[AMERICAN JOURNAL OF SCIENCE, VOL. 282, JUNE, 1982, P. 783-807]

PETROLOGY OF THE ROGUE RIVER ISLAND-ARC COMPLEX, SOUTHWEST OREGON

MICHAEL O. GARCIA
Hawaii Institute of Geophysics, University of Hawaii,
Honolulu, Hawaii 96822

ABSTRACT. The basement rocks of the western Jurassic belt and the coastal belt of southwestern Oregon are remnants of a Late Jurassic island arc. Although deformation has reduced the arc-trench gap to 30 to 55 km, remnants of all the major structural units of an island-arc complex are exposed along the Rogue River and its tributaries in southwestern Oregon. The western Jurassic belt is cut by high-angle faults juxtaposing rocks from different structural levels within the ancient island arc. The fragmental, predominantly andesitic volcanic and volcaniclastic rocks of the Upper Jurassic Rogue and Galice formations are the carapace of the arc, and intruding gabbroic to granodioritic rocks (136-157 m.y.) are its core. Metamorphosed ultramafic, mafic, and sedimentary rocks of unknown age constitute a disrupted ophiolite suite on which the arc may have been built.

The western Jurassic belt was thrust westward over the coastal belt, which consists of Upper Jurassic mudstones and graywackes, with minor pillow basalt and chert. The Otter Point Formation, the western unit of this belt, is strongly disrupted and includes exotic blocks of serpentinized peridotite, eclogite, and blueschist. This sequence of mélanges probably formed at the leading edge of the accretionary wedge. The Dothan Formation, the eastern segment of the coastal belt, is much less disrupted and contains abundant volcanic detritus and few exotic blocks. It may have been deposited in a fore-arc basin.

INTRODUCTION

Island arcs have long been recognized as zones of intense seismic activity, but little is known about their substructure. Mitchell and Reading (1971) and Mitchell and Bell (1973) outlined the evolution and some of the internal details of island arcs by examining active island arcs in various stages of development. Their outlines were necessarily diagrammatic because most of the internal character of active island arcs is concealed by a carapace of recent lavas and tephra. Therefore, to examine the internal features of an island arc an inactive, dissected island arc is required. Garcia (1978) proposed criteria for the recognition of ancient volcanic arcs. Based on these criteria, a sequence of calc-alkaline, volcanic rocks of volcanic arc origin has been delineated in the western Jurassic belt, Klamath Mountains, Oreg. (Garcia, 1979). Dott (1971) and Dickinson (1976) have also referred to the western Jurassic belt as an ancient arc terrane. The Rogue River and its tributaries in southwestern Oregon have dissected these calc-alkaline volcanic rocks, exposing the interior of an island-arc complex. This article provides petrographic and structural evidence from the western Jurassic belt and surrounding areas demonstrating that this region represents a dissected, ancient island-arc complex and thus, providing information about the anatomy of island arcs.

The basic components of an island arc complex are the subduction complex, the fore-arc basin, the volcanic-plutonic (magmatic) arc, and the underlying oceanic crust (fig. 1). The diagnostic, lithologic components of subduction complexes are incoherent units of mudstones and graywackes in a sheared matrix (mélanges), fragments of ophiolites (mafic and ultramafic plutonic rocks, basalts, cherts, and pelagic limestones), and blocks of eclogite and blueschist (Dickinson, 1976; Moore and Karig, 1980).

Key features of fore-arc basins are clastic sedimentary strata of volcanic-plutonic provenance which were deposited concurrently with magmatism in the adjacent volcanic arc. This clastic sequence should be only mildly deformed and relatively unmetamorphosed and should contain no intercalated lavas (Dickinson, 1976).

The basalt–andesite–dacite–rhyolite suite, and its plutonic equivalents, clastic debris, and metamorphic derivatives, are the dominant constituents of magmatic arcs (Ringwood, 1977). These rocks may be of tholeiitic and/or calc-alkaline compositions, but their texture is principally fragmental (Garcia, 1978).

Little is known about the basement of island arcs. It is assumed to be of oceanic crust and therefore to consist of an upper layer of pelagic sediments underlain by basic, tholeiitic volcanic and plutonic rocks that overlie cumulus and tectonitic ultramafic rocks (Christensen and Salisbury, 1975).

ANALYTICAL METHODS

For the plutonic rocks, whole-rock major elements, except Na and Mg, were analyzed with methods described by Fabbi (1972). Samples were fused by using a mixture of 1:14:3 for sample:flux:binder to reduce matrix effects and to eliminate grain-size and mineralogical effects. Na, Mg, and minor elements were analyzed with the technique described by Fabbi and Volborth (1970). Samples were corrected for iron effects by using standards with iron abundances similar to the samples.

Duplicate analyses for each sample (except the amphibolites) were made with a Phillips universal vacuum X-ray fluorescence spectrograph

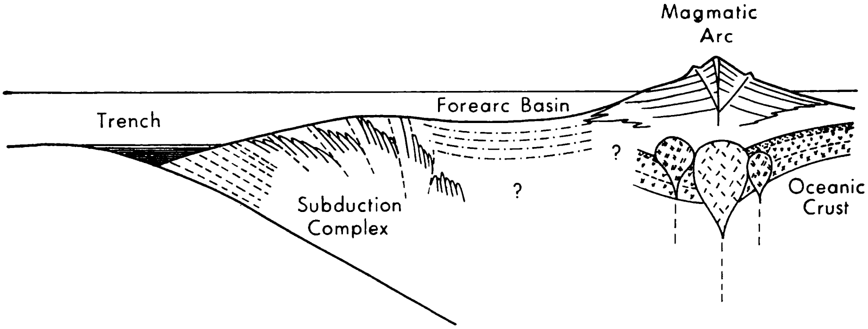


Fig. 1. Hypothetical cross section of an island arc (after Moore and Karig, 1980).

at the University of California at Los Angeles. Values listed in table 1 are an average of two analyses.

The amphibolites were analyzed at the University of Manitoba. Si, Al, Fe (total), Mg, Ca, K, Ti, and Mn were determined by X-ray fluorescence methods, and Na was measured by atomic absorption. Ferrous iron analyses were made by titration, with sodium diphenylamine sulfonate used as an indicator. P contents were determined by colorimetry. H_2O values were determined by heating samples in a stream of dry oxygen in an induction furnace at 1100°C; H_2O was collected on anhydrone and weighed. For CO_2 analyses, the sample was decomposed in warm HCl, then the evolved CO_2 was passed through a drying train and collected on ascarite.

Mineral analyses were made with an ARL-EMX electron microprobe, with natural and synthetic mineral standards. Both internal and external standards were used; the internal standards consisted of well-analyzed clinopyroxene, plagioclase, and ilmenite. Instrument operating conditions were usually 15 kV and 25 nA sample current. Each analysis is an average of six to eight points from a small area on each of four to six grains per sample. Core and rim analyses were made to check for zoning and overall homogeneity. Raw data were corrected for dead time of detectors, instrument current drift, and spectrometer background. Mineral analyses were calculated by the correction methods of Bence and Albee (1968) and Albee and Ray (1970). Accuracy is estimated to be 1 to 2

TABLE 1

New chemical analyses and modes for unaltered intrusive rocks from the Illinois River batholith (I) and the Grants Pass pluton (G). Modes are based on 1000 counts/sample

	I 125-73	I 128-73	I 135-73	I 136-73	I 147-73	I 183-73	G 92	G 98
SiO_2	47.6	48.0	41.60	41.7	42.3	45.7	57.0	64.3
TiO_2	0.35	0.82	0.70	0.43	0.58	0.64	1.29	0.59
Al_2O_3	18.2	20.5	22.75	21.1	20.2	21.1	15.8	15.3
$Fe_2O_3{}^t$	10.8	10.6	12.2	11.3	12.6	9.8	4.7	4.5
MgO	6.4	6.0	6.8	7.7	6.7	6.4	8.0	2.7
CaO	12.2	11.4	14.7	16.0	13.4	12.0	6.9	4.6
Na_2O	1.34	1.67	0.71	0.42	1.14	2.2	3.3	4.8
K_2O	0.32	0.37	0.09	0.06	0.36	0.48	1.9	2.4
MnO	0.22	0.22	0.21	0.14	0.22	0.17	0.14	0.08
P_2O_5	0.04	0.16	0.05	0.01	0.02	0.09	0.14	0.19
Ign. Loss	1.05	0.65	0.80	0.67	1.20	1.08	0.70	0.41
Total	98.5	100.4	100.6	99.5	98.7	99.7	99.9	99.9
Modes (volume %)								
Plagioclase	45	49	50	47	37	45	54	60
Amphibole	45	40	28	37	53	47	2	3
Pyroxene	< 1	< 1	13	11	< 1	< 1	15	
Magnetite	< 1	4	7	5	8	3	4	< 1
Quartz	9	7	2	< 1	2	4	10	23
K-Feldspar								6
Biotite							15	7

