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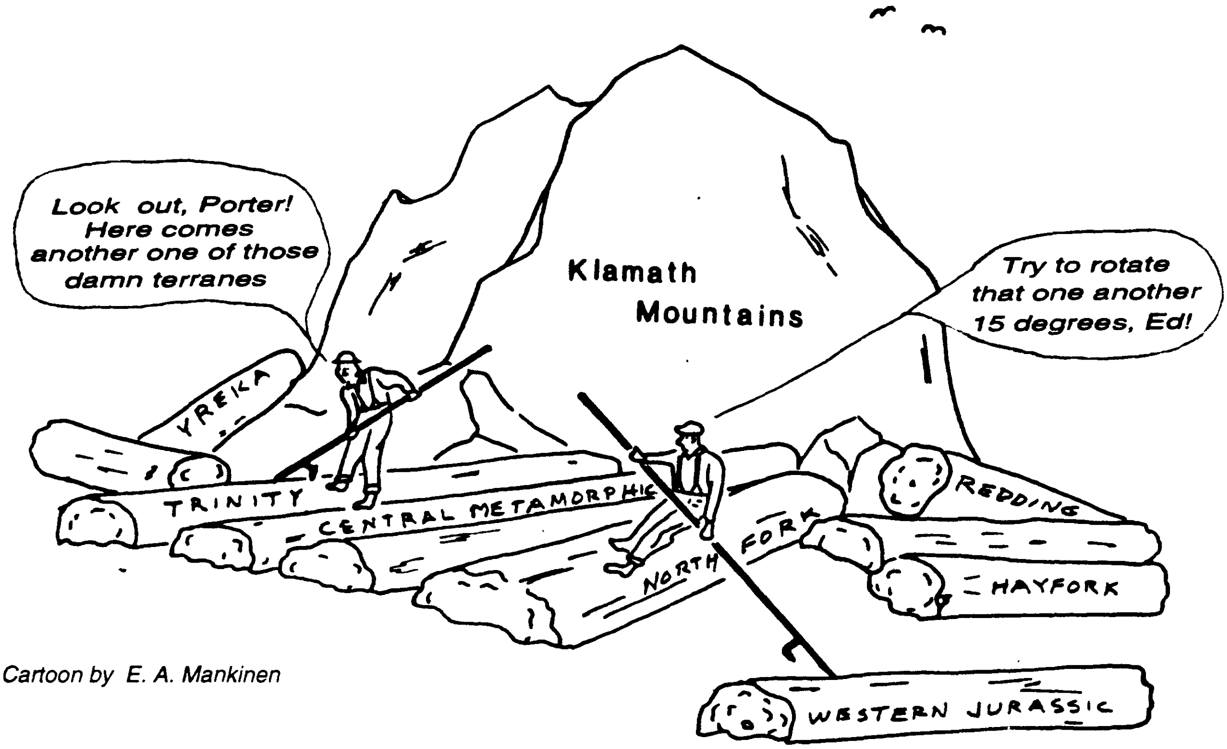

Cartoon by E. A. Mankinen

Field Guide for a GEOMAR & UNIVERSITY OF KIEL trip across the accreted terranes of the southern Klamath Mountains, California

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TERRANES OF THE KLAMATH MOUNTAINS, CALIFORNIA AND OREGON

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Abstract. The Klamath Mountains province is an accumulation of tectonic fragments (terranes) of oceanic crust, volcanic arcs, and melange that amalgamated during Jurassic time prior to accretion to North America. The nucleus of the province is the Eastern Klamath terrane, which consists of oceanic volcanic and sedimentary rocks ranging from early Paleozoic to Middle Jurassic in age and includes the Trinity ophiolite of Ordovician age. The volcanic arc and melange terranes lying west of the nucleus contain three additional dismembered ophiolites that range in age from late Paleozoic to Late Jurassic and that are sequentially younger oceanward (westward). The volcanic arc terranes also contain preamalgamation plutons that are of Devonian, Permian, and Jurassic age and that are cogenetic with the volcanic rocks they intrude. Following amalgamation, the terranes were stitched together by postamalgamation plutons during Middle Jurassic to earliest Cretaceous time. Accretion of the amalgamated Klamath terranes to North America seems to have occurred during intrusion by plutons of the Shasta Bally belt in earliest Cretaceous time, following large-angle clockwise rotation of the terranes during Triassic and Jurassic time. The accreted terranes are unconformably overlapped along much of the southeastern and eastern perimeter of the province by relatively weakly deformed Cretaceous and Tertiary strata. Along the arcuate western boundary, the rocks of the province are in fault contact with accreted Jurassic and Cretaceous rocks of the Franciscan Complex and related formations of the Coast Ranges province.

INTRODUCTION

The Klamath Mountains province is a small part of the vast collage of suspect terranes that make up the western margin of North America from Mexico to Alaska (Coney et al, 1980). The province is a west-facing arcuate region of approximately 30,645 km sq and is a composite of a number of individual terranes, each of which is an allochthonous tectonic fragment of oceanic crust, volcanic island arc, or melange. None of the terranes appears to be a fragment of a former continent, and there is no evidence that any were ever underlain by continental rocks. An uncommon aspect of the Klamath Mountains is the number of ophiolites of widely differing ages that constitute parts of some of the terranes of the province. The ophiolites, which consist partly of upper mantle and oceanic crust, represent oceanic spreading centers that existed during early Paleozoic, late Paleozoic, Triassic, and Jurassic time, and are now distributed in a sequence that is successively younger from east to west (oceanward). Some of the ultramafic rocks of the ophiolites have been mined for their chromite content during times of national emergency since the 1800's. One locality, where lateritic soil formed on the ultramafic rock, is the site of the only significant production of nickel in the United States.

The volcanic arc terranes are dominantly andesitic in composition, but range from basalt to rhyolite, and are the hosts for several economically important massive-sulfide deposits. Similar to the ophiolites, the various volcanic-arc terranes tend to be successively younger westward from the Eastern Klamath terrane. This common pattern of westward younging suggests that the joining together (amalgamation) of the terranes also was an east to west sequence of events. Important limestone formations are present at several stratigraphic horizons in the long-standing arc represented by the volcanic rocks of the Eastern Klamath terrane, and are valuable, particularly the Permian limestones, for the manufacture of cement. The fossil faunas contained in the limestones greatly facilitate determination of the age and stratigraphic succession of the numerous formations that constitute the Eastern Klamath terrane. However, determination of the precise age of the strata in the volcanic-arc and melange terranes that lie to the west is difficult, as limestone bodies are relatively scarce, small, and discontinuous, and their enclosed fossils commonly are destroyed by metamorphism. The faunas of a few limestone bodies are thought to indicate a site of deposition that was far distant from the present locality. Much of the dating of the western terranes is based on fossil radiolarians in thin-bedded chert that is locally interlayered with the volcanic rocks.

The amount of deformation of the terranes varies widely. In the Eastern Klamath terrane the stratigraphy and structure are fairly coherent, but the western terranes are more tectonically deformed and commonly consist of broken formation and melange. The mapping of many parts of this geologically complex province has been only in reconnaissance, particularly in the region beyond the Eastern Klamath terrane, and this has resulted in many imprecise and uncertain correlations. Much additional study is needed before the geology of the Klamath Mountains can be accurately told.

EASTERN KLAMATH TERRANE

The Eastern Klamath terrane is the oldest terrane of the province and also contains the oldest rocks. It consists of three subdivisions---the Trinity, Yreka, and Redding subterranes (Figure 1). The Trinity subterrane is a large broadly-arched sheet of ultramafic and gabbroic rocks thought to be at least in part a dismembered ophiolite. The ultramafic sheet crops out over a broad area in the central part of the Eastern Klamath terrane and extends northwest under the Yreka subterrane and southeast under the Redding subterrane. Evidence from magnetic, gravity, and seismic refraction studies indicate that the ultramafic sheet extensively underlies the Yreka and Redding subterranes (LaFehr, 1966; Griscom, 1973; Fuis and Zucca, 1984; Blakely et al., 1985). The western edge of the ultramafic sheet is upturned and is exposed for a length of 160 km where it forms the western boundary of the Eastern Klamath terrane. The

