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METALLOGENETIC MAPS OF THE OPHIOLITE BELTS OF THE WESTERN UNITED STATES

By Jocelyn A. Peterson

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INTRODUCTION

Ophiolite is a distinctive assemblage of mafic and ultramafic rocks which form a sequence, from bottom to top, of usually serpentinized ultramafic rocks, gabbroic rocks frequently exhibiting cumulus textures, a mafic sheeted-dike complex, and mafic volcanic rocks. Other associated rocks include chromitite bodies, sodic felsic igneous rocks, and overlying sedimentary rocks composed of ribbon chert, thin shale, and minor limestone (Coleman, 1977). The term ophiolite has been in use since the beginning of this century, but the definition and genetic models for ophiolite have been varied. However, it is now widely accepted that ophiolites represent oceanic crust that has somehow been emplaced onto the continents, although there is still much discussion about the mechanisms of emplacement.

Certain mineral commodities and types of ore deposits that are known to be associated with ophiolites have received widespread interest by mining companies and geologists in recent years. Some of these deposits, such as the chromitite pods in the ultramafic complex and massive sulfide bodies within the pillow lavas, are probably related to volcanic processes at spreading centers (Sillitoe, 1973), whereas other deposits, including lateritic nickel, some iron deposits, and asbestos deposits within serpentinized ultramafic complexes, result from weathering and emplacement of ophiolites (Coleman, 1977).

In 1974 the Board of the International Geological Correlation Program (IGCP) approved a project for the study of "Ophiolites of Continents and Comparable Oceanic Rocks." Thus Project 39 Ophiolites under the sponsorship of UNESCO (United Nations Educational, Scientific, and Cultural Organization) came into being with a general program having the following goals: (1) organize an ophiolite information center, (2) prepare an international ophiolite atlas, (3) organize field trips to outstanding ophiolites, and (4) publish reports on ophiolite areas. One important aspect of this program is the investigation of ore deposits in ophiolites. Geologic maps have been published at a scale of 1:2,500,000 for the Mediterranean region (Dietrich, 1979), the Himalayas (Gansser, 1979), California and Oregon (Irwin, 1979), and the Ural Mountains (Knipper, 1979). One group within the project is producing metallogenetic maps of these same areas to include data about chromium, platinum, nickel, copper, manganese, iron and titanium, talc, asbestos, and magnesite. The metallogenetic maps published with this paper complement Irwin's (1979) geologic map of the ophiolites for the California-Oregon region. The explanation for the commodities shown on the metallogenetic maps was developed by geologists who are involved with IGCP Project 39 and is similar to the symbology developed by Guild (1968). Table 1 indicates the criteria used in determining deposit size. Preliminary versions of these metallogenetic maps were presented at the meeting of Project 39 held in Athens, Greece, October 9–11, 1980 (Peterson, 1980).

Table 1.—Criteria for deposit size in tons of commodity

Commodity	Large	Small	Occurrence
Asbestos - -	>10,000,000	<10,000,000	Non-producer
Talc- - - - - -	>10,000,000	<10,000,000	Do.
Magnesite- -	>10,000,000	<10,000,000	Do.
Iron- - - - - -	>100,000,000	<100,000,000	Do.
Copper - - -	>1,000,000	<1,000,000	Do.
Chromite - -	>1,000,000	<1,000,000	Do.
Manganese-	>10,000,000	<10,000,000	Do.
Nickel - - - -	>500,000	<500,000	Do.
Platinum - -	*	*	Do.

* Undefined by Project 39 group

METHODS

Most of the initial data for the metallogenetic maps for this study were obtained from the CRIB (Computerized Resources Information Bank) files stored on the USGS (U.S. Geological Survey) Amdahl Computer[1]. CRIB is a set of variable-length records on the mineral resources of the United States and other countries, and any record may contain information about names and location, facts of discovery and exploration, data concerning mining methods, production and reserve figures where available, and geologic and commodity data (Calkins and others, 1978). Records may be for metallic or nonmetallic commodities, but the emphasis so far has been on gathering data for metallic commodities. The GIPSY (General Information Processing System) program (Office of Information Systems Programs, 1977) processes and maintains the data files and allows highly selective searching procedures. Output is available in several forms including map plotting capabilities when interfaced with other software packages such as CAM (Cartographic Automated Mapping) (Central Intelligence Agency, 1975).

[1]Any use of trade names is for descriptive purpose only and does not imply endorsement by the USGS.

The records of interest were first transferred to a working file, where the data were rearranged slightly to facilitate easy generation of maps by the computer. New records were added for some of the commodities, notably talc, asbestos, magnesite, and chromite, from a literature search. Because much of the literature for the commodities discussed in this paper is old (pre-1970), data pertinent to the present study were not always reported. Therefore, incomplete data on the map indicates that the information was not available in the literature.

When the information in the CRIB file was in the desired format, I plotted each parameter on a separate map using the CAM program and a Zeta 3600s plotter. Since the computer could not plot the symbols required, it was necessary to redraft the maps with the correct symbols. In this redrafting process it was also necessary for clarity to omit many points, particularly of chromite, manganese, and copper, where several or many mines clustered within a small geographic location. For these locations I retained the mines with the most available information assuming that other mines within the area would have similar geologic characteristics.

GEOLOGY OF THE WESTERN UNITED STATES OPHIOLITES

In the western United States, ophiolite occurs in a series of nearly parallel belts within the Sierra Nevada, California Coast Ranges, and Klamath Mountains (Irwin, 1979). Other ophiolite assemblages occur in the Ochoco-Blue Mountains of east-central Oregon (near Baker). The ophiolite belts have had a complex tectonic history which commonly resulted in deformation and dismemberment and in the preservation of few complete sequences. The ophiolitic terranes as outlined on Irwin's (1979) map also include arc-related volcanic rocks and flysch. The volcanic rocks, flysch, and ophiolites may occur as melanges or coherent blocks. Isotopic and radiolarian age dates have shown that the belts become younger from east to west, although there is uncertainty as to whether some ages represent time of formation or time of emplacement (Irwin, 1977). Nevertheless, the reported ages provide a relative time frame in which to work.

SIERRA NEVADA

The Sierra Nevada ophiolite belt is 450 km long and contains continental epiclastic rocks, island-arc volcanic rocks, pelagic and hemi-pelagic sedimentary rocks, and ophiolite slices (Saleeby, 1977). Ages of rocks within this belt range from Ordovician through Jurassic. Lithologic units are often bounded by steep faults, melange, or both, although depositional contacts may be found locally. A major fault, the Melones fault, traverses the center of the ophiolite belts. Within the Sierra Nevada belt there are several distinct ophiolitic terranes: the Feather River ultramafic body, the Kings-Kaweah ophiolite belt, the Calaveras Formation, the Logtown Ridge and Mariposa Formations, the Tuolumne River ophiolite, and the Smartsville complex. Paleozoic ophiolites include the Feather River body, the Kings-Kaweah belt, and the Calaveras Formation. The remaining ophiolitic terranes are considered to be Lower or Middle Jurassic (Irwin, 1977).

