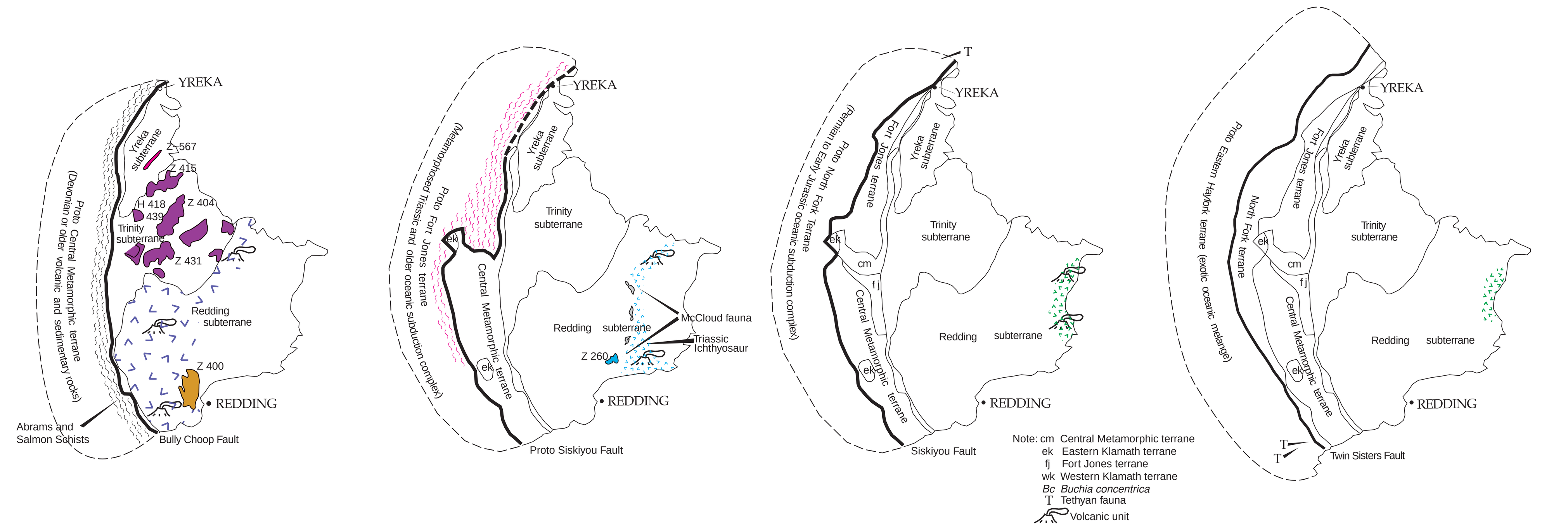
CORRELATION OF THE KLAMATH MOUNTAINS AND SIERRA NEVADA

Sheet 2: Successive accretionary episodes of the Klamath Mountains and northern part of Sierra Nevada, showing related plutonic, volcanic, and metamorphic events

