is associated with a wide range of other biota species common in serpentine soil. It grows along serpentine rock crevices where soil is shallow.

GEOLOGY

Located in northwestern California and extending into Oregon lies a stratigraphically and structurally complex region known as the Klamath Mountain province. This region consists of four arcuate lithic belts the Eastern Klamath belt, the Central Metamorphic belt, the Western Paleozoic and Triassic belt and the Western Jurassic belt (Harper, 1980). The Eastern Klamath belt contains the oldest terranes (Irwin, 1989). Because of its andesitic volcanic rocks and reefal limestones Irwin (1989) suggests this terrane represents a long-standing volcanic arc that perhaps was built on Ordovician and older oceanic crust. The second arcuate lithic belt, known as the Central Metamorphic belt, is located to the west of the Western Jurassic belt. It also lies west and structurally below the Trinity Ultramafic sheet and consists of sedimentary and volcanic rocks (Irwin, 1980; Figure 7). It was metamorphosed during the Devonian (Harper, 1980). Lying to the west of the Central Metamorphic Belt is the third arcuate lithic belt, known as the

Western Paleozoic and Triassic belt. It consists of sedimentary rocks including shale, sandstone, chert, limestone lenses, and additionally, ultramafic rocks (Harper, 1980). Finally, the belt known as the Western Jurassic belt (Ordovician to Jurassic), consists of: the Galice and the Rogue-Chetco Formations (Figure 7) and the Josephine ophiolite. The Galice Formation consists of a metasedimetary sequence of interbedded shale, metagreywacke, and uncommon pebble conglomerates (Harper, 1980). The Rogue Formation which lies beneath the Galice Formation is a thick sequence of basaltic to rhyolitic tuffs, breccias and flows (Harper, 1980). It contains late Jurassic (Oxfordian-Kimmeridgian) *Buchia concentrica* occurring in the pebble-conglomerate bed near Shelley Creek (Harper, 1980), within a flysch sequence. The Chetco is an intrusive complex. The Josephine ophiolite contains the Josephine Peridotite and underlies the younger Galice Formation as an east-dipping thrust sheet (Harper, 1980). The Josephine ophiolite is one of the largest and most complete ophiolites in the world (Harper, 1980). It consists of four units; harzburgite, a cumulate ultramafic and mafic rock of gabbro and diorite, sheeted mafic dike complex, and pillow lavas and breccias (Harper, 1980). It has undergone multiple deformation and regional low-grade metamorphism (Harper, 1980). It is the soils developed from the Josephine ophiolite that creates the unique ecology for *Arabis macdonaldiana.*

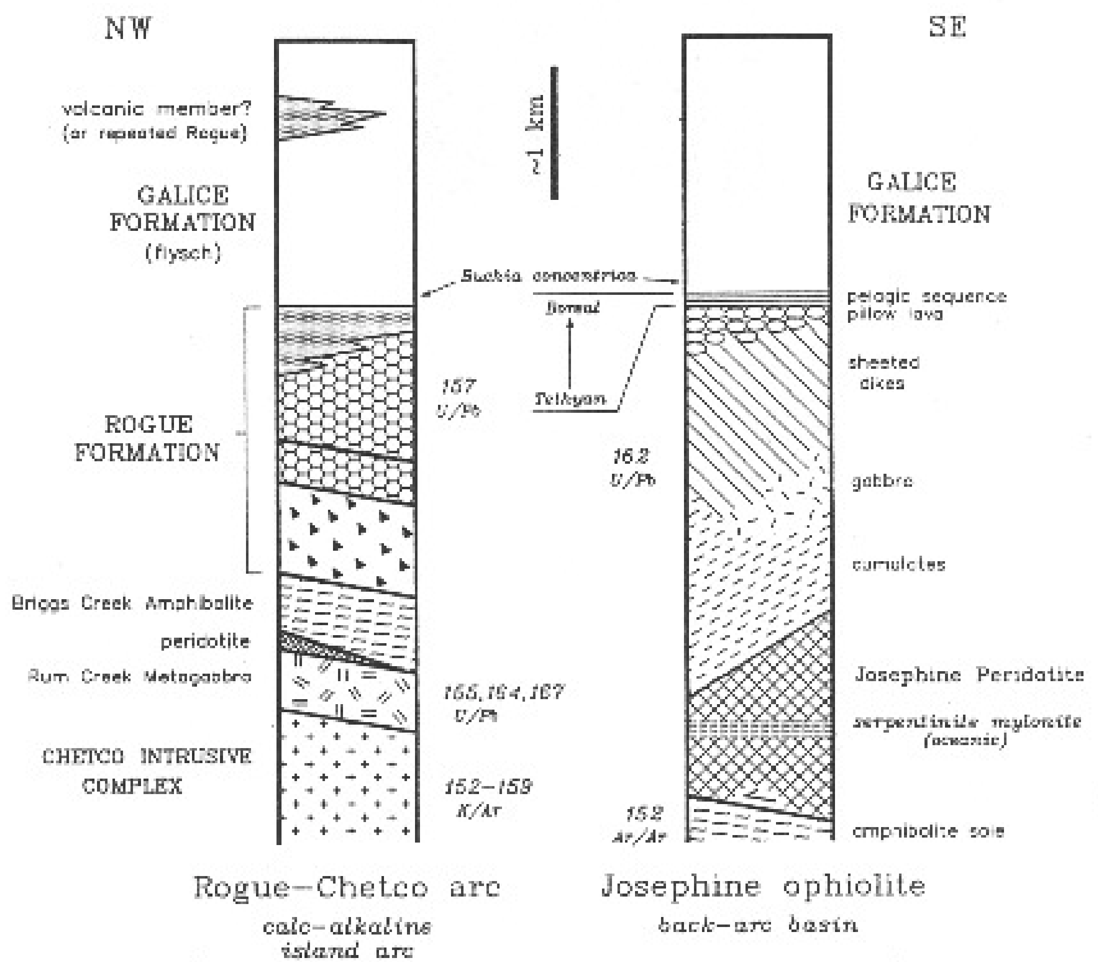

Figure 7
Stratigraphic columns for the Galice, Rogue-Chetco arc and the Josephine Ophiolite, from Harper (1989).

SAMPLING

Twenty-three different sites were occupied along Rowdy Creek Road, Smith River, California, and Gasquet Toll Road, Gasquet, California (Figure 3):

- Sites 98CAS1, 1a, 1b, 2, 2b, 2c, 3, 3a, 5, 6 and SS are located along Rowdy Creek Road.
- 98CAS1 and 98CAS1a are located near the Low Divide mine.
- 98CAS2, 98CAS2b, and 98CAS2c are located near the Hole-in-the-Wall mine.

- Sites 98CAS3, and 98CAS3a are located above the North Fork, Smith River, along the canyon where there were no mining activities.
- Sites 98CAS3 and 98CAS3a contain the highest plant density.
- Site 98CAS5, also not subjected to mining activity and has the second highest plant density.
- Site 98CASS is located near 98CAS1; however, the plant density consists of *Saxifragopsis fragarioides,* a different species of rock cress.
- Sites 98CAM1, 2, 3, 4, 5, 6, 7, 8, 9 and, 10 were collected farther northeast along Rowdy Creek Road, near Cleopatra mine.
- Sites 98CAS7 and 8 were collected along Gasquet Toll Road. Even though the area appears suitable for *Arabis macdonaldiana,* petrographic analysis for these sites reveals hornblende diorite. It is possible this rock type is unsuitable for *Arabis macdonaldiana*; however, data are used for plant-density comparison.

Sites 98CAS1, 2, 3, and 98CASM1-M10 were selected based on previous studies where *Arabis macdonaldiana* were found. Aerial photographs were used for selection of other sites that appeared to be suitable habitat for *Arabis macdonaldiana*. Samples of rock, soil, and dead plants were collected for chemical analysis. Analysis of soil was obtained by ICP-mass spectrometry. Clay data were obtained using a Nicolet-IT X-ray diffractometer. Clay samples were mounted on quartz plates and then heated to 500 °C. Diffraction patterns were obtained using the PC software *Jade 3.1* for characterization and identification of materials. These analyses showed the presence of antigorite (Appendix A).

SOIL ANALYSIS

Cation exchange

The formation of serpentine by hydrothermal alteration of mafic and ultramafic rocks such as peridotite and pyroxenite (Nesse, 1991) is not directly associated to plant growth, but the weathering of these parent materials is. When serpentine parent weathers, soils become rich in nutrients such as magnesium, iron, and silica (Moore et al, 1995). A series of cation replacement of clay particles results in a negatively charged clay material called micelles (Moore et al, 1995). These negatively charged micelles allow for binding of cations such as Ca^{2+} and K^{+}, and other nutrients to the clay surface (Moore et al, 1995). Cation-exchange processes between clay and plant root allow plants to extract these nutrients. The importance of this cation exchange is that the high cation-exchange capacity of clay structures makes these soils well suited for plant growth (Moore et al, 1995). However, in serpentine soil, this cation exchange often results in inadequate nutrient recycling (Kruckeberg, 1984). It is the quality of this ion-exchange capacity and ionic reserve that distinguishes serpentine soils from those derived from non-ferromagnesian rocks (Kruckeberg, 1984).

Unlike agriculturally rich soils, serpentine soils are commonly analyzed for each element according to (Kruckeberg, 1984). Other experts singled out limits to plant growth, such as an exceptionally high concentration of magnesium, causing magnesium toxicity, and low concentrations of calcium, or toxicity of nickel and chromium, or low concentrations of molybdenum. In this study, barium also plays an important role as an inhibitor of growth of the *Arabis macdonaldiana.* Barium is not an element resulting from weathering processes of serpentine, but in this study area it is anthropogenic. This study investigates the multiple possibilities limiting growth of *Arabis macdonaldiana*. According to Kruckeberg (1992), high concentrations of cobalt, chromium, iron, and nickel and a possible deficiency of molybdenum adversely affect plants (Figure 8). However, this study shows that high concentrations of cobalt seem to enhance the growth of *Arabis macdonaldiana*

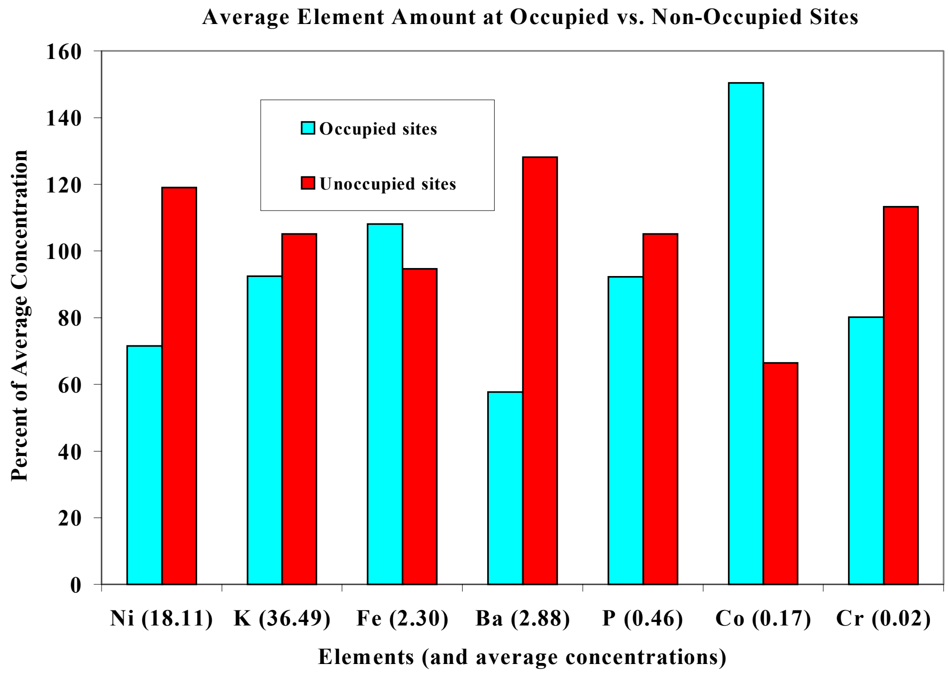

Figure 8
Graph showing percent average concentration of chemical elements for sites with occupied sites verses sites unoccupied sites. Nickel, barium, and chromium play a significant role in soil toxicity, while cobalt plays a significant role in plant growth.

