Geomorphology 135 (2011) 271–276

Contents lists available at ScienceDirect

Geomorphology

journal homepage: www.elsevier.com/locate/geomorph

Topographic and soil differences from peridotite to serpentinite

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ARTICLE INFO

Article history:
Received 3 September 2010
Received in revised form 29 December 2010
Accepted 4 February 2011
Available online 10 March 2011

Keywords:
Ultramafic rocks
Weathering
Alfisols
Mollisols

ABSTRACT

Pedologists commonly lump peridotite and serpentinite soils together without reporting differences between them. Peridotite and serpentinite are chemically similar, but mineralogically quite different. A detailed soil survey in which soils with peridotite and serpentinite parent materials were separated in mapping revealed appreciable differences in geomorphic and pedologic features between these two types of ultramafic rocks. In mountainous terrain of the Klamath Mountains, California and Oregon, slopes tend to be steeper on peridotite and the soils redder. More Luvisols (Alfisols) were found on peridotite and more Phaeozems (Mollisols) on serpentinite. Very shallow soils (7% of the area), which are Leptosols (mostly Mollisols and Entisols, few Alfisols), are more common on serpentinite. Sparsely vegetated barrens are commonly fragmental colluvium (talus) on peridotite and erodible, slightly to moderately stony summits and sideslopes on serpentinite. Large landslides are much more extensive in serpentinite terrain. Vegetative cover differences from peridotite to serpentinite are much less pronounced than the topographic and soil differences; the plant differences are obvious only on shallow soils.

1. Introduction

Peridotite is the common rock at the top of the upper mantle, and much of it is ultimately altered to serpentinite, but peridotite and serpentinite are sparse in the continental crust. Nevertheless, these rocks are well known by ecologists, who commonly call them serpentine and the soils on them serpentine soils, because of the unique plant communities on them (Brooks, 1987; Alexander et al., 2007a). This is easy to understand from a botanical perspective, because most of the same plants occur on both peridotite and serpentinite. Topographic and soil differences are more obvious than vegetation differences, but not so obvious that they are perceived in casual observations.

Serpentine soils are widespread in western North America (Alexander et al., 2007a), and some have been characterized thoroughly (Wildman et al., 1968; Graham et al., 1990; Bulmer et al., 1992; Alexander et al., 1994; Burt et al., 2001; Lee et al., 2003), but separate soils have not been mapped on peridotite and serpentinite until recently (Alexander, 2003). Although soil redness differences from peridotite to serpentinite have been documented (Alexander, 2004) and other topographic and soil differences have been identified tentatively (Alexander, 2009), a more rigorous investigation of the topographic differences is imperative. Our purpose has been to make a more rigorous assessment of topographic differences from peridotite to serpentinite terrains and to investigate possible causes for the differences. We have also reviewed the soil differences. Most of the data are from a detailed serpentine soil survey in the southern exposure of the Rattlesnake Creek terrane (Fig. 1).

2. Petrographic differences from peridotite to serpentinite

Peridotite is an ultramafic rock containing olivine and pyroxenes, with minor chromite. It is the precursor of serpentinite. Serpentinite is produced by the addition of water to peridotite in a metamorphic process called *serpentinization*. The complete alteration of peridotite to serpentinite requires the addition of about 13 or 14% water. Calcium and silicon may be lost, but otherwise the chemical composition is seldom changed in the metamorphosis (Coleman, 1971). The mineralogy, however, is almost completely altered from olivine and pyroxenes in peridotite to serpentine and accessory magnetite in serpentinite. Generally, only chromite remains unaltered from the complete serpentinization of peridotite (Coleman, 1971).

A 33% expansion during serpentinization, from heavy peridotite (3.2–3.3 Mg/m^3) to light serpentinite (2.4–2.6 Mg/m^3), is commonly accompanied by extensive fracturing and shearing. Consequently, most serpentinite breaks into smaller blocks than does peridotite. The shearing commonly smooths and polishes fracture surfaces in serpentinite, reducing its shear strength and making it more susceptible than peridotite to mass failure. With these profound structural differences we might expect to find differences in peridotite and serpentinite landscape topographies.