By William P. Irwin

2003



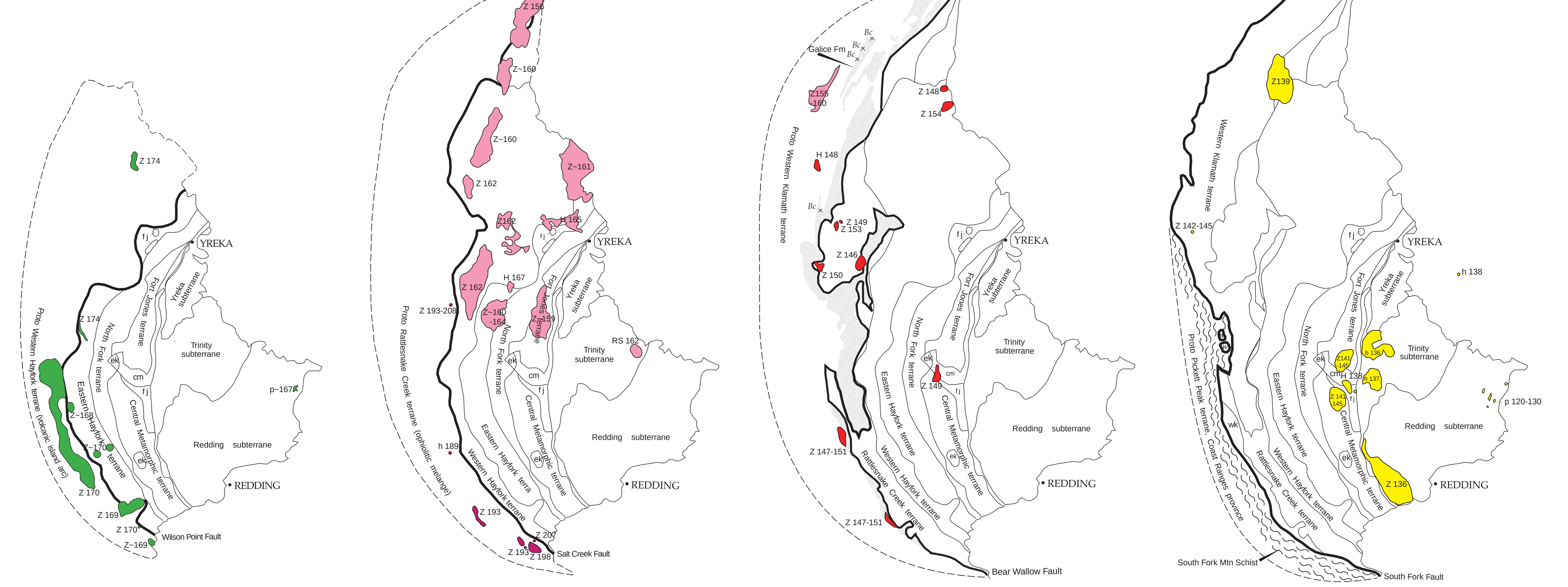


Figure 1. Central Metamorphic episode Late Silurian(?) to Devonian time

Figure 2. Fort Jones Episode Permian–Triassic time

Figure 3. North Fork episode Early Jurassic time

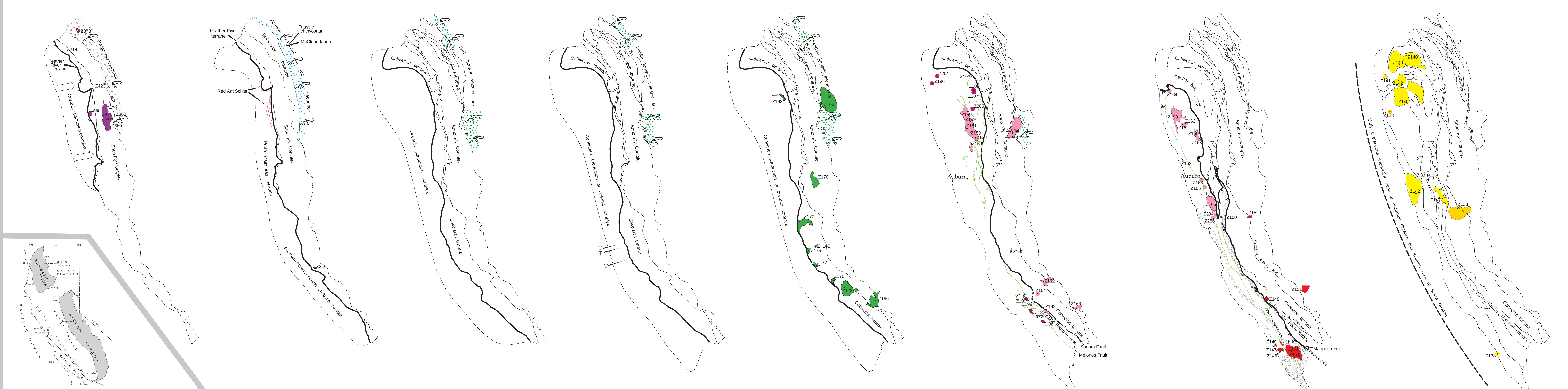
Figure 4. Eastern Hayfork episode early(?) Middle Jurassic (~Bajocian) time

Figure 5. Western Hayfork episode late Middle Jurassic (Bathonian to early Callovian) time

Figure 6. Rattlesnake Creek episode late Middle to early Late Jurassic (Callovian to early Oxfordian) time

Figure 7. Western Klamath episode Late Jurassic (late Kimmeridgian to early Tithonian) time (~150 Ma)

Figure 8. Separation episode Early Cretaceous time (~140 Ma to ~120 Ma)



Index map showing present geographic alignment of the Klamath Mountains and the Sierra Nevada. The figures shown in the succession of accretionary episodes are misaligned for illustrative convenience.