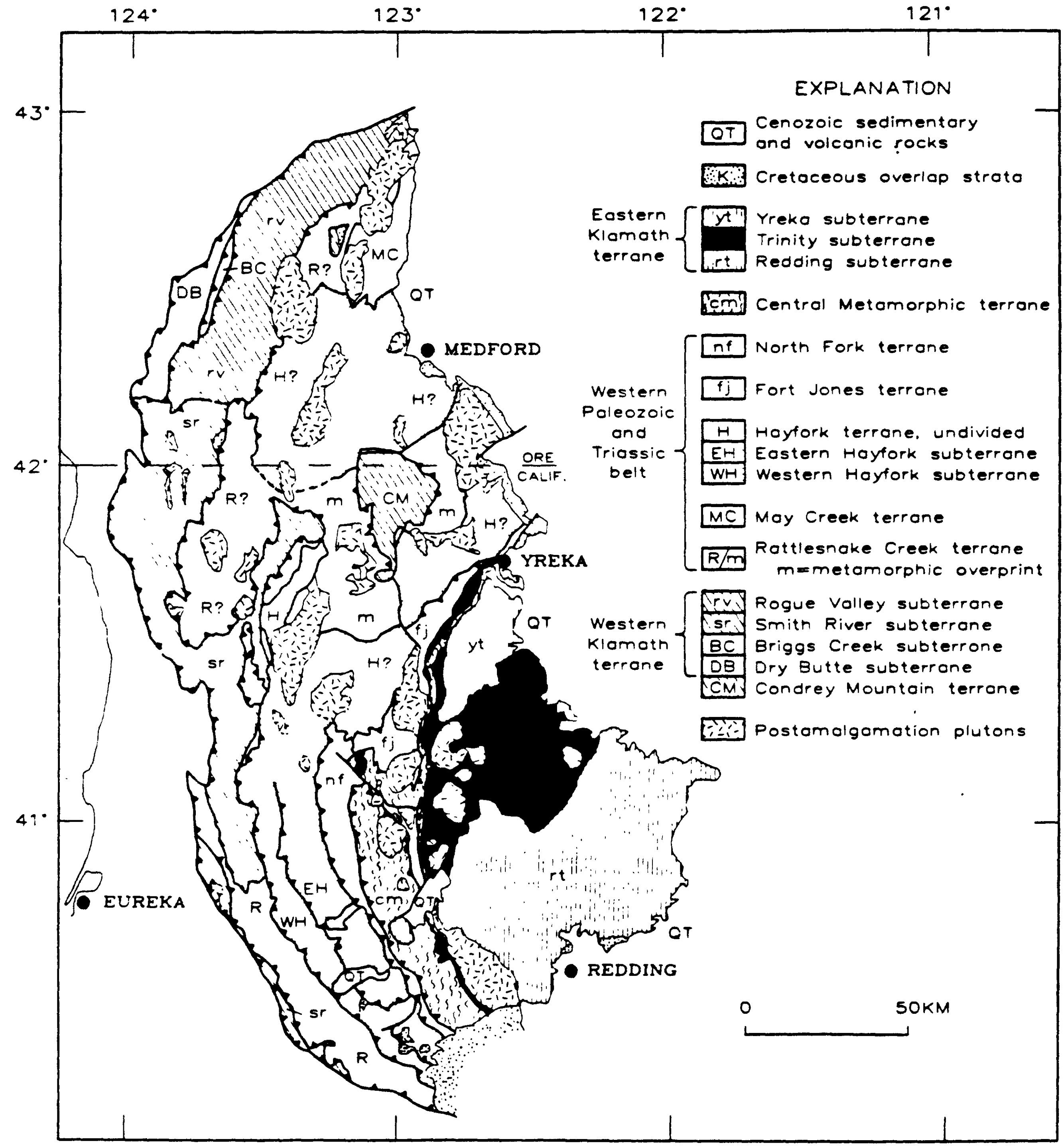

FIGURE 1 Map showing terranes, postamalgamation plutons, and overlap assemblages of the Klamath Mountains. Geology compiled mainly from Smith et al (1982), Wagner and Saucedo (1988), and Fraticelli et al (1987).

ultramafic rocks of the sheet are dominantly serpentinized tectonitic harzburgite, lherzolite, and minor dunite (Lindsley-Griffin, 1982). The gabbroic rocks include cumulate and layered hornblende gabbro grading into hornblende diorite and quartz diorite, and pegmatitic gabbro that may be younger. Locally the gabbro and diorite appear to grade upward into a complex of mafic dikes and sills and finally into mafic volcanic rocks (Lindsley-Griffin, 1977). U-Pb isotopic ages of 455-480 Ma measured on the layered gabbro and diorite, and 430 Ma on the pegmatitic gabbro (Lindsley-Griffin, 1977; Mattinson and Hopson, 1972), indicate an Ordovician age for the Trinity ophiolite. A more recent study reports the presence of tonalitic rocks that crystallized about 565-570 Ma (earliest Cambrian) and suggests that the Trinity ultramafic sheet is polygenetic (Wallin et al., 1988).

The Yreka subterrane is a structurally complex stack of several thrust(?) slices of Ordovician to Devonian strata that rest on the Trinity ultramafic sheet (Potter et al., 1977). The thrust(?) slices variously consist of volcanic and clastic sedimentary strata, locally abundant bedded chert and limestone, quartzite, phyllite, and melange. One melange (schist of Skookum Gulch) contains blueschist blocks, and also contains tectonic(?) blocks of Early Cambrian tonalite similar to that in the Trinity ultramafic sheet (Wallin et al., 1988).

The Redding subterrane consists of sixteen formations of volcanic and sedimentary strata that include representatives of all the Paleozoic and Mesozoic systems from the Devonian to the Middle Jurassic. It also includes preamalgamation plutons of Devonian and late Paleozoic age, which will be discussed on later pages. The volcanic and sedimentary strata are deformed, but they constitute a structurally coherent sequence that generally dips southeastward away from the Trinity ultramafic sheet and has an exposed thickness of more than 10 km (Kinkel et al., 1956; Albers and Robertson, 1961; Miller, 1986; and Sanborn, 1953). The presence of andesitic volcanic rocks and reefal limestones at many places throughout suggests that the sequence represents a long-standing volcanic arc that perhaps was built on Ordovician and older oceanic crust represented by the Trinity ultramafic sheet. However, the present northeast-trending contact between the Redding subterrane and the main area of exposure of the Trinity ultramafic sheet is thought to be a southeast-dipping extensional detachment fault along which some of the stratigraphically lower parts of the Redding subterrane locally have been cut out (Schweickert and Irwin, 1986). Part of the Redding subterrane is described in greater detail by M.M. Miller (this volume).

CENTRAL METAMORPHIC TERRANE

Exposed along the western boundary of the Eastern Klamath terrane, the Central Metamorphic terrane lies generally west of and structurally below the Trinity ultramafic sheet. It consists of mafic volcanic and sedimentary rocks that were metamorphosed during eastward subduction beneath the Trinity ultramafic sheet in Devonian time. The metamorphosed volcanic rocks (Salmon Schist) are the structurally lowest unit of the terrane and consist mostly of fine- to medium-grained hornblende-epidote-albite schist that is locally phyllonitic and retrograde (Davis et al., 1965). The metamorphosed sedimentary rocks (Abrams Schist) overlie the metavolcanic rocks, probably depositionally, and consist of quartz-mica schist, calc schist, and micaceous marble. The widest exposure of the Central Metamorphic terrane is in the southern part of the province. There the terrane forms a nearly detached synformal thrust plate that probably is 3-5 km thick at the axis. The eastern limit of the synform is sharply folded and thinned where it dips eastward beneath the Trinity ultramafic sheet. Klippen of the Eastern Klamath terrane rest on the Central Metamorphic terrane at three widely-spaced localities. The normal outcrop relation between the Central Metamorphic terrane and the Trinity ultramafic sheet is structurally reversed for 35 km along the western boundary of the Yreka terrane, where the Central Metamorphic terrane is represented by a relatively narrow sliver that crops out mostly along the east side rather than west of the northern extension of the Trinity ultramafic sheet. Assignment of a Devonian age of metamorphism is based on K-Ar ages of 390-399 Ma measured on amphibolite correlative with the Salmon Schist in the Yreka area (Hotz, 1977) and on Rb-Sr ages of approximately 380 Ma measured on the Abrams Schist (Lanphere et al., 1968). The Devonian age of metamorphism during subduction beneath the Trinity ultramafic sheet suggests that the Devonian volcanic and plutonic rocks (Copley Greenstone, Balaklala Rhyolite, and Mule Mountain stock) of the Redding subterrane are genetically related to that event.

TERRANES OF THE WESTERN PALEOZOIC AND TRIASSIC BELT

Lying west of the Central Metamorphic terrane is an extensive complex area that was called the Western Paleozoic and Triassic belt during early studies of the region (Irwin, 1960) and which includes the Applegate Group in the Klamath Mountains of Oregon. In the southern part of the province, the belt has been subdivided from east to west into the North Fork, Hayfork, and Rattlesnake Creek terranes (Irwin, 1972), and the Hayfork terrane into the Eastern Hayfork and Western Hayfork subterranes (Wright, 1982). Equivalents of some and perhaps all of these terranes may be present in the central and northern parts of the province (see Wagner and Saucedo, 1987; and Smith et al., 1982), but the correlations are not clearly known and the generalizations shown in figure 1 are speculative. The northern part of the Western Paleozoic and Triassic belt also includes the May Creek Schist which is now considered to be a separate terrane, and, at the California-Oregon border, a window of metamorphic rocks is called the Condrey Mountain terrane.

The North Fork terrane is exposed in the southern part of the province where it occupies a zone 2-10 km wide for a distance of 100 km along the western edge of the Central Metamorphic terrane. The structurally lowest part consists of dismembered ophiolite which is succeeded upward by generally eastward-dipping mafic volcanic rocks that are interlayered with argillite, thin-bedded chert, and discontinuous limestone lenses. Blocks of blueschist occur in a horizon of disrupted argillite (Ando et al., 1983). The age of the ophiolite is late Paleozoic based on the U-Pb isotopic age of a small plagiogranite body (265-310 Ma)(Ando et al., 1983) and on an uncertain relationship with nearby red radiolarian chert of Permian age (Blome and Irwin, 1983). The chert and tuff interlayered with the mafic volcanic rocks contains Permian, Triassic , and Early Jurassic radiolarians. The few limestone bodies that have yielded useful fossils are late Paleozoic in age.

A short distance north of the Salmon River the North fork terrane appears to end, and its position west of the Central Metamorphic terrane is occupied by the Fort Jones terrane of Blake et al. (1982). The rocks of the Fort Jones terrane, called the Stuart Fork Formation by Davis et al. (1965), are similar to those of the North Fork terrane except for a strong metamorphic overprint and the absence of ophiolitic rocks and may well be correlative. The rocks were metamorphosed to blueschist facies (Borns, 1980) and later overprinted to greenschist facies during the emplacement of nearby plutons (Jayko and Blake, 1984) in Jurassic and earliest Cretaceous time. K-Ar isotopic ages measured on blueschist blocks near Fort Jones are ~220 Ma (Triassic)(Hotz et al., 1977), which may indicate that the depositional ages of the volcanic and sedimentary protoliths are not younger than Triassic.