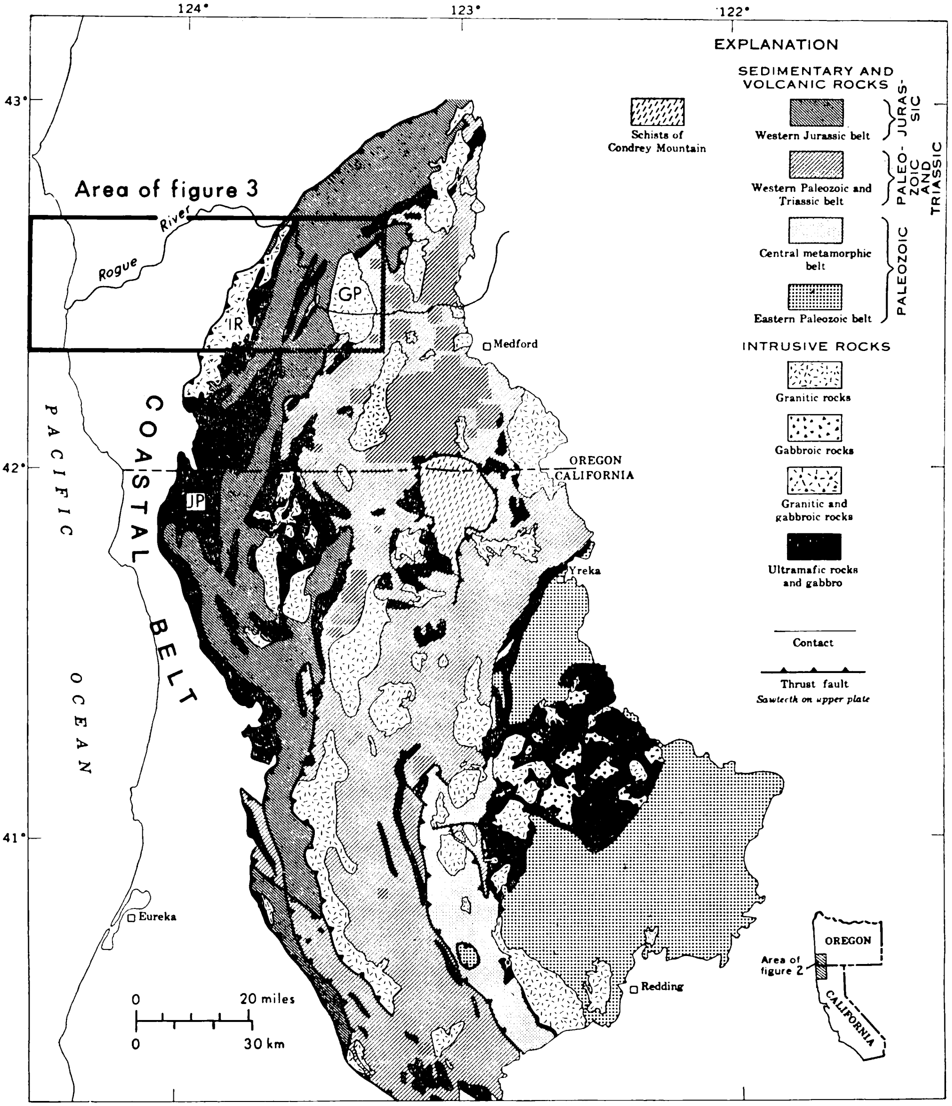


Fig. 2. Geologic map of the Klamath Mountains showing the four major lithologic belts (after Hotz, 1971). All contacts except thrust faults are shown as contacts. IR — Illinois River batholith. GP — Grants Pass pluton. JP — Josephine peridotite.

percent for major elements and 5 to 10 percent for minor elements, on the basis of replicate microprobe analyses compared with wet chemical analyses.

REGIONAL GEOLOGY

The western Jurassic belt (WJB) is the westernmost of the four lithologic belts comprising the Klamath Mountains Province (fig. 2). An east-dipping thrust fault separates the WJB on the east from the rocks of the western Triassic and Paleozoic belt (fig. 2). The western portion of this older belt consists of dismembered ophiolitic slabs (serpentinized peridotite, gabbro, basalt, chert, limestone, and argillite) metamorphosed to greenschist facies (Irwin, 1972; Snoke, 1977).

To the west of the WJB is the coastal belt (fig. 3), which is the northern extension of the Franciscan Complex but is referred to as the Dothan and Otter Point formations in Oregon. These upper Jurassic age formations have been overidden along a thrust fault by rocks of the WJB. The Otter Point Formation contains exotic blocks of ultramafic, blueschist, eclogite rocks, and mélange sequences (Dott, 1971; Coleman, 1972). The Dothan Formation consists of mudstones, graywackes, and minor fragmental, heterogeneous, basaltic to dacitic volcanic deposits of possible volcanic arc origin (Wiggins, 1979).

Three north-northeast trending, high-angle faults divide the western Jurassic belt along the Rogue River into four major subdivisions (fig. 4). They are, from west to east: the Illinois River batholith; an ultramafic-mafic sequence; the Briggs Creek amphibolite; and volcanic and sedimentary rocks of the Rogue and Galice formations and the granitic rocks that intrude them.

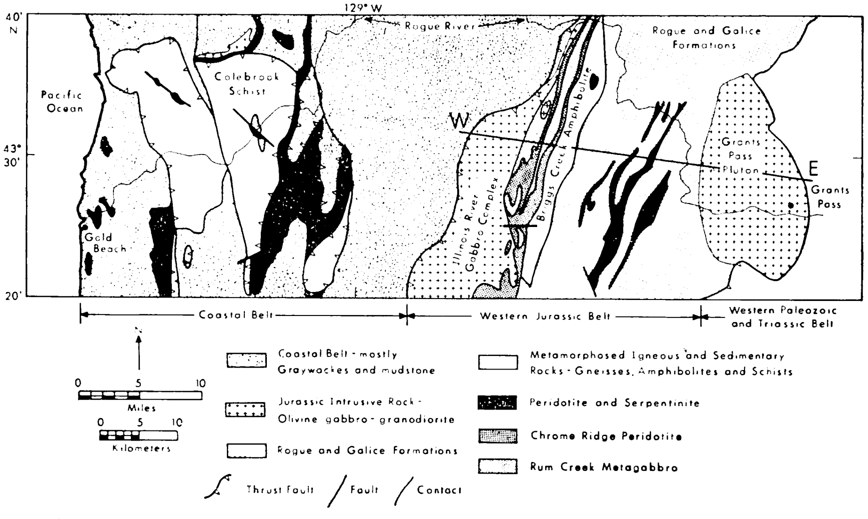


Fig. 3. Geologic map of the Rogue River area, southwestern Oregon (after Wells, 1955).

ROGUE AND GALICE FORMATIONS

The rocks from the Rogue and Galice formations have been described by Wells, Hotz, and Cater (1949) and Garcia (1979). This sequence includes a lower unit of predominantly fragmental, calc-alkaline, andesitic rocks and an upper unit of intercalated andesitic, fragmental volcanic rocks, mudstones, and graywackes. Fossils collected from the Galice Formation near the boundary between the lower and upper units have been identified as *Buchia concentrica,* thus indicating an age of late Oxfordian to early Kimmeridgan (D. Jones, 1975, personal commun.). The entire sequence has been metamorphosed under prehnite-pumpellyite to greenschist facies conditions.

Volcanogenic base metal sulfide deposits and gold-bearing quartz veins occur within this sequence (Kemp and Garcia, 1976). The sulfide ores occur as stratabound lenticular deposits of banded pyrite and sphalerite and as pyrite-chalcopyrite ± sphalerite bodies with varying amounts of gold, silver, galena, and barite. Metal zoning is characterized by Ag, Ba, and Zn enriched upper layers and Co, Cu, and Fe enriched lower layers. Cd and Ag are enriched in areas of sphalerite concentration. In some chloritized, sericitized, and silicified alteration pipes, low-grade Cu stockwork mineralization is present. These deposits are relatively small; lenses range in size up to 300 m long, 100 m wide, and 10 m thick, and with weights up to a few million tons. The gold-bearing quartz veins are most common in shear zones in the lower unit.

The sulfide deposits are similar to Kuroko-type volcanogenic sulfide deposits that form during the mature stage of island arc development (Mitchell and Bell, 1973). Gold-quartz veins are common in thick sequences of weakly metamorphosed andesitic lavas from island arcs and

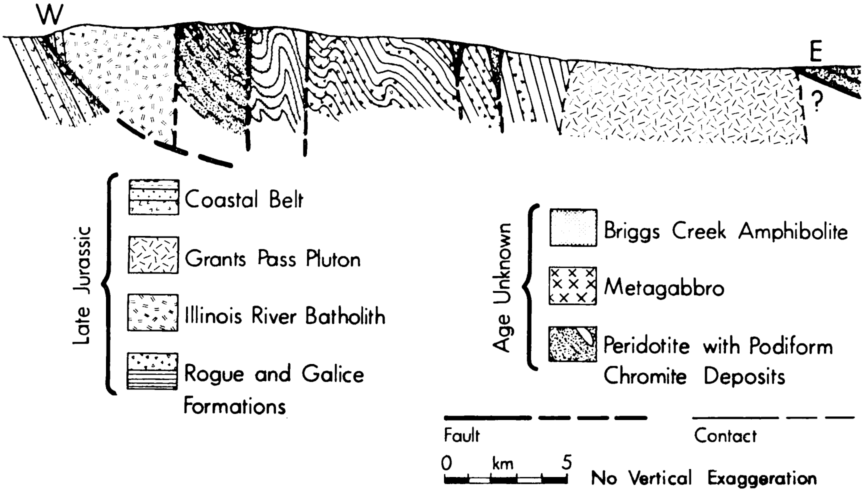


Fig. 4. East-west cross section across the western Jurassic belt near the Rogue River, southwestern Oregon.

may form during the mature to final stages of island arc formation (Mitchell and Bell, 1973).