Duffield and Sharp (1975) and Clark (1964, 1976) discuss in detail the lithologies and structure of the melange belts within the Sierra Nevada which include the more extensive melanges: the Calaveras, Logtown Ridge, and Mariposa Formations, which are composed of sequences of metasedimentary and metavolcanic rocks.

The Feather River ultramafic body is a metamorphosed alpine peridotite and gabbro (Weisenberg and Ave Lallemant, 1977), and the entire ophiolitic assemblage contains metasedimentary and metavolcanic units related to island-arc activity (Ehrenberg, 1975; Hietanen, 1977).

Saleeby (1977) believes the Kings-Kaweah ophiolite belt is a southward extension of the Paleozoic ophiolites and are exposures of the bottom part of the ophiolite. The area contains the most complete Paleozoic ophiolite sequence in the Sierra Nevada. Most of the Kings-Kaweah belt consists of discontinuous pendants or remnant inclusions of ophiolite in the Sierra Nevada batholith. Saleeby (1974, 1975a, 1975b, 1976, 1977) has described this ophiolite region in great detail.

A small Jurassic ophiolitic body termed the Tuolumne River ophiolite (equivalent to the Tuolumne ophiolite of Irwin, 1977) occurs near Sonora (Morgan, 1973). The mafic and ultramafic sequence includes dunite, wehrlite, gabbro dikes, gabbroic plutons, and pillow lavas. A metamorphosed melange lies at the base of the complex.

The youngest of the ophiolites in the Sierra Nevada is the Smartsville complex consisting of pillow lavas, sheeted dikes, trondhjemite, diorite, and gabbro (Moores, 1975; Buer, 1977) representative of upper levels of the Jurassic oceanic crust.

KLAMATH MOUNTAINS

The Klamath Mountains northwest of the Sierra Nevada are believed by some to be a northward extension of the Sierra Nevada foothills belt. Davis (1969) and Burchfiel and Davis (1981) present evidence for the structural and lithologic similarities of the two regions. They correlate the major Melones and Trinity faults and the ophiolite terranes in the Sierra Nevada and Klamath Mountains. The distribution of platinum-group elements in placers suggests that geochemical evidence may not support all of the comparisons (N. J Page, oral commun., 1981).

The ophiolites of the western United States are best developed in the concentric west-facing arcs of the Klamath Mountains which Irwin (1960) divides into four major subprovinces: the eastern Paleozoic belt, the central metamorphic belt, the western Paleozoic and Triassic belt, and the western Jurassic belt, which are separated from one another by major thrusts (Irwin, 1964; Davis, 1968). Many authors believe that the major belts were accreted from distinct island arcs, but Burchfiel and Davis (1981) propose a single evolving arc for the Middle and Upper Jurassic sequences. Each of these belts is further subdivided by various authors and the resulting literature is voluminous. The geology of each of the subprovinces is briefly reviewed below.

Eastern Paleozoic belt

The Trinity ultramafic sheet sandwiched between the central metamorphic belt and the eastern Paleozoic belt (Irwin and Lipman, 1962) covers 1,000 km^2, one of the largest ultramafic complexes in North America (Lipman, 1964). The Trinity sheet is a nearly horizontal mafic-ultramafic sheet with minor volcanic and diabasic rocks over which lies a melange assemblage of various ages from Ordovician to Devonian (Lindsley-Griffin, 1973, 1977; Lindsley-Griffin and others, 1974). The Trinity sheet is thought to be genetically related to the overlying rocks (Quick, 1981). Sparse volcanic rocks overlie the melange. On the west side, the Trinity sheet overlies Devonian metamorphic rocks and to the east it disappears beneath Paleozoic strata (Irwin, 1977). The ophiolite may have formed in the forearc region of an active island arc (Lindsley-Griffin, 1977). Mattinson and Hopson (1972) prefer an origin from oceanic crust that formed 455 m.y. ago and may have been emplaced as late as Devonian.

Central metamorphic belt

The central metamorphic belt contains three units: (1) the siliceous metasedimentary rocks and greenstones of the Stuart Fork Formation (formerly included in the Abrams Mica Schist), (2) a metavolcanic unit, the Salmon Hornblende Schist, and (3) the siliceous, calcareous, and amphibolitic rocks of the Grouse Ridge Formation of Lipman (1962) (also termed the Abrams Mica Schist by some geologists) (Davis and others, 1965; Davis and Lipman, 1962). These formations underwent two deformational periods, but the Stuart Fork Formation was less severely deformed by the early deformational period than the others.

Western Paleozoic and Triassic belt

Irwin (1972) has divided the southern part of the western Paleozoic and Triassic belt into three terranes: the Rattlesnake Creek terrane containing ophiolite with soda granite; the Hayfork terrane of andesites with the syenodioritic Ironside Mountain batholith; and the North Fork terrane, also ophiolitic. Radiolarian cherts and siliceous tuffs associated with the North Fork and Rattlesnake Creek terranes have yielded Late Triassic ages (Irwin and others, 1977). Ando (1977) believes that the western Paleozoic and Triassic belt is a large antiform that is steeply overturned to the west with the core of the antiform represented by the ophiolitic rocks. These two ophiolitic terranes are only partial sequences and are very dismembered (Ando, 1977).

Western Jurassic belt

The western Jurassic belt contains ophiolite of Late Jurassic age, which may be correlative with the Coast Range ophiolite (Irwin, 1977). A majority of the Lower and Middle Jurassic portion of the belt contains flysch and volcanic-arc sequences of the Galice and Rogue Formations (Garcia, 1976, 1979, Johnson, 1977, 1980; Johnson and Page, 1979). These authors have concluded from trace-elements studies of titanium, chromium, zirconium, and rare-earth elements that the Rogue and Galice Formations are the remains of a calc-alkaline volcanic arc (Garcia, 1979; Johnson, 1980). These units appear to overlie the South Fork Mountain Schist (in California) and Dothan Formation (in Oregon) on the west, while to the east they are thrust beneath the western Paleozoic and Triassic belt; however, the structural relationships between units in this province are usually complex and definitions of units are often uncertain. The Galice Formation contains slaty shales and graywackes with interlayered volcanic rocks, whereas the Rogue Formation contains predominantly pyroclastic units. The largest but not the only ophiolite (see Snoke, 1977, who discusses the Preston Peak area) in the Jurassic belt is the Josephine ophiolite (Harper, 1980). Whereas the trace elements from the Galice and Rogue Formations are representative of calc-alkaline arcs, the trace elements of the Josephine ophiolite point to normal oceanic crust (Vail and Dasch, 1977; Harper, 1980) that may have formed in a marginal basin by back-arc spreading. The Josephine ophiolite is a fully developed ophiolite containing tectonitic harzburgite cumulate rocks, gabbro, a sheeted-dike complex (Ramp and Gray, 1980), and pillow basalt (Harper, 1979). Harper and Saleeby (1980) have obtained zircon U-Pb ages of 157 m.y. from plagiogranite associated with the ophiolite.