The Hayfork terrane, as exposed in the southern part of the province, consists of the Western and Eastern Hayfork subterranes. The Western Hayfork subterrane is the structurally lower of the two units and is interpreted to represent a Middle Jurassic volcanic arc. It consists mainly of the Hayfork Bally Meta-andesite and the preamalgamation Ironside Mountain batholith and related plutons. The meta-andesite is mainly augite-bearing crystal-lithic tuff and tuff breccia of andesitic to basaltic composition and is interbedded locally with thin-bedded chert and argillite. The meta-andesite has yielded isotopic ages of 156 Ma (M.A. Lanphere, oral commun., 1977) and 168-177 Ma (Fahan, 1982). The Ironside Mountain batholith is largely pyroxene diorite that yields isotopic ages of approximately ~170 Ma (revised constant, Lanphere et al., 1968; Wright, 1982) and is thought to be cogenetic with the meta-andesite.

The Eastern Hayfork subterrane is a melange that is separated from the structurally underlying Western Hayfork subterrane by the Wilson Point thrust fault (Wright, 1982). The melange includes serpentinite, argillite, chert, quartzose sandstone, mafic and locally silicic volcanic rocks, limestone pods, and a few amphibolite blocks. The serpentinite commonly occurs as slivers along the Wilson Point thrust. The chert bodies variously contain Triassic and Jurassic radiolarians. Some of the limestone contains Permian fossils of Tethyan faunal affinity (Irwin and Galanis, 1976; Nestell et al., 1981).

The Rattlesnake Creek terrane is west of the Western Hayfork subterrane, from which it is separated by an east-dipping fault (Salt Creek thrust). It is a melange that consists of dismembered ophiolitic rocks, mafic to silicic volcanic and subvolcanic rocks, plagiogranite, thin-bedded chert, argillite, sandstone and conglomerate, and minor limestone. Bedrock relations are obscured over much of the terrane by widespread landslides and earthflows. The chert contains Triassic and Jurassic radiolarians, and the limestone bodies contain sparsely distributed fossils of Devonian(?), late Paleozoic, and Late Triassic age. U-Pb isotopic ages ranging from 193 to 207 Ma have been measured on the plagiogranitic rocks (Wright, 1982). In the central and northern parts of the province, the Rattlesnake Creek terrane may be represented by rocks of the Preston Peak area (Snoke, 1977), the Takilma melange and Sexton Mountain ophiolite (Smith et al., 1982), and by metamorphosed melange of the Marble Mountain area (Donato et al., 1982), the Condrey Mountain quadrangle (Hotz, 1967), and the Dutchmans Peak area (Smith et al., 1982).

The May Creek terrane consists of the May Creek Schist. The schist is divided into two units (Donato, 1987)---a lower unit of hornblende-plagioclase schist that may represent metamorphosed dikes, sills, and tholeiitic basalt, and an upper unit of metamorphosed quartzose sandstone, tuffaceous sandstone, calcareous metasedimentary rocks, and rare lenses of marble. The age of the schist is unknown. The schist was earlier considered gradational with the volcanic and sedimentary rocks of the Applegate Group (Wells and Peck, 1961), but now is thought to be separated from the Applegate rocks by faults (Smith et al., 1982). The May Creek Schist is herein considered a separate terrane because of its anomalous lithology and amphibolite grade of metamorphism and its fault contacts with the Applegate rocks.

The Condrey Mountain terrane consists of the Condrey Mountain Schist which is mostly metasedimentary rocks, consisting of generally well foliated quartz-albite-muscovite schist, and greenschist-facies metavolcanic rock (Coleman et al., 1983). Several large lenses of flaggy blueschist, consisting of alternating crossite-rich and chlorite-epidote-rich layers, are present in the dominantly metasedimentary unit. Isotopic ages ranging from Middle Jurassic to Early Cretaceous have been measured on various components of the terrane (see Helper, 1986a). The Condrey Mountain Schist is correlated with the Galice Formation of the Western Klamath terrane by some geologists (e.g. Klein, 1977) and with the South Fork Mountain Schist of the Coast Ranges province by others (Helper, 1986b; Brown and Blake, 1987).

WESTERN KLAMATH TERRANE

The Western Klamath terrane (Blake et al., 1985) consists of rocks earlier called the western Jurassic belt (Irwin, 1960). It is mainly a large ultramafic body overlain by volcanic arc and clastic sedimentary rocks, and also includes the Dry Butte and Briggs Creek subterranes. The volcanic arc deposits, assigned to the Rogue Formation (Garcia, 1979), are mostly in the northern third of the terrane, where they interfinger and generally are overlain with weakly slaty shale and sandstone of the Galice Formation. In the central part of the terrane, just south of the Oregon-California border, the ultramafic body forms the base of the Josephine ophiolite which is unusually complete and well exposed along the Smith River (Harper, 1984). There the Galice is deposited on the ophiolite rather than on the volcanic Rogue Formation. In the southern part of the terrane the ultramafic and other ophiolitic rocks are missing, except for a few relatively small fault slices, and volcanic strata associated with the Galice are rare. A continuation of the Josephine ophiolite near the southern end of the terrane is called the Devils Elbow ophiolite remnant by Wyld and Wright (1988) and is overlain by the Galice Formation (Wyld and Wright, 1988).

The age of the Josephine ophiolite is Late Jurassic, based on U-Pb isotopic ages of ~162 Ma of plagiogranite (J.B. Saleeby, oral commun., 1988), with an upper limit of 150-151 Ma based on the ages of dikes that cut the ophiolite and the overlying Galice Formation (Harper, 1984). A section of thinly interbedded argillite, chert, and limestone that directly overlies the Josephine ophiolite along the Smith River contains Late Jurassic radiolarians (Pessagno and Blome, in press). At a few localities elsewhere, clastic strata of the Galice contain sparse pelecypods of Late Jurassic age (mid-middle Oxfordian to Kimmeridgian) (Pessagno and Blome, in press). The Galice was weakly metamorphosed to lower-greenschist facies ~150 Ma (Lanphere et al., 1978), probably while being overridden by rocks of the Western Paleozoic and Triassic belt.

The Galice in the northern part of the terrane, which contains the type locality at Galice Creek and overlies the volcanic rocks of the Rogue Formation, is thought to be in a different thrust plate than to the south where the Galice lies on the Josephine ophiolite (Harper, 1984). The sedimentary rocks of the Galice that overlie the Rogue are volcanogenic in composition whereas those that overlie the Josephine are more quartzofeldspathic (Blake et al., 1985). The thrust relationship and the differences in composition of the Galice led Blake et al. (1985) to call the Josephine ophiolite-Galice sequence and the ultramafic rocks-Rogue-Galice sequence separate subterranes---the Smith River and Rogue Valley subterranes, respectively (Figure 1). An anomalous occurrence of Triassic radiolarian chert in the Rogue Valley subterrane (Roure and De Wever, 1983) is difficult to explain. The chert presumably lies below the Rogue and may indicate that the basement beneath the Rogue is older than previously considered (Blake et al., 1985), or that the chert may even be part of an unrecognized tectonic outlier of Rattlesnake Creek terrane.

The Briggs Creek and Dry Butte subterranes lie west of the ultramafic rocks-Rogue-Galice sequence, separated by northeast-trending faults thought to be southeast-dipping thrusts. The Briggs Creek subterrane consists of the Briggs Creek Amphibolite of Garcia (1979), which is mainly amphibolite but includes micaceous quartzite, quartz schist, and recrystallized manganiferous chert, all of unknown age. The original relationship of the Briggs Creek subterrane to the other parts of the Western Klamath terrane is not known. The Dry Butte subterrane is a complex of ultramafic and gabbroic rocks, tonalite and quartz diorite, and rhyodacite flows and tuffs with local andesite and basalt flows (see Smith and others, 1982). The tonalite and quartz diorite have yielded K-Ar isotopic ages of ~153 Ma (Late Jurassic)(Hotz, 1971). The rocks of the Dry Butte subterrane may represent the root zone of the Rogue volcanic arc.

PLUTONIC BELTS

Plutons are present in all the terranes of the Klamath Mountains. They vary widely in composition and range in age from early Paleozoic to Early Cretaceous. Their distribution is not uniform. Few plutons intrude the Rogue and Galice Formations, Yreka subterrane, and Redding subterrane. Many are strikingly elongate parallel to the regional structural trends, and the orientation of some, such as the Ironside Mountain batholith, may represent the orientation of the host volcanic arc. Important constraints on the ages of amalgamation of the terranes are provided by the plutons that are truncated by terrane boundaries and by those that intrude terrane boundaries. The plutons are catagorized as preamalgamation if they intruded before their host terrane joined to an adjacent terrane, and as postamalgamation if the plutons intruded after the joining.

Some preamalgamation plutons are similar in age and composition to the volcanic strata they intrude, forming plutonic-volcanic pairs, and probably represent the roots of volcanic arcs. Examples are the the Mule Mountain stock intruding the Balaklala Rhyolite (Devonian) of the Redding subterrane, plutons of the McCloud belt intruding the Dekkas Andesite (Permian) of the Redding subterrane, and the Ironside Mountain batholith intruding the Hayfork Bally Meta-andesite (Jurassic) of the Western Hayfork subterrane. In contrast, the postamalgamation plutons are significantly younger than their host rocks, seem genetically unrelated, and presumably intruded the host terrane as a result of crustal subduction.