Petrographic, field, and geochemical evidence from the Rogue and Galice formations indicate that these rocks were formed in a calc-alkaline volcanic arc (Garcia, 1979).

JURASSIC INTRUSIVES

The Rogue and Galice formations are intruded by two large, and numerous smaller, intrusive bodies. The largest is the Illinois River batholith, an elongate complex 60 km long and 1 to 9 km wide (fig. 3). The batholith has a wide range in rock types from olivine gabbro to granodiorite, but most are hornblende gabbro (Wells, Hotz, and Cater, 1949; Jorgenson, ms; Hotz, 1971). Eight samples from the batholith have been dated by K/Ar methods. Their calculated ages range from 140 to 157 m.y. (Hotz, 1971; Dick, ms).

The batholith has caused low-grade contact metamorphism of volcanic and sedimentary rocks of the Rogue and Galice formations along its western boundary. This contact has been modified by subsequent thrusting of the volcanic, sedimentary, and batholithic rocks westward over Dothan Formation mudstones, graywackes, and pillow basalts. The eastern boundary of the batholith is marked by a high-angle fault juxtaposing the batholithic and tectonitic ultramafic rocks. Internally, the batholith displays a crude chemical zonation. In two traverses across the batholith, Jorgenson (ms) found that the margins consist of quartz diorite or tonalite. Toward the core, the rock types generally grade into two-pyroxene gabbro and olivine gabbro, a trend that is also reflected in mineral compositions. The sequence of emplacement of the rock types in the batholith based on cross-cutting relationships is gabbro, quartz diorite, tonalite, and granodiorite.

Jorgenson (ms) proposed that the Illinois River batholith was part of a dismembered ophiolite sequence, but the field, whole-rock (table 1) and mineral compositional data are more consistent with a volcanic arc origin. The Illinois River batholith cuts and metamorphoses rocks of the Rogue and Galice formations and the ultramafic-mafic sequence. In addition, the batholith lacks a pseudostratiform sequence that is characteristic of ophiolites (Glennie and others, 1974). A tholeiitic, iron-enrichment trend is typical of most ophiolitic rocks (for example, Oman — Glennie and others, 1974; Papua — England and Davies, 1973). Analyses of the Illinois River batholithic rocks do not define such an iron-enrichment trend (fig. 5); rather, the trend displayed is similar to that of a typical suite of calc-alkaline volcanic rocks. In addition, the differences in phase compositions and assemblages between a typical ophiolite and the Illinois River batholith are striking (fig. 6). Olivine, calcium-rich pyroxene, and chromite are less abundant, and calcium-poor pyroxene, hornblende, quartz, and magnetite are more abundant in the Illinois River batholithic rocks. For rocks with a given plagioclase anorthite content, olivine and pyroxene grains from batholithic rocks are more iron-rich than in ophiolitic rocks. In contrast, the compositions and mineral assemblages of the batholithic rocks are similar to those of calc-alkaline plutonic rocks from the Peninsular Ranges of southern California (see fig. 6) and to cumulate gabbroic xenoliths in calc-alkaline lavas (Kuno, 1950; Nicholls, 1971; Lewis, 1973). These data suggest that the Illinois River batholith represents part of the intrusive core of a calc-alkaline island arc complex.

The other large intrusive body in the Rogue River area is the Grants Pass pluton, an elliptical body, 15 x 25 km, which intruded along the eastern margin of the WJB into the Galice Formation (fig. 3). Hotz (1971) reported a K/Ar age date of 136 m.y. on hornblende from the pluton. Rock types range from two-pyroxene, biotite, quartz diorite to quartz monzonite. The crystallization sequence of minerals (on the basis of textural evidence) is: plagioclase–pyroxene–amphibole–biotite–quartz–potassium feldspar. Two new whole-rock chemical analyses are reported in table 1. The FeO^t/MgO ratios for these two analyzed samples and a sample from the pluton analyzed by Hotz (1971) conform to a calc-alkaline trend (fig. 5).

Numerous mafic to silicic dikes and sills intrude the Rogue and Galice formations. These small intrusions, generally less than 5 m wide and 1 km long, are most common near the margins of the Illinois River batholith and the Grants Pass pluton. Therefore, they are probably apophyses of the two large intrusions.

ULTRAMAFIC AND MAFIC SEQUENCE

Chrome Ridge peridotite.—The ultramafic rocks within the Rogue River area are referred to here as the Chrome Ridge peridotite (from the

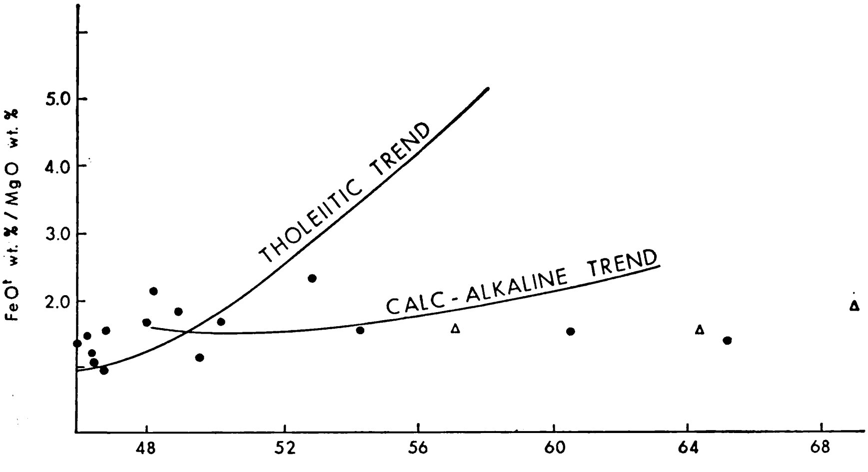


Fig. 5. Iron enrichment trend for Illinois River batholith (circles) and Grants Pass pluton (triangles) rocks. Data other than listed in table 1 are from Hotz (1971) and Jorgenson (ms). Tholeiitic trend is based on Oman ophiolitic rocks (Glennie and others, 1974). Calc-alkaline trend based on Quaternary volcanic rocks from Mt. Hood, Oregon (Wise, 1969).

principal location where these rocks crop out). The Chrome Ridge peridotite, 20 km north of the largest ultramafic body in North America, the Josephine peridotite (fig. 2), is the northernmost extension of a belt of discontinuous peridotite bodies that may represent a disrupted limb of the Josephine peridotite. The two peridotite bodies display many similar features. They are composed predominantly of harzburgite (Himmelberg and Loney, 1973; Dick, 1977), they both contain podiform chromite deposits (Ramp, 1961), and both display tectonite fabric (Loney and Himmelberg, 1976). Unlike the Josephine peridotite, the Chrome Ridge body contains a section of cumulus wehrlite and clinopyroxenite. Tremolite is a common metamorphic mineral in the Chrome Ridge peridotite but is absent within the main Josephine peridotite. Chrome spinel is opaque in the Chrome Ridge peridotite but predominantly translucent red-brown in the Josephine peridotite. Opaque spinels generally contain more ferric iron and chromium than do translucent spinels (Dickey, 1975) which can be caused by increased metamorphism (Evans and Frost, 1975). The differences between the two bodies do not negate the possibility that they were once linked. Rather, the apparent differences may result from local metamorphism, probably by the juxtaposed Illinois River batholith.

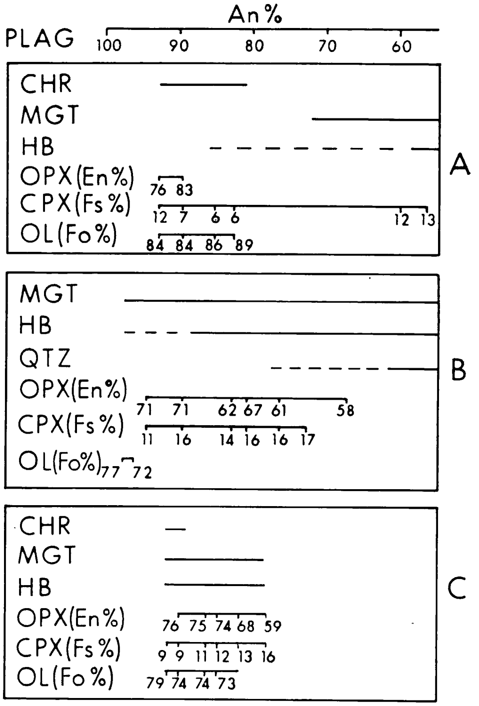


Fig. 6. Mineral compositions for specific plagioclase compositions for plutonic rocks from: (A) Oman ophiolite (Glennie and others, 1974); (B) Illinois River batholith (Jorgenson, ms); and (C) gabbros from the southern California batholith (Nishimori, ms).

The Chrome Ridge peridotite may be divided into two distinct units based on relict textures: a tectonite unit consisting predominantly of harzburgite, with lenses of dunite and chromitite; and a cumulus unit containing wehrlite with heteradcumulate texture, plagioclase wehrlite with mesocumulate texture, and clinopyroxenite with adcumulate texture.

