GEOBOTANICAL TECHNIQUES FOR DISCRIMINATING SERPENTINE ROCK TYPES IN WESTERN UNITED STATES

by

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ABSTRACT

Serpentine-derived soils have a significant affect on species composition, vegetation density, and vegetational spectral response as a result of several factors including low calcium/magnesium ratios and high concentrations of chromium, cobalt, and nickel.

Remote sensing techniques involving airborne scanner imagery and several statistical and image processing techniques were used in three diverse test sites in western United States to discriminate vegetation parameters associated with serpentine rock types.

Vegetation parameters which were found to be most useful for discriminating the serpentine rock types included species composition changes and density. In general, more xeric vegetation types occur within the areas of serpentine. In regions of mixed woodland and forest, serpentine soils tend to be characterized by coniferous tree species while in semiarid terrain, serpentine soils are characterized more by shrubby than by grassy species. These broad vegetation differences and more specific vegetation types were readily discriminated by the remote sensing analysis. Useful techniques involved relatively simple visual image analysis, contrast stretching of individual bands, stepwise discriminant analysis, and principal components analysis.

INTRODUCTION

Vegetation on serpentine soils is commonly sparser and of different composition than the vegetation occurring on neighboring non-serpentine soils. This phenomenon has been reported from various locations around the world, including New Zealand, Poland, the Soviet Union, and the United States (Whittaker, 1954; Brooks, 1972). The identification of serpentine and the host ultramafic rock types is of considerable interest as they commonly contain economic deposits of metals such as Cr, Ni, and Co.

There are several distinctive properties of serpentine soils that are adverse to the growth and development of many plant species. Serpentine soils are usually low in Ca and high in Mg. Both of these elements are

are required by plants and absorbed by the roots as divalent ions. In some instances, the low Ca concentration may result in a nutrient deficiency. In other instances, the similar size of these ions results in the plants not being able to selectively absorb enough Ca without suffering Mg toxicity. One of the proposed mechanisms by which plants may be able to adapt to serpentine soils is an ability to preferentially absorb Ca over Mg (Walker et al., 1954).

Serpentine soils are also quite high in Cr, Ni, and Co. These elements are not known to be required in plant nutrition, and in fact, rank as among the most toxic of all elements to plants even though they are nearly insoluble in soil solutions (Brooks, 1972). In addition, serpentine soils are low in plant nutrients such as Nitrogen, potassium, and molybdenum (Walker, 1954). Finally, serpentine soils tend to be drier than adjacent non-serpentine sites on account of shallow development and gravelly textures.

In most situations, it is likely that it is some combination of these factors that accounts for the effect of serpentine on local vegetation. Variation in the bulk composition of the parent material can likely result in an increased or decreased effect on the vegetation. Where the content of Cr, Ni, or Co is unusually high, for example, the adverse effect might be expected to increase. Species compositional differences in the natural vegetation with serpentine areas may provide valuable clues in mineral exploration.

The authors are currently involved in an investigation of several serpentine areas near the west coast of the United States. We are combining ground based examination of vegetation, rock types, and soils with the use of multispectral airborne scanner imagery. Our interest is to evaluate the utility of such imagery to identify and map areas of serpentine and to detect variations within the serpentine that may have exploration significance. This paper describes preliminary results involving the delineation of serpentine areas.

SOUTHWEST OREGON STUDY AREA

The southwest Oregon study area is located within the Siskiyou Mountains adjacent to and north of the California and Oregon border and approximately 40 km (on average) from the Pacific Ocean. The region is known for its unique vegetation and geology. A wide diversity of vegetation types has been recognized as occurring in relation to the steep climatic gradients and diverse parent materials of the region. Elevations within the study area range from 400m to over 1500m. The climate is strongly influenced by maritime air from the Pacific Ocean and has cool winters (mean January temperature is 5 degrees C) which are characterized by abundant precipitation (over 200 cm annually) and mild dry summers (the mean July temperature is 20 degrees C).