INTRODUCTION

This report graphically portrays the broadly parallel tectonic development of the Klamath Mountains and Sierra Nevada from early Paleozoic to Early Cretaceous time. It is dedicated to J.S. Diller of the U.S. Geological Survey who, during his pioneer field studies a century ago, recognized significant similarities between these two important provinces. The report is based mainly on the numerous published reports of the field and laboratory studies by various geologists and students during the last century, and to a lesser extent on my own field work which has been substantial in the Klamath Mountains but minimal in the Sierra Nevada. For brevity, required by the format of this report, little of the extensive literature pertaining to these two provinces is referenced. This report is preliminary in nature and was prepared as an aid to further study of the tectonic relations between the Klamath Mountains and Sierra Nevada.

This report consists of two sheets: Sheet 1, *Map showing accreted terranes and plutons of the Klamath Mountains and Sierra Nevada,* and Sheet 2, *Successive accretionary episodes of the Klamath mountains and northern part of Sierra Nevada, showing related plutonic, volcanic, and metamorphic events.* The map on Sheet 1 was compiled and modified from two Open-File maps (Irwin and Wooden, 1999 and 2001) which had been compiled and modified mainly from Jennings (1977), Harwood (1992), Irwin (1994), Jayko (1988), Graymer and Jones (1994), Edelman and Sharp (1989), Schweickert and others (1999), Saucedo and Wagner(1992), Saleeby and Sharp (1980), Wagner and others (1981), and various other sources. For detailed lists of the sources for the isotopic age data used in Sheets 1 and 2, see Irwin and Wooden (1999 and 2001).

On Sheet 2, the accretionary episodes are shown sequentially from left to right in two tiers of figures. Episodes for the Klamath Mountains are in the upper tier; correlative episodes of the Sierra Nevada are directly below in the lower tier. The sequence shown for the Klamath Mountains is modified from Irwin and Mankinen (1998) and Irwin and Wooden (1999). The episodes are named for the accreting terranes of the Klamath Mountains, but those names may not be suitable for reference to the correlative episodes of the Sierra Nevada. In the figure for each episode, a heavy black line represents the active suture that separated oceanic crustal rocks on the left from the earlier accreted terranes on the right.

Plutons are particularly useful for timing the accretionary episodes. The preaccretionary plutons, which commonly represent the roots of oceanic volcanic arcs, are shown in the accreting oceanic crustal rocks to the left of the heavy black line. The accretionary plutons consist of rock that has been subducted and remobilized as magma during the accretionary process and injected into an overlying earlier accreted terrane on the right of the heavy black line. Thus, isotopic dating of the accretionary plutons (preferably U/Pb dates measured on zircon extracted from the plutonic rock) provides a useful basis for assigning ages to the accretionary episodes. Many plutons are rootless at depth, as they tend to be truncated by the subduction zone sutures of younger accreting terranes.

Volcanic deposits resulting from accretionary episodes apparently are uncommon except for those deposited on the backstop terranes. In the Klamath Mountains, the Eastern Klamath terrane, which consists of the Yreka, Trinity and Redding subterranes, was the backstop for the Central Metamorphic and younger accretionary episodes, and displays a remarkable record of sedimentation, volcanism and plutonism from Silurian-Devonian to Jurassic time. In the Sierra Nevada, the correlative backstop was the Northern Sierra terrane which shows a similar long record of volcanism in the Taylorsville, Permian, and Jurassic volcanic arc sequences.

During some accretionary episodes the subducting oceanic rocks were dynamically metamorphosed to schist along the suture zone beneath the overriding accreted terranes. Examples of this in the Klamath Mountains are the Devonian Salmon and Abrams Schists of the Central Metamorphic terrane, the Triassic(?) schist of the Fort Jones terrane , and the Early Cretaceous South Fork Mountain Schist that structurally underlies Klamath Mountains terranes along much of the western edge of the province. The Fort Jones terrane and South Fork Mountains Schist were metamorphosed under blueschist-facies conditions. In the Sierra Nevada, schist that is correlative with the Central Metamorphic terrane is present in patches along the Feather River terrane (see Hacker and Peacock, 1990); the Triassic(?) Red Ant Schist is correlative with the Fort Jones terrane; but a correlative of the South Fork Mountain Schist is not present.