EAST-CENTRAL OREGON

The ophiolitic assemblages of east-central Oregon, near Baker, can be divided into four distinct terranes: (1) the Seven Devils volcanic arc terrane, (2) the Huntington volcanic arc terrane, (3) the Central melange terrane, and (4) the Mesozoic clastic terrane (Ave Lallemant and others, 1980). These terranes are now exposed through windows in the overlying Cenozoic rocks (Irwin, 1977). The Canyon Mountain Complex, largest of the ophiolitic blocks, contains a pseudostratigraphic sequence including: (1) harzburgite tectonite, (2) metacumulate units of dunite, wehrlite, clinopyroxenite, and gabbro, (3) cumulate units of gabbro and poikilitic wehrlite, and (4) mafic sheeted-dike units, keratophyre, and plagiogranite (Himmelberg and Loney, 1980). Chromium-to-aluminum ratios in the cumulate sequence suggested to Thayer (1977) that the Canyon Mountain Complex may have formed in a ridge environment similar to the Mid-Atlantic Ridge of today. More recent interpretations suggest that the ophiolite formed in an island-arc environment because of the absence of pelagic sediments and pillow basalts and because of chemical and lithologic affinities (Himmelberg and Loney, 1980; Ave Lallement and others, 1980; Dickinson, 1979). Radiometric age dates indicate that the ophiolite formed during the Permian and that metamorphism occurred during orogenesis at the end of the Triassic (Ave Lallemant and others, 1980). Accretion to the continent took place in Late Jurassic time.

CALIFORNIA COAST RANGES

The literature discussing the Coast Ranges is voluminous, and several interpretations have been proposed for various structural and petrologic features. In a broad sense, the Coast Range ophiolite can be divided into three parts: the Great Valley sequence of flysch-type sedimentary rocks depositionlly overlying the ophiolite itself which outcrops discontinuously over the length of the

Coast Ranges, and the Franciscan Complex which has been thrust beneath the ophiolite but which contains klippen of ophiolite (Irwin, 1977).

The Great Valley sequence includes graywackes, silty mudstones, and local conglomerates (Maxwell, 1974). The Franciscan Complex is similar to the Great Valley sequence, but it has been metamorphosed and contains melange zones of chaotic rocks (Hsu, 1968). North of San Francisco, the Franciscan can be divided into three belts (Blake and Jones, 1981) consisting of (1) a coastal belt that may be a deep-sea fan system, (2) a central belt composed predominantly of melanges with fan structures in the nonchaotic parts, and (3) the Yolla Bolly belt composed of metasedimentary rocks derived from turbidity currents in the upper part of a fan. Individual gravity flows can be distinguished locally in the fan system (Aalto, 1976). South of San Francisco, the Franciscan was deposited on the continental platform where the sediments were derived from a magmatic arc and a volcanically active continental platform (Jacobson, 1978). One portion of the Franciscan Complex that remains somewhat of a mystery is the South Fork Mountain Schist, which may either be the metamorphosed equivalent of part of the Franciscan or a block of Great Valley sequence that was metamorphosed and thrust on top of the Franciscan (Bishop, 1977).

Several interpretations have been put forth for the tectonics involved in juxtaposing the Franciscan Complex and the Great Valley sequence. Blake and others (1967, 1969) point out that the Franciscan can be divided into several metamorphic zones from metagraywacke through high-grade blueschist which they interpret as resulting from high water pressure along the thrust plate. The thrust contact between the Franciscan Complex and the Coast Range ophiolite is termed the Coast Range thrust (Bailey and others, 1970). Raney (1973) and Raymond (1973), however, believe that many of the faults termed the Coast Range thrust may actually be tectonic adjustments that postdated the emplacement of the Franciscan. Suppe (1977, 1978) interprets the structural boundary between the Franciscan and the Coast Range ophioilite as a decollement that remained active into the Cenozoic. Irwin (1964), Hamilton (1978), and Page (1981) emphasize that the plate margin interactions have been complicated by the activity of the San Andreas fault system.

Twenty-three ophiolites exposed within the Coast Ranges, when combined, contain a complete ophiolite sequence including basal serpentinized harzburgite, cumulate dunite to noncumulate gabbros to uralitic gabbros, hornblende diorite, quartz diorite and minor plagiogranite, a sheeted dike or sill complex, submarine lava flows, and breccias (Hopson and others, 1981). Nearly complete sequences exist at Point Sal (Hopson and Frano, 1977), Del Puerto (Evarts, 1977), and South Fork of Elder Creek (Bailey and others, 1970). Lanphere (1971) has dated the ophiolite at 155 m.y.

Of the Upper Jurassic ophiolites near the California-Oregon coast, only the ophiolite at Riddle and the associated Myrtle Group (Jones, 1973) can be correlated definitely with the Coast Range ophiolite. The several other ophiolite masses described by Dott (1971) and Koch (1966) have an uncertain relationship with the Coast Range ophiolite.

CENTRAL NEVADA

Small bodies of serpentinite can be found throughout central Nevada as small elongate bodies tectonically mixed with lower and upper Paleozoic oceanic rocks in the upper plates of the Roberts Mountains and Golconda thrusts (Poole and Desborough, 1973). The largest of these bodies occurs in the Candelaria district, where lenses of serpentinite as much as 70 m long occur in sheared zones within a metadolerite intrusive (Page, 1959; Ross, 1961). Roberts and others (1958) outline the differences between rocks to the east of the Roberts Mountains thrust and rocks to the west. Rocks east of the thrust are predominantly limestone and dolomite with minor shale and quartzite of a miogeosynclinal facies, whereas those to the west consist of eugeosynclinal clastic sedimentary rocks and cherts with intercalated volcanic and pyroclastic rocks. Chemical and mineralogical studies indicate that the serpentinite bodies were derived from rocks of dunite to harzburgite composition, and low-temperature reactions at the serpentinite margins indicate nonmagmatic emplacement. Poole and Desborough (1973) infer from this that the serpentinite represents Paleozoic (or older) mantle fragments that were incorporated into the oceanic crust during the Paleozoic and emplaced in their present position during the Late Devonian and Early Mississippian Antler Orogeny. The serpentinite bodies need much more study before they can be conclusively said to represent small portions of ophiolites.

MINERAL COMMODITIES

The mineral commodities associated with ophiolites in the western United States include asbestos, talc, magnesite, iron and titanium, manganese, copper, chromite, and platinum. The following sections discuss each of these commodities, outline geologic features of major deposits, and discuss the items pertinent to the map explanation. The literature for many of these commodities predates the recognition of ophiolites and their relationship to plate tectonics of western North America, so some desired information is unavailable or is based on interpretation of the older literature.