The study area's vegetation follows the distribution of vegetation zones as described by Franklin and Dyrness (in Mouat et al., in press). This zonal outline follows:

Zone	Dominant species or genera
Interior Valley Zone	Pine (*Pinus* sp.), Oak (*Quercus* sp.) Douglas fir (*Pseudotsuga menziesii*)
Mixed-Evergreen Zone	Douglas fir - sclerophyll shrubs
Mixed Conifer Zone	Pine, Douglas fir, Incense cedar (*Calocedrus decurrens*)
White fir Zone	White fir (*Abies concolor*)

Serpentine vegetation occurs within all of these zones. At the lowest elevations, it differs from the surrounding vegetation by having virtually no broadleaved evergreen tree species. The vegetation often consists of a very open Jeffrey pine (*Pinus jeffreyi*) mixed grassland type often with scattered manzanita (*Arctostaphylos sp.*). This contrasts with the much denser surrounding vegetation which usually has an important broadleaf tree component. At somewhat higher elevations (approximately 600m), other coniferous tree species are present in the serpentine flora. The understory often has an open cover of broadleaf tree species which are highly stunted. At this elevation, non-serpentinized peridotite becomes an important associated ultramafic rock type. This parent material can be vegetationally differentiated from the serpentine vegetation by the much denser sclerophyll shrub and stunted broadleaf evergreen tree understory (Figure 1 illustrates this difference). At higher elevations (approximately 1,000m) the serpentine flora is distinct from the surrounding flora by certain indicator species, many of which are stunted, and a scattered shrub-grass understory. The broadleaf tree component, which is so typical of the surrounding non-ultramafic rocks is virtually absent. Trees which typically grow upon the higher elevation serpentine rocks include Port Orford cedar (*Chamaecyparis lawsoniana*), Jeffrey pine, incense cedar, western white pine (*P. monticola*), sugar pine (*P. lambertiana*), and Douglas fir.

Image Analysis

The primary imagery used in the analysis consisted of color and color infrared aerial photography at scales varying between 1:15,840 and 1:130,000, and high altitude multispectral scanner imagery. The latter was acquired by the NASA Ames Research Center over the study area on September 11, 1981. It was made with a modified Daedalus DEI-1260 scanner with ten operating channels in the visible, near IR and thermal infrared (Table I). The imagery was acquired at an altitude of 20,000m and , with a 1.25mrad IFOV, has a ground resolution of approximately 25m X 25m.

The aerial photography was useful for separating the serpentine-bearing rock types from the non-ultramafic rock types. A simulated false color composite (FCC) made from the airborne scanner imagery was also useful for separating those rock types. However, it required a ratio color composite (made from ratioing the near IR to the red band, the red to a green band, and the green to a blue band) and an enhanced 2.05 - 2.35 channel to separate the serpentine from the non-serpentinized peridotite. A modified unsupervised classification employing extensive ground data has been successful in a limited area in separating those rock types. Attempts at using principal components analysis techniques have so far not been successful for separating the serpentine from the non-serpentinized peridotite. Further attempts will be made with this technique.

JASPER RIDGE STUDY AREA

The Jasper Ridge Biological Preserve of Stanford University is located 50km south of San Francisco and is situated on a low lying ridge on the eastern flank of the Santa Cruz Mountains. It is bounded on the west by the San Andreas Fault. Elevations within the study area range from 70m to 190m. The study area receives most of its precipitation (approximately 70cm annually) in the winter. Temperatures rarely reach freezing. Geologically, the ridge consists of greenstone, chert, graywacke, and serpentine of the Jurassic-Cretaceous Franciscan Formation and the Eocene Butano sandstone (Page and Tabor, 1967).

The top of the ridge is a broad gently roll-ng plateau covered with grassland. The surrounding north and east facing slopes are covered with oak-woodland. South and west slopes are covered with chaparral. This distribution is largely due to differences in moisture availability.

The chaparral on non-serpentine sites forms a dense shrubland dominated by chamise (Adenostoma fasciculatum). A number of other shrubs are associated with the chamise. There is virtually no understory beneath the shrub layer. Along the border of the chaparral with the grassland there is often a fringe of California sage (Artemisia californica) from one to three meters wide. The chaparral growing on serpentine is marked by a pronounced decrease in plant density. There is also a decrease in variety of shrubs present. The vegetation is dominated by chamise and leather oak (Quercus durata). Minor amounts of toyon (Photinia arbutifolia) and Ceanothus sp. are present. Soap plant (Chlorogalum pomeridianum) is abundant in the understory. There is no fringe of California sage at the border with the grassland. Leather oak is largely restricted to the serpentine sites. It is a scrubby plant less than three meters in height.

The grassland on non-serpentine sites is dominated by a number of introduced species. Except for soft chess (Bromus mollis), these introduced species are unable to become established on the serpentine. As a result, the serpentine grassland area has become a refugia for a wide variety of native prairie plants that are unable to successfully compete with the introduced species on the non-serpentine sites. Native plants on the serpentine grasslands include perennial bunchgrasses and numerous flowering spring annuals.