Nickel accumulation

A common attribute of serpentinized soils is a high concentration of nickel. Nickel is found in peridotite occurring naturally with olivine. Flora growing in ultramafic environments have adapted to this high concentration of nickel through hyperaccumulation, according to Robertson (1985). In this study, the range of nickel concentration within soil samples ranges from 1850 to 5980 parts per million (ppm). Sites with high plant densities have low nickel concentrations (Figure 9). According to Robertson (1985), when there is enough calcium and magnesium, nickel toxicity can be reduced or removed. However, when magnesium concentrations are high and exchangeable calcium low, magnesium becomes toxic to non-serpentine biota. If they have the capability to adapt to high nickel concentrations, their survival is likely. This investigation, however, suggests the likelihood of nickel being a growth inhibitor of serpentine biota (Figure 10).

- Site 98CAS1: Plant density of *Arabis macdonaldiana* 50.
- Site 98CAS1a: Plant density of *Arabis macdonaldiana* 0. Plant found: *Claytonia* sp.
- Site 98CAS1b: Plant density of *Arabis macdonaldiana* 0. Plant found: *Claytonia* sp.
- Site 98CAS2: Plant density of *Arabis macdonaldiana* 50
- Site 98CAS2b: Plant density of *Arabis macdonaldiana* 14.
- Site 98CAS3: Plant density of *Arabis macdonaldiana* 1000
- Site 98CASS: Plant density of *Arabis macdonaldiana* 0. Plant found: *Saxifragopsis fragarioides*

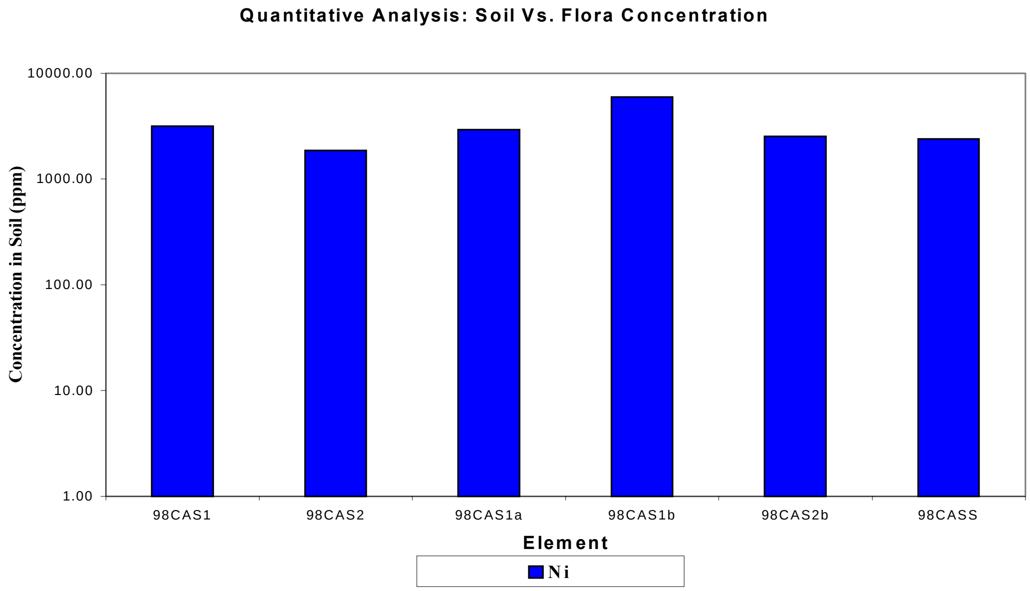

Figure 9
Concentration of nickel found in soils at various sites. At site 98CAS1, 2, 2b, 3 host *Arabis macdonaldiana.* Site 98CAS1a and 98CAS1b hosts *Claytonia* sp., and site 98CASS hosts *Saxifragopisi fragaioides. Arabis macdonaldiana* were not found at the latter sites

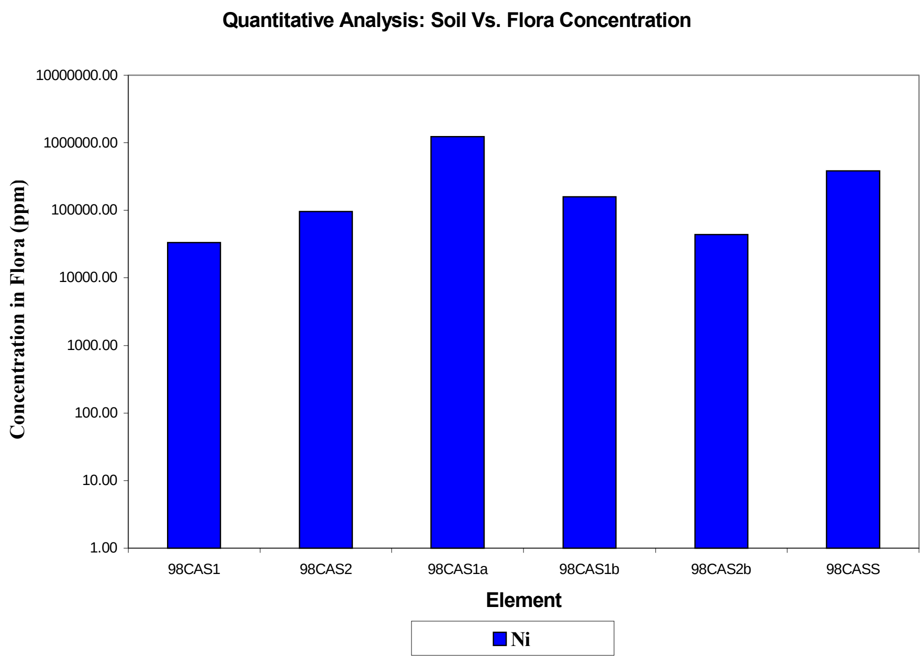

Figure 10
Concentration of nickel found in flora at various sites (data in Appendix C).

Cobalt

Cobalt concentrations within the soil apparently are not inhibiting *Arabis macdonaldiana* (Figures 11 and 12). These graphs show plant density has a positive correlation with cobalt concentrations. According to Kruckeberg (1984), however, elevated cobalt concentration within the soil is a growth inhibitor. It is possible that other factors contribute to ability for *Arabis macdonaldiana* to tolerate these concentrations.

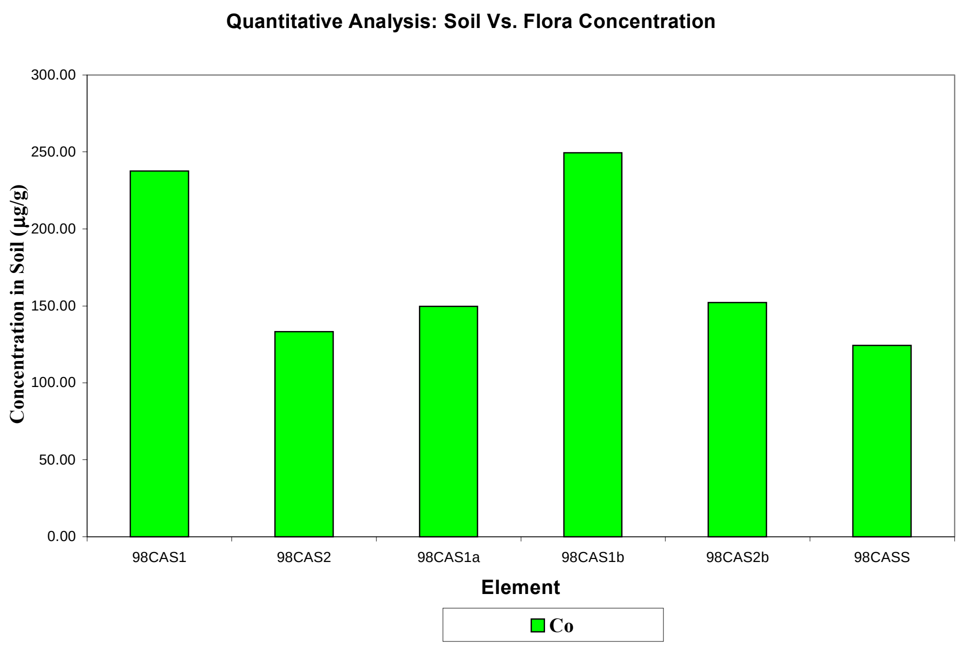

Figure 11

Concentration of cobalt in soil samples at sites with high plant density versus unoccupied sites, (see sampling section). At sites 98CAS1, 2, 2b, 3 host *Arabis macdonaldiana.* Site 98CAS1a and 98CAS1b hosts *Claytonia* sp., and site 98CASS hosts *Saxifragopisi fragaioides. Arabis macdonaldiana* were not found at the latter sites.