In addition to the similarities in the sequences of accretion, plutonism, volcanism, and metamorphism, strong ties between the two provinces are also provided by paleontologic data. The Permian McCloud fusulinid fauna of the Redding subterrane also is present in the Northern Sierra terrane. Rare Tethyan fusulinids are found in Permian limestone of the Eastern Hayfork terrane of the Klamath Mountains and also in limestone blocks in the Central Belt of the Sierra Nevada. Ichthyosaur fossils have been collected from the Triassic of both the Redding subterrane and Northern Sierra terrane. Jurassic ammonites and the pelecypod *Buchia concentrica* occur in both the Galice Formation of the western Klamath Mountains and the Mariposa Formation of the western Sierra Nevada.

Events that preceded the Central Metamorphic episode prior to Silurian-Devonian time are not clearly understood and are not shown in the succession of diagrams on Sheet 2. The oldest rocks of the Klamath Mountains are Neoproterozic and they predate the Central Metamorphic episode by possibly a hundred million years or more. They include ophiolitic rocks of the Trinity subterrane and the Antelope Mountain Quartzite of the Yreka subterrane (see Mankinen and others, 2002). In the Sierra Nevada, correlatives of the ancient ophiolitic rocks may be part of the Feather River terrane. Although Neoproterozoic fossils have not yet been found in the Sierra Nevada, petrologic study shows the quartzite of the Lang sequence is closely similar to the Antelope Mountain Quartzite (see Bond and Devay, 1980). Correlation of the two quartzite formations is also suggested by the similarity of their positions in the accretionary sequence.

CENTRAL METAMORPHIC EPISODE

The Eastern Klamath terrane, consisting of the Yreka, Trinity, and Redding subterranes, was the nucleus of the Klamath Mountains during Silurian-Devonian time. During the Central Metamorphic episode, the oceanic crustal protoliths (schist pattern) of the Central Metamorphic terrane, including metabasites representing MORB (Barrow and Metcalf, 2002), were subducted beneath the Klamath nucleus. Remobilization of the subducted rocks resulted in gabbroic intrusions (Z 431-401 Ma) into the peridotitic Trinity subterrane and, at a higher level, the development of a volcanic arc (purple volcanic pattern) represented by the Copley Greenstone and Balaklala Rhyolite of the Redding subterrane. The volcanic rocks are intruded by a cogenetic granitoid pluton, the Mule Mountain stock (Z~400 Ma). The schists of the Central Metamorphic terrane yield Devonian isotopic metamorphic ages (Rb/Sr 380 Ma: K-Ar 390-399 Ma) that are somewhat younger than the relevant Silurian-Devonian plutons: This may reflect the difference in dating method, or the sampled schists may represent a late stage of subduction. The oldest granitoid rocks (Z 567 Ma) in the Eastern Klamath terrane are exotic blocks of unknown provenance in the Skookum Gulch melange of the Yreka subterrane and are too old to have been generated by the Central Metamorphic episode.

The Northern Sierra terrane is broadly correlative with the Eastern Klamath terrane; the Feather River terrane representing the Trinity subterrane, the Shoo Fly Complex representing the Yreka subterane, and the Taylorsville sequence representing the Redding subterrane. Only a few remnants of schist thought equivalent to the Central Metamorphic terrane are found locally along the length of the Feather River terrane (shown schematically on Fig. 1). Accretionary plutons in Sierra Nevada are the Bowman Lake batholith (Z409-385 Ma), which intrudes the Shoo Fly Complex, and the Wolf Creek stock (Z~378 Ma) which intrudes the Sierra Buttes Fm. (A discrepancy between the paleontologic age of the Sierra Buttes Fm. and the isotopic age of the Wolf Creek stock is discussed by Harwood, 1992). The Sierra Buttes Fm., a Devonian volcanic unit generated by this eposide, is in the lower part of the Taylorsville sequence and is depositional in places on the Shoo Fly Complex though locally underlain by the Grizzly Fm. Associated volcanic units above the Sierra Buttes are the Taylor Fm. and the lower member of the Peale Fm. which range into Early Mississippian in age.

