U.S. DEPARTMENT OF THE INTERIOR
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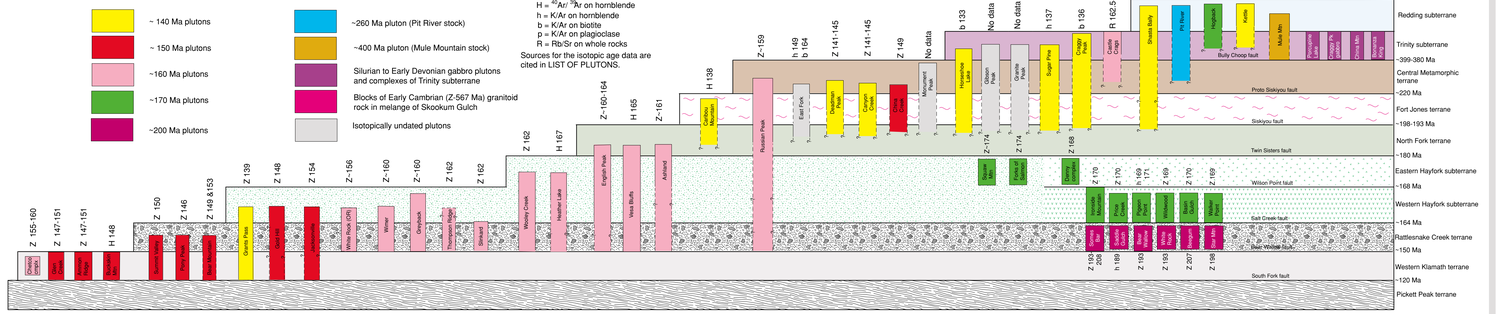
Figure 10. Schematic vertical section showing the stacked accreted terranes of the Klamath Mountains, and the intrusive relations of the plutons.



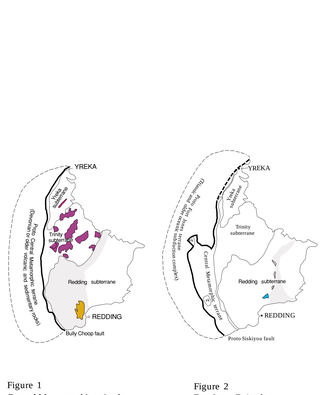


Figure 1
Central Metamorphic episode
Late Silurian(?) to Middle Devonian time
(~400 Ma—380 Ma)

Figure 2
Fort Jones Episode
Permian—Triassic time
(~260—~240Ma)

Figure 3
North Fork episode
Early Jurassic (Pliensbachian)
time (~198—193 Ma)

Figure 4
Eastern Hayfork episode
Early(?) Middle Jurassic (~Bajocian)
time (~180 Ma)

Figure 5
Western Hayfork episode
Late Middle Jurassic (Early Callovian)
time (~168 Ma)

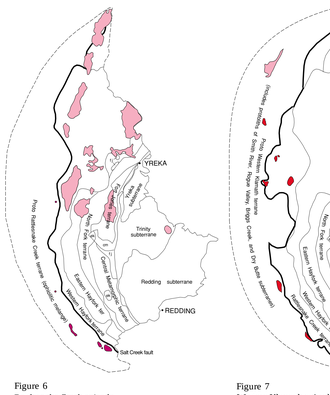


Figure 6
Rattlesnake Creek episode
Late Middle to early Late Jurassic
(Callovian to Oxfordian) time (~164 Ma)

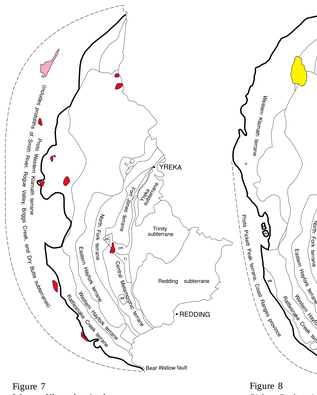


Figure 7
Western Klamath episode
Late Jurassic (Late Kimmeridgian or
early Tithonian) time (~150–2 Ma)