The pattern of distribution of the plutons is important to an understanding of the tectonic history of the province. Isotopic ages have been measured on many of the plutons, and, although some of the isotopic ages measured by different methods are conflicting, the data indicate that plutons of similar age tend to occur in belts that are generally parallel to trends of other regional lithic and structural features (Figure 2). Most of the isotopic dating has been by M.A. Lanphere, J.M. Mattinson, J.B. Saleeby, and J.E. Wright (for listing of age data see Irwin, 1985). Plutonic belts in the northwestern part of the province trend northeast, at large angles to plutonic belts in the southwestern part. The Paleozoic belts are all in the Eastern Klamath terrane and trend northeast-southwest. Jurassic plutons are remarkably rare in the Eastern Klamath terrane. West of the Eastern Klamath terrane, the northeast trending belts are of successivley younger Jurassic and Cretaceous ages except for the

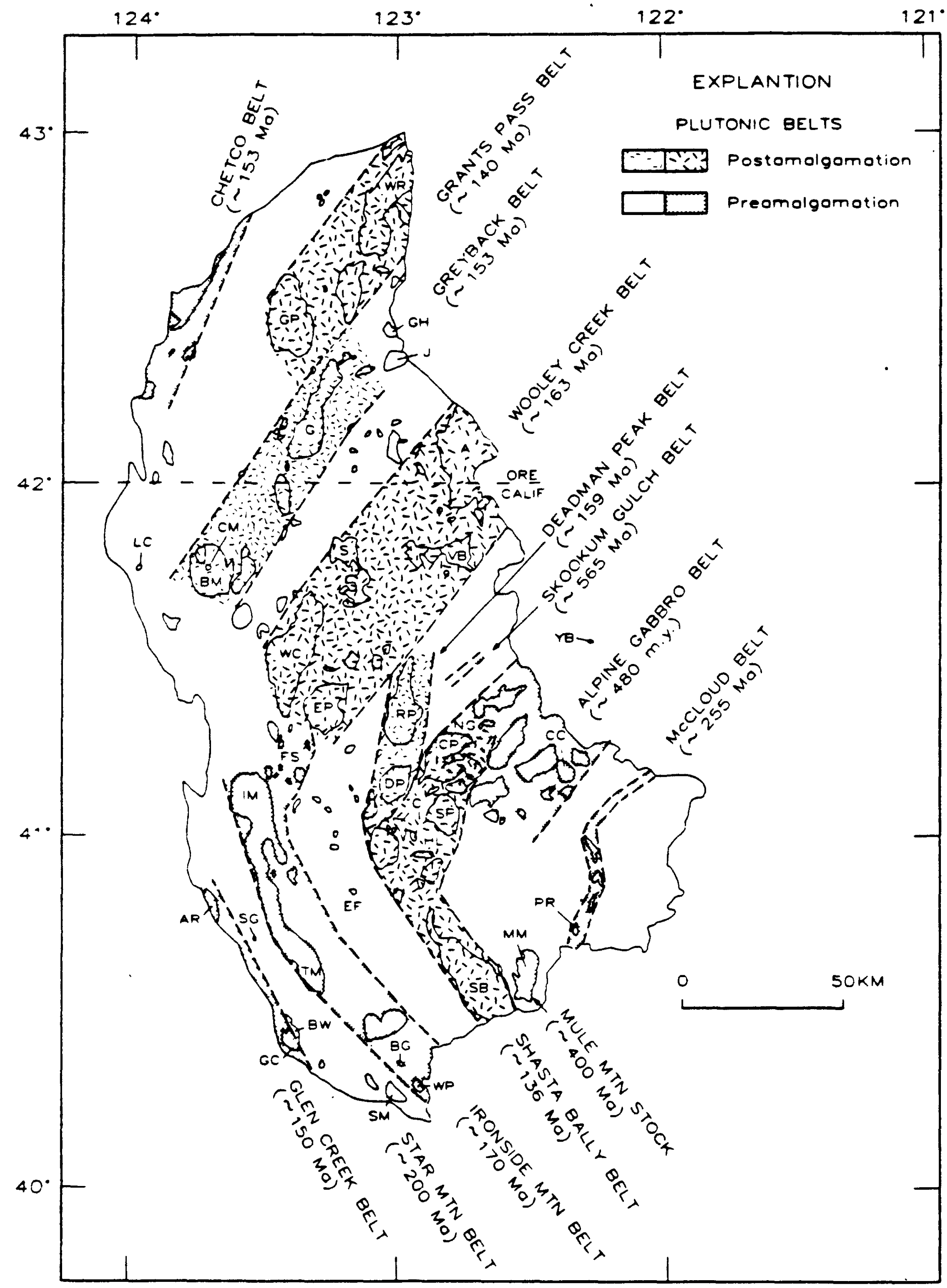

FIGURE 2 Map of Klamath Mountains province showing outlines of major plutons and trends of plutonic belts (modified from Irwin, 1985). Ultramafic rocks are not shown. Letter symbols on map correspond to names of isotopically dated plutons: A, Ashland; AR, Ammon Ridge; BG, Basin Gulch; BM, Bear Mountain; BW, Bear Wallow; C, Caribou Mountain; CC, Castle Crags; CM, Cracker Meadow; CP, Craggy Peak; DP, Deadman Peak; EF, East Fork; EP, English Peak; FS, Forks of Salmon; G, Greyback; GC, Glen Creek; GH, Gold Hill; GP, Grants Pass; HL, Horseshoe Lake; IM, Ironside Mountain; J, Jacksonville; LC, Lower Coon Mountain; MM, Mule Mountain; NG, unnamed gabbro, PR, Pit River; RP, Russian Peak; S, Slinkard; SB, Shasta Bally; SG, Saddle Gulch; SM, Star Mountain; SP, Sugar Pine; VB, Vesa Bluff; WC, Wooley Creek; WP, Walker Point; WR, White Rock; YB, Yellow Butte.

westernmost belt (Chetco belt) which is Late Jurassic. The northwest trending belts also are of Jurassic and Cretaceous age, but the youngest (Shasta Bally belt) is furthest from the ocean and partly overprints an early Paleozoic belt (Alpine gabbro belt).

TECTONIC DOMAINS

The change in orientation of the plutonic belts occurs across a vague northwest-trending zone of discontinuity that divides the province into northeastern and southwestern domains (Irwin, 1985). The change is accompanied by differences in the ages and numbers of plutonic belts and by differences in other regional features. The Paleozoic plutonic belts are all in the northeast domain. Jurassic and Cretaceous belts are in both domains but differ somewhat in age and terrane relations. The number of plutonic belts in the northeast domain is nearly twice that of the southwest domain. In the northeast domain the Western Paleozoic and Triassic belt contains the greatest number of plutons, including nearly all of the postamalgamation Jurassic plutons of the province, but seems to be devoid of preamalgamation plutons (Figure 3). In contrast, most plutons of the Western Paleozoic and Triassic belt in the southwest domain are preamalgamation in age.

Differences in the age of plutonic belts are particularly puzzling where the host terrane seems to be virtually continuous across the zone of discontinuity. The Ironside Mountain and Wooley Creek plutonic belts intrude the Hayfork Bally Meta-andesite on opposite sides of the zone of discontinuity, and virtually coincide at the zone. The Ironside Mountain batholith (~170 Ma) is considered preamalgamation because of its genetic relation to the meta-andesite and its truncation by terrane boundaries. The Wooley Creek belt (~163 Ma) is only a few million years younger than the Ironside Mountain belt, but is postamalgamation because the Wooley Creek, Slinkard, and Vesa Bluffs plutons cross terrane boundaries (Donato et al., 1982; Barnes, 1983; and Mortimer, 1984). Cretaceous plutons of the Grants Pass belt intrude the boundary between the Western Klamath terrane and the rocks of the Western Paleozoic and Triassic belt in the northeastern domain, but comparable plutons and relations are unknown in equivalent terranes in the southwestern domain.

The distribution of the terranes and other features suggest that rocks of the Klamath Mountains are regionally deformed by broad open folding and by doming (Figure 4). The axes of the folds generally are parallel to the overall trends of the terranes and to the trends of the plutonic belts. In the southwest domain, an open synform and a tighter complementary antiform on its eastern limb account for the unusually wide exposure of the Central Metamorphic terrane. The axes of these folds trend northwest to the zone of discontinuity, which at that point is the Browns Meadow fault of Davis et al. (1965). In the northeast domain, the western part of the Western Paleozoic and Triassic belt appears to be a thin synformal thrust plate that rests on the Galice Formation over a broad area. The axis of the synform trends

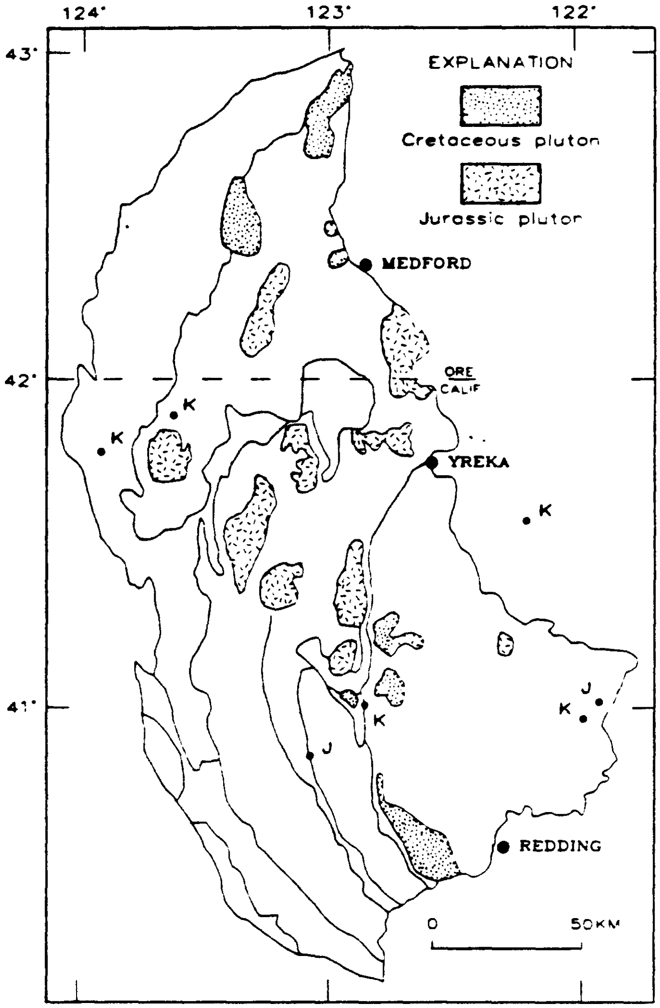

FIGURE 3 Distribution of isotopically-dated postamalgamation plutons. Letter symbols indicate age of small dated plutons: J, Jurassic; K, Cretaceous.