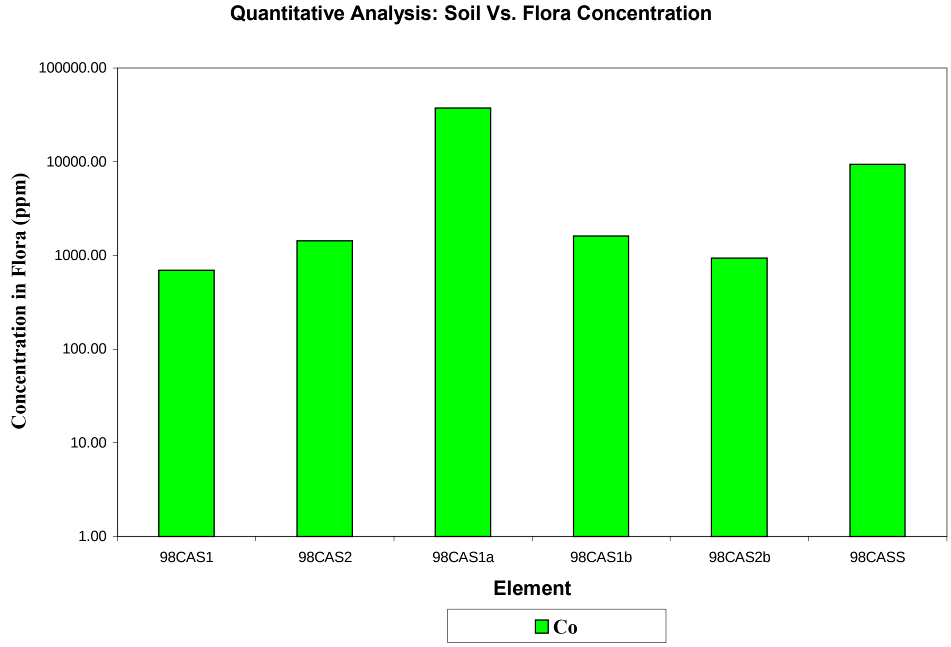

Figure 12
Concentrations of cobalt in flora samples at various sites (data in Appendix C).

Exchangeable calcium and high exchangeable magnesium

A common characteristic attribute of serpentinized soils is a low concentration of exchangeable calcium and high exchangeable magnesium. In this study, a correlation between occupied and unoccupied sites shows that unoccupied sites fall below the average magnesium/calcium ratio, (Figure 13). According to Proctor and Nagy (1985), when exchangeable magnesium concentrations are high and exchangeable calcium low, magnesium becomes toxic and the pH of soil increases to levels intolerable to serpentine biota.

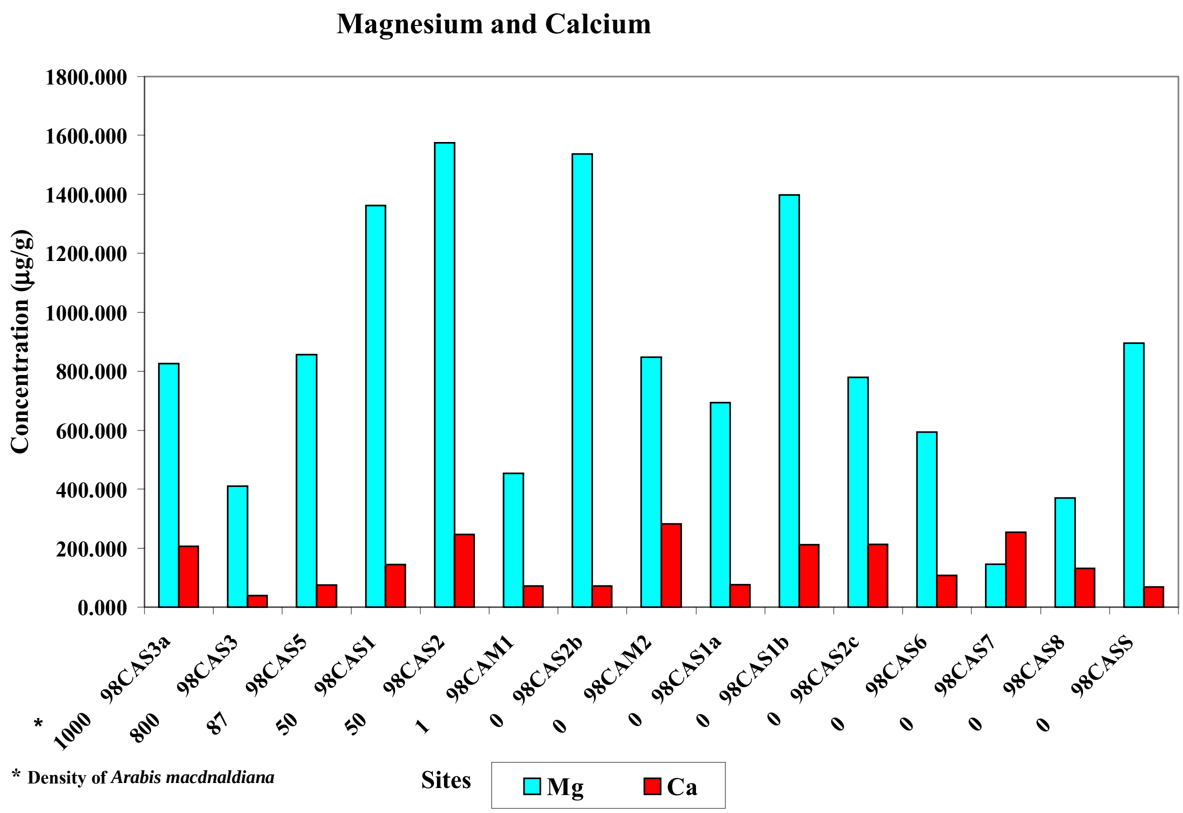

Figure 13

A common characteristic attribute of serpentinized soil is a low concentration of exchangeable calcium and high exchangeable magnesium (Kruckeberg, 1984). In this graph, a comparison of occupied sites and unoccupied sites, thus showing unoccupied sites fall below the average magnesium/calcium ratio. However, notice sites, 98CAS2b and 98CASS: they are near populated sites and these soils should support *Arabis macdonaldiana.* According to Proctor and Nagy (1985), when exchangeable magnesium concentrations are high and exchangeable calcium low, magnesium becomes toxic.

Barium

In this study, barium concentrations within soil samples range from 0.7240 to 5.360 µg/g. The data for barium show it is an inhibitor of *Arabis macdonaldiana* (Figure 8). It is possible that barium is anthropogenic. Occupied sites of the *Arabis macdonaldiana* with the highest density are in areas where there are little effects of mining, while unoccupied sites are near old mining areas. Although not conclusive, logging roads may be repaired with mine tailings, thus introducing barium into areas where there was no mining.

Chromium

This element exists in the environment in a variety of oxidation states. As Cr (III) it is benign, however, Cr (VI) is toxic and easily transported in soils and groundwater (Fendorf, 1995). This problematic metal affects flora and fauna because of its redox reactivity. Although chromium is the tenth most abundant element in the Earth's mantle (Fendorf, 1995), and it is not toxic in low concentrations, in high concentrations it alters the pH of soils and groundwater. However, according to Fendorf (1995), manganese will oxidize Cr (III), and Fe (II) will reduce Cr (VI). He points out that Cr (III) is not a problem to the environment but it can oxidize to Cr (VI). However, the stability of this metal is dependent on reaction with Fe (II), which is often used in industry to diminish Cr (VI) waste. For example, site 98CAS1a, where the plant density equals zero, chromium is at the highest concentration (0.04 μg/g), while iron concentration are at the lowest concentration (1.130 μg/g), (Appendix B). Whereas 98CAS3 plant density equals approximately a thousand, the chromium concentration are much lower (0.01 μg/g), while iron concentration much higher (2.080 μg/g). Although not conclusive, it is possible that if enough iron is present, the chromium will have little effect on *Arabis macdonaldiana.* In this study, chromium is likely an inhibitor of *Arabis macdonaldiana*, (Figure 14).

Nutrients

The absence of biota may be attributed to low concentrations of nutrients and a high concentration of cobalt, chromium, nickel, and iron, according to Kruckeberg (1992).

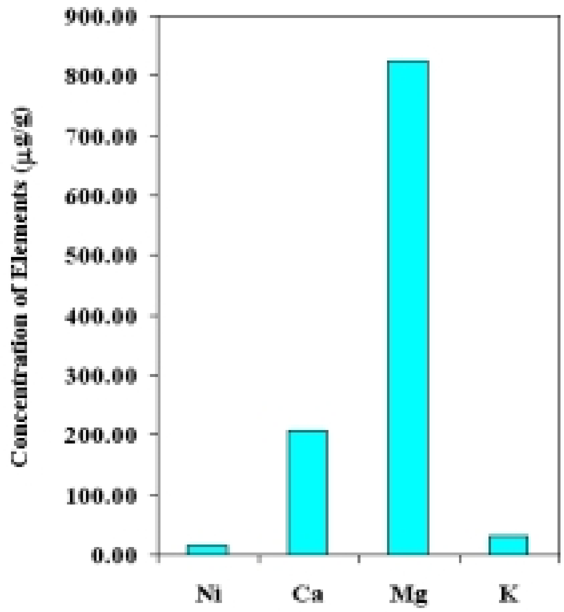

Figure 14a

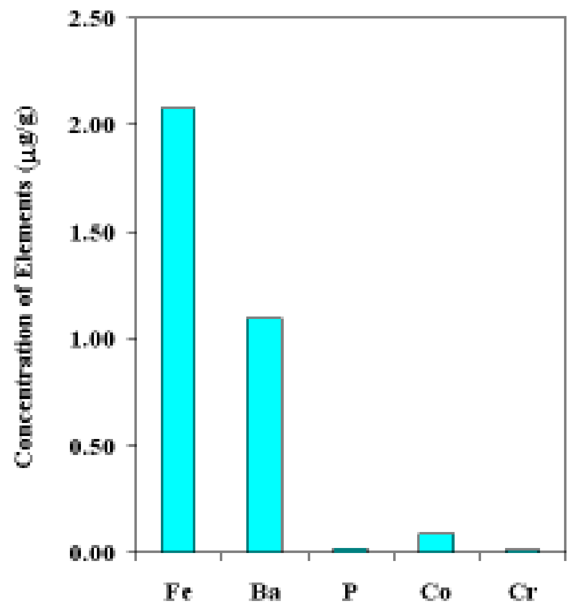

Figure 14b

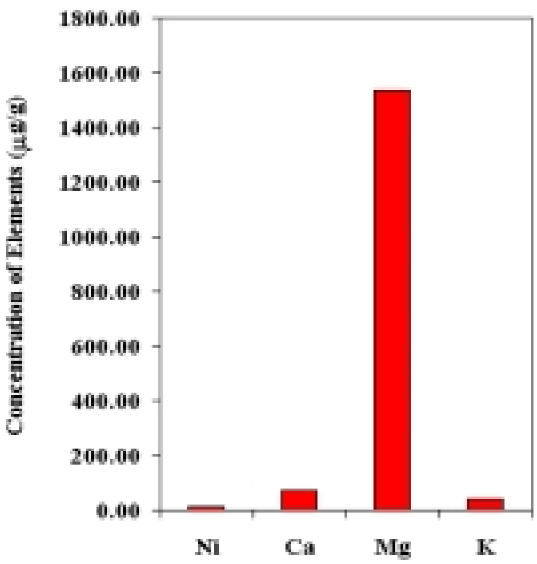

Figure 14c

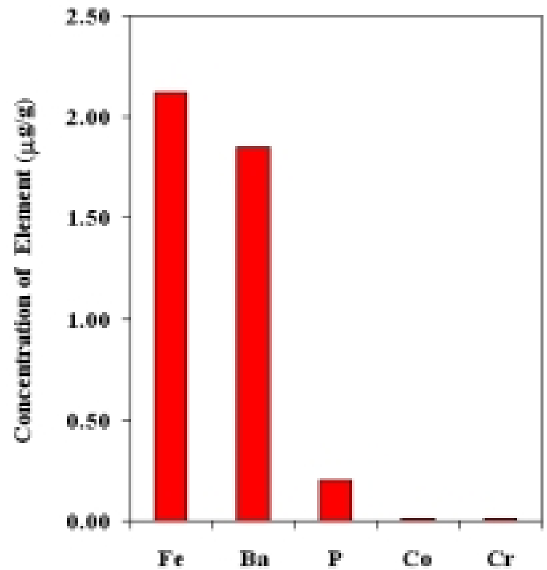

Figure 14d

Figure 14

When 98CAS3a, highest plant density (Figures. 14a and b) and 98CAS2b, zero plant density (Figures 14c and d) are compared, noticeable effects of barium and cobalt become apparent. A high concentration of barium seems to be the growth inhibitor at site 98CAS2b where there is zero plant density. Conversely, elevated levels of cobalt seem to be permissive for higher plant densities.