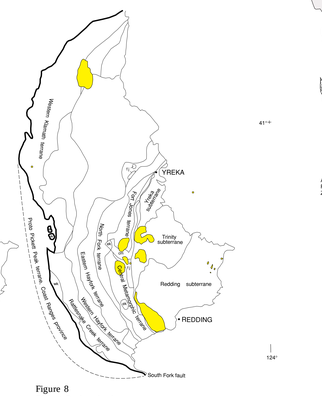


Figure 8
Pickett Peak episode
Early Cretaceous time
(~140–5 Ma)

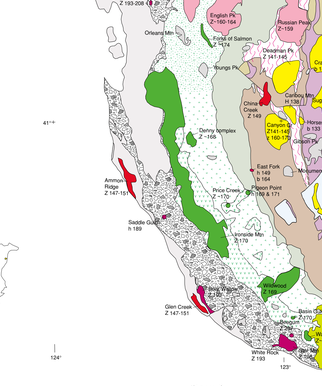


Figure 9
Present time
Geology modified from Irwin (1994)

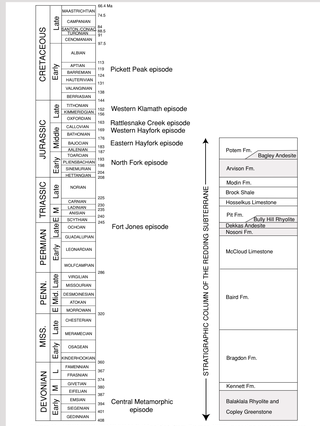


Figure 11. GEOLOGIC TIME SCALE (Modified from Palmer, 1983), showing the approximate timing of the sequential accretionary episodes that formed the Klamath Mountains of California and Oregon. The generalized stratigraphic column of the Redding subterrane is shown for comparison. The dominantly volcanic formations are shaded. The possibly Silurian part of the Copley Greenstone is not shown.

INTRODUCTION

The Klamath Mountains consist of various accreted terranes and include many plutons that range in composition from gabbro to granodiorite. Some of the plutons (preaccretionary plutons) were parts of terranes before the terranes accreted; others (accretionary plutons) intruded during or after the accretion of their host terrane(s). This report attempts to (1) graphically illustrate how the Klamath Mountains grew by the accretion of allochthonous oceanic terranes during early Paleozoic to Cretaceous times, (2) identify the plutons as either preaccretionary or accretionary, and (3) genetically relate the plutonic intrusions to specific accretionary episodes.

The eight accretionary episodes portrayed in this report are similar to those shown by Irwin and Mankinen (1998) who briefly described the basis for the timing of the episodes and who illustrated the ~110 degrees of clockwise rotation of the Klamath Mountains since Early Devonian time. Each episode is named for the accreting terrane. In all episodes (Figs. 1-8), the heavy black line represents a fault that separates the accreting oceanic rocks on the left from earlier accreted terranes on the right. The preaccretionary plutons are shown within the accreting oceanic crustal rocks to the left of the heavy black line, and the accretionary plutons in most instances are shown intruding previously accreted terranes to the right. Episodes earlier than the Central Metamorphic episode (Fig. 1), and that may have been important in the formation of the early Paleozoic nucleous of the province (the Eastern Klamath terrane), are not known. Also not described in the sequential Figures 1 to 8 are the May Creek and Condrey Mountain terranes. The Present Time distribution of the accreted terranes and plutons is shown at a large scale in Figure 9.

The schematic vertical section (Fig. 10) depicts the terranes as a stack of horizontal slabs that include or are intruded by vertical plutons. All of the slabs are shown as extending to the right-hand edge of the schematic section, but this is not meant to imply that there is evidence that the structurally lower slabs extend to beneath the eastern limits of the uppermost slabs. Note that at their base the ~170 Ma preaccretionary plutons of the Western Hayfork subterrane are truncated by the ~164 Ma Salt Creek accretionary fault, the ~160 Ma accretionary plutons are truncated by the ~150 Ma Bear Wallow accretionary fault, and the ~150 Ma accretionary plutons (and questionably the Grants Pass ~139 Ma accretionary pluton) are truncated by the ~120 Ma South Fork fault.