Tectonitic ultramafic rocks.—The tectonitic harzburgites are 50 to 100 percent serpentinized with relict xenoblastic granular texture. Relict textures indicate that olivine was predominant (60-70 percent), 2 to 15 mm long, but that also present were grains of orthyopyroxene (25-35 percent), 2 to 5 mm in diameter; minor clinopyroxene (< 2 percent), 0.5 to 2.0 mm in diameter; and chromian spinel (1-4 percent), 0.5 to 2.5 mm in diameter. These minerals have been partially replaced by antigorite, tremolite and magnetite. Subsequent low grade (or retrograde) metamorphism has partially replaced this assemblage with chrysotile, chlorite, and brucite. Foliation within the harzburgite is defined by trains of chromian spinels and elongate orthopyroxene grains.

Dunite occurs as lenses within the harzburgite. It is easily distinguished from harzburgite in the field, because it lacks a knobby surface produced by resistant pyroxene grains and has a distinctive yellowish to

TABLE 2

Representative mineral compositions from a dunite and two chromitite bodies from the Chrome Ridge peridotite

	Dunite		Chromite Deposits	
	OL	OPX	CHR	CHR
SiO_2	41.50	56.97		
TiO_2			0.27	0.21
Al_2O_3		1.20	11.24	9.43
Cr_2O_3		0.43	56.25	59.58
FeO*	7.73	5.68	18.56	17.16
MnO			0.41	0.38
MgO	50.46	34.77	12.74	13.09
CaO		0.91		
Total	99.69	99.96	99.47	99.85
Si	1.01	1.96		
Al		0.04		
Al		0.01	3.43	2.88
Ti			0.05	0.04
Cr		0.01	11.50	12.21
Fe^{3+}			1.02	0.87
Fe^{2+}	0.16	0.16	3.00	2.85
Mn			0.09	0.09
Mg	1.83	1.79	4.91	5.06
Ca		0.03		
Total	3.00	4.00	24.00	24.00
Oxygens	4	6	32	32
Fo	92.1			
Ca		1.5		
Fe		8.1		
Mg		90.4		

rusty-brown weathering color. The mineralogy of the dunite generally is olivine (98 percent), orthopyroxene (1 percent), and chromian spinel (< 1 percent). Grains of olivine are 2 to 6 mm long, orthopyroxene grains are 0.5 to 2.0 mm across, and chromian spinels are 1.0 to 2.5 mm across. The dunites display xenoblastic granular texture. Kink banding of olivine is common. The compositions of the phases in the dunite (table 2) are similar to those of dunites from other alpine peridotites of the western U.S. (Loney, Himmelberg, and Coleman, 1971; Himmelberg and Loney, 1973; Dick, 1977).

Chromite deposits are common within the tectonitic peridotite and were mined during World War II. They occur as lenticular concentrations of massive or disseminated chromite in discrete horizons within dunite and harzburgite (Ramp, 1961) near a transition zone with cumulus wehrlite. In many of the deposits the chromite grains are concentrated in layers or in schlieren. The layers vary from several millimeters to a meter in thickness. Chromite layers at the Lower Violet mine are size-graded, with sharp basal contacts (Ramp, 1961). Ramp (1961), utilizing the foliation of the chromite layers, suggested that the peridotite is isoclinally folded about a north-south axis and overturned to the west, with both limbs dipping steeply to the east. Several hinges of small isoclinal folds (1-5 m wide) overturned to the west occur in the harzburgite unit supporting this structural interpretation. Chromite is also present locally as ellipsoidal nodules; most are less than 2 cm long, but a few are up to 4 cm long. These chromite deposits may be classified as podiform deposits (Dickey, 1975).

Cumulus ultramafic rocks.—The cumulus section of the Chrome Ridge peridotite consists of wehrlite, with minor plagioclase wehrlite and clinopyroxenite. All three units display cumulus texture somewhat modified by predominantly thermal metamorphism. The thickness of the section is difficult to estimate due to its poor exposures and the complex structure, but it is relatively thin (perhaps 50-100 m) compared to the tectonitic peridotite (> 1000 m). Unfortunately, the contact between the cumulus and tectonitic peridotites is not exposed, but within a zone of approx 10 m there is a change from tectonitic harzburgite to wehrlite with heteradcumulate texture.

Wehrlite is the predominant cumulus peridotite rock type. It consists of 35 to 55 percent olivine, 45 to 60 percent clinopyroxene, 2 to 5 percent orthopyroxene, and minor chromian spinel (< 1 percent). Olivine grains are 0.5 to 7.0 mm across, clinopyroxene grains are 2 to 10 mm across, and orthopyroxene grains are 2 to 5 mm across. Commonly, olivine forms rounded grains poikilitically enclosed by clinopyroxene. Chromian spinel occurs as interstitial, subhedral to anhedral grains, 0.2 to 0.5 mm across. Antigorite, tremolite, talc, and magnetite partially replace the primary minerals. Subsequent metamorphism produced rare grains of brucite, chrysotile, and chlorite.

Plagioclase wehrlite is rare in the cumulus sequence. The cumulus minerals are clinopyroxene and olivine in roughly equal proportions and orthopyroxene (3 to 5 percent), and the texture is mesocumulate. Plagioclase and chromian spinel occur as fine-grained (0.05-1.0 mm long) accessory phases (< 1 percent). Plagioclase is a post-cumulus phase. Tremolite, antigorite, chlorite, iddingsite, magnetite, and prehnite are present as alteration products of the primary phases.

Mineral compositions of a representative sample of wehrlite and plagioclase are presented in table 3. Relict orthopyroxene grains were too thoroughly serpentinized to yield reasonable analyses. Olivine compositions (Fo 80.4-85.0) are well below values for typical alpine peridotites (Fo 87-94; Jackson and Thayer, 1972).

Olivine clinopyroxenites and clinopyroxenites form a distinct horizon between cumulus peridotite and metagabbroic rocks. Clinopyroxene is the predominant phase (80-98 percent), forming euhedral to subhedral grains 3 to 12 mm long. Orthopyroxene (1-10 percent) and olivine (1-10 percent) are subordinate. Orthopyroxene grains are subhedral and 3 to 5 mm long. Olivine grains are interstitial and 1 to 3 mm long. Opaque

TABLE 3

Phase compositions from a wehrlite (W) and a plagioclase wehrlite (PW) from the Chrome Ridge peridotite

	PW			W	
	OL	CPX	Plag	OL	CPX
SiO_2	39.39	52.35	45.89	40.23	53.15
TiO_2		0.58			0.27
Al_2O_3		3.57	33.74		2.40
FeO*	16.46	5.16		14.41	3.29
MnO	0.27	0.25		0.10	0.11
MgO	44.19	16.50		45.71	17.46
CaO		21.61	18.24		23.22
Na_2O			1.50		
K_2O			0.03		
Total	100.31	100.02	99.40	100.45	99.90
Si	0.99	1.92	2.13	1.00	1.94
Al		0.08	1.88		0.06
Al		0.07			0.04
Ti		0.02			0.01
Fe	0.35	0.16		0.30	0.10
Mn		0.01		0.01	0.01
Mg	1.66	0.90		1.70	0.95
Ca		0.85	0.91		0.91
Na			0.14		
K			0.00		
Total	3.00	4.01	5.06	3.01	4.02
Oxygens	4	6	8	4	6
Fo	82.5			84.9	
Ca		44.5			46.4
Fe		8.3			5.1
Mg		47.3			48.5
An			86.9		

grains are rare (< 1 percent) occurring at fine-grained (0.05-0.15 mm) anhedral grains. The clinopyroxenites display orthocumulate and mesocumulate texture. Common secondary minerals are tremolite, antigorite, chrysotile, and chlorite.

Rum Creek metagabbro.—The metamorphosed intrusive rocks discussed here (including olivine gabbro, anorthosite, pyroxene, and hornblende gabbro) are referred to as the Rum Creek metagabbro. Rum Creek is one of the major streams draining the area underlain by the metagabbroic rocks.

Wells, Hotz, and Cater (1949) included the Rum Creek metagabbro with other metamorphosed rocks in the Kerby quadrangle and called them "amphibole gneisses of uncertain age." Wells and Walker (1953) subdivided the amphibole gneisses of Wells, Hotz, and Cater (1949) and named the Rum Creek metagabbro "amphibolite of gabbroic habit," recognizing its intrusive parentage. Hotz (1971) included the metagabbro with the Illinois River batholith, calling them the Chetco River Complex. The metagabbro is separated from the Illinois River batholith by a high-angle fault and bears little resemblance to it, except for its relict igneous texture. The metagabbro unit contains relict cumulus features and rare sulfide minerals and has been metamorhposed to lower amphibolite facies. All these features distinguish the Rum Creek metagabbro from the Illinois River batholith.

Two K/Ar dates are available for the metagabbro. Hotz (1971) reported a date of 150 m.y. from a metagabbro collected near a 140-m.y.-old pluton that intrudes the metagabbro. M. A. Kays (1976, written commun.) has an unpublished K/Ar date of 182 ± 12 m.y. (analysis by H. Dick) for amphibole from two samples of metagabbro collected along the Rogue River. The 150-m.y. date reported by Hotz (1971) probably reflects the heating effects of the younger plutonism, whereas the 182-m.y.-old sample was collected away from any later intrusive body and may record an earlier metamorphic event or represent a cooling age for the original gabbro intrusion.