Image Analysis

High altitude multispectral scanner imagery was acquired over Jasper Ridge on October 16, 1981 and on April 23, 1982 (Table 1). The two flights employed somewhat different spectral configurations.

The vegetation conditions for the two image dates were quite different. In October, the grasslands were completely senesced and were brown, the chaparral was still dormant after the annual summer drought, and the oaks were damaged by a summer moth infestation. On April 23, the grasslands were at their annual peak in green biomass, the chaparral was actively growing, and the oaks had many new leaves.

A serpentine unit was clearly visible within the oak-woodland as a canopy opening. The serpentine chaparral is distinctive from non-serpentine chaparral on the ground and discernable on the scanner imagery. It is also possible to distinguish the dense rim of leather oak and the sparse interior features of the main area of serpentine chaparral. These features form a spatial anomaly on the imagery that is not present anywhere else.

The grassland sites show a dynamic phenological change between the two images. In the October imagery, when the vegetation on the grasslands had senesced, the visual difference between the two areas is faint. At the time the April imagery was acquired, the serpentine grassland was carpeted with goldfield (Lasenthia californica), make it quite distinctive from the non-serpentine grassland (Figure 2). To examine the effect that flowering goldfields have on the imagery, training sets for both grasslands were extracted for the two image dates. The training sets were analyzed with stepwise discriminant analysis (BMDP-7M). While the bandpasses for image data for the two flights are not identical, there is a general correspondence that makes the comparison useful. The results for the analyses are given in Table 2.

In the October imagery, the second green channel and an infrared channel were selected as being the most useful bands for discriminating the two types. The classification accuracy was approximately 80%. In the April imagery a classification accuracy of 100% was reached with the red channel. The red radiation was being strongly absorbed by chlorophyll pigments in the non-serpentine grassland, whereas the red radiation was strongly reflected by the carpet of yellow goldfield flowers on the serpentine. This phenomenon is short lived as the goldfields are only in bloom for a period of three weeks.

SIERRA NEVADA FOOTHILLS STUDY AREA

The Sierra Nevada foothills study area is located 160 km east of San Francisco in Calaveras and Tuolumne Counties. This area is physically similar to Jasper Ridge. Elevations range from 300 to 600 meters. Annual precipitation averages about 60 cm, coming mostly as winter rain. Winters are somewhat cooler than on Jasper Ridge and are similar in temperature to the southwest Oregon study area. The vegetation consists of a mosaic of grassland and oak-woodland of varying density, and chaparral.

Image Analysis

High altitude airborne scanner imagery was acquired over the Sierra Nevada foothills study area on April 23, 1982. The imagery is similar in configuration to the April imagery acquired over Jasper Ridge (Table 1). The vegetation in the foothills on this date was near its peak of green biomass, similar to the conditions on Jasper Ridge.

The study area consists of Jurassic-Triassic metavolcanics, Upper Jurassic metasediments, undifferentiated Mesozoic ultramafic intrusives (primarily serpentinized), and the Pliocene Table Mountain andesite (Jenkins, 1966; Clark and Lydon, 1962; Taliaferro and Solari, 1948). The metasediments and metavolcanics are covered by oak woodland and grassland. Figure 3 illustrates the vegetation on a typical metavolcanic area. Serpentine areas are covered by an open *Ceanothus* sp. chaparral with scattered digger pine (*P. sabiniana*)(see Figure 4). The ground between the *Ceanothus* sp. individuals is sparsely covered by the same annual plants occurring on the serpentine grasslands on Jasper Ridge. Monkeyflower (*Mimulus cutatus*) is abundant along streams and moist drainages. The Table Mountain andesite is covered by a sparse grassland cover with widely scattered digger pine. The species present in the andesite grassland are similar to those located on the nearby serpentine.

The scanner imagery was processed to form a false color composite for use in the field. On the false color composite (FCC), the non-serpentine grasslands and oak woodlands are represented by various shades of red. The serpentine areas, however, are brown. Although the andesite has a similar color, it is distinguishable from the serpentine. The major serpentine areas are represented on the imagery in a brown color, indicative of its scrubby vegetation; an area mapped as serpentine (Jenkins, 1966; Taliaferro and Solari, 1948) appeared to have a denser vegetation not characteristic of serpentine. When the area was field checked, it was found that this second area was covered with oak-woodland and grassland. Rock outcrops, sampled in the area, were found to be metavolcanic greestones with plagioclase phenocrysts. The area was apparently mismapped by Taliaferro and Solari (1948). Other maps continued the error.

