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Arid to humid serpentine soils, mineralogy, and vegetation across the Klamath Mountains, USA

Earl B. Alexander *

Soils and Geoecology, 106 Leland Lane, Pittsburg CA 94565, USA

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ABSTRACT

Ultramafic rocks are extensive in the Klamath Mountains of California and Oregon and there is a great diversity of climate, soils, and vegetation. Soils were sampled and vegetation described over serpentinized peridotite at sixteen low altitude, well drained sites from arid to humid parts of the Mountains receiving from 400 to 3200 mm/year of precipitation. The soils are dry Mollisols and Alfisols, moist Alfisols, Ultisols, and a moist Mollisol. All of the soils have subsoil exchangeable Ca:Mg ratios < 0.5 mol/mol. Subsoil dithionite extractable, or "free", iron (Fe_d) ranged from 1.5% at a dry site about 130 km from the Pacific Ocean to 27% at a much wetter site near the coast. With "free" iron increases from 1.5 to 27%, soil pH differences in molar KCl and in distilled water decrease from about 0.7 to −0.1, indicating net positive charge in the soils with very high "free" iron contents. Net positive charges in soils lacking tephra are unique for nontropical soils. The main clay minerals, other than serpentine and chlorite inherited from the soil parent materials, are smectite in the drier soils and goethite in the wetter soils with more "free" iron. A warm dry site at 40.2°N had chamise chaparral with scattered gray pine trees. Plant communities on the cooler remainder of the transect, near 42°N latitude, from arid to humid, were sagebrush steppe, open conifer forest with shrubs and grass, semidense conifer forest with shrubs, and dense conifer forest.

1. Introduction

The Klamath Mountains have the largest concentration of ophiolites in North America., and there is a great variety of ultramafic rocks in them. Climates range from humid on the Pacific coast to arid on the inland side of the mountains. There is a great diversity of soils and vegetation from dry to humid parts of the Klamath Mountains, and from sea level to the highest elevation, which is 2751 m asl on ultramafic rocks of Mount Eddy.

Most of the Klamath Mountains area is mountainous terrain, with only minor parts of it suitable for agriculture. The geology and vegetation have been much more thoroughly investigated than the soils. The national forests, which occupy major parts of the Klamath Mountains have general (not intensive) soil maps. Although some counties have soil maps with moderate detail, the detail is generally less in the mountains, which is where the serpentine occurs.

Vegetation of the Klamath Mountains, including serpentine habitats, has been described qualitatively by Franklin and Dyrness (1988) and in some chapters in the *Terrestrial Vegetation of California* (Barbour et al., 2007), and in more detail in parts of Oregon and California by Atzet et al. (1996) and Jimerson et al. (1995). Areas of the driest and the most humid serpentine ecosystems in the Klamath Mountains are small and lack ecosystem descriptions.

Some important properties of soils on ultramafic rocks derived from ocean crust peridotite are dependent on the degrees of serpentinization and weathering. Weathering and the pedogenesis of ultramafic rocks and soils in arid interior to humid coastal climates in the Klamath Mountains have produced soils and clay minerals with a broad range of ion exchange properties that are unique among nontropical soils of North America.

Most investigations of clay minerals in the inorganic fractions of soils on ultramafic rocks (commonly called serpentine soils) of the Klamath Mountains have indicated that smectite dominates the ion–exchange complexes (Graham et al., 1990; Istok and Howard, 1982; Lee et al., 2003). The ionic charges of smectites are almost exclusively permanent, independent of pH. A recent report indicates that some Klamath Mountains serpentine soils with high iron contents have ion–exchange complexes dominated by pH dependent, or variable, charges (Alexander, 2010). Soils with substantial variable charge are generally either highly weathered tropical soils or soils developed from the weathering of tephra (Qafoku et al., 2004). There are no volcanoes in the Klamath Mountains and most of the soils lack tephra. The development of soils with substantial variable charge at 40 to 43°N latitude in Klamath Mountains is an unusual feature of nontropical soils lacking tephra.