Gabbro is the predominant rock type within the metagabbro sequence. It consists of plagioclase (40-60 percent), green hornblende (30-50 percent), relict clinopyroxene (0-10 percent), minor magnetite, and rare relict orthopyroxene. Grain size varies from 1 to 3 mm for most plagioclase and amphibole grains, but some amphibole oikocrysts reach 15 mm in length. Plagioclase is euhedral to subhedral. Relict pyroxene grains are ragged and enclosed by green hornblende, which occurs as coarse oikocrysts or as interlocking, anhedral, fine-grained aggregates. Cumulus textures are preserved locally in the pyroxene gabbros, including rhythmic layering, graded bedding, and mesocumulate and adcumulate textures.

Interbedded and gradational with pyroxene gabbro are anorthositic layers, 4 to 8 cm thick. Outcrops of anorthosite are rare, but float from several areas contains anorthosite. Plagioclase grains in the anorthosite are 1 to 5 mm long, subhedral to anhedral. The anorthosites have orthocumulate texture, and the long axes of plagioclase grains are aligned, possibly as a result of crystal settling.

Phase compositions from a representative two-pyroxene gabbro and an anorthosite are presented in table 4. Note the extremely high anorthite content of the plagioclase from the anorthosite.

Quartz diorite comprises 10 to 20 percent of the Rum Creek metagabbro. Plagioclase (45-60 percent) occurs as either euhedral or subhedral grains, 0.5 to 3.0 mm long, with albite, Carlsbad, and pericline twinning. Patchy oscillatory zoning is common. Green hornblende (35-40 percent) is present as either fine-grained, interlocking aggregates or as oikocrysts. Quartz (5-10 percent) and magnetite ($<$ 1 percent) occur as anhedral interstitial grains. The predominant texture displayed by the quartz diorite unit is hypidiomorphic granular. Locally, a weak foliation is defined by elongate plagioclase and amphibole grains.

Tonalite and trondhjemite dikes intrude the metagabbro. Tonalite dikes are dark gray, fine-grained, and weakly foliated. They consist of plagioclase (35-45 percent), green hornblende (30-35 percent), quartz (20-25 percent), and magnetite (2-3 percent). Plagioclase grains are anhedral, untwinned, and 0.1 to 0.3 mm long. Amphibole and quartz grains are anhedral and 0.1 to 0.3 mm long; magnetite grains are very fine grained,

TABLE 4

Phase compositions from a typical pyroxene gabbro and an anorthosite from the Rum Creek metagabbro

	Pyroxene gabbro			Anorthosite	
	CPX	OPX	Plag	Plag	
SiO_2	52.88	53.70	45.34	44.51	44.50
TiO_2	0.53				
Al_2O_3	1.64	1.15	34.45	35.09	35.56
FeO*	7.91	19.35			
MnO		0.39			
MgO	15.51	24.43			
CaO	21.85	0.46	19.31	19.74	19.91
Na_2O			0.94	0.51	0.33
K_2O			0.02	0.01	0.02
Total	100.32	99.48	100.06	99.86	100.32
Si	1.95	1.98	2.09	2.06	2.05
Al	0.05	0.02	1.88	1.92	1.93
Al	0.02	0.03			
Ti	0.01				
Fe	0.24	0.60			
Mn		0.01			
Mg	0.85	1.34			
Ca	0.86	0.02	0.96	0.98	0.98
Na			0.08	0.05	0.03
Total	4.00	4.00	5.01	5.01	4.99
Ca	44.5	0.9	An 91.9	95.5	97.1
Fe	11.6	30.5	Ab 8.1	4.5	2.9
Mg	43.9	68.6			
En		69.2			

commonly less than 0.1 mm across. Trondhjemite dikes are light in color and intrude both the cumulus peridotite and metagabbro sections. These dikes consist of 55 to 80 percent plagioclase, 20 to 45 percent quartz, < 1 percent magnetite, and 1 to 2 percent biotite and/or amphibole. Subhedral plagioclase grains vary in size from 0.3 to 2.0 mm and display albite, Carlsbad, and periclase twinning, with minor oscillatory zoning. Anhedral quartz grains are 0.5 to 2.0 mm across and consist of interlocking, fine-grained aggregates. Biotite, amphibole, and magnetite grains are anhedral and fine grained (0.2-0.6 mm across). Slabs of tonalite and trondhjemite were stained for potassium feldspar, but none was detected.

Mineral compositions.—Relict mineral compositions were determined further to characterize each lithology and to determine whether cryptic variation is present within the ultramafic-mafic sequence and, if so, to compare it to variations in typical ophiolites. Detailed investigation of cryptic variation of the Rogue River area rocks is nearly impossible because of the structural complexity of the region and the amphibolite facies metamorphism that has modified most of the primary minerals. Nevertheless, general trends can be determined utilizing the relict minerals.

In general, the ultramafic-mafic sequence does display cryptic variation which is similar to some ophiolites (fig. 7) despite the possible effects of metamorphism. Tectonitic peridotite, which forms the base of the ultramafic-mafic sequence, contains the most magnesium-rich minerals. The iron content of clinopyroxene (shown by the Fs percent endmember in fig. 6) illustrates the differentiation trend exhibited by the ultramafic-mafic sequence. Unfortunately, clinopyroxene, if originally present, has been replaced by green hornblende in the upper Rum Creek metagab-

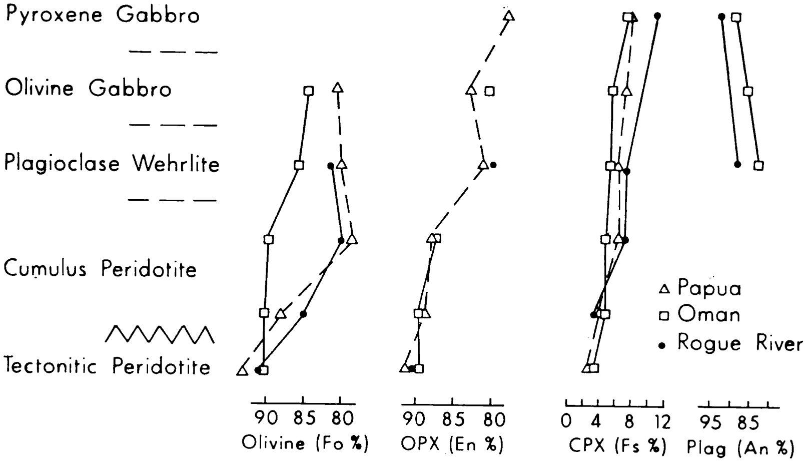


Fig. 7. Cryptic variations for ophiolitic rocks from Papua, New Guinea (England and Davies, 1973), Oman (Glennie and others, 1974), and the Rogue River area. Contact between the cumulus and tectonitic peridotites is a sharp structural break. Mineral compositions are shown as plagioclase (anorthite content percent), orthopyroxene (enstatite content percent), clinopyroxene (ferrosilite content percent), and olivine (forsterite content percent).

bros. Therefore, it is not possible to describe the differentiation trend of the entire suite.

The compositional trends of plagioclase presented in figure 7 show a trend opposite to normal plagioclase crystallization from a magma. This abnormal trend reflects the change in the position of plagioclase in the sequence of crystallization. In plagioclase wehrlite, plagioclase (An 87) was the last phase to crystallize from a melt depleted in calcium by crystallization of diopside. In pyroxene gabbros, plagioclase (An 92) crystallized simultaneously with clinopyroxene. In the anorthosite layer, where plagioclase was the only liquidus phase, the calcium content of plagioclase was greater (An 95). Similar trends are displayed by the Oman ophiolite suite (Glennie and others, 1974).

Origin of the ultramafic-mafic sequence.—The ultramafic-mafic sequence from the Rogue River area may represent a deformed and metamorphosed basal portion of an ophiolite suite. The variation in lithology within the complex is identical to that in other ophiolites (fig. 8). The lower part of the hypothetical Rogue River meta-ophiolite suite consists of tectonitic harzburgite and dunite, with podiform chromite deposits near an upper boundary with cumulus peridotite. The cumulus peridotite grades from wehrlite through plagioclase wehrlite and clinopyroxenite into pyroxene gabbro with relict cumulus textures. The upper part of the intrusive sequence consists of hornblende gabbro and quartz diorite. The intrusive sequence is intruded by tonalite and trondhjemite

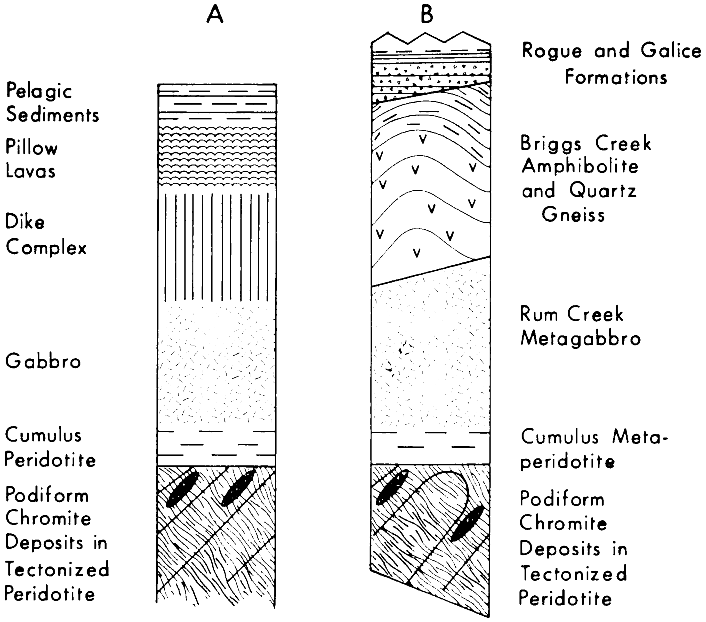


Fig. 8. Comparison of a typical ophiolite sequence (A) (Dickey, 1975) and the Rogue River metaophiolite (B).

dikes, which are similar to the leucocratic rocks in ophiolites (Coleman and Peterman, 1975).