ASBESTOS

Asbestos is present wherever there are serpentinized ultramafic rocks, but it seldom occurs in sufficient quantity to be considered an economic deposit. The majority of the western United States deposits contain the serpentine asbestos chrysotile, but several deposits in Oregon (Bright and Ramp, 1965) and others in the northern Sierra Nevada (Wiebelt and Smith, 1959) contain the amphibole asbestos tremolite and more rarely anthophyllite. Only two amphibole asbestos deposits in Oregon have been productive (Oregon Department of Geology and Mineral Industries, 1943; Wagner, 1963), but several in California produced small amounts for a number of years (Wiebelt and Smith, 1959). However, in the early 1960's, two major deposits were discovered in California, one near Copperopolis (fig. 1, No. 1) and the other near Coalinga (fig. 1, No. 2). Most of the western United States asbestos deposits contain short cross-fiber veinlets usually irregularly distributed throughout the host serpentinite. Little information is available about the association of these deposits with younger volcanic rocks, although it can be presumed from a knowledge of the geology that some of the deposits may be spatially close to intermediate differentiates of the lava flows overlying the ultramafic bodies in the ophiolites. However, if the serpentinization occurred during tectonic emplacement rather than while the ophiolite was still part of the ocean floor, the genetic associations of asbestos with volcanics would be somewhat reduced.

Of the two major new productive asbestos deposits, the Copperopolis asbestos deposit is fairly typical of other deposits in California and Oregon and also resembles major deposits in Canada. The chrysotile occurs as stockworks of cross-fiber veinlets in a serpentinized dunite within peridotite (part of the Tuolumne River ophiolite) (Merritt, 1962; Rice, 1963, 1957). The veins are between 0.8 and 25 mm wide though few are thicker than 6 mm. There are also minor quantities of slip-fiber chrysotile. The ore body occurs in the crest of an anticline, and the bottom of the deposit has not yet been found.

The extremely large Coalinga deposit in the Coast Range ophiolite is unlike any other in the western United States. It occurs in a large serpentinite mass, parts of which have also yielded mercury, magnesite, chromite, and some gem materials (Rice, 1957, 1963). The host serpentinite has been sheared into chips and plates with slickensided faces (Munro and Reim, 1962). This sheared serpentinite contains residual blocks of serpentine and partially serpentinized peridotite, occasionally reaching 1.5 m in diameter. In the southeast one-third of this 23-km-long serpentinite body, the serpentinized plates are soft and flexible. They range in size from microscopic to greater than 2.5 cm. The chrysotile fibers are randomly oriented and matted into the flakes. Favorable areas for these flakes occur at contacts with the surrounding sedimentary rocks along shears both paralleling and cutting across the regional grain (northwest) and at the intersection of shears. These chrysotile flakes may make up to 50 to 90 percent of the host serpentinite (Merritt, 1962). As at Copperopolis this ore deposit lies in the crest of an anticline, and the bottom of it has not yet been found. The only other similar occurrence known is at Stragari, Yugoslavia (Munroe and Reim, 1962).

TALC

Like asbestos, talc is nearly ubiquitous throughout the western United States ophiolite belts, but unlike asbestos, the talc deposits are uneconomic except for a few small deposits in the Sierra Nevada foothills that have produced minor quantities (Wright, 1950, 1963). The talc associated with ophiolites usually has a high iron content, making it undesirable for many economic applications (Chidester and others, 1964; Wright, 1963).

In a study of the talc deposits in the eastern United States, Hess (1933) concluded that in all cases where serpentinization and talc mineralization (steatitization) occurred in the same place the serpentinization preceded the talc. Hess (1933) and Chidester and others (1964) indicate that talc generally occurs near silicic to intermediate igneous rocks. Therefore, although it is not specifically stated in most of the deposit descriptions, it is assumed that igneous rocks are associated with the talc.

Most of the talc forms irregular bodies rather than veins and is not reported to be associated with carbonate rocks. Since carbonate rocks are not mentioned, the upper portion of the circle on the map was left blank because of a lack of definitive knowledge.

MAGNESITE

Magnesite occurs ubiquitously throughout the ophiolitic terranes of the western United States but mostly in amounts too small to be considered economic. The literature dealing with magnesite is quite old, going back to the early 1900's, and it emphasizes mining engineering and specifics of the magnesite vein systems; however, it does mention that some deposits contain cryptocrystalline or amorphous magnesite as an alteration product of serpentinized ultramafic rocks (Hess, 1908; Gale, 1912; Bradley, 1925). Also, Hess (1908) mentions that cinnabar and chromite are often associated with the magnesite. The Red Mountain district, Calif., (fig. 1, No. 3) is the only area where details of the geology of the magnesite have been published (Bodenlos, 1950); but it is probably representative of the occurrences throughout the Coast Ranges and Sierra Nevada. The ultramafic rocks include peridotite, dunite, pyroxenite, and gabbro surrounded by the Franciscan Complex. The dunite has been serpentinized, but the other ultramafic rocks remain relatively fresh except where sheared. The magnesite, which formed in shear zones, occurs as cryptocrystalline nodular aggregates replacing serpentine or as fissure fillings in irregular fractures, breccias, and shears. Sometimes magnesite nodules coalesce into massive lenses. The magnesite is accompanied by dolomite, manganese oxides, chalcedony, opal, deweylite, sepiolite, and calcite.

The Bald Eagle mine (fig. 1, No. 4), unlike other magnesite mines, is thought to have formed in an old landslide of serpentine breccia. The magnesite occurs as a blanket in the landslide debris (Perry and Kirwan, 1942).

Bodenlos (1950) indicates that all of the Coast Range deposits occur in rocks that resemble the silica-carbonate rocks of Taliferro (1943a). Silica-carbonate rocks are composed of any of several forms of silica and a carbonate which may be pure calcite or a highly ferruginous magnesian calcium carbonate. Silica carbonate rock typically occurs in elongate zones along faults. Both Bodenlos (1950) and Davis (1957) ascribe the magnesite formation to ascending hydrothermal fluids that came after the serpentinization, and Taliaferro (1943a) relates the ore-forming solutions directly to Tertiary and Pleistocene volcanism. However, descriptions of individual deposits do not indicate nearby volcanic rocks, so the volcanic symbol has been omitted from the map.

Because most of the geologic in formation is lacking, many of the symbols for magnesite on figure 1 have been left empty. No mention is made of lateritic soils, but in noting the distribution of nickel laterites (fig. 3), it is assumed that lateritic crusts near magnesite deposits are lacking or relatively unimportant. Several of the deposits do have stockworks of magnesite, but the shear zones are the primary structural controls which resulted in large veins; consequently, the vein symbol was used.

IRON AND ITIANIUM

The iron and titanium deposits within the ophiolite belts are difficult to characterize because of their wide variety. In some cases the mineralization postdated the ophiolite formation; in others the ore formed simultaneously with the ophiolite.