PETROGRAPHIC ANALYSIS

Hand Samples

Harzburgite coloration in fresh samples is dark green to black, with veins of chrysotile, but has a reddish-yellow weathering, and is approximately 90 percent serpentinized.

Thin Sections

The ultramafic rock protolith minerals in this study include olivine and orthopyroxene; protolithic materials are harzburgite, peridotite, and dunite. Mafic rock protolith minerals include orthopyroxene (Figure 15).

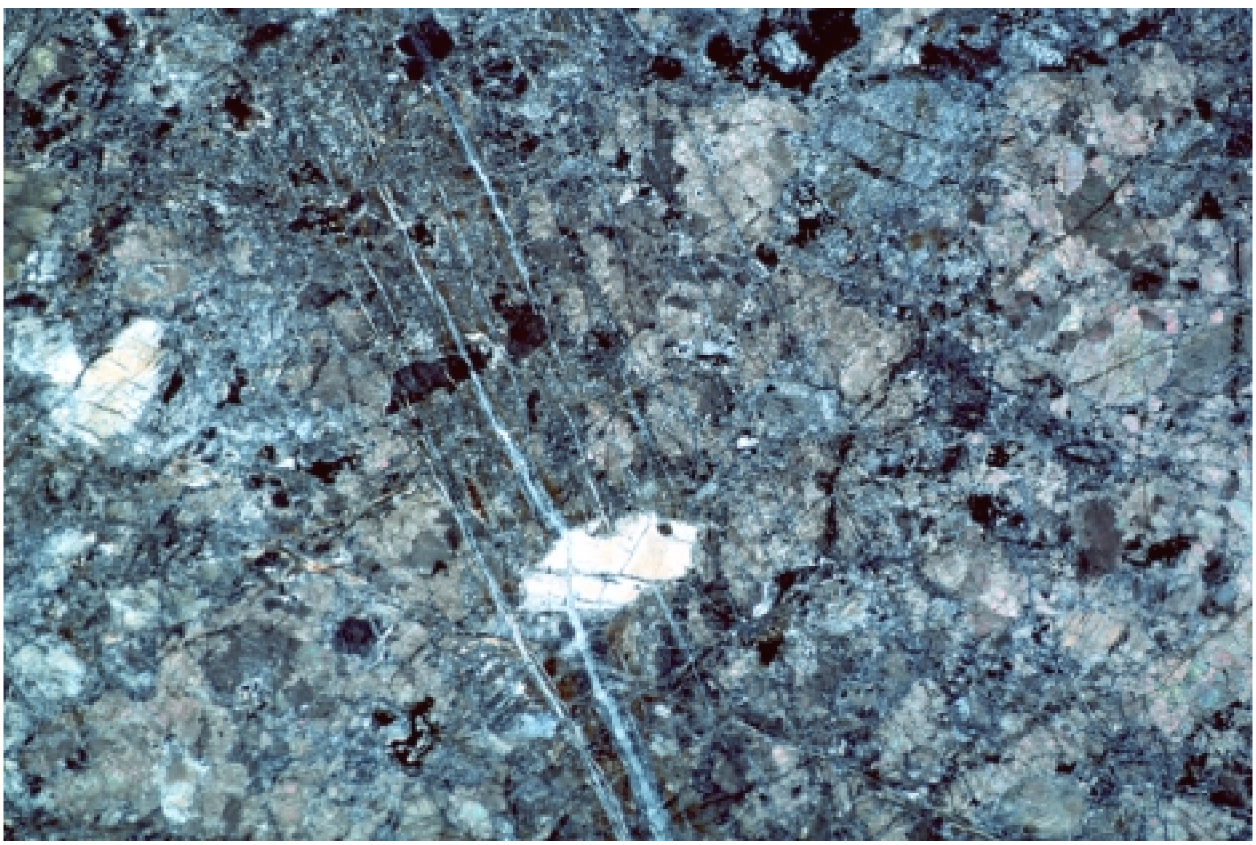

Figure 15
Photomicrograph showing identifiable orthopyroxene (white) and chrysotile (blue fibers) Field of view: 24x36 mm.

Harzburgites studied in thin section are highly serpentinized. However, characteristic attributes are still identifiable. For example, first-order gray birefringence and exsolution lamellae are indicative of orthopyroxene (Harper, 1980). Identifiable attributes of orthopyroxene include parallel extinction and large 2V (Figure 17). High-order colors are secondary materials outlining relict grains of olivine (Steven Silva, oral communication, 1998) (Figure 17). Other observable attributes of olivine include lack of cleavage, high-order birefringence and large 2V. Black grains are opaque oxides (Figure 16).

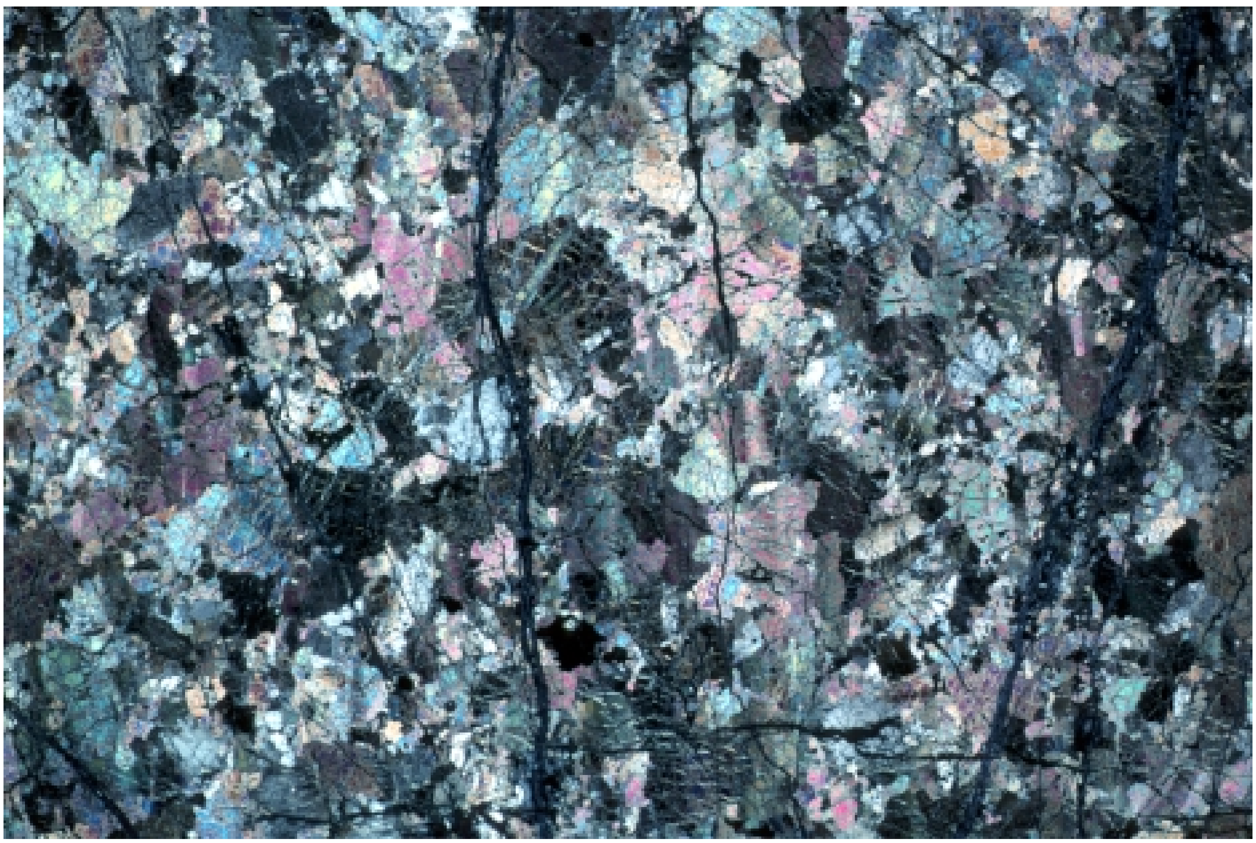

Figure 16
Photomicrograph of serpentinized harzburgite. Field of view: 24x36 mm.

Figure 17
Photomicrograph showing relict crystal edges of olivine. Field of view: 24x36 mm.

Clay Material

Antigorite is the predominant clay sized material in soil samples. Clay analysis was conducted using a Nicolet IT X-ray defractometer. Data were processed using PC software, (Jade 3.1). This software characterizes and identifies crystalline material (Appendix A).

Twenty-five samples were collected at various sites along Rowdy Creek Road and Gasquet Toll Road. Of these samples 98CAS6 - 98CAS8 are hornblende diorites. It is understood that these rock type are unsuitable for *Arabis macdonaldiana*, and they are therefore omitted from this discussion.

CONCLUSIONS

This geochemical study has shown a significant correlation between heavy metal concentrations and *Arabis macdonaldiana* growth distribution. Toxic elements contribute to the disruption of growth of *Arabis macdonaldiana,* along with a combination of many factors that probably inhibit growth. Serpentine soils are characterized by high nickel concentrations and low concentrations of exchangeable calcium and magnesium. Some serpentine taxa have adapted to these extreme conditions; however, chromium and barium may have added to the infertility of serpentine soils within this area. This investigation shows a possible correlation between low plant density and presence of mining activities, that is barium is anthropogenic. For example, sites 98CAM2, 98CAS1b, and 98CAS1c, near old mine sites contain the highest concentrations of barium, and low density of *Arabis macdonaldiana*.