The isotopic ages shown for the plutons are mostly from various published sources (see LIST OF PLUTONS). Most are U/Pb ages measured on zircon, which are thought to most reliably represent the crystallization ages of the plutons. Isotopic ages measured on hornblende, biotite, or plagioclase by other methods are used where U/Pb ages are not available. R. W. Kistler generously provided a 80-Sr isotopic age for Castle Crags pluton. New U/Pb isotopic ages for this study were measured on zircon from five plutons by J. L. Wooden. Many small plutons in the Klamath Mountains are not isotopically dated.

The Eastern Klamath terrane, which consists of the Redding, Trinity, and Yreka subterranes, was the backstop to subsequent accreting terranes. The stratigraphy of the Redding subterrane is a remarkable record of sedimentation, volcanism, and plutonism from Silurian-Devonian to Jurassic time, and is the longest span of time of virtually continuous stratigraphy of any terrane in the Klamath Mountains. Notably, the principal volcano-plutonic units of the Redding subterrane are fluvially connected in time with accretionary episodes, which suggests that the accretionary episodes caused coeval volcanism and plutonism in the Redding subterrane. The Copley Greenstone-Balaklala Rhyolite volcanics, intruded by the coeval Mule Mountain pluton, are correlated with the Central Metamorphic episode: the Dekkas Andesite-Bully Hill Rhyolite volcanics and Pit River stock (and Redding dike) probably correlate with the Fort Jones episode; and the Arvison-Bagley Andesite volcanics and Hosselkus Limestone-Modin Mountain intrusives correlate with the North Fork episode (see Fig. 11). Both the early Paleozoic Balaklala Rhyolite and the late Paleozoic Bully Hill Rhyolite were hosts to important base-metal sulfide deposits. Note that the Redding stratigraphic column spans from Silurian-Devonian to Middle Jurassic time (Fig. 11). During this ~220 m.y. life-span as an intermittently active volcanic arc the Redding subterrane was intruded by early to late granitoid plutons, the Mule Mountain stock (400 Ma) and Pit River stock (260 Ma), and several smaller intrusives (Fig. 9). It was later that the large Cretaceous granitoids such as Shasta Bally batholith (136 Ma) intruded the Redding and other subterranes.

THE ACCRETIONARY EPISODES

Central Metamorphic episode (Fig. 1)–Protoliths of the Central Metamorphic terrane were subducted beneath the Eastern Klamath terrane. The Eastern Klamath terrane was the nucleus of the Klamath Mountains in Silurian-Devonian time and consisted of the Redding, Trinity, and Yreka subterranes. During the Central Metamorphic episode, the Redding subterrane developed as a Silurian-Devonian volcanic arc, built on peridotitic upper mantle of the Trinity subterrane. [Alternatively, Wallin and Metcalf (1998) consider these rocks a supra-subduction zone ophiolite]. The volcanic rocks of the arc are Copley Greenstone and Balaklala Rhyolite (gray area, Fig. 1). They were intruded by a cogenetic granitoid pluton, the Mule Mountain stock (Z~400 Ma). Several large gabbroic plutons and complexes intrude the peridotite of the Trinity subterrane. They range from Z 433 to 404 Ma and probably represent the roots of the volcanic arc. Magma for the plutonism and volcanism probably was generated by subduction of oceanic crust along the Bully Choop thrust fault. The rocks of the lower plate of the fault were metamorphosed to hornblendic and micaceous schists of the Central Metamorphic terrane and yield isotopic ages ranging from Rb/Sr 380 Ma (Lanphere and others,1968) to K-Ar 390-399 Ma (Hotz, 1977). These Devonian metamorphic ages, which are somewhat younger than the crystallization ages of the relevant Silurian-Devonian plutons, may reflect the difference in dating method or that the sampled schistose rock represents a late phase of the subduction. The Yreka subterrane, which also lies above the Trinity subterrane, is though by Wallin and Metcalf (1998) to be mainly early Paleozoic trench-forearc sedimentary basin deposits. It includes the Skookum Gulch melange which contains exotic large blocks of granitoid plutonic rock (Z~567Ma) of unknown provenance (Wallin, 1990).