northeast and is parallel a narrow corridor of the Galice formation to the southeast that represents a complementary antiform and which nearly reaches the Condrey Mountain window. The Trinity ultramafic sheet is a broad northeast-trending antiformal upwarp with a complementary northeast-trending synform represented by the Yreka subterrane. The southeast limb of the antiform includes the southeast-dipping stratigraphic section of the Redding subterrane. The Condrey Mountain window represents the core of a structural dome (Coleman and Helper, 1983). The rocks in the core of the dome may well include metamorposed Galice and Rogue Formations. The window is not far from the Galice exposed in the narrow antiformal corridor, and in the usual order of structural stacking the Galice should be overlain by the Rattlesnake Creek terrane. Although the domal structure is complicated by faulting, most of the rocks surrounding the core are indeed metamorphosed melange that is correlative with the Rattlesnake Creek terrane. Generally further from the core of the dome are volcanic rocks that may be correlative with the Hayfork terrane.

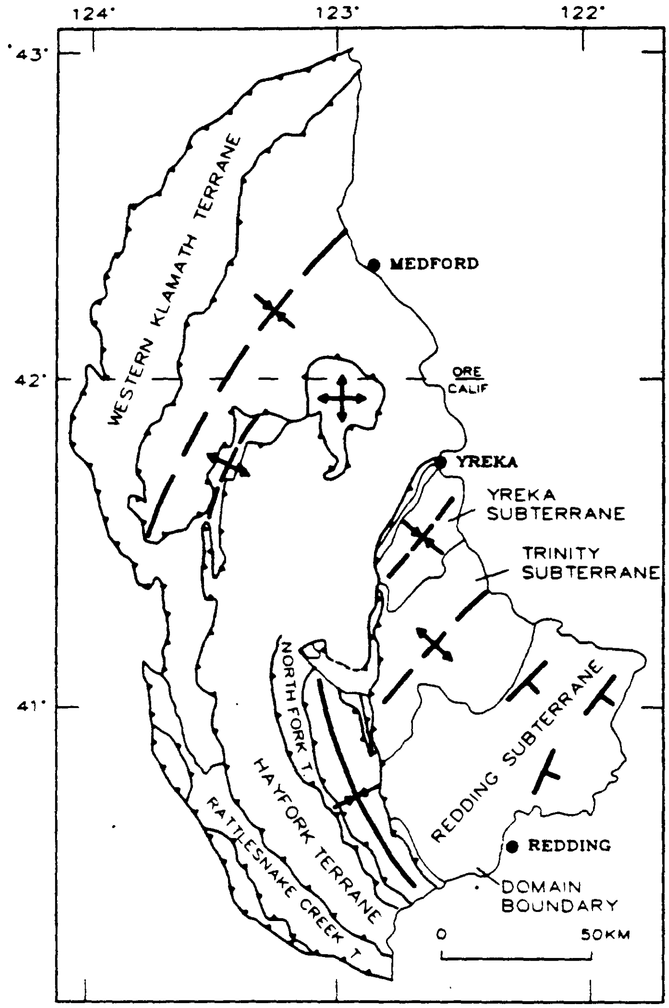

FIGURE 4 Some major structural feature of the Klamath Mountains. Shown are the axes of postulated regional synforms and antiforms, the Condrey Mountain dome, the generally easterly-dipping strata of the Redding subterrane, and the approximate boundary between the southwest and northeast domains.

TERRANE AMALGAMATION

The sequence and timing of terrane amalgamation is established by various kinds of evidence including (1) the age of the youngest rock of the subducted terrane, (2) the age of metamorphism that in some instances occurs in the lower plate adjacent to the terrane boundary during subduction, (3) the age of postamalgamation plutons, and (4) a minimum limit imposed by the age of strata that overlap the terrane boundary. The boundary between the Eastern Klamath and Central Metamorphic terranes is Devonian in age based on the age of the metamorphism that occurred when the protoliths of the Abrams and Salmon Schists were overridden by the Trinity ultramafic sheet (Lanphere et al., 1968). The boundary is intruded by Early Cretaceous plutons of the Shasta Bally belt, and, as with other terranes of the southern Klamath Mountains, it is overlapped by Lower Cretaceous strata of the Great Valley sequence.

The boundary between the Central Metamorphic terrane and the rocks of the North Fork and Fort Jones terranes is intruded by Middle and (or) Late Jurassic plutons (East Fork and Deadman Peak plutons). The North Fork terrane contains radiolarian chert as young as Early Jurassic in age (Pliensbachian)(Blome and Irwin, 1983). Therefore, the age of the terrane boundary must be in the range of late Early to Late Jurassic.

The age of the Eastern Hayfork melange and its boundary with the North Fork terrane is equivocal. The Western Hayfork subterrane includes the cogenetic Middle Jurassic (~170 Ma) Ironside Mountain batholith in the southwest domain. The batholith is cut by the boundary fault between the the Western Hayfork subterrane and Rattlesnake Creek terrane. In the northeast domain, Middle Jurassic (~163 Ma) plutons of the Wooley Creek belt cut the boundary between correlatives of the Western Hayfork subterrane and the structurally underlying Rattlesnake Creek terrane. This suggests that the Western Hayfork subterrane and Rattlesnake Creek terrane were juxtaposed during an interval of ~7 m.y. during Middle Jurassic time.

The youngest part of the Western Klamath terrane is the Galice Formation, which contains Late Jurassic (Oxfordian to Kimmeridgian) pelecypods and radiolarians (see Harper, 1984). In the southern part the of the terrane, the Galice was metamorphosed to lower-greenschist facies in Late Jurassic time (~150 Ma), presumably during overriding by the Rattlesnake Creek terrane. In the northern part, the boundary between the Galice and rocks of the Western Paleozoic and Triassic belt is intruded by Early Cretaceous plutons of the Grants Pass belt, which places an upper limit on the age of the boundary and supports the Late Jurassic age of amalgamation indicated by the metamorphism. The suturing of the Briggs Creek and Dry Butte subterranes to one another and to the other rocks of the Western Klamath terrane probably postdates the Late Jurassic (~153 Ma) plutons of the Dry Butte subterrane and predates the Early Cretaceous fault boundary with the Coast Ranges to the west.

The foregoing data indicate that the amalgamation of the Klamath terranes was a series of Jurassic events, except for the Devonian suturing of the Eastern Klamath and Central Metamorphic terranes, and appears to have been sequential westward.

ACCRETION TO NORTH AMERICA

The time of accretion of the Klamath terranes to North America is not known with certainty. Nor is it clear whether the Eastern Klamath terrane accreted to the continent before being joined by the other terranes, or whether all the terranes of the province amalgamated in an oceanic setting and then accreted to the continent as a composite body. The kinds of evidence used to determine the timing of amalgamation of the various terranes are not available for use in determining the time of accretion of the Eastern Klamath terrane to the continent, mainly because the terrane boundaries along the eastern and southeastern border of the province are concealed by a broad cover of Cretaceous and younger sedimentary and volcanic strata. However, indirect evidence for the time of accretion is given by the results of paleomagnetic studies. Most of the studies have been of the middle Paleozoic to Middle Jurassic strata of the Redding subterrane and of some of the plutons. Although the results of some of the studies are conflicting, most indicate that the rocks of the province have experienced large clockwise rotation, but none indicates significant latitudinal displacement.

Large clockwise rotations are reported for the Galice Formation of the Western Klamath terrane (Bogen, 1986), for some plutons of the northeast domain (Schultz, 1983), and for Devonian and Permian strata of the Redding subterrane (Achache et al., 1982; Fagin and Gose, 1983). Paleomagnetic measurements made by Mankinen et al., (1984) in the Redding subterrane were along a northern and a central transect of the Permian and younger strata, and the results of their study indicate clockwise rotations of ~100° for the Permian and Triassic rocks, and clockwise rotation of ~60° for the Lower and Middle Jurassic rocks, relative to stable North America. The data gathered along both transects are consistent with the concept that the Eastern Klamath terrane rotated essentially as a rigid block (Mankinen et al., 1984). However, this is disputed by Renne et al (1988) whose paleomagnetic study of Permian rocks of the central transect indicates no rotation, and who interpret their results as indicating oroclinal bending rather than block rotation.

Paleomagnetic measurements on the postamalgation plutons of the Shasta Bally belt indicate clockwise rotation of ~25° following the intrusion event in Early Cretaceous time (Mankinen et al., 1988). Lower Cretaceous strata of the Great Valley sequence, which overlap the Klamath terranes and Shasta Bally batholith (136 Ma) at the south end of the province, have rotated clockwise ~14° (Mankinen et al., 1988), as have the Tertiary volcanic rocks of the Cascade Range that lie just east of the Klamath Mountains (Beck et al., 1986). This suggests that the Klamath terranes virtually ceased to rotate for a period of ~100 m.y. while the onlapping Cretaceous and Tertiary volcanic strata were deposited. The emplacement of Shasta Bally batholith, which preceeded the deposition of the onlapping Cretaceous (Hauterivian) strata and the long pause in rotation by no more than a few million years, may well mark the time of accretion of the Eastern Klamath terrane.