Ultramafic rocks in ophiolites have relatively high iron contents and very low aluminum contents (LeMaitre, 1976). Most of the primary ultramafic rocks in the Klamath Mountains are harzburgite or lherzolite, which are peridotites dominated by olivine and pyroxenes. Most of the iron in these peridotites is in olivine, which is readily weathered to release the iron (Alexander, 2004). Serpentinization of the peridotites produces serpentinites containing serpentine, brucite, and magnetite.

* Tel.: +1 9252126570.
E-mail address: alexageoeco@gmail.com.

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Most of the iron in serpentinites is in magnetite, which is resistant to weathering, and serpentine weathers less readily than olivine and pyroxenes to release iron more slowly. Therefore it might be expected that the iron oxide concentrations are greater in soils of peridotite than in those of serpentinite, especially in soils of wetter climates where weathering is more rapid. High free iron contents that are responsible for variable charge characteristics in Klamath Mountain soils (Alexander, 2010) were perceived to be related to parent materials, climate, and weathering.

Soils were sampled at 20 sites with cool (mesic STRs) soils and one site with a warm (thermic STR) soil (STR = soil temperature regime; Soil Survey Staff, 1999), with an objective of characterizing the progression of serpentine soils, their mineralogy, and accompanying plant communities from the drier inland to the humid coastal environments of the Klamath Mountains. No soils were sampled above 1250 m in order to concentrate on the moisture gradient without including soils with large temperature differences related to higher altitude. Only well drained, moderately deep to deep soils were sampled and plant communities described on the soils. Soil parent materials at 16 of the sites were serpentinized peridotite with negligible colluvium from other kinds of rocks, and those 16 sites were chosen to represent arid to humid soils and plant communities in the transect across the Klamath Mountains (Fig. 1). They are representative of unglaciated sites below 1250 m altitude.

2. Area description and sampled sites

The Klamath Mountains are a composite of oceanic terranes that were accreted to the west coast of the North American continent before the Mesozoic Nevadan tectonic event and were modified by subsequent plutonic and tectonic activity (Irwin, 1994, 1997). The Franciscan complex and Yolla Bolly terrane west of the Klamath Mountains (Fig. 1) are oceanic terranes that were accreted to the North American continent after the Nevadan tectonic event; they are considered to be in the California Coast Ranges. Terranes of the Klamath Mountains were thrust over the Franciscan and Yolla Bolly terranes and remnants of Klamath Mountains terranes are found westward as far as the Pacific coast (Irwin, 1994; Orr and Orr, 1996). The South Fork Mountain and Colebrooke schists formed at the base of the Klamath Mountains thrust.