Fort Jones episode (Fig. 2)–The Eastern Klamath and and Central Metamorphic terranes overrode a subduction complex along the proto Siskiyou fault and and its northern extensions, forming the Fort Jones (aka Stuart Fork) terrane. South of Deadman Peak pluton, the Fort Jones terrane is exposed only in an antiformal window in Central Metamorphic terrane. Note the small structural outliers (ek) of Eastern Klamath terrane resting on Central Metamorphic terrane. The age of the Fort Jones terrane is not clearly known. Fossils are not found except for vestiges of radiolarians in some of the least metamorphosed chert. Whole-rock samples yielded K-Ar isotopic ages of 133 and 158 Ma (Lanphere and others, 1968). K-Ar isotopic ages of ~220 Ma (Late Triassic) were measured on blueschist facies metamorphic rocks in the northern part of the Fort Jones terrane (Hotz and others, 1977), but these and especially the younger K-Ar ages are suspect. No preaccretionary plutons are recognized in the accreting rocks. The oldest pluton intruding the Fort Jones terrane is the Russian Peak pluton (Z~159 Ma). However, in Redding subterrane the accretionary Pit River stock (Z 260 Ma) intrudes Baird Fm (Miss.-Penn.), and a chain of irregular linear intrusions of quartz-augite diorite, the Redding dike of Hinds (1933), extends northward 15 or more miles (Fig. 9). The Redding dike intrudes mostly along the contact between the Baird Fm and McCloud Limestone, locally engulfing the McCloud Limestone and locally intruding the Nosoni Fm and Dekkas Andesite (Hinds, 1933). Although not isotopically dated, the Redding dike is evidently Permian or younger and may well be the feeder for the Nosoni-Dekkas-Bully Hill (Permian-Triassic(?)) volcanic formations (gray area, Fig. 2). The age of the Fort Jones accretionary episode was originally considered Late Triassic based on the ~200 Ma K-Ar isotopic age of the blueschist (Irwin and Mankinen, 1998). However, the episode is herein considered Permian-Triassic(?) based on a probable coeval relation with the Pit River- Redding dike intrusives and the Nosoni-Dekkas-Bully Hill volcanics of the Redding subterrane.

North Fork episode (Fig. 3)–Protoliths of the North Fork terrane were overridden along the Siskiyou and correlative faults by the Fort Jones, Central Metamorphic, and Eastern Klamath terranes. Note that south of Deadman Peak pluton the Fort Jones terrane is exposed only through an antiformal window in Central Metamorphic terrane (Figs. 3 and 9). The protoliths of the North Fork terrane were a subduction complex that included dismembered ophiolite, mafic volcanic and sedimentary rocks, radiolarian chert, and minor limestone. They range from late Paleozoic to Jurassic. The youngest fossiliferous rocks are radiolarian chert of Early Jurassic (Pliensbachian) age (Blome and Irwin, 1983), which is the basis for the approximate age of 198-193 Ma assigned to the North Fork accretionary episode. The North Fork terrane contains no evident preaccretionary plutons, but is intruded by several large ~160 Ma plutons related to a younger (Rattlesnake Creek) accretionary episode. However, in the Redding subterrane, abundant andesitic volcanic rocks of the Arvison Fm and Bagley Andesite are present (gray area, Fig. 3) in the lower Jurassic part of the stratigraphic section and are correlative in time with the North Fork episode (see Fig. 11). According to Renne (1987), some of the rocks considered to be Bagley Andesite by early geologists are actually small stocks of diorite to quartz diorite. He assigned some to the Hog Mountain suite, which yield K-Ar isotopic ages of ~167 Ma (plagioclase), and others to the Kettle Mountain suite, which yield K-Ar isotopic ages of 120-130 Ma (plagioclase). These small plutons may well be coeval with the geographically associated Arvison Fm and Bagley Andesite but because of their isotopic ages, although suspect, they are shown tentatively as accretionary plutons of later episodes (Figs. 5 and 8).

Eastern Hayfork episode (Fig. 4)–Protoliths of the Eastern Hayfork subterrane were subducted beneath the North Fork terrane along the Twin Sisters and correlative faults. The protolith was a melange of oceanic rocks including minor serpentinite, mafic volcanic and sedimentary rocks, radiolarian chert, limestone, and scattered blocks of schist. Fossils in the chert and limestone are mainly Late Permian and Triassic. Some is clearly Jurassic. Some of the Late Permian fossils are of Tethyan faunas that are unknown to most of North America. The age of the accretionary episode is poorly constrained and is estimated to be ~180 Ma (~Bajocian), approximately midway between the preceeding and following episodes. No plutonism for this episode is recognized.