I have used the average concentration of elements at occupied sites versus unoccupied sites for determining a distinct threshold of heavy metal tolerance for *Arabis macdonaldiana*. Concentration of nickel in soil samples ranges from 1850 to 5980 parts per million (ppm), barium concentration ranges from 0.7240 to 5.360 μg/g, and chromium concentration ranges from 0.4 to 0.0 μg/g. These three elements play a role in inhibiting growth of *Arabis macdonaldiana*, while high concentrations of cobalt ranging from 0.830 to 0.010 μg/g seem to enhance its growth. Further taxonomic research is needed to understand enigmatic growth patterns of *Arabis macdonaldiana*, and continued monitoring is needed for the restoration of plant population.

Future Research

During the course of this investigation, the need for further research became clear. The direction of further studies should include:

- Deficiencies in soil nitrogen and phosphorus, and
- Continue soil investigation.

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Appendix A. X-Ray defractometer plots of clay analyses

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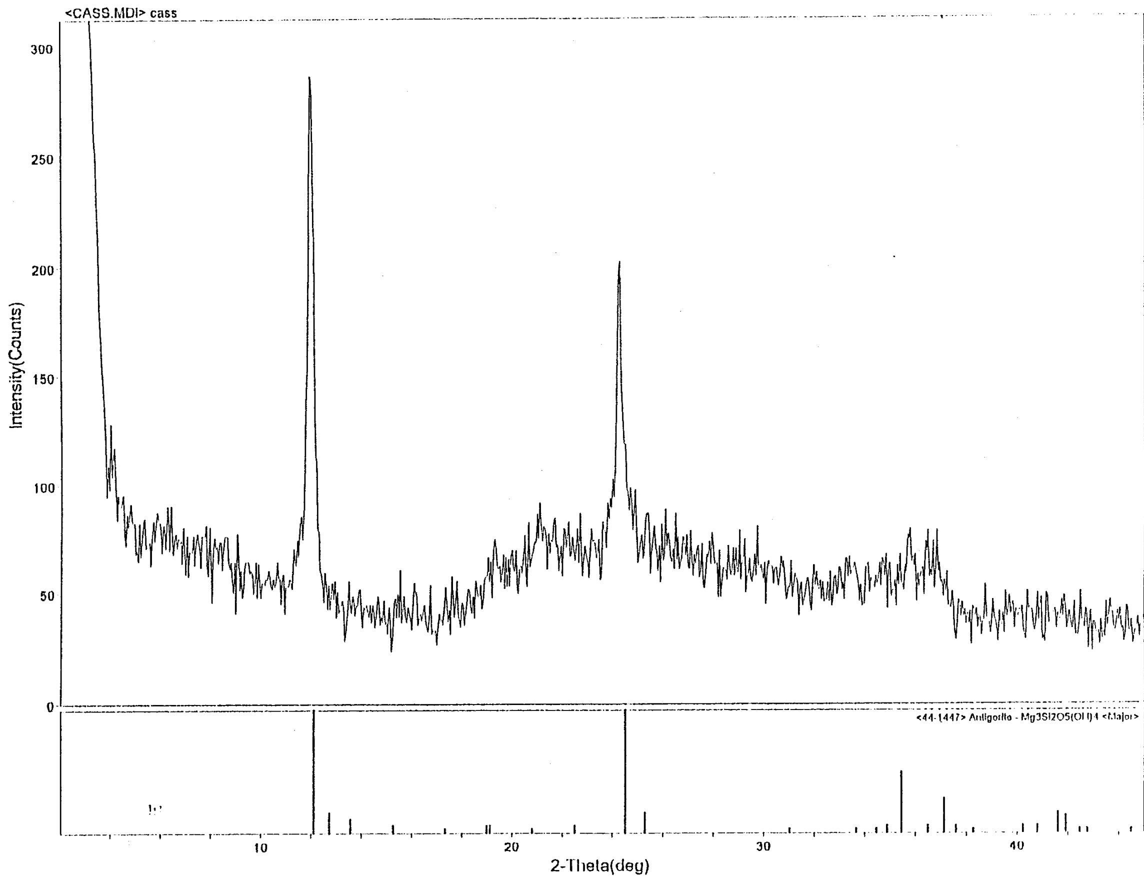

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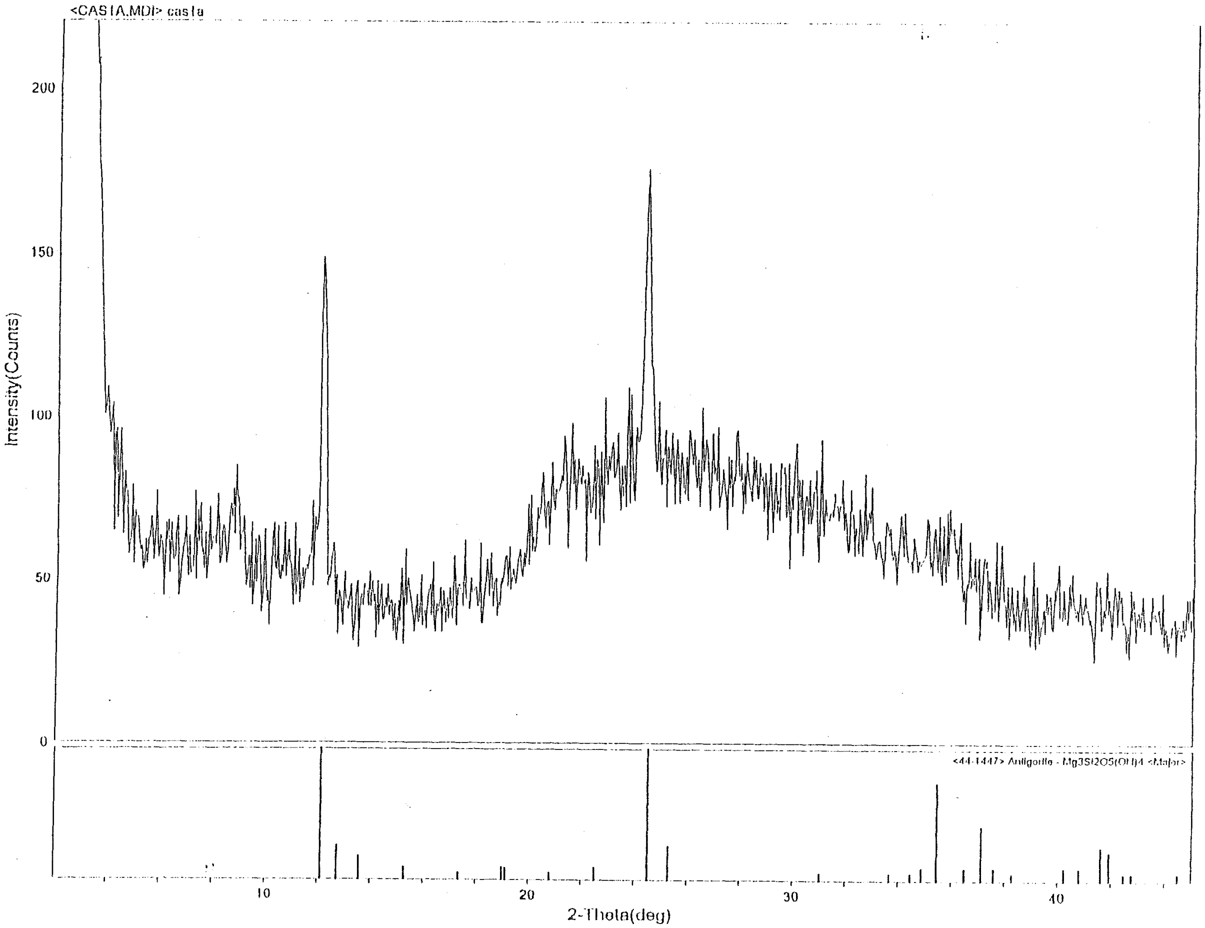

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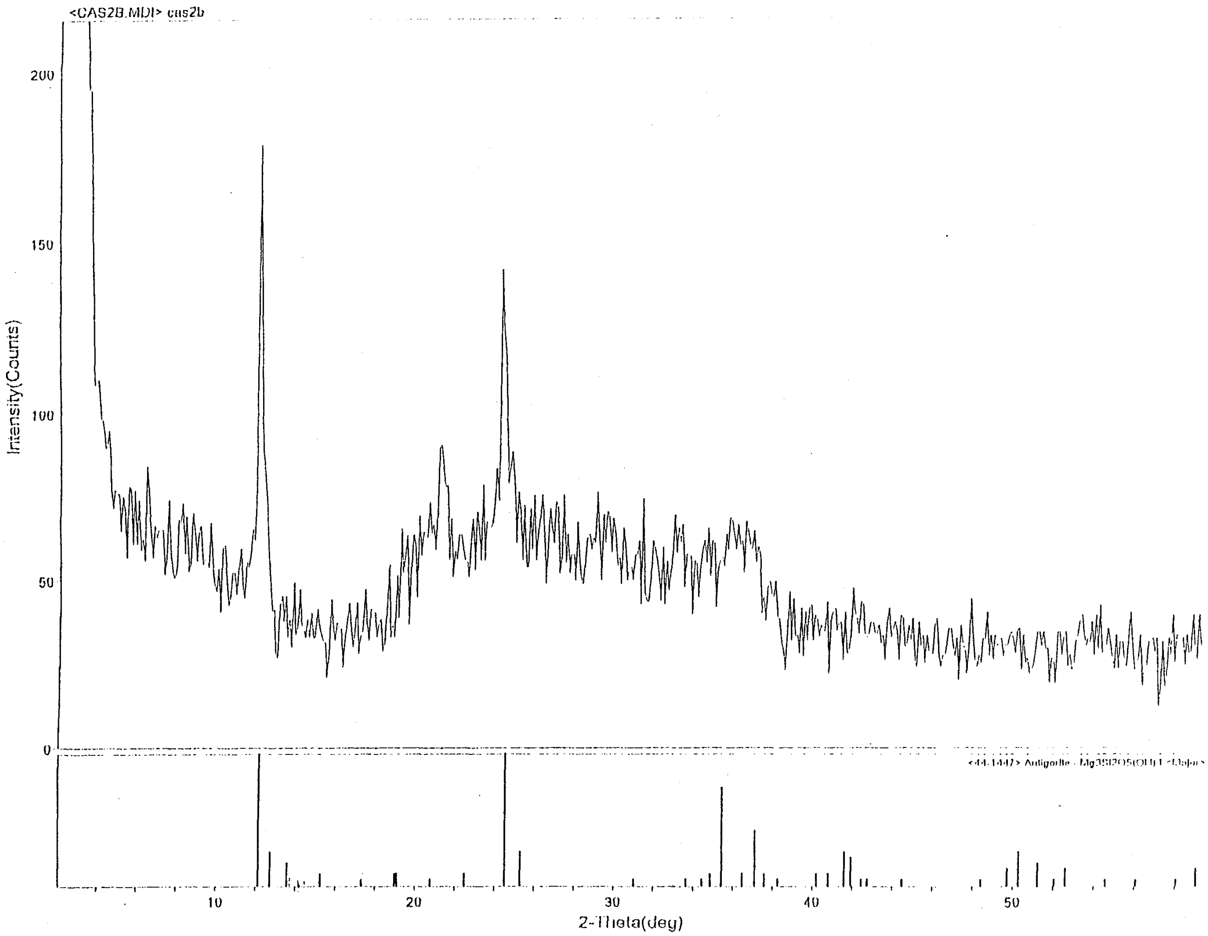