Mineralogy is very important in weathering and soil formation. Olivine and the orthorhombic pyroxenes in harzburgite, a common

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doi:10.1016/j.geomorph.2011.02.007

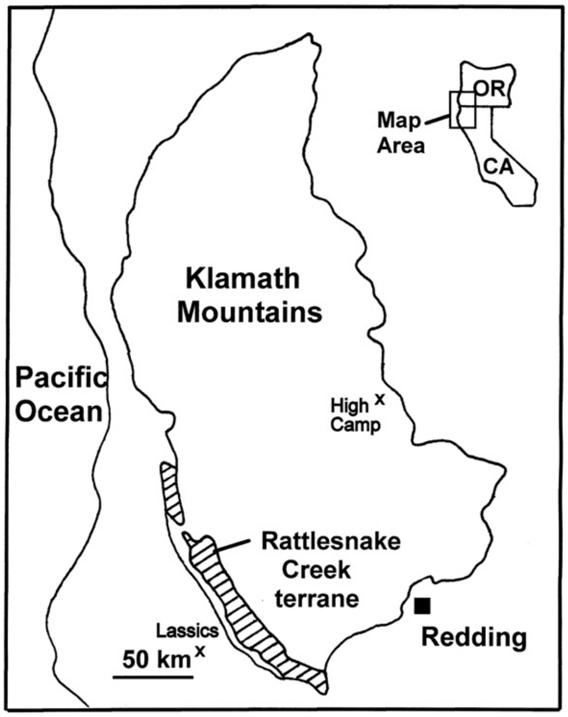

Fig. 1. Location of the southern exposure of the Rattlesnake Creek terrane in the Klamath Mountains, which are at latitudes 40 to 43°N on the western margin of North America. The Lassics area is in the California Coast Ranges.

variety of peridotite in terrestrial evironments, are more readily weatherable than serpentine. Serpentinite formed from dunite (nearly all olivine), however, contains much brucite which is even more readily weathered than olivine (Alexander, 2004).

3. Field-site description

The Rattlesnake Creek terrane (RCT) is an allochthonous block that was annexed to the North American continent during the Mesozoic era. It contains serpentinized harzburgite, gabbro, basalt, graywacke (clastic marine sediments), chert, and minor limestone. Some small granitic plutons intruded the terrane after it was accreted to the continent (Wright and Wyld, 1994).

The RCT is in mountainous terrain, with narrow valleys more common than broad ones. Neither exposures of bare rock nor stream deposits are extensive, and there was no Pleistocene glaciation in the southern exposure of the RCT. Altitudes range from a few hundred to 1718 m asl. The current climate is temperate, with warm, dry summers and cold, wet winters. Mean annual temperatures range from 16 at the lower elevations to 8°C at the higher elevations. Mean annual precipitation is mostly in the range from 1000 to 1500 mm, with extremes about 750 cm on the southeast and 2000 mm on the northwest. Soil temperature regimes are mesic and thermic, mostly mesic, with minor areas of frigid soils; and soil moisture regimes are xeric (Soil Survey Staff, 1999).

The vegetation is mostly open conifer forest and chaparral. Tree, shrub, and herb species distributions differ substantially from hotter and drier low elevations to cooler and wetter high elevations. Tree and grass species distributions, however, are somewhat similar from southeast to northwest at the intermediate elevations in the RCT where mesic STRs prevail.

4. Methods

A detailed soil survey of the approximately 12,000 ha of serpentine in the southern exposure of the Rattlesnake Creek terrane (RCT, Fig. 1) was conducted with stereo pairs of 1:16,000 aerial photographs (Alexander, 2003). The minimum delineation was about one hectare and most of the map polygons were observed on the ground. Soils chosen to represent those of the map units were described to bedrock, or to about 150 cm depth, at 209 sites: 73 on peridotite, 109 on serpentinite, 14 on other rocks associated with serpentine, and 13 on large landslides. Soils were classified according to Soil Taxonomy (Soil Survey Staff, 1999) and the World Reference Base for Soil Resources (FAO-ISRIC,-ISSS, 1998). Soil depth classes recognized in soil series differentiation were very shallow (depth <25 cm), shallow (25–50 cm), moderately deep (50–100 cm), deep (100–150 cm), and very deep (depth>150 cm).