Western Hayfork episode (Fig. 5)–Protoliths of the Western Hayfork subterrane were subducted beneath the Eastern Hayfork subterrane along the Wilson Point and correlative faults. The protoliths were a volcanic arc consisting mainly of the Hayfork Bally Meta-andesite and the Ironside Mountain batholith and other cogenetic plutons. These preaccretionary rocks range in isotopic ages from 168 to 177 Ma (Fahan, 1982; Lanphere and others, 1968; Wright, 1981), the youngest of which is assumed to approximate the age of subduction. The Denny Complex presumably is accretionary in the Eastern Hayfork subterrane. In the central and northern parts of the Klamath Mountains, the Eastern Hayfork and Western Hayfork terranes are not clearly distinguished and are shown together as undivided Hayfork terrane (see Figs. 9 and 10). As previously mentioned in Figure 3, the Hoghack Mountain suite of small plutons (p 166 and 167 Ma) is here shown in the Jurassic strata of the Redding subterrane and, if the isotopic ages are correct, would be considered accretionary plutons of the Western Hayfork episode.

Rattlesnake Creek episode (Fig. 6)–Protoliths of the Rattlesnake Creek terrane were subducted beneath the Western Hayfork subterrane along the Salt Creek and correlative faults. The protoliths were a melange of mainly ophiolitic rocks, bodies of limestone, radiolarian chert, minor blocks of amphibolite, and Early Jurassic (~200 Ma) preaccretionary plutons. The limestone and chert contain late Paleozoic, Triassic, and Early to Middle Jurassic fossils. The chert is mostly Late Triassic and Early to Middle Jurassic, some of which may be as young as Bathonian. The time of subduction is broadly constrained to Callovian-Oxfordian (~164 Ma) by Middle Jurassic fossils and by ~160 Ma accretionary plutons that cut the subduction zone fault.

Western Klamath episode (Fig. 7)–Protoliths of the Western Klamath terrane were subducted beneath the Rattlesnake Creek terrane along the Bear Wallow and correlative faults. They consisted mainly of the Josephine ophiolite, the Rogue and Galice formations, and several other subterranes. A volcanogeplagic section directly overlying Josephine ophiolite, beneath Galice Fm, contains late Callovian and early Oxfordian [~163 Ma ?] radiolarians (E. A. Pessagno, oral comm., 1990). Shelly fossils in Galice Fm are Oxfordian and Kimmeridgian [~163-152 Ma?]. Zircon from tuff breccia in Rogue Fm yielded a Pb/U isotopic age of 157 Ma (Saleeby, 1984). The Summit Valley pluton, which yielded a Pb/U zircon age of 150-2 Ma, cuts both plates of the thrust fault that separates the Galice Fm from the overlying Rattlesnake Creek terrane (Harper and others, 1994). The age of the Western Klamath episode is constrained to late Kimmeridgian or early Tithonian (150-2 Ma). Note that the subdivisions of the Western Klamath terrane (the Smith River, Rogue Valley, Dry Butte, and Briggs Creek subterranes), and the Onion Mountain complex of Yule (1996) are not distinguished in Figures 7 and 9. The Chetco Complex (Z 155-160 Ma) is preaccretionary relative to the Western Klamath episode.

Pickett Peak episode (Fig. 8)–Protoliths of the Pickett Peak terrane were subducted beneath the Western Klamath terrane along the South Fork and correlative faults. The Western Klamath terrane overrode westward the Franciscan(?) sedimentary and volcanic rocks along the South Fork fault, forming the South Fork Mountain Schist and Chinquapin Metabasalt of the Pickett Peak terrane of the California Coast Ranges. Structural outliers of correlative schist (Colebrooke Schist) lie west of the Klamath Mountains in the Coast Ranges of Oregon. The isotopic (K-Ar) age of the South Fork Mountain Schist is ~120-115 Ma (Lanphere and others, 1978), but a metamorphic episode that age is too young to have generated the ~140 Ma plutons. Thus the K-Ar isotopic age is suspect and the Pickett Peak episode is tentatively considered early Early Cretaceous (~140-5 Ma). Alternatively, the ~140 Ma plutons may represent either a late phase of the Western Klamath episode or an unrecognized accretionary episode.