Titanium ore minerals, derived from the ophiolite of the Coast Ranges, occur only in the black sands along the Pacific coastline, particularly at the Santa Cruz area (fig. 2, No. 1) and in northern California extending up into Oregon (fig. 2, Nos. 2, 3). These sands contain a wide variety of heavy minerals including magnetite, ilmenite, garnet, rutile, epidote, zircon, gold, platinum, and others (Hubbard, 1943; Hutton, 1959; Twenhofel, 1943). These deposits are found in both the present beaches and older beach terraces now exposed in river channels. In the Santa Cruz area (fig. 2, No. 1), magnetite and ilmenite are generally the most abundant heavy minerals. Analyses have shown that the magnetite contains appreciable quantities of titanium (specific amount not stated) and that some of the ilmenite contains as much as 0.5 percent of UO_2 (uranium oxide) (Hutton, 1959). The beach sands west of the Klamath Mountains are similar, but contain much more chromite (Griggs, 1945; Twenhofel, 1943). In both regions, the heavy iron and titanium minerals are thought to come from sources within the Coast Ranges and Klamath Mountains including the ophiolitic assemblages. More descriptive details of the beach sands are in the chromite discussion below.

In addition to the beach-sand deposits, iron occurs in several localities within the Sierra Nevada and Klamath Mountains. It is absent from the Coast Ranges except for a limonite deposit in the Franciscan Complex near San Luis Obispo (Harder, 1909; Franke, 1935).

The Minaret deposit (fig. 2, No. 4) is an elongate lens of magnetite and magnetite + actinolite in Jurassic and Triassic meta-andesites which have been intruded by a variety of rocks including diabase, diorite, and quartz monzonite (Severy, 1946; Trask and Simons, 1945). Four granitic bodies nearby are older than the mineralization, for magnetite stringers cut across them. Textural analyses of the magnetite and actinolite indicate that there may have been several periods of magnetite formation. Within the ore lens, magnetite and actinolite occur in sheetlike masses which vary in composition and grade into one another. Small quantities of hematite have been found in isolated places elsewhere (Severy, 1946).

Several iron deposits of hydrothermal origin occur as replacements in the Calaveras Formation (fig. 2 , northern Sierra Nevada). Both the magnetite deposits and their host rocks have been metamorphosed, which implies that the magnetite predates the Nevada orogeny (Durrell and Proctor, 1948). The deposits are genetically related to metadiorite and associated dikes. There are two types of deposits, those in which the magnetite is associated with talc in clastic sedimentary rocks and tuffs and, less commonly, those in which magnetite is associated with calcite in dolomite. The ore occurs as small irregular lenses usually in fault contact with the host rock.

About 40 km northeast of Redding a group of iron deposits known as the Hirz Mountain deposits (fig. 2, No. 5) occur in Permian limestone at the contact of an intrusive quartz diorite of Late Jurassic or Early Cretaceous age. The magnetite replaces the sedimentary rocks (limestone and tuffaceous sedimentary rocks) and is disseminated within the quartz diorite (Lamey, 1945a). Locally, the ore is associated with garnet and epidote, and some of the limestone has been silicified. These ore bodies are small, discontinuous, and shallow. Similar deposits occur about 16 km south, but they additionally contain pyroxene, serpentine, and a mineral similar to anthophyllite. Also, some manganese and chromium are present (Lamey, 1945b).

The Myrtle Group in the western part of the Klamath Mountains hosts an unusual iron deposit in which the magnetite fills interstices between sand grains in a sandstone situated between two greenstone dikes. The magnetite is thought to have formed when the dikes were metamorphosed and serpentinized (Butler and Mitchell, 1916). In the Kalmiopsis Wilderness, black sands containing magnetite have been found overlying the Myrtle Group (N. J Page, written commun., 1981), and it is possible this is what Butler and Mitchell (1916) saw as well.

Lenses of magnetite occur parallel to foliation in the Colebrook Schist (Butler and Mitchell, 1916). The lenses extend over several kilometers and may contain manganese as well as iron; they are thought to have formed contemporaneously with the metamorphism.

A few occurrences within the Applegate Group contain titanium as well as iron (Mason, 1969).

NICKEL

Both nickel sulfide and nickel laterite deposits are represented in the western United States ophiolite regions, but neither type, with the exception of Nickel Mountain in Oregon, is economically significant. The nickel sulfide sometimes occurs in deposits predominantly containing copper, and at other times is associated with platinum or other elements. None of the nickel-sulfide occurrences in this region contain economic amounts of nickel. In some deposits the nickel sulfides millerite and nicollite typically occur in a metamorphic host rock. (See Hundhausen, 1952, for a description of one such deposit). Other sulfide deposits have nickel, copper, cobalt, and minor platinum metals in a norite sill containing the sulfides pyrrhotite, pentlandite, and chalcopyrite (Ramp, 1978).

The western United States contains two types of nickel laterites, siliceous and ferruginous. In the siliceous type, nickel occurs in nickel magnesian silicates generally called garnierite. The only deposit of this type in the western United States is the Nickel Mountain deposit near Riddle, Oregon. In the ferruginous-type deposits, the nickel is found in a brown blanket containing no discernable nickel minerals which overlies the bedrock. In both types of laterite, the bedrock underlying them is peridotite or serpentinized peridotite.

Most of the nickel laterite deposits in the western United States occur in the Klamath Mountains, where the climatic history was favorable for lateritic development. However, a few deposits are scattered throughout the other ophiolitic terranes. In eastern Oregon the deposits resemble those in the Klamath Mountains except that the laterization is not as intense (Tooker and Cornwall, 1979). An extensive study of the Klamath Mountains laterite indicates that the parent peridotite is typically little serpentinized (Hotz, 1964). The lateritic covering is a few to 15 m thick. A well-developed profile includes, from top to bottom, a reddish-brown soil containing vegetative matter and iron oxide pellets, a yellowish-orange soil with or without decomposed peridotite fragments, yellowish-brown saprolite, weathered peridotite, and fresh peridotite (bedrock). Most of the deposits show variations of this profile. In ferruginous laterite, nickel may occur (1) in montmorillonite, chlorite, and talc, where it substitutes for magnesium, (2) in combination with ferrous oxides, or (3) in unaltered peridotite. The ferruginous laterite generally also contains chromite and minor cobalt. These Klamath Mountains laterites, although similar to other nickel laterites (Cuba, New Caledonia), are typically higher in SiO_2 and MgO and lower in Fe_2O_3. They are also smaller and have a lower metal content. The laterization itself took place between Miocene and Holocene (Ramp, 1978). Hundhausen and others (1954), Benson (1963), Libbey and others (1947), and Mason (1949) describe some of the ferruginous deposits of the Klamath Mountains, and Ramp (1978) describes nickel deposits throughout Oregon.