If the Eastern Klamath terrane accreted to North America in Early Cretaceous time as the preceeding scenario suggests, it would have been as part of a composite body that included the other terranes of the province, because the sutures between the terranes are established as Jurassic and older in age. This concept is also supported by the general similarity of the amount of rotation of the Jurassic postamalgamation plutons northwest of the Eastern Klamath terrane and of the amount of rotation of the Jurassic strata of the Redding subterrane, which suggests that the rocks of both areas probably rotated as a single unit.

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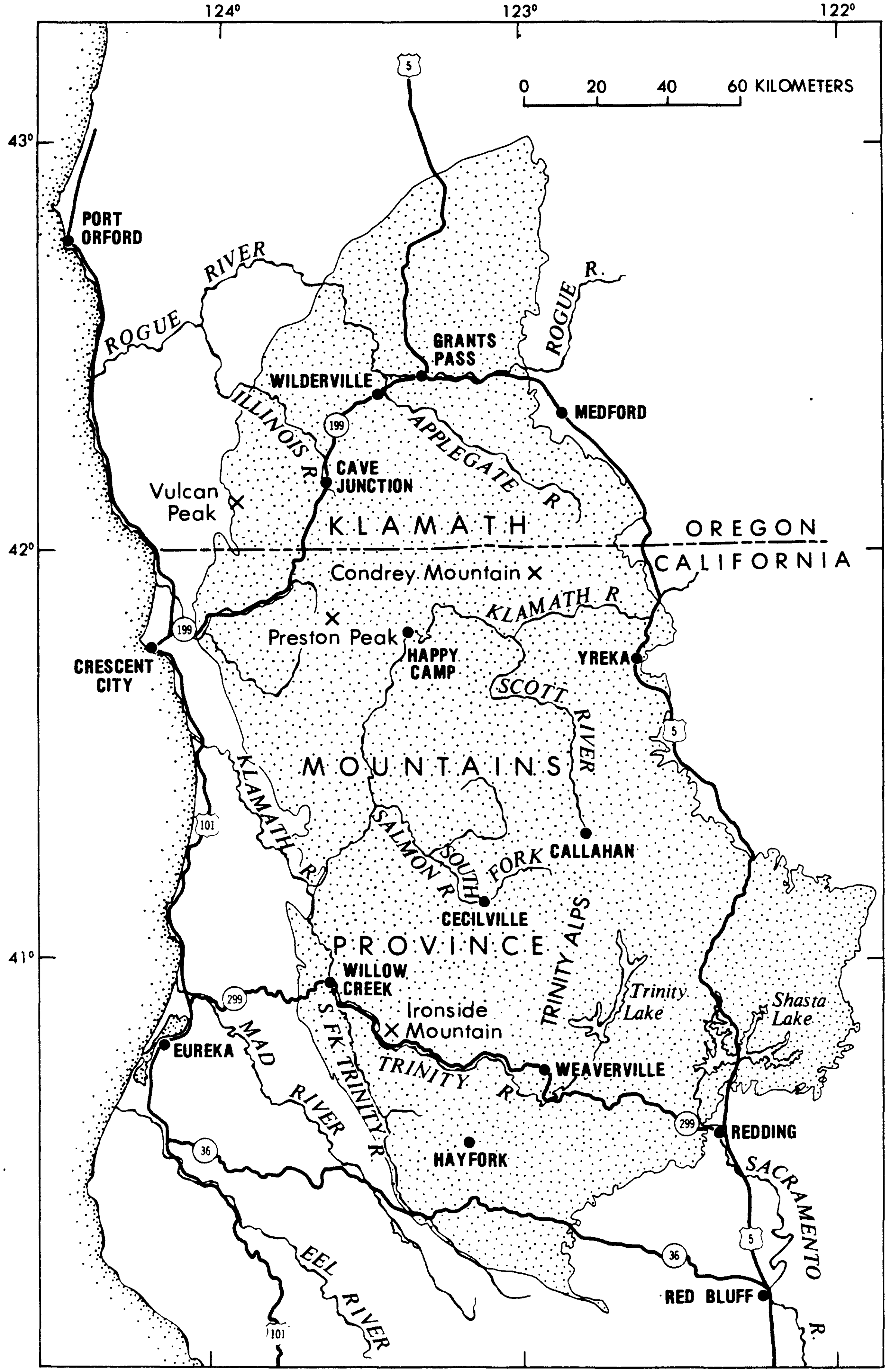
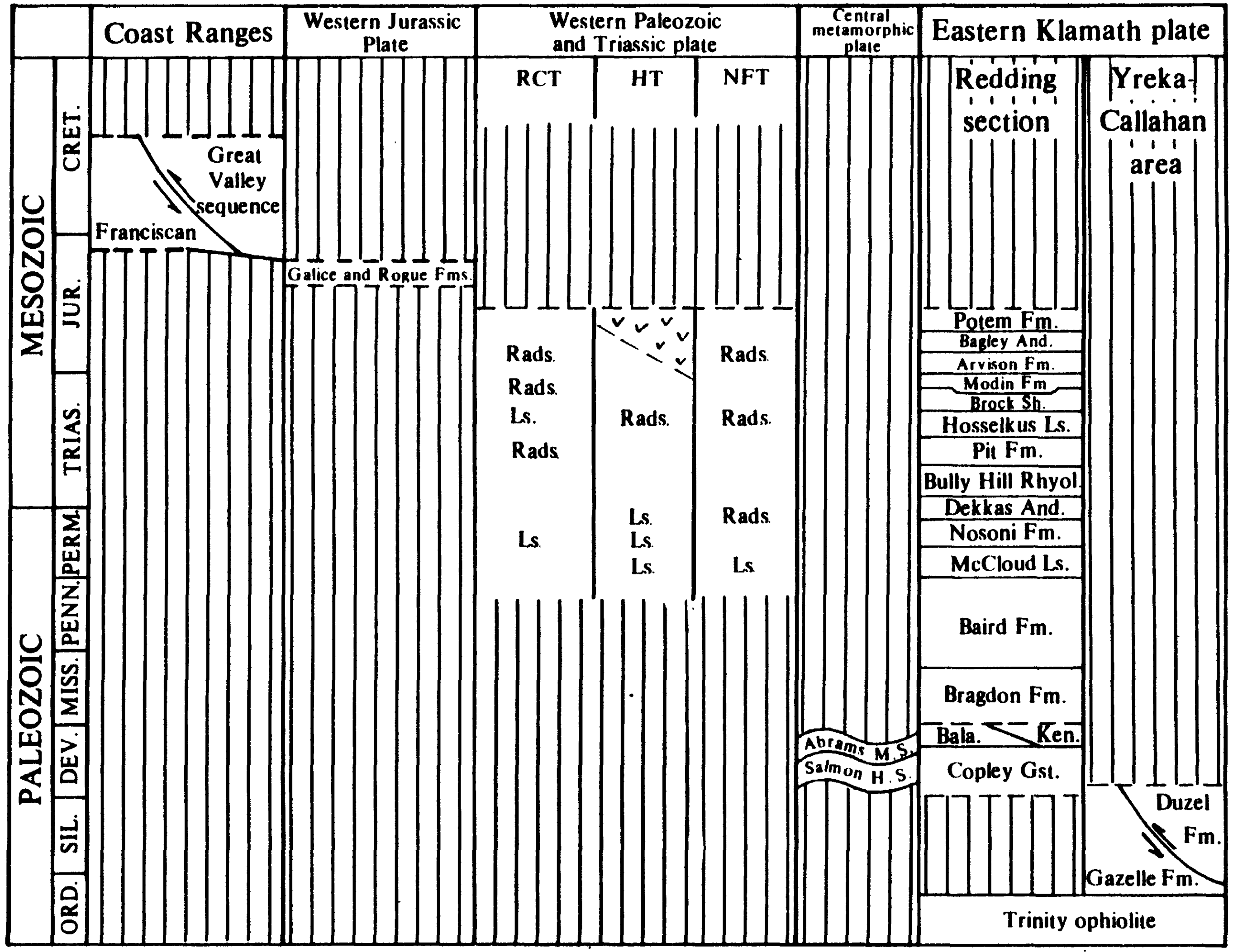
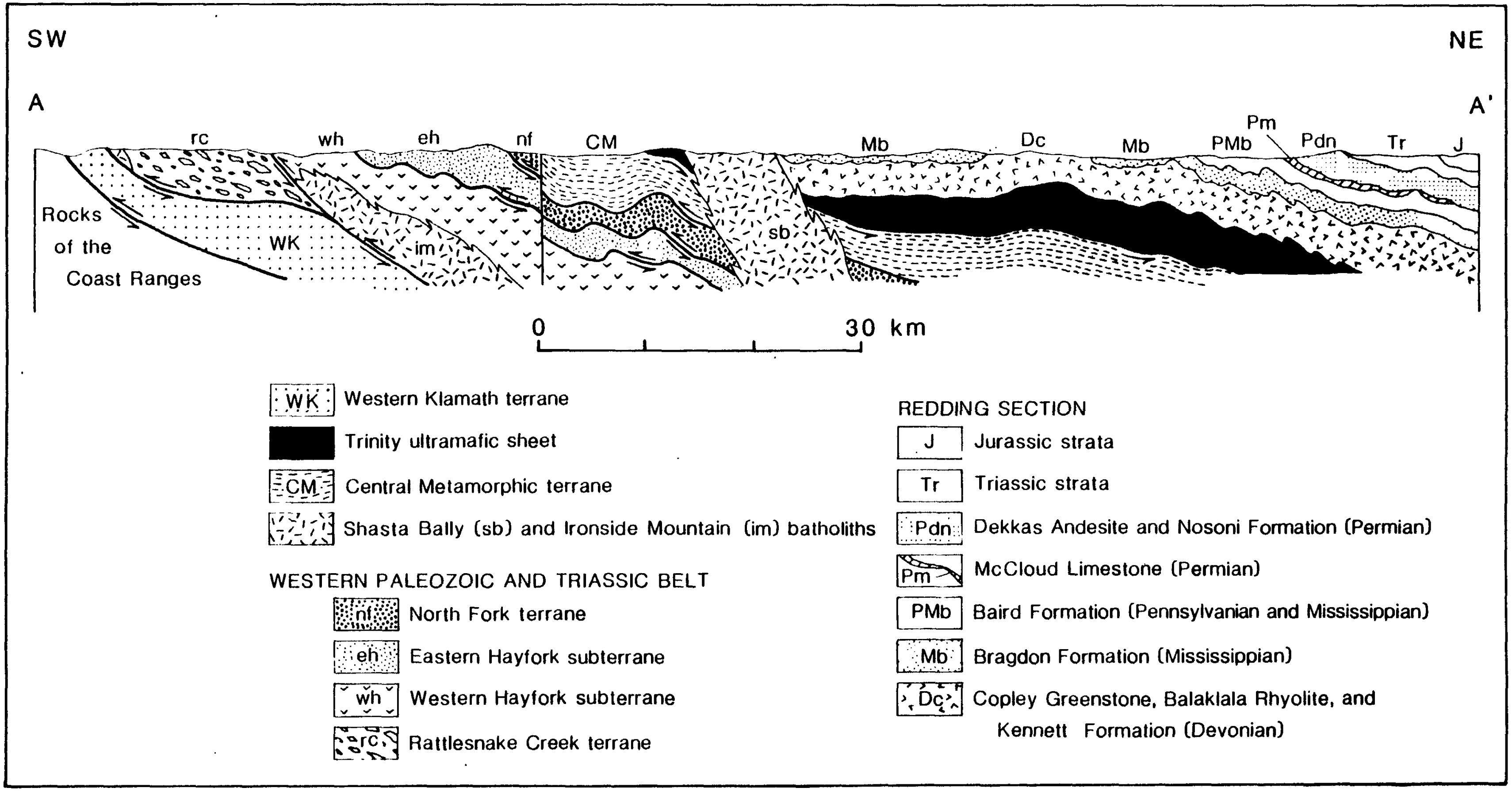