LIST OF PLUTONS

Name	Isotopic age (Ma)	Reference
Ammon Ridge	Z 147-151	Wright and Fahan, 1988
Ashland	Z ~161	Yule, 1996
Basin Gulch	Z 170	Wright and Fahan, 1988
Bear Mtn complex	Z 149 & 153	Saleeby and Harper, 1993
Bear Wallow	Z 193	Wright, 1981
Bergern	Z 207	Wright, 1981
Bonanza King	Z 431	Wallin and Metcalf, 1998
Buckskin Peak	H 148	Harper and others, 1994
Canyon Creek	Z 141-145; 160-170	Wright and Fahan, 1988
Caribou Mountain	H 138	Hacker and Ernst, 1993
Castle Crags	R 162.5	R. W. Kistler, pers. commun, 1999
Chetco complex	Z ~155-160	Yule, 1996
China Creek	Z 149	J. L. Wooden, This report
China Mountain	Z 415	Wallin and Metcalf, 1998
Coon Mtn complex	Z 142 &145	Saleeby and others 1982; Harper and others,1994
Craggy Peak	h 136	Lanphere and others, 1968
Craggy Peak gabbro	H 418 & 439	Lanphere and others, 1968
Deadman Peak	Z 141-145	Wright and Fahan, 1988
Denny complex	Z 168	Wright and Fahan, 1988
East Fork	h 149; h 164	M. A. Lanphere, in Irwin, 1985
English Peak	Z ~160-164	Wright and Fahan, 1988
Forks of Salmon	Z 174	Wright and Fahan, 1988
Gibson Peak	No date	
Glenn Creek	Z 147-151	Wright and Fahan, 1988
Gold Hill	Z 148	J. L. Wooden, This report
Granite Peak	No date	
Grants Pass	Z 139	Harper and others, 1994
Greyback	Z~160	Yule, 1996
Heather Lake	H 167	Hacker and Ernst, 1993
Hoghack Mountain	p~167	Renne, 1987
Horseshoe Lake	h 133	Evernsd and Kistler, 1970
Ironside Mountain	Z 170	Wright and Fahan, 1988
Jacksonville	Z 154	J. L. Wooden, This report
Kettle Mountain	p~120-130	Renne, 1987
Monument Peak	No date	
Mule Mountain	Z 400	Albers and others, 1981
Orleans Mountain	No date	
Pigeon Point	h 169 &171	Wright and Fahan, 1988
Pit River	Z 260	Fraticelli and others, 1985
Pony Peak	Z 146	Saleeby and Harper, 1993
Porcupine Lake	Z 404	Wallin and Metcalf, 1998
Price Creek	Z 170	Wright and Fahan, 1988
Russian Peak	Z~159	Wright and Fahan, 1988
Saddle Gulch	h 189	M. A. Lanphere, in Irwin, 1985
Shasta Bally	Z 136	Lanphere and Jones, 1978
Shelly Lake	No date	
Skookum Gulch	Z~567	Wallin ,1990
Slinkard	Z 162	Saleeby and Harper, 1993
Somes Bar	Z 193-208	Gray, 1985
Squaw Mountain	Z 174	J. L. Wooden, This report
Star Mountain	Z 198	Wright, 1981 [PCGK]
Sugar Pine	h 137	Lanphere and others, 1968
Summit Valley	Z 150	Saleeby and Harper, 1993
Thompson Ridge	Z 162	Yule, 1996
Vesa Bluffs	H 165	Hacker and Ernst, 1993
Walker Point	Z 169	Wright and Fahan, 1988
White Rock (OR)	Z 156	J. L. Wooden, This report
White Rock (CA)	Z 193	Wright, 1981 [WR-1]
Wildwood	Z 169	Wright and Fahan, 1988
Winer	Z~160	Yule, 1996
Wooley Creek	Z 162	Saleeby and Harper, 1993
Yellow Butte	h 138	Hotz, 1971

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PLUTONS AND ACCRETIONARY EPISODES OF THE KLAMATH MOUNTAINS, CALIFORNIA AND OREGON

By WILLIAM P. IRWIN and JOSEPH L. WOODEN

1999