Because Nickel Mountain is the only silicate-type nickel-bearing laterite in the west, and because it is the only productive nickel deposit in the United States, I will describe it here (fig. 3, No. 1) on the basis of the findings of Cumberlidge and Chace (1968). Nickel Mountain has two main ore bodies that developed on Jurassic harzburgite. The two ore bodies may be associated with two separated episodes of peneplanation and laterization in which the garnierite-bearing saprolite developed on top of the peridotite from groundwater action. Faults and joints in the peridotite provided the zones of permeability for saprolite development. Garnierite-chalcedony boxworks formed along fault and joint surfaces and at the former water table. These boxworks are entirely supergene, with the chemical constituents being derived from higher in the soil profile. When the laterization took place, the climate was postulated to be subtropical to warm temperature. Presently, the saprolite is turning into soil rather than the peridotite turning into saprolite. Six types of ores have been defined on the basis of their textures and structures, with the most important ore horizon being the saprolite. The richest ore occurs in the nickel silica boxwork, but the nickel content of the garnierite changes within a few centimeters where a light-colored garnierite appears. Pecora and others (1949) believe that this light-yellow nickel-poor garnierite resulted from direct alteration of the peridotite, that light-green garnierite resulted from groundwater action on earlier formed garnierite, and that the dark-green nickel-rich garnierite was deposited from groundwater solutions that leached the light-green garnierite.

MANGANESE

Small manganese deposits are abundant in the Coast Ranges and Sierra Nevada, less so in the Klamath Mountains. Modes of occurrences are similar for all the deposits, with differences being attributed to varying degrees of metamorphism.

Within the Coast Ranges, manganese occurs only in sedimentary rocks of the Franciscan Complex where it is usually interbedded with red or green chert, typically in the more massive chert beds rather than in the thin beds that alternate with shales (Taliaferro and Hudson, 1943). The manganese lenses have the same shape, modes of occurrence, and structure as the chert. Ore zones may be 2.54 cm to 7.5 m thick, but they average 1.25 m. The lateral extent is usually 12–15 m. The manganese originally was spherulitic or finely divided rhodochrosite, manganese carbonate, and manganiferous opal (Taliaferro and Hudson, 1943; Hewett and others, 1961). Most manganese ore bodies formed as a mixture of these minerals. Alteration of the original ores has produced granular rhodochrosite and various hydrated manganiferous oxides, in some places only as thin surface films but in others as thick as several meters. Hewett and others (1963) believe that some manganese oxides may be of hypogene rather than supergene origin, and they outline some trace-element studies that can be used in determining the origin of the oxides. Most, if not all, of the Coast Range oxides probably are a product of weathering. The chert in which these manganese deposits occur is almost invariably associated with basalt or andesite (with or without pillow structure) and with pelagic shale (Taliaferro and Hudson, 1943). Radiolarians are abundant in the chert and may also be present in the manganese ore.

The highly oxidized manganese ores are the only kind that can be economically mined. An area within San Joaquin County (fig. 4, No. 1) has been the largest producer in California (Davis, 1957), but it has not produced more than 100,000 tons.

Manganese occurrences within the Sierra Nevada are similar of those in the Coast Ranges except that they have undergone various degrees of metamorphism. Host formations include the Logtown Ridge (formerly a part of the now-abandoned Amador Group) and Calaveras Formations (Hewett and others, 1961). These manganese deposits always show the same degree of metamorphism and structural deformation as the host rock (Taliaferro, 1943b). As in the Coast Ranges, the manganese typically occurs in the more massive metachert lenses. The metamorphic manganese minerals include rhodonite, the manganiferous garnet spessartite, a manganese-bearing pyroxene, piemontite, and a manganiferous olivine tephroite (Hewett and others, 1961).

Three geographically overlapping groups of manganese deposits in the Klamath Mountains are defined by their mineralogy. In Eocene sedimentary rocks, along the coast, manganese oxides predominate. Further inland are deposits termed manganiferous iron by Appling (1958), and still further inland are manganese silicate deposits. Of importance are the latter two types of deposits, both of which occur in the siliceous metasedimentary rocks of the Applegate Group (Appling, 1969) and the Dothan Formation (Wells and others, 1949a). The manganiferous iron deposits consist of rhodonite or mixed oxides with hematite. These are typically lower in grade but are larger than the silicate deposits, which consist of rhodonite mixed with quartz.

Many of the authors cited above indicate that the manganese and probably some of the silica in the cherts resulted from volcanic exhalations. This is supported by the obvious syngenetic nature of the manganese deposits and by its inevitable close proximity to the cherts and volcanic rocks. Hewett and others (1963) stress the importance of volcanism in the formation of manganese nodules, which further supports the volcanic association of the manganese deposits.

Several aspects of the manganese map (fig. 4) require explanation. In general, where the manganese occurs in a massive lens of chert within a chert-shale pelagic sequence, I used the chert country-rock color symbols. The pelagic sediment color symbol was used only for deposits associated with thin chert layers, and the volcanic color symbol for those associated with volcanic rocks. Undesignated deposits are probably in thick cherts. Rhodochrosite is the dominant manganese mineral in the Coast Ranges, but manganiferous opal and silicates occur in many deposits as well. Thus, the designation is based on the minerals specified in the literature. Many of the empty symbols may be assumed to indicate deposits containing rhodochrosite. The form of undesignated deposits is probably a bed or lens. The deposits of the Coast Ranges tend to occur in thicker bedded cherts than those of the Sierra Nevada or Klamath Mountains. Finally, it should be noted that due to great overlap of symbols, it was necessary to omit many of them from the map, but sufficient information is present to accurately represent the distribution of manganese occurrences.

COPPER

Many of the copper deposits of the western United States ophiolites occur in the Sierra Nevada foothills belt and in the East and West Shasta mining districts of the Klamath Mountains (fig. 3, No. 2), but deposits within the Coast Ranges are sparse.

Massive sulfide deposits in ophiolite are typically found within pillow lavas and consist primarily of pyrite with significant chalcopyrite, sphalerite, and marcasite, and sometimes minor amounts of pyrrhotite, galena, gold, and silver (Coleman, 1977). Gangue minerals include quartz, gypsum, chlorite, and various sulfates. Massive sulfides often show compositional banding, and most of the chalcopyrite is evidently deposited later than the pyrite. These sulfides probably represent hydrothermal deposits formed at the seawater interface.