Map showing Klamath Mountains province and geographic localities



Comparative stratigraphic columns of tectonic plates of the Klamath Mountains and adjacent Coast Ranges.



Schematic SW-NE structure section across the southern Klamath Mountains (after Irwin and Dennis, 1979)

GEOLOGIC TRAVERSE ACROSS THE KLAMATH MOUNTAINS AND NORTHERN COAST RANGES--WESTWARD ALONG HIGHWAY 299 FROM REDDING TO HIGHWAY 101 NEAR ARCATA, CALIFORNIA

Prepared for GEOMAR and University of Kiel field trip, June 14, 1997, by William P. Irwin

The traverse from Redding to Highway 101 near Arcata crosses two major geologic provinces--the Klamath Mountains and the northern Coast Ranges. It crosses parts of seven accreted terranes in the Klamath Mountains, and two or more terranes in the Coast Ranges. The traverse begins at Market Street in downtown Redding and follows Highway 299 in a generally westward direction to its junction with Highway 101, covering a distance of approximately 139 miles. The traverse begins in the drainage of the Sacramento River, and at Buckhorn Summit (mile 24: altitude 3212 ft) it crosses into the Trinity River drainage. It follows along the course of the Trinity River for 47 miles from Junction City to Willow Creek. A few miles west of Willow Creek the traverse crosses the western boundary of Klamath Mountains province, and at Berry Summit (mile 110.6: altitude 2871 ft) crosses into Redwood Creek drainage.

<u>Mileage</u>

0.0 Heading west on Highway 299 at Market Street in downtown Redding. Traveling on thick veneer of weakly consolidated Quaternary gravels (including Red Bluff Formation).

0.7 Passing from gravels into poorly exposed Copley Greenstone (Devonian) of the Redding subterrane.

3.6 Passing from Copley Greenstone into albite granite of the Mule Mountain stock (400 Ma). Better exposures of the granite will be seen a few miles farther along the traverse, beyond the town of Shasta.

5.4 Entering the historic old town of Shasta and continuing through Mule Mountain stock to Whiskeytown Summit.

7.6 At Whiskeytown Summit in Mule Mountain stock. Whiskeytown Reservoir is seen to the left in the view ahead. Water for the reservoir comes mainly from Trinity Lake (aka Clair Engle Lake) through an 11.8 mile tunnel in the eastern side of Shasta Bally batholith. Eastward from Whiskeytown Summit can be seen the north end of the Great Valley, and, on a clear day, the volcano Mount Lassen can be seen at the south end of the Cascade Range. Lassen last erupted in 1914-1915.

Continuing westward on the long downgrade from Whiskeytown Summit, the traverse passes from albite granite into similarly light-colored exposures of Balaklala Rhyolite (Devonian). The Balaklala Rhyolite is one of several Paleozoic formations in this region of the Redding subterrane, and is part of a dominantly arc-related stratigraphic section that ranges from Devonian upward into Jurassic. The oldest stratigraphic unit is the Copley Greenstone which consists of andesitic and basaltic flows, pillow lavas, breccias and tuffs. It is estimated to be at least 1,130 m thick, but there are no distinctive marker beds and the base is not clearly known. The Copley is considered Middle Devonian as it locally interfingers with overlying Balaklala Rhyolite or with Kennett Formation, both of which are Middle Devonian.

The Balaklala Rhyolite consists mainly of quartz keratophyre flows and tuffs, and probably is cogenetic with the Mule Mountain stock. It was deposited on a highly irregular surface and locally may be as much as 1,000 m thick. It is the principal host rock for base-metal sulfide deposits that were mined extensively in the West Shasta district. The only fossil reported from the Balaklala is a plate from a marine armored fish of Middle Devonian (Eifel) age.

The Kennett Formation depositionally overlies the Balaklala and Copley formations, and is unconformably overlain by the Bragdon Formation. Much of the Kennett is cut out between the Bragdon and Balaklala or Copley by the Spring Creek thrust. The Kennett consists of black siliceous shales, rhyolitic tuff, and limestone that contains abundant Middle Devonian marine fossils. It is highly discontinuous and probably does not exceed 120 m in thickness. The Bragdon Formation consists mostly of mildly slaty sandstone and shale with locally abundant grit and conglomerate. The conglomerate is distinctive for the presence of abundant clasts of chert, white quartz, and limestone. The thickness of the Bragdon is estimated to be as much as 1,800 m. At some places the Bragdon lies unconformably on the Kennett, but elsewhere it lies variously in thrust contact over Copley, Balaklala, and questionable Kennett.

Just before reaching the turnoff to Whiskeytown, the traverse passes stratigraphically downward from Balaklala Rhyolite to Copley Greenstone and continues in Copley for several miles along the northern side of Whiskeytown Reservoir.

15.0 Good exposures of Bragdon Formation in the road cuts and along Clear Creek.

15.5 Junction of road to French Gulch. The town of French Gulch, about 2 miles to the north, was the center of one of the most productive lode gold mining districts in the Klamnath Mountains. The gold was mostly in quartz veins, both as free gold and in sulfides. The veins were in both the Copley and the Bragdon, but those in the Bragdon were by far the more productive.

18.0 Traverse crosses into contact metamorphic aureole of Shasta Bally batholith. The aureole includes gneissic and amphibolitic equivalents of Copley, Balaklala, and Bragdon Formations.

19.9 Approximate eastern boundary of Shasta Bally batholith. The batholith is elongate in a northwesterly direction. Its composition is dominantly biotite diorite on the northeast side and hornblende-biotite diorite on the southwest side. Shasta Bally batholith (136 Ma) is part of the youngest plutonic belt of the Klamath Mountains. Lower Cretaceous (Hauterivian) beds of the Great Valley sequence that lie depositionally on the eroded crest of the batholith at the south end of the province are a stratigraphic upper limit to the age of the batholith. The batholith is exposed only in the Redding subterrane. However, the age relations of the batholith and the presence of a few small xenoliths of ultramafic rock suggest that the batholith has also penetrated the regionally underlying Trinity subterrane.

20.3 Many aplite dikes in batholith near eastern boundary

24.0 Crest of Buckhorn Summit, altitude 3212 ft. Crossing into Trinity River drainage.

28.9 Junction of Lewiston Road.

29.8 Western boundary of Shasta Bally batholith.

30.4 Dike-injected border zone of Shasta Bally batholith

32.8 Junction of old Lewiston road. Here the traverse passes into weakly consolidated fluvial sands and gravels of the continental Weaverville Formation (Upper Oligocene and/or Lower Miocene), locally containing thin-bedded tuff and minor coal beds.

34.8 Passing into Salmon Hornblende Schist (Devonian) on the east limb of a north-trending synform of Central Metamorphic terrane. At this latitude, the Salmon Hornblende Schist and overlying Abrams Mica Schist are a synformal slab that is several kilometers thick. Regionally, the schists lie structurally below the Trinity ultramafic sheet (Trinity subterrane). A Devonian (380-400 Ma) metamorphic age of the schists is thought to represent the time that the protoliths of the schists were overridden by the Trinity ultramafic sheet and other rocks of the Eastern Klamath terrane.