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FIGURES

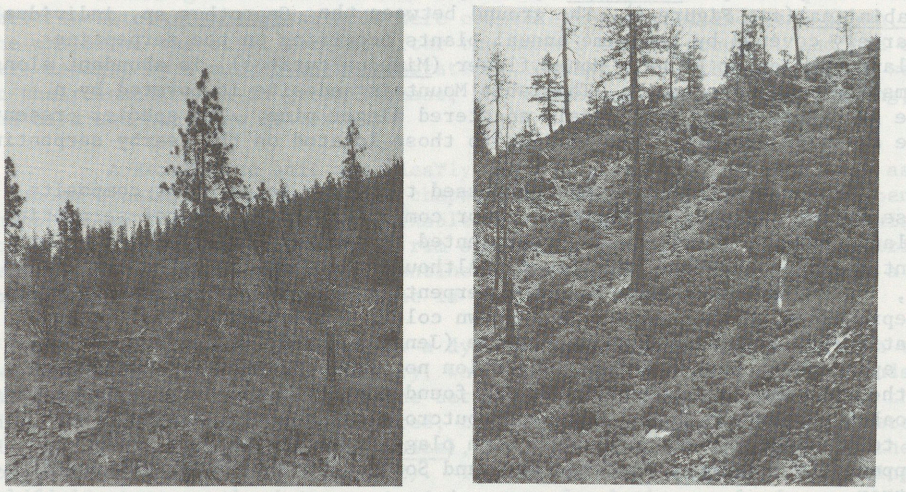

Figure 1. Vegetation on ultramafic rock types at lower elevations (approximately 500m) at the southwest Oregon study area. The left photograph illustrates an open pine grassland developed on serpentine soils while the photograph on the right illustrates a dense sclerophyll shrub layer beneath scattered pines on largely unserpentinized peridotite.

Figure 2. Goldfields (Lasenthia californica) mixed with grasses (foreground) occurring on serpentine soils at the Jasper Ridge Study area. In the background, a grassland consisting predominantly of introduced species is growing on non-serpentinized soils.

Figure 3. Vegetation on metavolcanic soils at the Sierra Nevada foothills study area. The vegetation is an oak-woodland and grassland complex.

Figure 4. Vegetation on serpentine soils (foreground) at the Sierra Nevada foothills study area. The vegetation consists largely of scattered Ceanothus sp., digger pine (Pinus sabiniana), and annual forbs abd grasses.

TABLES

Table I. Spectral characteristics of the Daedalus DEI-1260 scanner.

Configuration A

Channel #	Bandwidth
- *	0.38 - 0.42um
1	0.42 - 0.45um
2	0.45 - 0.50um
3	0.50 - 0.55um
4	0.55 - 0.60um
5	0.60 - 0.65um
6	0.65 - 0.69um
7	0.70 - 0.79um
8	0.80 - 0.89um
9	0.90 - 1.10um
10	2.05 - 2.35um

Imagery used for:
Southwest Oregon 11Sept 1981
Jasper Ridge 16Oct 1981

*not recorded

Configuration B

Channel #	Bandwidth
1	0.42 - 0.45
2**	0.45 - 0.52
3**	0.52 - 0.60
4	0.60 - 0.62
5**	0.63 - 0.69
6	0.68 - 0.75
7**	0.76 - 0.90
8	0.91 - 1.05
9**	1.55 - 1.75
10**	2.08 - 2.35
11**	10.40 - 12.50

Imagery used for:
Jasper Ridge and Sierra Foothills
23April 1982

**these channels approximate the characteristics of the Thematic Mapper sensor on Landsat 4.

Table I
serpentin
dates.

Table II. Stepwise discriminant analysis classification matrices for serpentine and non-serpentine grasslands on Jasper Ridge for the two image dates.

OCTOBER

Channels selected: 9,4

	% Correct	Observations	
		Serpentine	non-serpentine
Serpentine	77.3%	34	10
non-serpentine	83.1%	10	49
Total	80.6%	44	59

APRIL

Channel selected: 5

	% Correct	Observations	
		Serpentine	non-serpentine
Serpentine	100.0%	35	0
non-serpentine	100.0%	0	55
Total	100.0%	35	55

ABSTRACT

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