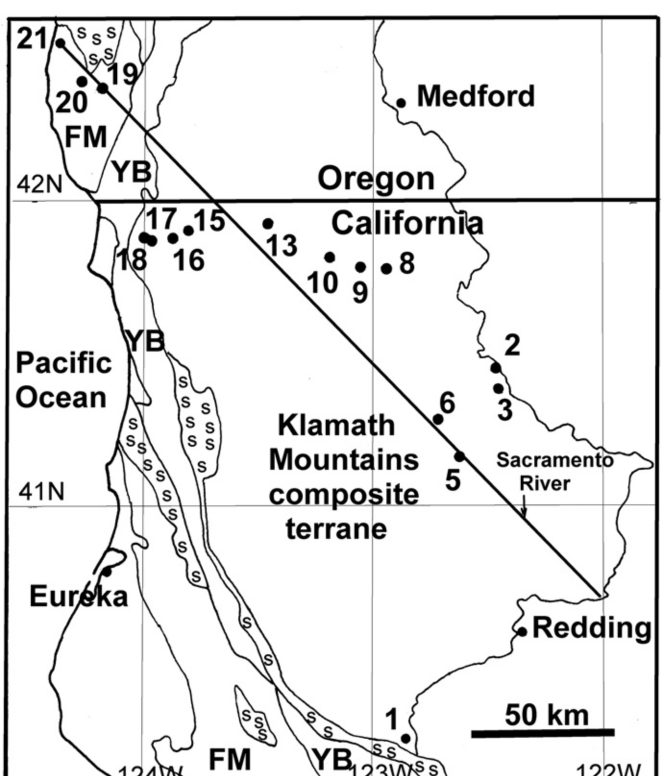

Fig. 1. Klamath Mountain and adjacent terranes that were accreted to the North American continent during the Mesozoic Era, and locations of the soil and vegetation sampling sites. The FM and YB units are the Franciscan melange and Yolla Bolly terrane and the units with *s* symbols are the South Fork Mountain and Colebrooke schists.

Serpentine rocks and soils are widely distributed in large to small bodies across the Klamath Mountains. The serpentine transect crosses many mountains, which are generally oriented in arcs that are roughly parallel to the western edge of the Klamath Mountains (Fig. 2). Major streams cross the mountains on courses that were antecedent to the rise of the mountains.

A summer–dry climate prevails throughout the Klamath Mountain area, with fog adding considerable summer moisture along the Pacific coast. All of the sample sites are cool (mesic STRs) except warm (thermic STR) at Site 1. Sites numbered 2 to 21 follow an east to west, or an arid to moist, progression. Sites W and G, which are near Site 17, were sampled for a previous investigation (Alexander, 2010). The sampling sites are all below 1250 m altitude, from arid steppe (Site 2) to open forest (sites 3, 5, 6, 8, 9, 10) and dense to semidense forest with a dense understory of shrubs (Table 1). All of the soils are well drained, most are moderately deep, and all except the very deep soil at Site G are on steep (22–68%) slopes. Site G is on a nearly level mountain bench about 90 m below the presumed surface of a Miocene peneplain (Aalto, 2006; Cater and Wells, 1953; Diller, 1902). Site W with a deep soil is on the shoulder of a rounded ridge that is presumed to be an eroded remnant of the Klamath peneplain. The soil at Site 20 is deep in colluvium. All sites other than W and G are on erosion surfaces that are far below the Klamath peneplain and much younger than the peneplain. Weathering differences related to soil age do not appear to be an issue other than for the deeper, strongly weathered soils at sites G, W, and 20.

There have been both wetter and drier periods during the 15,000 years since the end of the last major glaciation at higher elevations in the Klamath Mountains, causing shifting vegetation patterns (Briles et al., 2011). Current ecosystems at lower elevations may be clues to the kinds of ecosystems that will occur at higher elevations as the climate warms.

3. Methods

Soils at the transect sites were described sufficiently to classify them, and the dominant plants in tree, shrub, and grass, or graminoid, layers were named as currently recommended on the US Department of Agriculture site for plant classification (http://plants.usda.gov/classification). Volumes of stones, cobbles, and coarse gravel (pebbles > 30 mm) were estimated visually. About three kg of finer soil (particles < 30 mm) were taken from surface (0–12 cm) and subsoil (30–48 cm) depths. The surface samples were composites of three subsamples taken within 3 m of each other at each sample site. These samples were air dried and passed through a 2-mm sieve to obtain fine-earth for analyses. Gravel was weighed and its volume estimated by assuming that it was twice as dense as the fine-earth represented by the weight of particles <2 mm.

3.1. Evapotranspiration

Monthly potential evapotranspiration (ETp, mm) was estimated by an equation of Hargreaves reported in Jensen et al. (1990) and modified for the computations (Eq. 1). Predictions of potential evapotranspiration by the Hargreaves equation, which was developed for crop land, are very high for natural habitats, but it was utilized because it has solar radiation and daily temperature difference factors. Constants in the Hargreaves equation were adjusted to obtain results comparable