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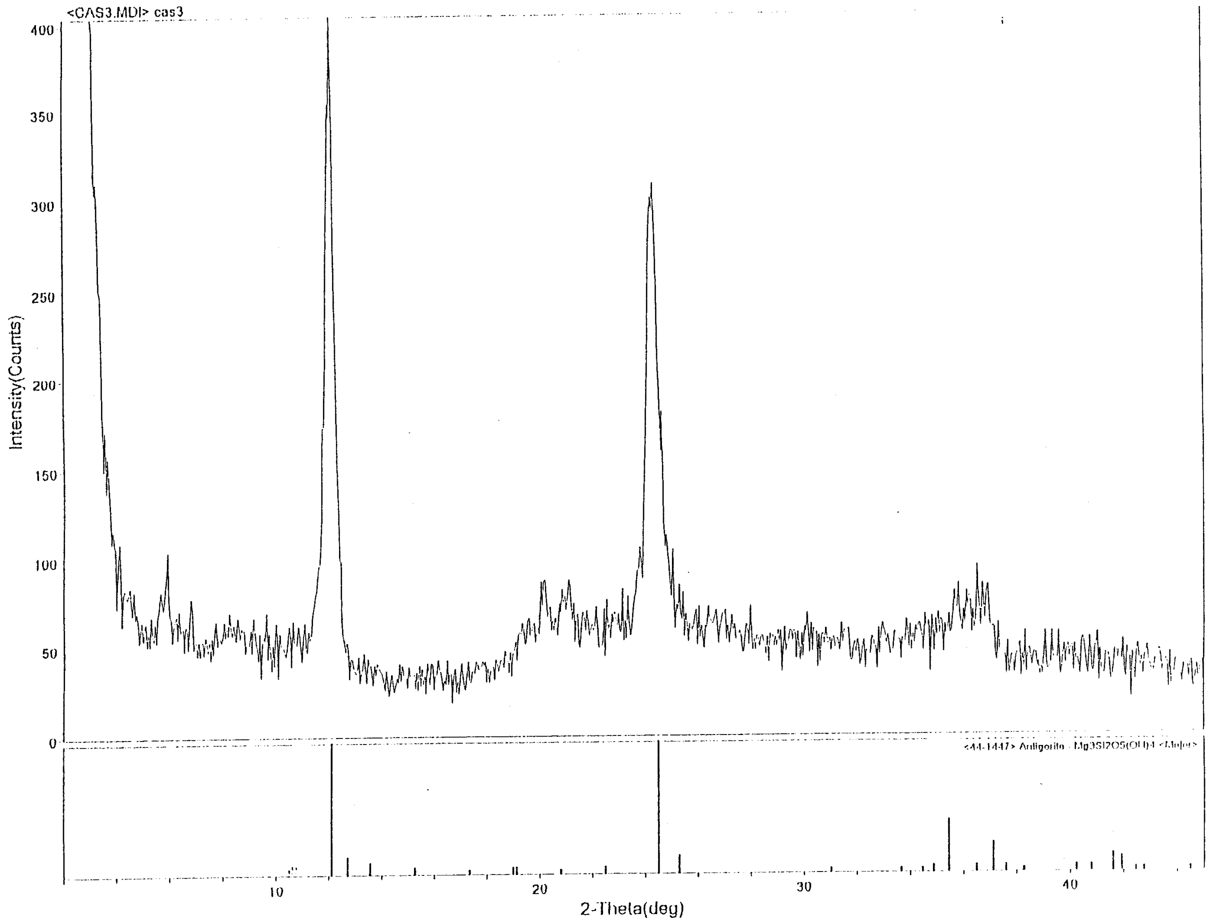

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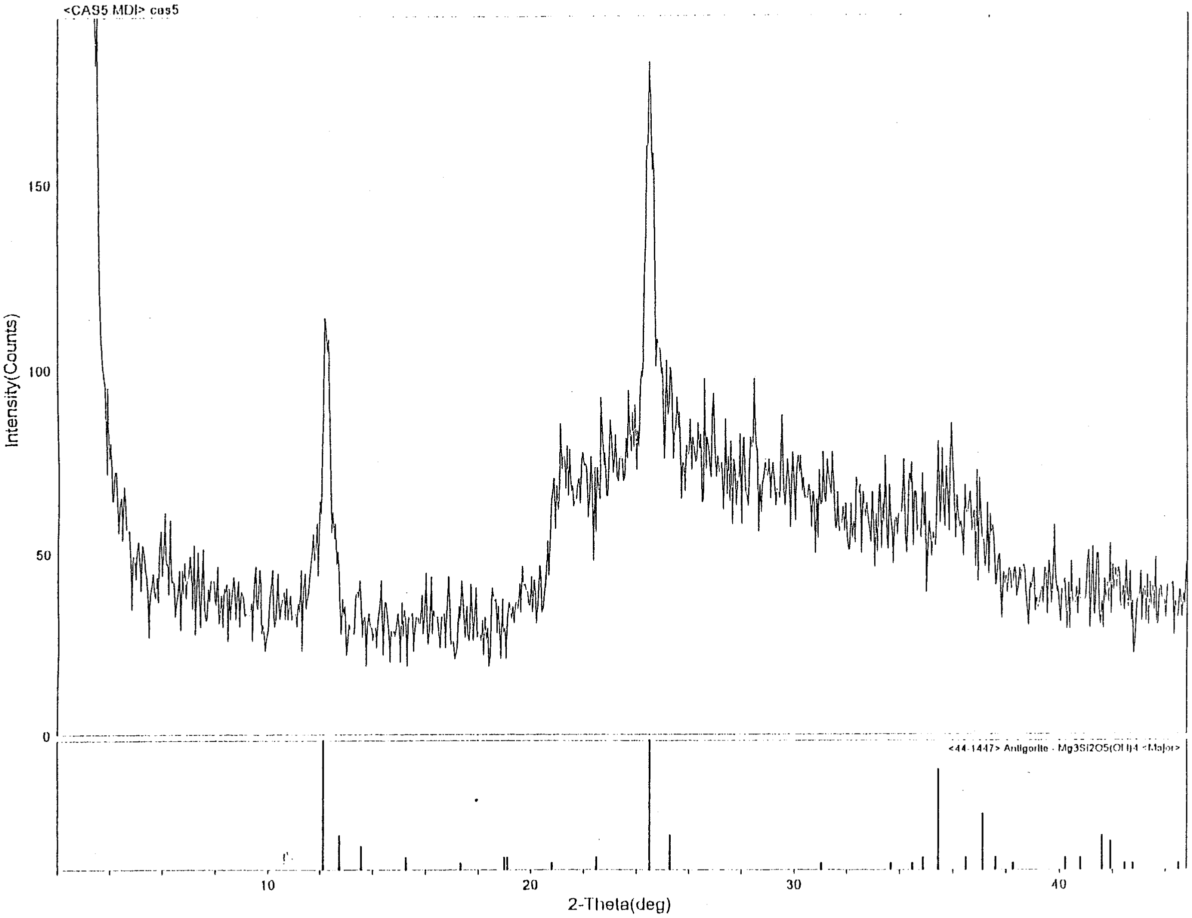

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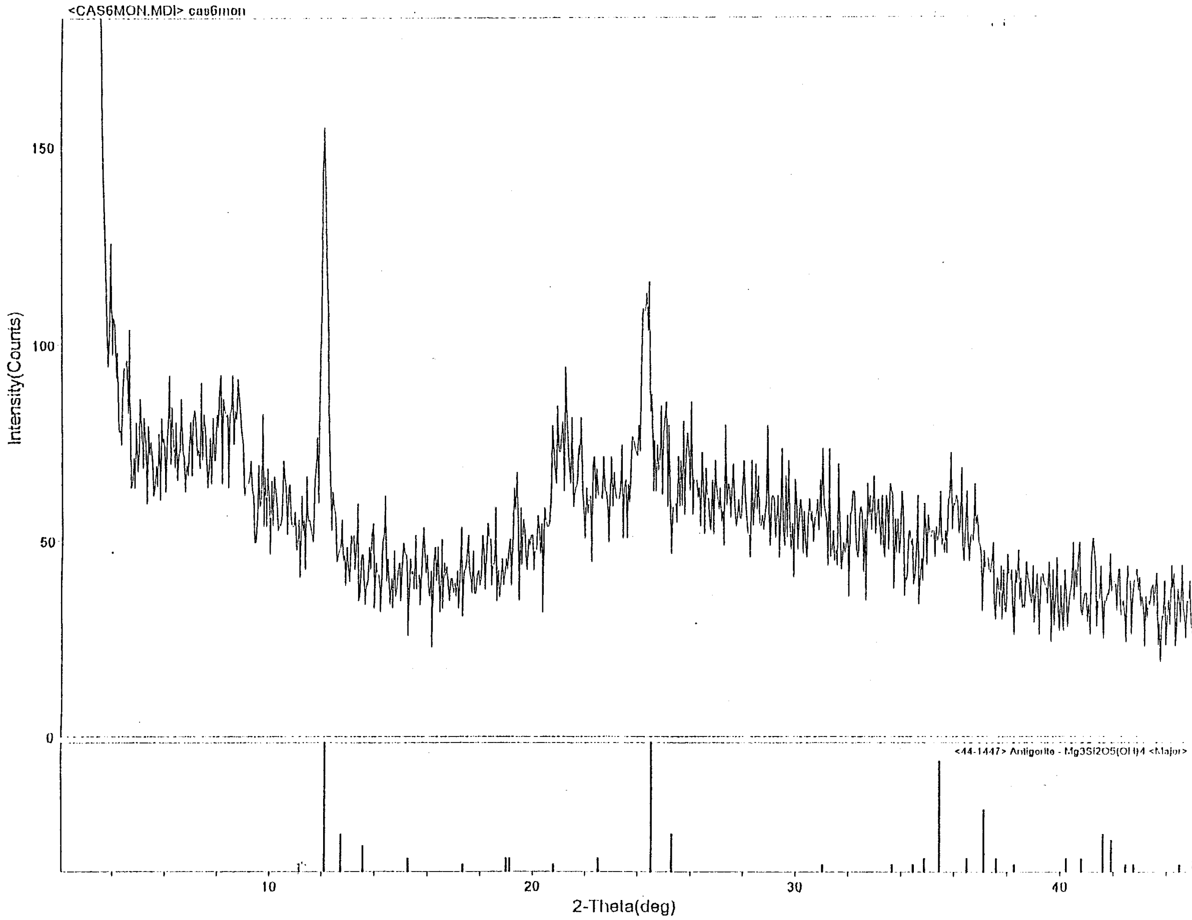