The upper part of a typical ophiolite suite (that is, dike complex, pillow basalts, and pelagic sedimentary rocks) is missing from the ultramafic-mafic sequence of the Rogue River area. A suite of basic and sedimentary rocks metamorphosed to amphibolite facies conditions is separated from the ultramafic-mafic sequence by a high-angle fault. This sequence of rocks, the Briggs Creek amphibolite (Coleman, Garcia, and Anglin, 1976), may represent the upper portion layers of the Rogue River meta-ophiolite.

BRIGGS CREEK AMPHIBOLITE

This elongate belt (3.3 x 40 km) of amphibolite and quartz gneiss is separated by high-angle faults from peridotite and metagabbro on the west and the Rogue and Galice formations to the east (fig. 3). The type section for this formation is exposed along Briggs Creek (Coleman, Garcia, and Anglin, 1976). Hornblende from an amphibolite in the southern portion of the belt yielded a K/Ar age of 128 ± 4 m.y. (Coleman, 1976, personal commun.) which is probably a minimum age of metamorphism reflecting cooling during uplift since there is no evidence of any Cretaceous thermal event in this area (see Dick, ms). The unit consists of two dominant lithologies: gneissic amphibolite (80-90 percent) and quartz-rich gneiss (10-20 percent). The amphibolite contains pargasitic hornblende (45-65 percent), plagioclase (An 17-41 percent; 30-50 percent), magnetite (1-4 percent) ± quartz ± garnet ± sphene ± apatite, and lower grade alteration products (for example, chlorite, clinozoisite, and epidote). Representative mineral compositions for an amphibolite (#33) and a garnet amphibolite (#36) are presented in table 5, and major element analyses for these samples are given in table 6. Garnet amphibolites represent a minor portion of the total section of amphibolite. Garnet always occurs with quartz in the amphibolites, and the two minerals are restricted to rocks with more intermediate bulk compositions.

Quartz gneiss is most abundant in the western portion of the belt. It consists of 5 to 10-cm-thick bands of quartz separated by micaceous layers, 0.5 cm thick. Although strongly folded and recrystallized, the quartz gneiss displays a strong resemblance to rhythmically bedded cherts from the Franciscan Complex. The mineral assemblage in the quartz gneiss consists of quartz (80-90 percent), muscovite (1-12 percent), biotite (2-6 percent), garnet (1-3 percent), ilmenite (1 percent), and altered plagioclase (1-4 percent).

Two small and economically unimportant manganese deposits have been discovered in the quartz gneiss. One contains rhodonite and wad minerals; the other has manganese-rich garnet (12.3-18.5 wt percent MnO) and clinopyroxene (1.6-2.0 wt percent Mn) with quartz and magnetite. There are no Mn-deposits in any other rock unit in the area. The presence of the Mn deposits in the quartz gneisses and the strong resemblance of the gneisses to cherts from the Franciscan Complex suggest that Mn nodule-bearing cherts were the protoliths for the quartz gneisses.

The presence of almadine-rich garnet, hornblende, and plagioclase with An > 17 percent suggests a minimum temperature of metamorphism of 500°C for the amphibolites (Winkler, 1974). It is unlikely that temperatures were greater than 600°C because quartz and muscovite coexist in the quartz gneisses (Winkler, 1974). The mineral assemblages of the Briggs Creek amphibolite are representative of intermediate temperature and pressure conditions.

The tectonic setting where metamorphism of the Briggs Creek amphibolite occurred and the parentage of the amphibolite cannot be unambiguously determined; however, some plausible suggestions can be made. Most of the amphibolite is basaltic in composition. The association of quartz gneisses, which are probably metacherts, with the amphibolite strongly suggests an oceanic crust protolith for the amphibolite belt.

TABLE 5

Chemical analyses of minerals from two amphibolites (33, 36) and a quartz gneiss (110) from the Briggs Creek amphibolite

	36			33		110		
	Amphibolite	Plagioclase	Garnet	Amphibolite	Plagioclase	Garnet	Muscovite	Biotite
SiO_2	41.12	60.57	37.44	41.24	63.16	37.47	45.40	35.54
TiO_2	0.76			1.35			1.38	2.23
Al_2O_3	13.50	24.46	21.32	12.12	23.27	22.05	35.10	19.35
FeO^t	17.48	0.13	27.60	19.87	0.12	30.23	1.24	18.22
MnO	0.10		1.10	0.28		4.07	0.09	0.44
MgO	8.39		2.98	9.09		5.08	0.77	9.97
CaO	11.88	5.59	9.31	10.96	4.32	1.82		0.10
Na_2O	2.60	8.44		2.22	9.22		1.15	0.03
K_2O	1.01	0.30		1.05	0.50		8.99	9.68
Total	96.84	99.49	99.75	98.18	100.59	100.72	94.12	95.56
Si	6.36	2.71	2.98	6.28	2.78	2.96	6.09	5.38
Al	1.64	1.29	0.02	1.72	1.21	.04	1.91	2.62
Al	0.76		1.96	0.46		2.01	3.64	0.83
Ti	0.09			0.16			0.14	0.25
Fe	2.21	0.01	1.88	2.53	0.01	1.99	0.14	2.30
Mn	0.01		0.07	0.04		0.27	0.01	0.06
Mg	1.89		0.35	2.06		0.60	0.15	2.25
Ca	1.92	0.73	0.79	1.79	0.79	0.15		0.02
Na	0.76	0.27		0.66	0.20		0.30	0.01
K	0.20	0.02		0.20	0.03		1.54	1.87
Total	15.84	5.03	8.05	15.90	5.02	8.02	13.92	15.59
Norm % Ab		71.9			77.3			
An		26.4			20.0			
Or		1.7			2.7			
Almandine			58.9			66.1		
Andradite			1.0			0.0		
Grossular			26.1			5.1		
Pyrope			11.6			19.8		
Spessartine			2.4			9.0		

The Briggs Creek amphibolite may have been metamorphosed within the Rogue River island arc. In Ernst's (1974) model of metamorphic zonation in an island arc, the Briggs Creek amphibolite would correspond to a low-rank amphibolite (fig. 9). Similar amphibolite bodies have been reported in several island arcs, where they occur as the basement for the island arc (for example, Malaysia — Hutchinson and Dhonau, 1969; Puerto Rico — Tobisch, 1968; Solomon Islands — Coleman, 1970; Yap Island — Shiraki, 1971). Therefore, it seems likely that the Briggs Creek and other amphibolites associated with island arcs were metamorphosed near the core of the arc.

THE COASTAL BELT

The basement rocks of the coastal region of southern Oregon are composed of Upper Jurassic graywackes, mudstones, and volcanic rocks of the Dothan and Otter Point formations. These two units are structurally overlain by klippen of Colebrooke Schist, peridotite, and amphibole gneiss (Coleman, 1972). The Dothan and Otter Point formations are apparently Oregon subdivisions of the Franciscan Complex of California (Dott, 1971). They are chemically, mineralogically, and lithologically similar to the Franciscan Complex (Coleman, 1972).

TABLE 6

Chemical analyses and modes from a garnet amphibolite (36) and an amphibolite (33) from Briggs Creek amphibolite. Modes based on 500 counts

	36	33
SiO_2	55.70	48.25
TiO_2	0.68	3.40
Al_2O_3	14.86	15.99
Fe_2O_3	1.36	4.67
FeO	9.24	8.12
MnO	0.19	0.21
MgO	4.60	4.15
CaO	7.79	7.26
Na_2O	2.59	4.77
K_2O	1.04	0.78
H_2O^+	1.56	1.50
H_2O^-	0.15	0.16
CO_2	0.20	0.07
P_2O_5	0.10	0.57
Total	100.06	99.90
	Modes (volume %)	
Amphibole	47	46
Plagioclase	28	50
Quartz	12	—
Garnet	6	—
Opaques	< 1	3
Sphene	—	< 1
Apatite	< 1	< 1
Chlorite	6	

The thrust fault separating the WJB from the coastal belt is the northern extension of the Coast Range thrust fault. A well-defined zone of metamorphism including blueschists occurs along the northern California portion of this fault (Blake, Irwin, and Coleman, 1967; Suppe, 1979). In Oregon, metamorphism of the rocks underlying the thrust fault is of lower grade. Some segments of the fault have thin (150-330 m wide) zones of quartz-albite-white mica schist (textural zone 2 of Blake, Irwin, and Coleman, 1967) developed in the Dothan Formation (Hotz, 1969). Other segments of the fault are nearly devoid of any apparent metamorphism (textural zone 1 of Blake, Irwin, and Coleman, 1967) related to the fault. Wood (1971) suggested that the Oregon segment of the fault formed after the California segment, probably during Cenozoic time, and at a higher structural level.