Peridotite is easy to identify where rock surfaces have weathered to reddish brown and have a few millimeters of knobby relief with pyroxene highs and olivine lows (Fig. 1 and 2 in Alexander et al., 2007a). Serpentinite is easy to identify where it has been tectonically sheared to reveal smooth greenish mottled surfaces, or where rocks have weathered to smooth gray surfaces (Alexander, 2004). Where the ultramafic rocks are massive and lack distinctive weathering surfaces, partially serpentinized peridotite can be recognized by the cleavage faces of pyroxenite in freshly broken rocks. All of the ultramafic rocks in the RCT are at least partialy serpentinized (except pyroxenite, which is not extensive)–the presence or absence of pyroxene cleavage faces seemed to be a good criterion for distinguishing between peridotite that has been only partially serpentinized and serpentinite that lacks pyroxene (Alexander, 2003).

Surface boulder (nominal diameter>60 cm), "stone" (25–-60 cm), and cobble (7.5–-25 cm) cover were estimated by 100 step-point counts at each soil description site. Plant cover (percentage) was estimated visually at each of the 209 soil description sites. Because the sites were chosen to represent soil-topographic map units, vegetation bias in choosing the sites was minimal.

Three new soil series were established in the RCT . Typical pedons, one for each of these soils, were sampled for laboratory analyses. These pedons represent the most extensive shallow soils on peridotite (Wildmad series) and serpentinite (Bramlet series) and the most extensive moderately deep soil on serpentinite (Hyampom series); no other soils in the RCT were sampled for complete characterization. Cations were extracted with 0.5 M KCl and Ca and Mg were measured by EDTA titration (Heald, 1965). Acidity was extracted with KCl-nitrophenol buffer, pH 7.0, and with $BaCl_2$-TEA buffer, pH 8.2, and the buffer solutions were titrated to a bromocresol green endpoint with standard hydrochloric acid; these are procedure modifications from Schofield (1933) and Peech (1965). Soil pH was ascertained with a glass electrode after 30 minutes in 1:1 water:soil suspensions. Iron and Mn were reduced and extracted with Na-dithionite in 0.3 M Na-citrate (Holmgren, 1967) and analyzed by atomic absorption spectrometry. Soil organic matter (SOM) is approximately equal to the loss on ignition (LOI) at 360°C. It was estimated from the equation $SOM = 0.88\ LOI - 0.14\ Fe_d$ where Fe_d is the citrate-dithionite extractable Fe. This equation is based on data from Alexander et al. (1989) for LOI and

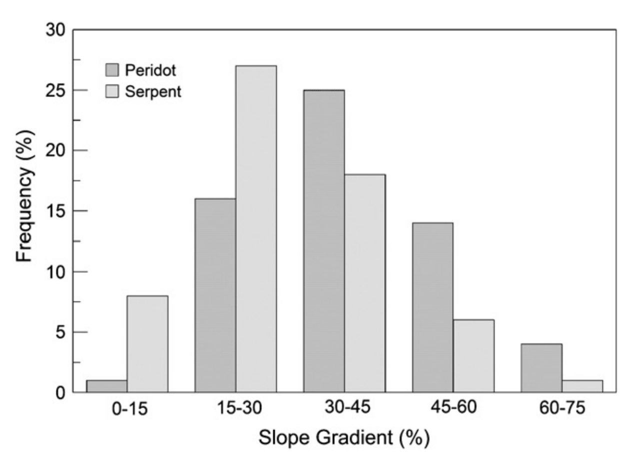

Fig. 2. Slope distributions of serpentine soils, other than those in large landslides, as mapped in the southern exposure of the Rattlesnake Creek terrane.