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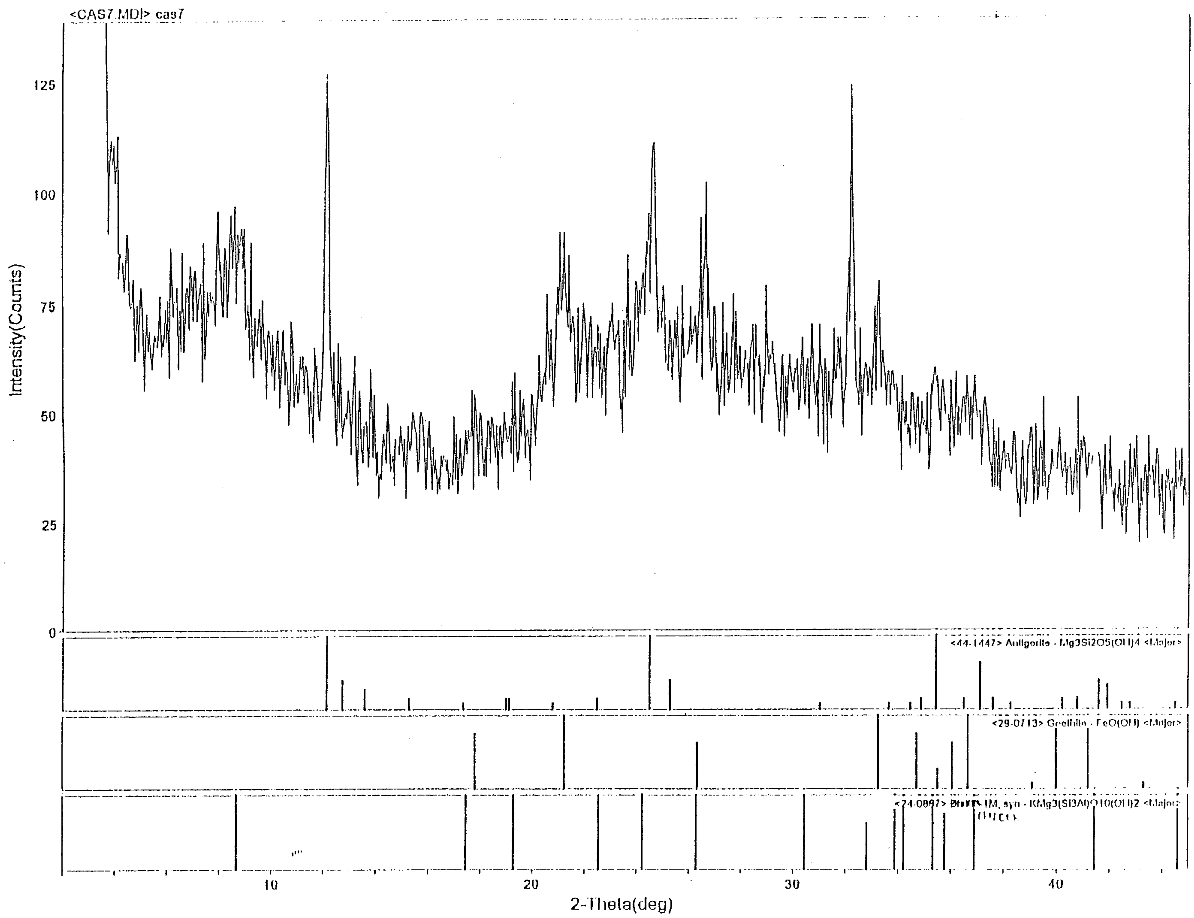

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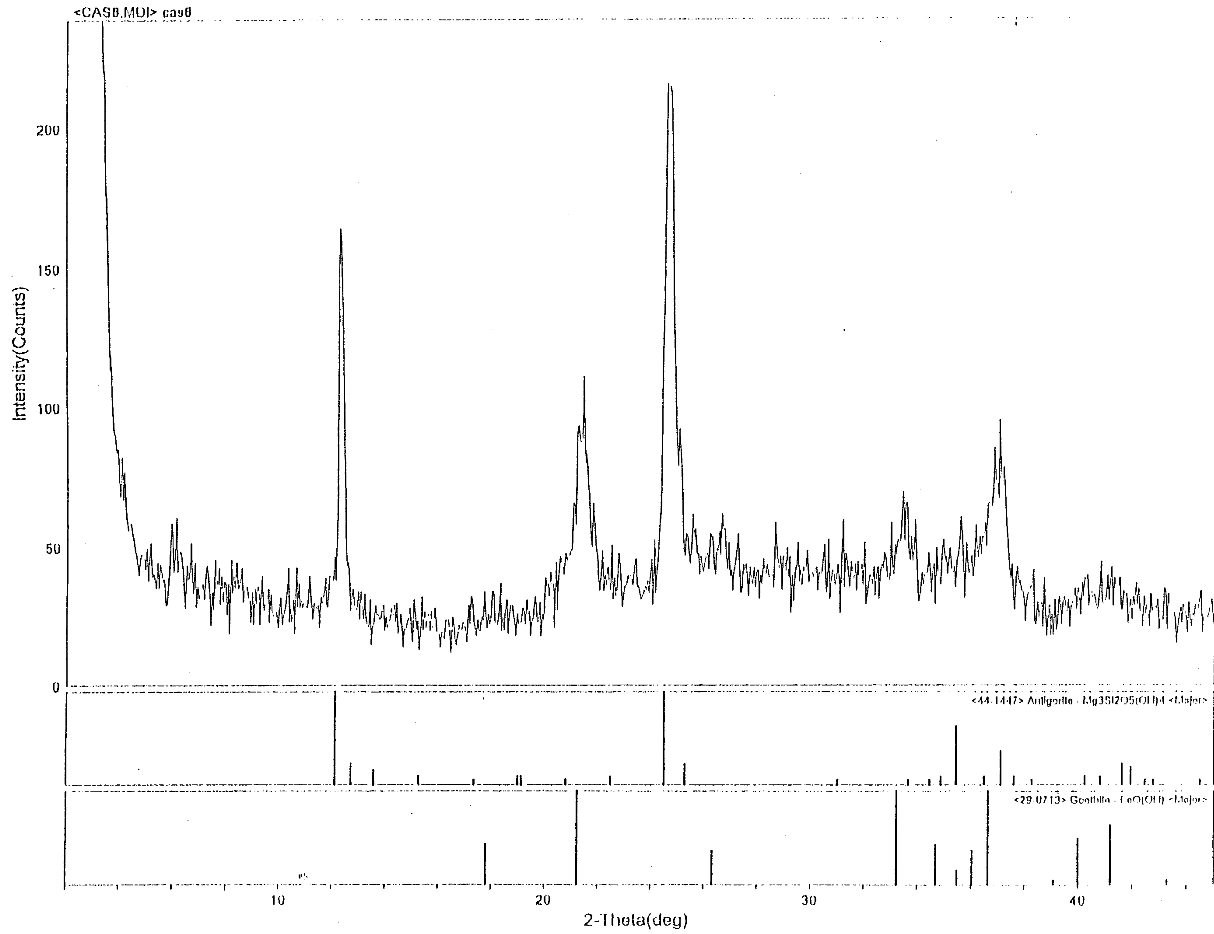

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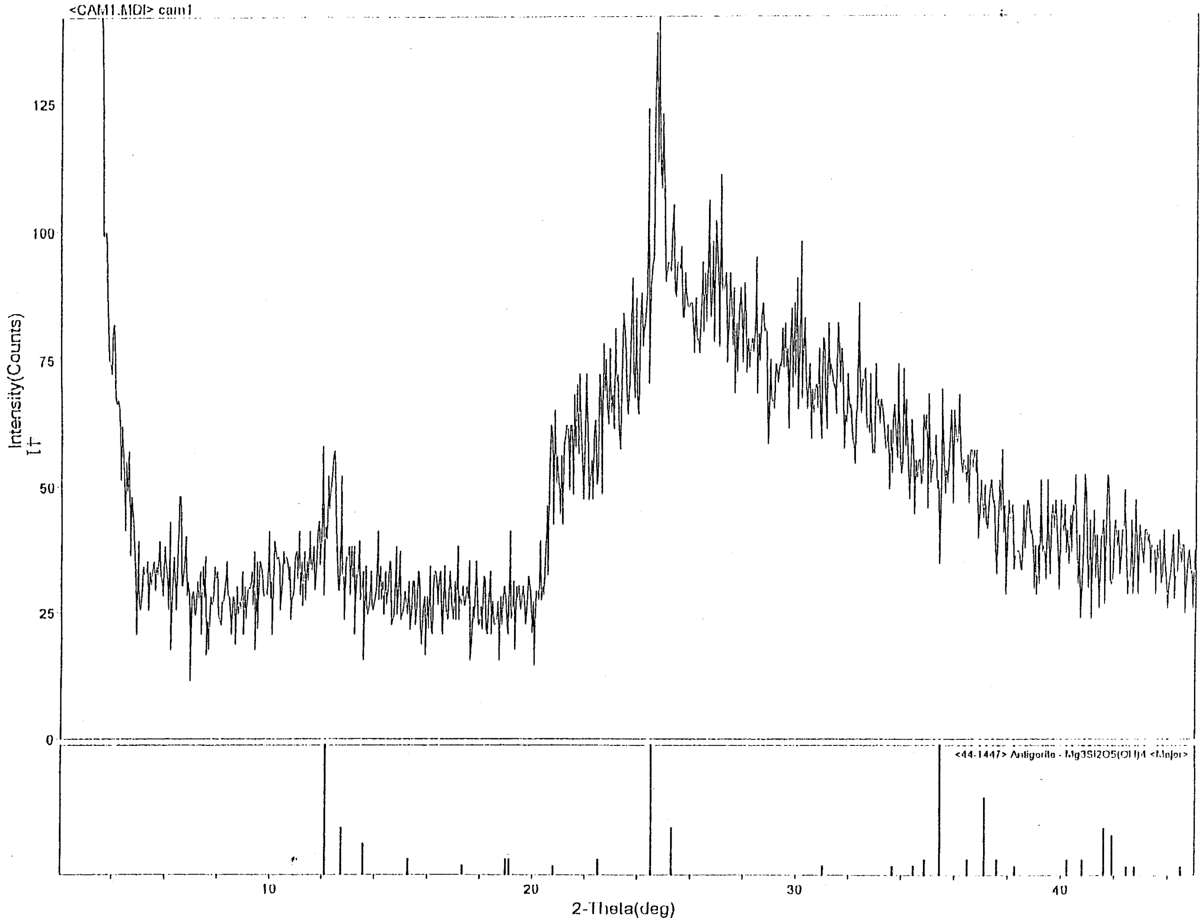