Descriptively the ophiolite-related copper deposits in the western United States fit well into this depositional model. However, the host rock is typically other than basalt and is in island-arc-related volcanic rocks rather than the ophiolites themselves. Nevertheless, some massive sulfides are ophiolitic, including the Queen of Bronze and Cowboy in Oregon (fig. 3, No. 3); these deposits are indeed syngenetic with the volcanic rocks in which they are found, but they have experienced some remobilization during emplacement (John P. Albers, oral commun., 1981). Deposits in the West and East Shasta copper-zinc districts in California, although larger than others shown on figure 3, are typical deposits (Kinkel and others, 1956, and Albers and Robertson, 1961). In both districts, the sulfides occur in rhyolitic units that are structurally within a broad anticlinorium, and the ore occurs in massive sulfide lenses a few centimeters to 1.6 km in largest dimension, usually grouped along shear zones or faults. Although some gradational contacts with the rhyolite do occur, most of the contacts between ore and host are sharp and have a small gouge zone. Below a couple of the massive lenses, disseminated ore occurs within the adjacent host rocks. The ore is predominantly massive pyrite with chalcopyrite, sphalerite, and minor gold and silver. The ore lacks abundant gangue minerals but may contain small amounts of barite, quartz, gypsum, chlorite, and calcite. It does not show a constant grade of copper or zinc throughout and displays compositional banding parallel to the foliation of the host rock. Gossans have formed over these copper deposits from which the gold and silver have been recovered. In most cases silicification, sericitization, or chloritizaton of the host may have taken place during ore formation.

The copper belt of the Sierra Nevada trends along the foothills for 400 km southward from the Feather River area (Heyl, 1948). The ore occurs as stratabound lenticular sulfide bodies in the metavolcanic host rocks. Although pyrite is the major iron sulfide, pyrrhotite becomes more abundant toward the south. As in the Shasta area, the ore is in sericitized, silicified, or chloritized host rocks. In some places the host rocks are also pyritized. Unlike the Shasta area, the host rocks may be mafic or felsic and the ore occurs in subaqueous (and possibly subaerial) volcanic rocks of an island-arc sequence (Kemp and Payne, 1975); Kemp, 1976). In both areas, argillic sedimentary rocks overlie the host rocks (Kinkel and Kinkel, 1966).

Kemp (1976) defined two types of copper deposits in the Sierra Nevada. The copper-zinc variety is found primarily in felsic pyroclastic sequences and resembles Kuroko- or Noranda-type massive-sulfide deposits. The copper-rich variety occurs more often in intermediate volcanic rocks but otherwise resembles Cyprus-type volcanogenic deposits. The eastern part of the Sierra Nevada copper belt contains small rich veins and replacement deposits of bornite and chalcocite in metamorphic and igneous host rocks with quartz gangue. These may be genetically related to the Sierra Nevada batholith rather than to the island-arc assemblages (Heyl, 1948). Some of the sulfide minerals in Sierra Nevada deposits have been deformed, and some have been enriched with chalcocite and minor covellite.

In Oregon, occurrences of copper ores similar to those in the Sierra Nevada have been documented (Shenon, 1933a; Gilluly, 1931; Swartley, 1914). The lack of copper deposits in the Coast Ranges may be due to a paucity of volcanic units to serve as hosts.

As shown on the map (fig. 3), most of the copper ores are associated with lava flows, or sedimentary rocks and lava flows. That is probably also true for the undesignated deposits. Only a few deposits are specifically mentioned in the literature as being associated with diabase or gabbro. My designation of form is rather arbitrary and relates to whether the sulfide body is thick or thin and horizontal or steeply dipping. Nearly all of the sulfide bodies contain zinc and lead sulfide rather than nickel sulfide.

CHROMITE

Small amounts of chromite are found at many places within the ultramafic rocks of the western United States ophiolites. It occurs in both high-grade podiform deposits and low-grade disseminated deposits. In some places these types grade into one another. The chromite deposits are similar throughout all the ophiolite belts. All are relatively small, with most containing less than 100 tons of ore, although several disseminated deposits contained over 100,000 tons. The chromite occurs almost exclusively in dunite pods within a host massif of harzburgite (saxonite in the older literature) where serpentinization has not obscured the original composition. Shear zones within the peridotite are the locus for most chromite pods, which may be single or clustered (Wells and Cater, 1950, and other articles in that bulletin). Textures within the chromite pods vary from massive to disseminated to nodular to orbicular to layered. Chromite compositions also vary. Chromium-to-aluminum ratios have not been reported in the literature, but chromium-to-iron ratios vary from about 2:1 (Rynearson, 1948) to greater than 3:1 (Wells and others, 1946). In a very general sense, there appears to be a difference between the major provinces. The Sierra Nevada chromite deposits have lower Cr:Fe ratios than do those of the Coast Ranges (Dow and Thayer, 1946; Rynearson, 1948, 1953; Cater, 1948a, b; Mathews, 1961). Values within the Klamath Mountains are similar to those in the Sierra Nevada (Wells and Cater, 1950), although high values are also reported (Wells and others, 1946). Chromites in eastern Oregon have Cr:Fe ratios of less than 2:1 (Hundhausen and others, 1956). Wells and others (1949b) indicate that in the Seiad and McGuffy Creeks areas (fig. 2, Nos. 6 and 7) the disseminated ores tend to have a lower Cr:Fe ratio than the massive ores. The ore bodies tend to be nearly parallel to the dunite-harzburgite boundary, and most dunite bodies parallel the boundary between the peridotite and country-rock. The ore bodies may be any shape, but the larger ones tend to be less irregular.

Mechanisms of forming podiform chromitites are not yet understood, but several hypotheses have been put forward. Thayer (1964, 1969) studied many chromitites throughout the world and emphasized that (1) chromite is characteristically anhedral and shows the effects of granulation and magmatic corrosion, (2) lineations and foliations within the chromitite and dunite may often parallel these same features in the peridotite, (3) size of the peridotite mass does not necessarily correlate with the size of the ore body, and (4) relict cumulate features like those in the large stratiform ultramafic complexes have been preserved in some chromitites. Experimental work showed that only a small Cr_2O_3 content in a peridotite melt will lead to an early precipitation of spinel and that during fractional crystallization only a small amount will precipitate with forsterite or magnesian pyroxenes (Irvine, 1967). Chromitites of the Troodos complex, Cyprus, have primary cumulate textures and schlieren textures from subsequent deformation, whereas orbicular structures may be due to mechanical accretion around a dunite nucleus (Greenbaum, 1977). At Troodos there is a spatial pattern to chemical and textural features, which appears to be also true of chromitites in the western United States. The Troodos complex may have evolved from differentiated cumulates lain on a basement of depleted mantle harzburgite, and the chromitites formed as isolated magma segregations near the base of cumulate dunite during episodic crystallization at localized centers within the magma (see also Greenbaum, 1972). Postcumulus deformation of the lower ultramafic rocks left a tectonic overprint on the primary magmatic textures which included rock flowage features and folding between lithologic units. Structures within the Josephine Peridotite in the Klamath Mountains support similar conclusions about chromitite formation (J. G. Evans, written commun., 1982). Chromite deposits of New Caledonia are divided into structural groups determined by how concordant they are with foliation and lineation within the harzburgite massif (Cassard and others, 1981). The most discordant type contained primary textures such as nodular and foam type chromites, whereas the more concordant bodies show evidence of strong deformation. These observations led to the conclusion that the chromite crystallized and was dynamically concentrated along steep conduits through the host harzburgite, being supplied by the magma chambers, and that the chromitite "pipes" were subsequently deformed and reoriented toward the foliation in the harzburgite (Cassard and others, 1981).