FORT JONES EPISODE

Oceanic crustal protoliths of the Fort Jones (aka Stuart Fork) terrane (red schist pattern) were subducted beneath the Central Metamorphic and Eastern Klamath terranes. The age of the Fort Jones terrane is not known paleontologically. Only vestiges of radiolarians are found in some of the least metamorphosed chert. Blueschist facies rocks in the northern part of the terrane yielded K-Ar isotopic ages of ~220 Ma (Hotz and others,1977). No preaccretionary plutons have been found in the accreting rocks. The oldest pluton that intrudes 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 several irregular linear intrusions of quartz-augite diorite (the "Redding dike" of Hinds, 1933) extends northward 15 or more miles. The "Redding dike" intrudes mostly along the contact between the Baird Fm and the McCloud Limestone, locally engulfing the McCloud Limestone and locally intruding the Nosoni Fm and Dekkas Andesite (Hinds, 1933). The "Redding dike" is evidently Permian or younger, and may well be the feeder for the Nosoni-Dekkas-Bully Hill (Permian-Triassic(?)) volcanic formations (blue pattern). Although the Fort Jones episode originally was considered Triassic because of the isotopic age of the blueschist (Irwin and Mankinen, 1998), It is herein regarded as Permian-Triassic(?) because accretion of the Fort Jones terrane probably caused the Pit River stock and"Redding dike" intrusions as well as the Nosoni-Dekkas-Bully Hill volcanic sequence of the Redding subterrane.

In the Sierra Nevada, the accreting oceanic rocks were metamorphosed to the Triassic(?) Red Ant Schist (red schist pattern). Whether the Red Ant Schist developed beneath a substantial slab of early Paleozoic schist such as the Central Metamorphic terrane is not clear, as only small amounts of the early schist are found along the Feather River terrane (see Hacker and Peacock, 1990). Furthermore, the present distribution of the Red Ant Schist is perplexing because much of it now appears to be in the eastern part of the Feather River terrane rather than west of it as shown diagramatically in Figure 2. Perhaps both the paucity of outcrop of the early schist and present position of the Red Ant Schist are the result of substantial post-accretion tectonic dislocations.

Plutons related to the Fort Jones episode are not evident in the Northern Sierra terrane. However, volcanism is represented by the Permian volcanic arc sequence (blue volcanic pattern) which includes the Arlington, Goodhue, and Reeve Formations, and which unconformably overlies the Taylorsville sequence. Other correlative features of this general time frame include the Permian fusulinid fauna of the McCloud Limestone of the Redding subterrane, which is also found in the Reeve Fm and Soda Ravine unit of the Northern Sierra terrane. Triassic ichthyosaur fossils are found in the Hosselkus Limestone of the Redding subterrane and also in the Hosselkus Limestone and Soda Ravine unit of the Northern Sierrra terrane.

NORTH FORK EPISODE

Oceanic crustal protoliths of the North Fork terrane were accreted to the Fort Jones and earlier terranes of the Klamath Mountains. The protoliths included ophiolite, sedimentary and mafic volcanic rocks, radiolarian chert and minor limestone, and ranged from Paleozoic to Jurassic. The youngest was radiolarian chert of Early Jurassic (Pliensbachian) age (Blome and Irwin, 1983), which is the principal basis for the approximate age assigned to this episode. No plutons clearly related to this episode are known. However, abundant volcanic rocks (green pattern) of the Arvison Fm and Bagley Andesite in the Lower Jurassic of the Redding subterrane are correlative with the North Fork episode. According to Renne (1987), some rocks earlier considered to be Bagley Andesite are actually small stocks of diorite to quartz diorite. He assigned some of these to the Hog Mountain suite of plutons (K-Ar on plagioclase; 166 and 167 Ma) and others to the Kettle Mountain suite (K-Ar on plagioclase; 120-130 Ma). These small plutons may well be coeval with the geographically associated Arvison and Bagley, but although their K/Ar isotopic ages are herein considered to be anomalously young and may possibly be related to later episodes.