Dothan Formation.—The Dothan Formation was named by Diller (1907) for a now-abandoned post office and railroad station along Cow Creek, north of the Rogue River. Graywacke is the predominant rock type; Wiggins (1979) interpreted some of the graywacke deposits as proximal submarine deposits. Dark gray to black mudstone is abundant, and varicolored, rhythmically bedded recrystallized chert is locally present. The Dothan Formation also includes minor pillow basalts; unpillowed, dacitic to basaltic volcanic rocks, and pebbly conglomerate (Dott, 1971; Wiggins, 1979). Pumpellyite is present in the matrix of the Dothan Formation graywackes, indicating incipient metamorphism (Coleman, 1972).

The Dothan and Galice formations are apparently coeval (Baldwin, 1969; Dott, 1971). A chert sample from a mélange zone in the Dothan Formation near the thrust contact separating the coastal belt from the Illinois River Batholith yielded abundant radiolaria including *Mirifusis baileyi,* which is of Tithonian age (Late Jurassic), the same age as most cherts from the Franciscan Complex (D. L. Jones, 1978, written commun). A K/Ar analysis of a Dothan Formation dacite yielded an age of 149 ± 4 m.y. (Dott, 1971).

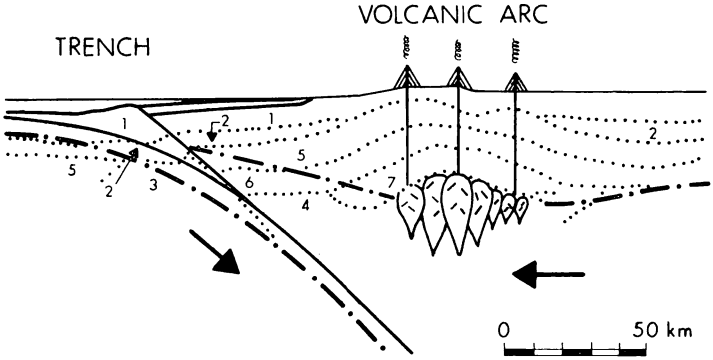


Fig. 9. Diagrammatic cross section through an island arc showing hypothetical zones of metamorphism by facies: 1. zeolite; 2. prehnite-pumpellyite; 3. blueschist; 4. eclogite; 5. greenschist; 6. low-rank amphibolite; 7. high-rank amphibolite (after Ernst, 1974).

Otter Point Formation.—Koch (1966) defined the Otter Point Formation as an Upper Jurassic flysch assemblage containing steeply dipping and locally sheared mudstones, graywackes, and minor conglomerates. Eclogite, high-grade blueschist, amphibolite, and tectonitic peridotite blocks occur within the formation (Ghent and Coleman, 1973). K/Ar analyses of micas and amphiboles from blueschist blocks gave ages of 132 to 151 m.y., which Coleman and Lanphere (1971) conclude represent a metamorphic episode that occurred approx 150 m.y. ago. The Otter Point Formation was probably deposited at or near an ancient convergent plate margin and was tectonically accreted to the leading edge of the nonsubducted plate (Dott, 1971).

Klippen of serpentinite and Colebrooke Schist structurally overlie the Otter Point Formation (Coleman, 1972). Mineral assemblages from the Colebrooke Schist reflect metamorphism intermediate between blueschist and greenschist facies (Coleman, 1972). K/Ar dating of the Colebrooke Schist yielded ages of 125 ± 6 m.y. and 138 ± 10 m.y. and a Rb-Sr isochron gave an age of 128 ± 18 m.y. (Coleman, 1972). Its age of metamorphism is virtually identical to that of the Briggs Creek amphibolite. Together, the two units form a paired metamorphic belt that is characteristic of convergent plate margins (Ernst, 1974).

STRUCTURE

The deformational styles of the two major rock units of the proposed island-arc complex are dissimilar. The coastal belt is characterized by thrust faults and mélange sequences (Dott, 1971; Coleman, 1972); the WJB is cut by high-angle faults and has been slightly to moderately deformed (Wells and Walker, 1953). These distinctive structures corroborate the petrologic interpretations. Thrust faults and mélanges are diagnostic features of the accretionary wedge in volcanic arc complexes with moderately fast subduction rates (Moore and Karig, 1980). These features form beneath the trench inner slope as a result of underthrusting of the volcanic arc by the oceanic plate (Seely, Vail, and Walton, 1974). This process leads to successive accretion of sediments and (rarely) slabs of oceanic crust to the nonsubducted plate.

High-angle faulting oriented parallel to the plate margin typifies volcanic arc terranes (fig. 10). The high-angle faults in the WJB are parallel to the structures in the coastal belt and the present plate margin. Although the age of the faulting in the Rogue River area cannot be determined absolutely, it may have occurred during the Late Jurassic period, when the island arc was active. Regardless of when the faulting transpired, it provides an opportunity to examine blocks from several different structural levels within the island arc. These include the volcanic carapace (Rogue and Galice formations), the intrusive core (Illinois River batholith and Grants Pass pluton), and the basement (Chrome Ridge peridotite, Rum Creek metagabbro, and Briggs Creek amphibolite) on which the volcanic arc probably was built.

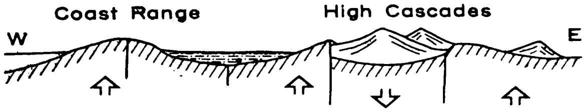
The time of the thrusting of the WJB over the coastal belt rocks is also uncertain. It is probably later than the volcanic arc (post-Jurassic) and may be as recent as Cenozoic (Wood, 1971). The westward thrusting telescoped the fore-arc basin, resulting in a separation of only 30 to 55 km between the volcanic arc deposits and the coastal belt mélanges. Nevertheless, all the major components of a subduction zone complex are present.

CONCLUSIONS

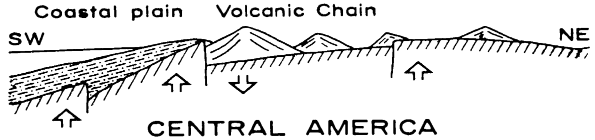
Petrographic, geochemical, and field evidence indicate that the western Jurassic belt is a disrupted and dissected island arc. The volcanic and sedimentary rocks of the Rogue and Galice formations and associated ore deposits are products of a calc-alkaline island arc. These deposits are intruded by nearly coeval calc-alkaline plutonic rocks (the Illinois River batholith, Grants Pass pluton, and related dikes and sills). This volcanic-plutonic complex was built on and intruded into ultramafic, mafic, and siliceous rocks that are interpreted here to be remnants of oceanic crust. To the west of this island arc during the Late Jurassic, the Dothan and Otter Point formations probably were formed as part of the accretionary wedge. Metamorphic rocks from the Coastal Belt and the western Jurassic belt are coeval and constitute a paired metamorphic belt, as is characteristic of convergent plate boundaries. Subsequent westward thrusting has reduced the arc-trench interval to 30 to 55 km.

ACKNOWLEDGMENTS

This work was part of Ph.D. dissertation at the University of California at Los Angeles. Comments on a preliminary version of this manuscript by W. G. Ernst, C. A. Nelson, L. G. Medaris, D. Christie, E. Moores, J. M. Sinton, and K. D. Watson are gratefully acknowledged. Discussions with R. G. Coleman, C. A. Hopson, W. G. Ernst, M. C. Blake,



OREGON CASCADES



CENTRAL AMERICA

Fig. 10. Diagrammatic cross section through two active volcanic arcs (from Fyfe and McBirney, 1975).

Jr., and Len Ramp improved the manuscript. Financial support for this research was provided by Penrose Fund of the Geological Society of America, American Association of Petroleum Geologists, Oregon Department of Geology and Mineral Industries, and Sigma Xi. Hawaii Institute of Geophysics contribution no. 1245.

REFERENCES

Albee, A. L., and Ray, L., 1970, Correction factors for electron probe microanalysis of silicates, carbonates, phosphates and sulfates: Analyt. Chem., v. 42, p. 1408-1414.

Baldwin, E. M., 1969, Thrust faulting along the lower Rogue River, Klamath Mountains, Oregon: Geol. Soc. America Bull., v. 80, p. 2047-2052.

Bence, A. E., and Albee, A. L., 1968, Empirical correction factors for the electron microprobe analysis of silicates and oxides: Jour. Geology, v. 76, p. 382-403.

Blake, M. C., Jr., Irwin, W. P., and Coleman, R. G., 1967, Upside-down-metamorphic zonation, blueschist facies, along a regional thrust in California and Oregon: U.S. Geol. Survey Prof. Paper 575-C, p. 1-9.

Christensen, N. I., and Salisbury, M. H., 1975, Structure and constitution of the lower oceanic crust: Rev. Geophysics Space Physics, v. 42, p. 71-85.

Coleman, P. J., 1970, Geology of the Solomon and New Hebrides Islands, as part of the Melanesian re-entrant, southwest Pacific: Pacific Sci., v. 34, p. 289-314.

Coleman, R. G., 1972, The Colebrook Schist of southwestern Oregon and its relation to the tectonic evolution of the region: U.S. Geol. Survey Bull., 1339, 61 p.

Coleman, R. G., Garcia, M. O., and Anglin, C., 1976, The amphibolite of Briggs Creek: a tectonic slice of metamorphosed oceanic crust in southwestern Oregon: Geol. Soc. America Abs., v. 8, p. 363.

Coleman, R. G., and Lanphere, M. A., 1971, Distribution and age of high-grade blueschists, associated eclogites and amphibolites from Oregon and California: Geol. Soc. America Bull., v. 82, p. 2397-2512.