Detrital chromite occurs in beach sands near Aptos, Calif., and along the southwest coast of Oregon extending into California for 120 km. It is found in both the present beach sands and older marine terraces, but most of the deposits are in the low terraces (Griggs, 1945). These black sands occur in layers and lenses a few centimeters to 12.8 m thick and may be greater than 1.6 km long by 300 m wide, although most are considerably smaller. They include chromite, olivine, pyroxene, zircon, ilmenite, rutile, garnet, magnetite, and epidote plus gold and platinum in minute quantities. The sands originated both on and off shore, and the two environments can be distinguished by form and mineral distribution. The terrace deposits are usually cemented with iron and manganese oxides where they have been exposed to erosion or where they have been above the water table for a long time. The chromite in these sands is high-iron chromite with a Cr:Fe ratio of 1.75:1. Commonly the grains are rounded, but near the Rogue River, Oreg., they are angular. Much of this chromite has probably come from reworked Tertiary sediments and may have passed through several erosion cycles (Griggs, 1945), but their ultimate source is the ultramafic rocks of the Klamath Mountains.

On the metallogenetic map (fig. 2), the square symbols represent mines where the most data are known, or they represent areas without showing every known occurrence.

PLATINUM

Most of the platinum produced in the western United States has come from placer deposits as a byproduct of gold mining. Few lode deposits have been found (Blair and others, 1977). The platinum occurs in three major geographic areas: (1) the foothills belt of the Sierra Nevada, (2) the Klamath-Trinity Rivers drainage and other drainage areas in the Klamath Mountains, and (3) in beach sands along the southwest coast of Oregon extending into California (Clark, 1970).

The placer deposits contain all six of the platinum-group metals, but generally platinum, osmium, and iridium occur in major proportions relative to ruthenium, rhodium, and palladium. These elements commonly occur as metal alloys, particularly platinum-iron and osmium-iridium (Sjoberg and Gomes, 1981), but they also occur in sulfides, arsenides, and other minerals (Sjoberg and Gomes, 1981; Snetsinger, 1971b, 1972). The relative abundance of the platinum-group minerals is dependant upon the geologic terrane. Platinum-iron alloys dominate the drainage of the American River in the Sierra Nevada. Platinum-arsenic compounds are more common south of the American River. Osmium-iridium alloys are prevalent north of the American River (Sjoberg and Gomes, 1981; see also Logan, 1919). The southern Sierra Nevada has the fewest platinum mineral phases, and the Klamath Mountains have the most. Shapes of the minerals are usually irregular to rounded. Most minerals occur as small grains, but some nuggets of platinum have been reported (Snetsinger, 1971a; Mertie, 1969).

The placers of the Takilma-Waldo area of southwestern Oregon (fig. 4, No. 2) have been described by Shenon (1933b). Three types of placers are found. In the first type the platinum and gold occur evenly distributed throughout a Tertiary conglomerate; the platinum is not concentrated near the bedrock. The second type is a residual surface mantle that resulted from weathering of the conglomerate. The third type consists of resorted deposits in gulches and flats below the conglomerate. It is these resorted gravels that have the highest gold and platinum content; the platinum in these deposits occurs on or near the bedrock surface.

Most authors state that the platinum has probably been derived from nearby serpentine or peridotite, but few lode deposits have been found, particularly in California. In Oregon, the lode occurrences are associated with chromitite deposits (Ramp, 1961). Page and others (1975) indicate that chromitites have 10 times as much of the platinum-group metals as do other ultramafic rocks of the same areas and that there seems to be a relative enrichment of rhodium and platinum as well as iridium and ruthenium in the chromitites. In the Gold Hill district of Oregon (fig. 4, No. 3) an occurrence of a platinum-bearing quartz vein which passes through schist, serpentine, and granite is reported (Kellogg, 1922; Mertie, 1969). Platinum values were not detected in the vein walls but seemed to be restricted to a blue quartz that is pitted and lined with a sooty black material which may contain the platinum. N. J Page (written commun., 1981) was unable to find this occurrence during a field examination of the area. As so few lode deposits of platinum have been documented, it is unclear from what rock units the placers were derived. However, if the platinum is associated with chromite, it likely occurs in dunites within a harzburgite massif as does chromite.

In the Sierra Nevada platinum + paladium predominates over osmium + iridium, whereas in the Klamath Mountains area, the opposite holds true; in the Coast Ranges platinum is of little importance despite the large amount of ultramafic rocks present.

CONCLUSIONS

This report has outlined and described the distribution and the various physical and chemical characteristics of certain mineral commodities typically associated with the ophiolitic terranes of the western United States. While preparing metallogenetic maps, several trends became evident.

(1) Lower Paleozoic ophiolites are hosts for nonproductive titanium deposits.

(2) Upper Paleozoic and Triassic ophiolites do not contain much asbestos or iron and titanium. In the Sierra Nevada they contain nickel-bearing laterites. Near Canyon Mountain they contain nickel sulfide occurrences and amphibole asbestos. They are the only ophiolites in the Klamath Mountains that contain abundant manganese occurrences.

(3) Lower and Middle Jurassic ophiolites contain productive iron and titanium deposits. Additionally, in the Klamath Mountains they contain nickel laterites near the Josephine Peridotite.

(4) Upper Jurassic ophiolites do not have much copper, nickel, or platinum relative to the other belts, but magnesite is present (it is mostly absent in older ophiolites) and a large nickel deposit is in these rocks.

(5) Magnesite and nonproductive iron and titanium occur in the southern Sierra Nevada.

(6) Talc deposits occur most commonly in the Sierra Nevada. Amphibole asbestos and volcanically associated manganese occur along the Melones fault in the Sierra Nevada. Also in the Sierra Nevada, platinum + palladium values are greater than osmium + iridium values.

(7) In the Klamath Mountains, manganese is virtually absent except as mentioned above, and osmium + iridium values are greater than platinum + palladium values.

It is beyond the scope of this report to evaluate whether the trends noted in the conclusions are a result of dissimilar weathering cycles, different portions of the ophiolite sequence occurring in each terrane, or basic chemical or structural differences between the various ophiolitic terranes. Some current studies are beginning to reevaluate many of the deposits and areas in light of plate-tectonic theories (Koski, 1981; Derkey, 1981; Juhas and others, 1981), particularly comparing the massive sulfide deposits with Kuroko-type ores. Other studies are examining metallogenesis on a broader scale in order to develop models for metallogenic terranes in the United States (Tooker, 1979; Albers, 1978). Further studies of the kind undertaken here should also include mercury, precious metals, lead, and zinc, since all of these are also found within the ophiolitic terranes, and should begin to relate the geographic occurrences and characteristics of commodities to specific ophiolite terranes and to the various environments where the ophiolites have formed.

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