In the Sierra Nevada, accretionary plutons related to the North Fork episode have not been recognized. However, andesitic volcanic rocks (green pattern) related to the North Fork episode occur in the Sailor Canyon Fm and in the Mount Jura and Kettle Rock sequences of the Northern Sierra terrane.

EASTERN HAYFORK EPISODE

Protoliths of the Eastern Hayfork subterrane were subducted beneath the North Fork terrane along the Twin Sisters and correlative faults. The protoliths were a melange of oceanic rocks consisting of minor serpentinite, sedimentary and volcanic rocks, chert, limestone, and scattered blocks of schist. Fossils in the chert and limestone are mainly Late Permian and Triassic. None is clearly Jurassic. Some of the Late Permian fossils are of Tethyan faunas (noted by T symbol) that are unknown in most of North America. The age of the accretionary episode is poorly constrained and is estimated to be ~180, approximately midway between the preceding and following episodes. Accretionary plutons related to the Eastern Hayfork episode are unknown in the Klamath Mountains. However, volcanism related to the episode may be represented by the Potem Fm (green pattern) which is the highest stratigraphic unit of the Redding subterrane. The Potem Fm includes tuffaceous sandstone and coarse pyroclastic beds and is late Pliensbachian to early Bathonian in age.

In the Sierra Nevada, accretionary plutons of this age are not known. Some limestone blocks in melange of the Central belt contain Permian fusulinids of Tethyan faunal affinity which are shown here to indicate correlation of the Central belt probably includes some rocks equivalent to the Eastern Hayfork terrane. Andesitic volcanism continued in the Jurassic volcanic arc of the Northern Sierra terrane during this episode.

WESTERN HAYFORK EPISODE

Protoliths of the Western Hayfork subterrane were a volcanic arc that was accreted to the Eastern Hayfork subterrane along the Wilson Point and correlative faults. The arc consisted of Hayfork Bally Meta-andesite and of cogenetic plutons (solid green) including the Ironside Mountain batholith. These preaccretionary plutons range from 177 to 168 Ma in isotopic age, the youngest of which is assumed to approximate the time of accretion. The Denny Complex presumably is accretionary in the Eastern Hayfork terrane. In the central and northern parts of the Klamath Mountains, the Eastern Hayfork and Western Hayfork subterranes are not clearly distinguished and are shown together as undivided Hayfork terrane. As previously noted, the Hogback Mountain suite of small plutons (K-Ar 167 and 166 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.

In the Sierra Nevada, accretionary plutons (solid green) of the Western Hayfork episode are numerous, intruding the Calaveras terrane, and the Shoo Fly Complex and Jurassic volcanic arc (green pattern) of the Northern Sierra terrane. Some of these plutons are cut by the Melones and Calaveras-Shoo Fly faults. The accretionary Haypress Creek pluton (Z 166 Ma) intrudes the Sailor Canyon Fm which is early Bajocian and older Jurassic in age. Overlying the Sailor Canyon Fm is the volcanic-rich and slightly younger Jurassic Tuttle Lake Fm., which together with the Jurassic volcanic arc includes dominantly andesitic volcanic rocks of the Mount Jura and Kettle Rock sequences. The Scales pluton (Z 168 Ma), shown west of the accretionary suture, intruded upward from the Fiddle Creek complex (upper Paleozoic to Jurassic (?)) into an overthrust plate of the Lower Jurassic Slate Creek complex (Saleeby and others, 1989), thereby establishing a minimum age for the amalgamation of the Fiddle Creek and Slate Creek complexes.

RATTLESNAKE CREEK EPISODE

The Rattlesnake Creek terrane of the Klamath Mountains and the Central belt of the Sierra Nevada are similar complexes that indicate substantial tectonic disruption of the oceanic crustal and volcanic arc rocks west of the accretionary suture. Both complexes include dismembered ophiolite, slabs of mafic volcanic and sedimentary formations, radiolarian chert, minor limestone, and blocks of amphibolite. In the Sierra Nevada, the Central belt has been mapped as eight or more individual terranes (see Sheet 1). Both complexes contain Permian,Triassic, and Early and Middle Jurassic fossils. Both complexes include preaccretionary ~200 Ma plutons.