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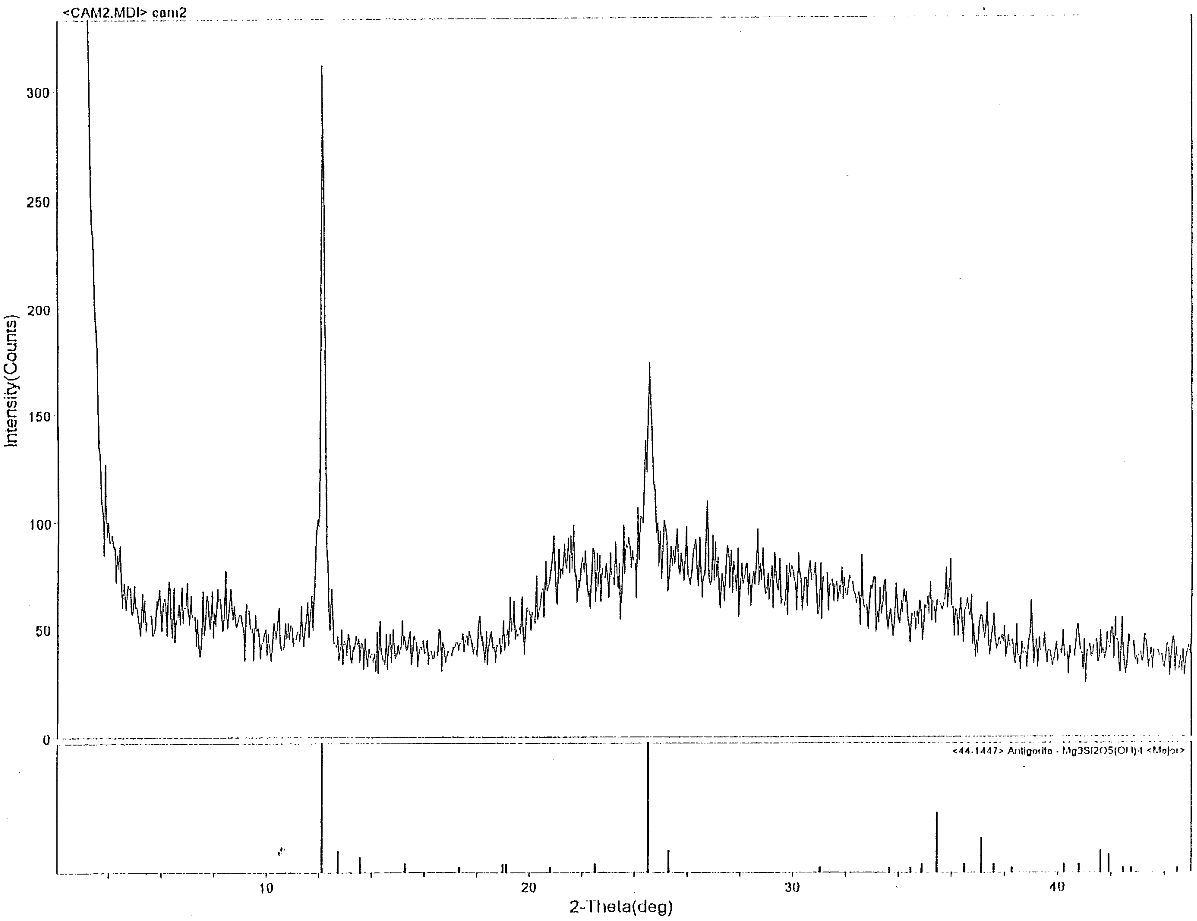

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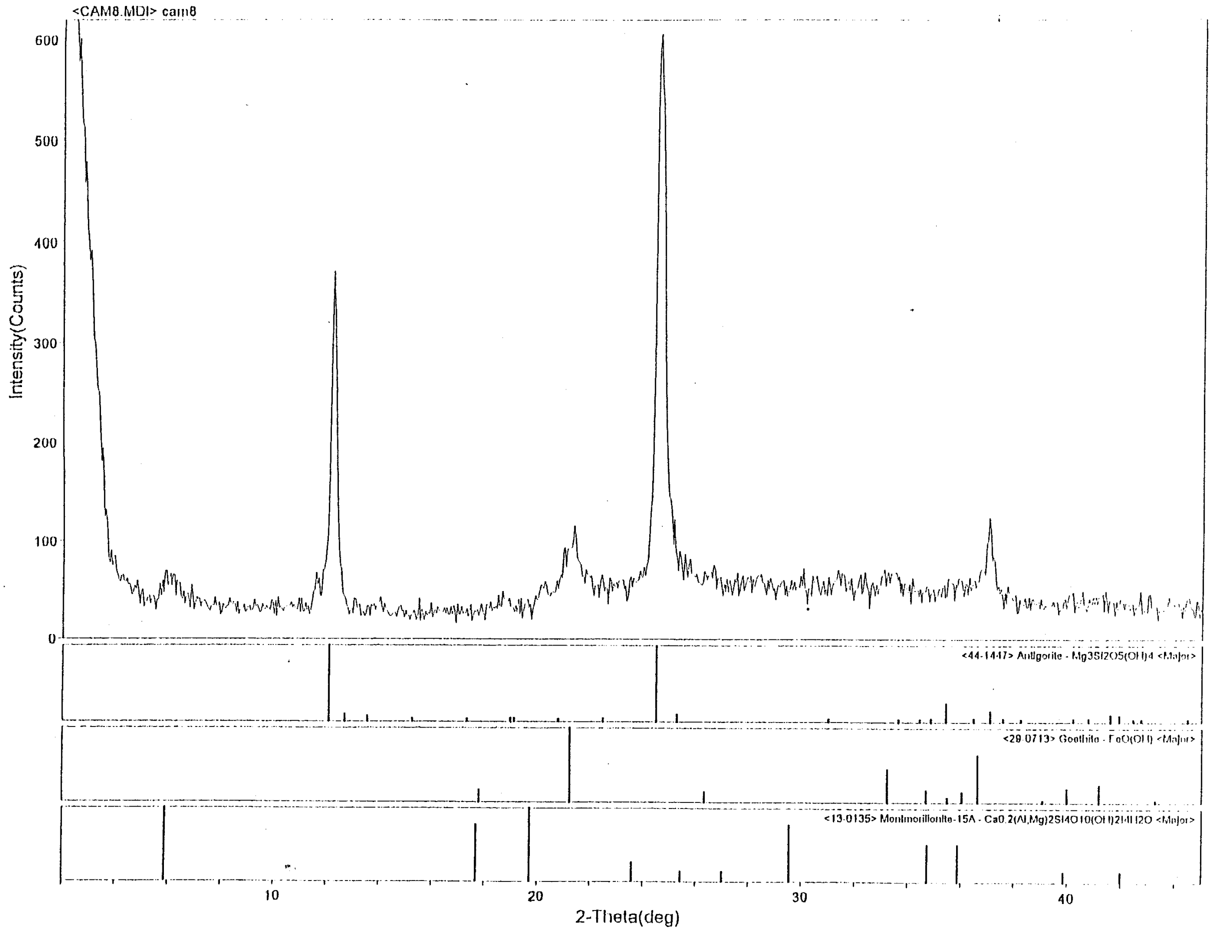

Sample 98CAM8

Appendix B. Source data for element graphs (soils)

[Concentrations in ppm]

Site Number	Ni	Ca	Mg	K	Fe	Ba	P	Co	Cr	Mg/Ca
98CAS3a	16.03	206.59	825.39	30.20	2.08	1.09	0.02	0.09	0.01	4.00
98CAS3	9.06	38.33	410.77	10.92	2.26	0.50	0.37	0.04	0.03	10.72
98CAS5	2.24	74.73	856.71	15.90	2.78	1.37	0.22	0.12	0.01	11.46
98CAS1	13.86	143.60	1362.44	57.81	2.41	4.49	0.56	0.83	0.00	9.49
98CAS2	27.49	246.45	1575.92	66.52	2.40	1.76	0.89	0.45	0.01	6.39
98CAM1	9.10	71.77	454.01	20.92	2.97	0.77	0.50	0.04	0.02	6.33
98CAS2b	13.17	70.93	1537.11	41.04	2.12	1.85	0.20	0.01	0.01	21.67
98CAM2	21.66	282.60	847.30	39.84	1.67	4.51	0.70	0.04	0.03	3.00
98CAS1a	11.07	76.22	693.70	18.15	1.13	1.94	1.28	0.04	0.04	9.10
98CAS1b	30.33	210.90	1398.05	35.67	2.00	3.26	1.05	0.03	0.02	6.63
98CAS2c	53.12	212.17	779.14	48.21	2.80	5.36	0.18	0.03	0.02	3.67
98CAS6	11.99	107.55	592.96	27.27	2.89	2.78	0.28	0.77	0.00	5.51
98CAS7	38.23	254.34	145.95	79.13	1.69	7.55	0.32	0.06	0.03	0.57
98CAS8	6.24	130.56	370.72	40.38	2.83	4.54	0.05	0.04	0.01	2.84
98CASS	8.08	68.24	895.33	15.42	2.43	1.44	0.31	0.02	0.01	13.12
w/ Arabis macdonaldiana	12.96	130.25	914.21	33.71	2.48	1.66	0.43	0.26	0.01	8.06
w/o Arabis macdonaldiana	21.54	157.06	806.70	38.35	2.17	3.69	0.49	0.12	0.02	7.35
Average Element	18.11	146.33	849.70	36.49	2.30	2.88	0.46	0.17	0.02	7.63
w/ Arabis macdonaldiana/ Average	71.58	89.01	107.59	92.38	108.10	57.74	92.35	150.38	80.06	105.64
w/o Arabis macdonaldiana/ Average	118.95	107.33	94.94	105.08	2.13	128.17	0.53	66.41	113.29	96.24

Appendix C. Source data for element graphs (flora)

[Concentrations in ppm]

Site Number	Ni	Co	Ni	Co
98CAS3	1845.98	92.46	15570.00	896.00
98CAS1	3154.75	237.58	33130.00	696.00
98CAS2	1856.89	133.19	95900.00	1430.00
98CAS1a	2932.53	149.66	1224500.00	37240.00
98CAS1b	5978.90	249.52	158800.00	1620.00
98CAS2b	2528.68	152.16	43750.00	938.00
98CASS	2392.80	124.19	384700.00	9400.00
w/ *Arabis macdonaldiana*	2285.87	154.41	48200.00	1007.33
w/o *Arabis macdonaldiana*	3458.23	168.88	452937.50	10041.07
Average Element	2955.79	162.68	279478.57	7460.00
w/ Flora/Average	77.34	94.92	17.25	13.50
w/o Flora/Average	117.00	103.81	162.07	134.60