Coleman, R. G., and Peterman, Z. E., 1975, Oceanic plagiogranite: Jour. Geophys. Research, v. 80, p. 1099-1108.

Dick, H. J. B., ms, 1976, The origin and emplacement of the Josephine Peridotite of southwestern Oregon: Ph.D. thesis, Yale University, 409 p.

——— 1977, Partial melting in the Josephine peridotite I, the effect on mineral composition and its consequence for geobarometry and geothermometry: Am. Jour. Sci., v. 277, p. 801-832.

Dickey, J. S., Jr., 1975, A hypothesis of origin for podiform chromite deposits: Geochim. et Cosmochim. Acta, v. 39, p. 1061-1074.

Dickinson, W. R., 1976, Sedimentary basins developed during evolution of Mesozoic-Cenozoic arc-trench system in western North America: Canadian Jour. Earth Sci., v. 13, 1268-1287.

Diller, J. S., 1907, The Mesozoic sediments of southwestern Oregon: Am. Jour. Sci., ser. 4, v. 22, p. 401-421.

Dott, R. H., Jr., 1971, Geology of southwestern Oregon coast west of the 124th meridian: Oregon Dept. Geol. Min. Industries Bull., 69, 63 p.

England, R. N., and Davies, H. L., 1973, Minerology of ultramafic cumulates and tectonites from eastern Papua: Earth Planetary Sci. Letters, v. 17, p. 416-425.

Ernst, W. G., 1974, Metamorphism and ancient continental margins, *in* Burke, C. A., and Drake, C. L., eds., The geology of continental margins: Springer-Verlag, New York, p. 907-918.

Evans, B. W., and Frost, B. R., 1975, Chrome-spinel in progressive metamorphism — a preliminary analysis: Geochim. et Cosmochim. Acta, v. 39, p. 959-972.

Fabbi, B. P., 1972, A refined fusion x-ray fluorescence technique, and determinate of major and minor elements in silicate standards: Am. Mineralogist, v. 57, p. 237-245.

Fabbi, B. P., and Volborth, A., 1970, Quantitative x-ray fluorescent trace analysis for 20 elements in igneous rocks: Nevada Bur. Mines Rept. 6, p. 31-47.

Fyfe, W. S., and McBirney, A. R., 1975, Subduction and the structure of andesitic volcanic belts: Am. Jour. Sci., v. 272-A, p. 285-297.

Garcia, M. O., 1978, Criteria for the identification of ancient volcanic arcs: Earth Sci. Reviews, v. 14, p. 147-165.

——— 1979, Petrology of the Rogue and Galice formations, Klamath Mountains, Oregon: identification of a Jurassic island arc sequence: Jour. Geology, v. 86, p. 29-41.

Ghent, E. D., and Coleman, R. G., 1973, Eclogites from southwestern Oregon: Geol. Soc. America Bull., v. 84, p. 2471-2488.

Glennie, K. W., Boeuf, M. G. A., Clarke, M. W. H., Moody-Stuart, M., Pilaar, W. F. H., and Reinhart, B. M., 1974, Geology of the Oman Mountains: Koninkl. Nederlandse Geol. Mijnb. Genoot. Verh., v. 30 and 31, 423 p.

Himmelberg, G. R., and Loney, R. A., 1973, Petrology of the Vulcan Peak alpine-type peridotite, southwestern Oregon: Geol. Soc. America Bull., v. 84, p. 1585-1600.

Hotz, P. E., 1969, Reationship between the Dothan and Rogue formations, southwestern Oregon: U.S. Geol. Survey Prof. Paper 650-D, p. 131-147.

——— 1971, Plutonic rocks of the Klamath Mountains, California and Oregon: U.S. Geol. Survey Prof. Paper 684-B, p. 1-20.

Hutchinson, C. S., and Dhonau, T. J., 1969, Deformation of an alpine ultramafic association in Darvel Bay, east Sabah, Malaysia: Geologie en Mijnb., v. 48, p. 481-494.

Irwin, W. P., 1972, Terranes of the western Paleozoic and Triassic belt in the southern Klamath Mountains, California: U.S. Geol. Survey Prof. Paper 800-C, p. 103-111.

Jackson, E. D., and Thayer, T. P., 1972, Some criteria for distinguishing between stratiform, concentric and alpine peridotite-gabbro complexes: Internat. Geol. Cong., 24th, Montreal 1972, p. 289-296.

Jorgensen, D. B., ms, 1970, Petrology and origin of the Illinois River gabbro, a part of the Josephine peridotite-gabbro complex, Klamath Mountains, southwestern Oregon: Ph.D. dissertation, Univ. California at Santa Barbara, 195 p.

Kemp, W. R., and Garcia, M. O., 1976, The Klamath Mountains and Sierra Nevada volcanic arc sequences, western USA — volcanogenic sulfide provinces: Internat. Geol. Cong., 25th, Paris 1976, v. 1, p. 168-169.

Koch, J. G., 1966, Late Mesozoic stratigraphy and tectonic history, Port Oxford-Gold Beach area, southwestern Oregon coast: Am. Assoc. Petroleum Geologists Bull., v. 50, p. 25-71.

Kuno, H., 1950, Petrology of Hakano Volcano and the adjacent areas: Geol. Soc. America Bull., v. 61, p. 957-1020.

Lewis, J. F., 1973. Mineralogy of the ejected plutonic blocks of the Soufriere Volcano, St. Vincent: Contr. Minerology Petrology, v. 38, p. 197-220.

Loney, R. A., and Himmelberg, G. R., 1976, Structure of the Vulcan Peak alpine-type peridotite, southwestern Oregon: Geol. Soc. America Bull., v. 87, p. 259-274.

Loney, R. A., Himmelberg, G. R., and Coleman, R. G., 1971, Structure and petrology of the alpine-type peridotite at Burro Mountain, California, U.S.A.: Jour. Petrology, v. 12, p. 245-309.

Mitchell, A. H., and Bell, J. D., 1973, Island-arc evolution and related mineral deposits: Jour. Geology, v. 81, p. 381-405.

Mitchell, A. H., and Reading, H. G., 1971, Evolution of island arcs: Jour. Geology, v. 79, p. 253-284.

Moore, G. F., and Karig, D. E., 1980, Structural geology of Nias Island, Indonesia: Implications for subduction zone tectonics: Am. Jour. Sci., v. 280, p. 193-223.

Nicholls, I. A., 1971, Petrology of Santorini Volcano, Cyclades, Greece: Jour. Petrology, v. 12, p. 373-388.

Nishimori, R. K., ms, 1976, Petrology and geochemistry of gabbros from the Peninsular Ranges batholith, So. California, and a model for their origin: Ph.D. dissert., Univ. California at San Diego, 234 p.

Ramp, Len, 1961, Chromite in southwestern Oregon: Oregon Dept. Geology Mineral Indust. Bull., 52, 169 p.

Ringwood, A. E., 1977, Petrogenesis in island arc systems, *in* Talwani, M., and Pitman, W. C., III, eds., Island arcs, deep sea trenches and back-arc basins: Am. Geophys. Union, Maurice Ewing Ser., v. 1, p. 311-324.

Seely, D. R., Vail, P. R., and Walton, G. G., 1974, Trench slope model, *in* Burke, C. A., and Drake, C. L., eds., The geology of continental margins: New York, Springer-Verlag, p. 249-260.

Shiraki, K., 1971, Metamorphic basement rocks of Yap Islands, western Pacific· possible oceanic crust beneath an island arc: Earth Planetary Sci. Letters, v. 13, p. 167-174.

Snoke, A. W., 1977, A thrust plate of ophiolitic rocks in the Preston Peak area, Klamath Mountains, California: Geol. Soc. America Bull., v. 88, p. 1641-1659.

Suppe, John, 1979, Structural interpretation of the southern part of the northern Coast Ranges and Sacramento Valley, California: Summary: Geol. Soc. America Bull., Pt. I, p. 327-330.

Tobisch, O. T., 1968, Gneissic amphibolite at Las Palmas, Puerto Rico, and its significance in the early history of the Greater Antilles island arc: Geol. Soc. America Bull., v. 79, p. 557-574.

Wells, F. G., 1955, Preliminary geologic map of southwestern Oregon: U.S. Geol. Survey Min. Invest. Map, MF38.

Wells, F. G., Hotz, P. E., and Cater, F. W., 1949, Preliminary description of the geology of the Kerby quadrangle, Oregon: Oregon Dept. Geol. Min. Indust. Bull., v. 40, 23 p.

Wells, F. G., and Walker, G. W., 1953, Geology of the Galice quadrangle, Oregon: U.S. Geol. Survey Quad. Map GQ25.

Wiggins, B. D., 1979, Evidence for a Late Jurassic island arc of the Franciscan Complex, southwestern Oregon: Geol. Soc. America Abs. with Programs, v. 11, p. 135.

Winkler, H. G. F., 1974, Petrogenesis of Metamorphic Rocks: New York, Springer-Verlag, 320 p.

Wise, W. S., 1969, Geology and petrology of the Mt. Hood area: a study of high Cascade volcanism: Geol. Soc. America Bull., v. 80, p. 969-1006.

Wood, B. L., 1971, Structure and reationships of late Mesozoic schists of nw California and sw Oregon: New Zealand Jour. Geology Geophysics, v. 14, p. 219-239.