35.4 Near the bottom of the long down-grade, the traverse, still on the east limb of the synform, passes stratigraphically(?) upward from Salmon Hornblende Schist into Abrams Mica Schist. It continues in Abrams Mica Schist to the bridge crossing the Trinity river at Douglas City.

37.5 Junction of Route 3 (to Hayfork). The high ridge on the left (south) side of Highway 299 is capped by an outlier of Lower Cretaceous Great Valley sequence (not visible from the road). The high cliff at the Junction exposes Abrams Schist. Continue on Highway 299, crossing bridge over the Trinity River, and past Douglas City.

38.5 Highway Rest Stop

39.4 Weaver Creek Bridge. Passing into the eastern side of the Oregon Mountain outlier. The outlier consists mostly of Bragdon Formation (Redding subterrane), and along its east side includes a large slab of serpentinized ultramafic rock (Trinity terrane). The ultramafic rock may be at the base of much of the outlier, as thin slivers of serpentinite are found elsewhere along the contact of the outlier with underlying Abrams Mica Schist (Central Metamorphic terrane). The highway trends northward along the west side of the ultramafic slab for nearly a mile, then curves sharply eastward to cut through the slab into Abrams Mica Schist, and continues northward toward Weaverville.

41.3 The Gables Restaurant

42.0 Entering Weaverville basin, an area underlain mainly by moderately deformed beds of weakly consolidated fluvial silt, sand, and gravel of the Weaverville Formation (Late Oligocene and/or Early Miocene in age). Along the highway, much of the Weaverville Formation is concealed by Pleistocene terrace gravels and Recent alluvium from which significant quantities of gold were once placer mined. Directly ahead while passing through the outskirts of Weaverville, Weaver Bally Mountain (highest peak, 7,771 ft) is seen, which is the southernmost extension of the Trinity Alps. The mountain is mostly Salmon Hornblende Schist. Light-colored outcrops in some of the higher parts are granitic plutons.

44.1 The center of Weaverville, the seat of Trinity County.

44.7 Moderately-dipping beds of Weaverville Formation are exposed in road cuts from this point to mileage 46.2. At mileage 46.2 a conglomerate that may represent a basal part of the Weaverville Formation consists almost entirely of subangular fragments of Salmon Hornblende Schist.

46.7 Salmon Schist exposed in road cuts to mileage 47.0.

47.2 Oregon Mountain Pass. Crest of hill at La Grange placer-gold mine, just beyond the north end of the Oregon Mountain outlier. About 100 ft before reaching the crest, note the highly jumbled mass of Abrams Schist on the right side of the road. The Abrams Schist apparently is on the hanging wall of the La Grange fault, although it probably has been dislocated by landsliding. After reaching the crest of the road, and looking ahead at the downgrade, the remarkably well exposed surface of the La Grange fault can be seen to dip about 22 degrees southward (to the left) toward the Oregon Mountain outlier.

47.9 La Grange hydraulic mine. Abandoned placer working are seen on both sides of the highway. The hydraulic mining for placer gold was chiefly between the early 1850's and World War I. Water for the mining was supplied by two ditches, one about 30 miles long and the other about 12 miles long. The California Division of Highways is said to have hydraulicked about 6 million cubic yards of gravel and rock during the 1930's in order to make a deep notch in the ridge through which the present highway passes. The footwall surface of the La Grange fault is widely exposed on the north side of the road and trends subparallel to it. The footwall of the fault is Salmon Hornblende Schist. A thin layer of black dense mylonite, locally as much as a foot thick, covers much of the footwall surface. Mullion structures in the mylonite indicate that the hanging-wall block moved downward toward the south. The hanging-wall block, which was removed by hydraulicking above the level of the highway, is said to have consisted chiefly of Weaverville Formation that dipped toward the fault.

49.2 Salmon Hornblende Schist of Devonian metamorphic age. From this point to mileage 50.2, the large quantity of tailings discharged from the La Grange mine can be seen to the left of the highway.

50.9 Reddish remnants of high-level terrace deposits that were mined for placer gold are seen chiefly to the left across the Trinity River. Piles of tailings, resulting from the dredging of river gravels for placer gold, are seen for miles downstream to beyond Junction City.

53.5 Junction City, at the mouth of Canyon Creek. Canyon Creek formerly was an important source for placer gold. Its headwaters are in the glaciated Trinity Alps about 15 miles to the north.

57.4 Crossing the Siskiyou fault approximately where highway curves sharply to left, passing from Central Metamorphic terrane (Salmon and Abrams Schists) into North Fork terrane.

57.6 Recrystallized limestone, argillite, and chert of the North Fork terrane are exposed at a sharp hairpin curve and intermittently for the next mile. At this transect, the North Fork terrane is disrupted and attenuated, apparently by complex faulting, and the ophiolitic part appears to be missing.

59.4 Crossing bridge over the North Fork of Trinity River at Helena. Passing into Western Hayfork terrane. Note the prominent lineation and jointing in rocks on both sides of the river.

59.7 Pigeon Point Campground

60.0 Metaandesite of the Western Hayfork terrane forms the steep canyon walls for next 4 miles.

62.4 Approximate site of proposed Helena dam.

64.4 Big Flat Campgroud. Rapids in the river at this locality are popular with river rafters. Here the traverse passes from metaandesite of the Western Hayfork terrane into melange of the Eastern Hayfork terrane.

66.7 Bridge at Big Bar. A few small patches of Lower Cretaceous sandstone and conglomerate correlative with the Great Valley sequence are present a short distance downstream on the opposite (south) side of the river. To examine these rocks, cross the bridge, turn right at the first road intersection, and travel about one-half mile.

73.7 Outcrop of recrystallized crinoidal limestone on right side of road before reaching Del Loma. A trail at Del Loma leads to caves of considerable extent in the limestone.

75.0 Hayden Flat Campground. Here the traverse passes from Eastern Hayfork terrane melange into Western Hayfork terrane metaandesite, and, about one-half mile farther, passes back into melange until near Little Swede Creek (76.0) where the traverse passes back into metaandesite. The traverse remains in the metaandesite until near Sandy Bar Creek.

78.5 Sandy Bar Creek. The traverse passes from metaandesite into the Ironside Mountain batholith, both in the Western Hayfork terrane. The batholith is largely diorite and gabbro of Middle Jurassic (approx. 170 Ma) age. Its similarity to the metaandesite in age, composition, and distribution, suggests that the two units are cogenetic.

81.7 Highway bridge. Upstream from the bridge, the narrow terrace on the left side of the road is a popular take-out locality for river rafters. The traverse crosses the bridge to the south side of Trinity River and continues in Ironside Mountain batholith. For several miles it roughly follows the western border of the batholith, just a short distance east of the fault contact of the batholith with the Rattlesnake Creek terrane. Much of the highway is along landslide that consists of serpentinite and other mixed debris from the melange of the Rattlesnake Creek terrane.

83.0 The bedrock scar of the China landslide is visible high on the left side of the highway. The landslide occurred in 1890 and is reported to have dammed the river, forming a lake many miles in length. The slide was named for Chinese gold miners who are said to have drowned because of the slide.

83.3 Near the site of a proposed Burnt Ranch dam. Chert, pillow basalt, and other rocks of the Rattlesnake Creek terrane. The batholith is well exposed on the steep slopes of Ironside Mountain on the opposite side of the river.

87.2 Viewpoint overlooking the mouth of the New River. Approximately one-quarter mile further north, the highway curves sharply eastward and crosses from Rattlesnake Creek terrane into Galice Formation of the Western Klamath terrane. The terrane boundary fault is marked by a thin slab of serpentinite (seen on the left side of the highway). The Galice Formation consists mainly of shale and sandstone that ranges from mildly slaty to phyllitic and is Late Jurassic in age. The traverse continues through Galice Formation for the next 12 miles to beyond the village of Willow Creek.

88.1 Gray Falls Campground

96.1 The highway crosses a bridge over the mouth of the South Fork of Trinity River. Leaving Trinity County and entering Humboldt County.

100.2 Passing through the village of Willow Creek, the home of Big Foot.

102.5 Crossing a fault, passing from Galice Formation into melange of the Rattlesnake Creek terrane.

105.1 Crossing fault, passing back into Galice Formation.

106.8 Highway crosses fault, passing through metavolcanic rock that represents Rogue(?) Formation, and then into serpentinite and other rocks that represent dismembered Josephine(?) ophiolite.

107.9 Highway crosses fault and passes into South Fork Mountain Schist (Pickett Peak terrane). The fault is the boundary between the Klamath Mountains province on the east and the northern Coast Range province on the west. The schist forms a belt that is present along much of the western boundary of the Klamath Mountains and, continuing southward, along the western boundary of the Coast Range ophiolite. It is thought to represent Franciscan(?) rocks that were metamorphosed during Early Cretaceous time (approx 125 Ma) when overthrust by Klamath and other terranes.

108.3 Highway passes into non-schistose sandstone and shale of the Franciscan Complex.

110.6 Berry Summit (altitude 2,871 ft). Note the widespread landslide topography on the western slope of the mountain, and the uniform crestline of Redwood Mountain across the main valley to the west.

116.9 Cross Redwood Creek into schistose metasedimentary rock similar to South Fork Mountain Schist. The highway continues in the schistose rock to beyond Lord Ellis Summit.

121.2 Lord Ellis Summit (altitude 2262 ft) of Redwood Mountain.

123.0 Approximate point where the highway leaves the schistose rocks of Redwood Mountain and travels westerly through non-schistose Franciscan rocks. The geologic description of the traverse ends here. Continue traveling westerly on highway 299.

126.0 Cross bridge over the Mad River.

139.0 Junction with Highway 101. Turn right for travel to Crescent City, or cross the overpass for travel to Arcata and Eureka.