Protoliths of the Rattlesnake Creek terrane were subducted beneath the Western Hayfork subterrane along the Salt Creek and correlative faults. Fossils in the limestone range from late Paleozoic to Triassic. Those in chert are mostly Triassic and Early to Middle Jurassic, some of which may be as young as Bathonian. During the accretionary episode, many large ~160 Ma plutons intruded the Western Hayfork and other structurally higher terranes, including the Trinity Complex. The time of accretion is broadly constrained to Callovian-Oxfordian (~160 Ma) by the Middle Jurassic fossils, and by the abundance of ~160 Ma accretionary plutons.

In the Sierra Nevada, the central belt includes many small oceanic volcanic arc terranes of probable Triassic and Early Jurassic age, ophiolitic rocks, rare Carboniferous and Permian limestone, chert containing Late Triassic and Early Jurassic radiolarians, and small Early Jurassic (~200 Ma) preaccretionary intrusions. In the southern part of the belt the ~200 Ma plutons intrude the Jasper Point and Penon Blanco Fms (Saleeby, 1982). As in the Klamath Mountains the ~160 Ma plutons are widespread, intruding several small terranes of the Central belt (including the Don Pedro) as well as the Calaveras and Northern Sierra terranes to the east. The Don Pedro terrane is herein shown as part of the Central belt (aka Tuolumne River terrane) following Edelman and Sharp (1989) despite weak evidence for the Jurassic age assigned to the volcanic and sedimentary unit of the Don Pedro and for the controversial existence of the southern part of the Sonora fault. In the Northern Sierra terrane, the andesitic volcanic Tuttle Lake Fm., which unconformably overlies the Sailor Canyon Fm., may be genetically related to the Emigrant Gap pluton (163-164 Ma) of this accretionary episode (see Harwood, 1992).

During a late stage or shortly following the Rattlesnake Creek episode of both provinces, Late Jurassic volcanic arcs represented by the Rogue and Logtown Ridge Fms. erupted west of the accretionary sutures, and were followed by widespread deposition of the overlying clastic Galice and Mariposa Fms. These volcanic and clastic formations are described as preaccretionary units in the following episode.

WESTERN KLAMATH EPISODE

In the Klamath Mountains the proto Smith River and Rogue Valley subterranes were subducted beneath the Rattlesnake Creek terrane along the Bear Wallow and correlative faults. The Smith River subterrane consists of the Josephine ophiolite overlain by thin-bedded volcanopelagic strata which in turn are overlain by Galice Fm. (black stipple pattern). Zircons from plagiogranite of the ophiolite yield a Callovian age (162 Ma; Saleeby, 1987). The volcanopelagic strata contain mid-middle Oxfordian radiolarians (Pessagno and Blome, 1990). The Rogue Valley subterrane consists mainly of Rogue Fm and the conformably overlying Galice Fm. The Rogue Fm consists of basaltic and andesitic rocks that represent a volcanic arc. Zircon from tuff in the Rouge Fm indicates an Oxfordian age (157 Ma; Saleeby, 1984) and that the Rogue is comparable in age to the volcanopelagic unit that overlies the Josephine ophiolite. The Galice Fm. at the type locality in the Rogue Valley subterrane contains mid-middle Oxfordian radiolarians at its base where it rests on Rogue Fm, and higher in the Galice are ammonites and *Buchia concentrica* of middle Oxfordian to early Kimmeridgian age (Pessagno and Blome, 1990). Large irregularities in the present trace of the accretionary suture were caused by post-accretion deformation and local erosion of the upper plate, so that the Galice Fm. of the accreting plate is seen to have been subducted many miles eastward beneath the Rattlesnake Creek terrane. The Summit Valley (150 Ma) and Pony Peak (146 Ma) accretionary plutons cut both the Galice Fm and overlying Rattlesnake Creek terrane (Saleeby and Harper, 1993), constraining the age of the accretionary suture. The ~160 Ma plutons in the Rattlesnake Creek terrane above the accretionary suture presumably were truncated by the underthrusting and now are rootless. The only ~160 Ma pluton shown in the proto Western Klamath terrane is tonalite of the Chetco complex of the Dry Butte subterrane, but its possible relation to the Rogue volcanic arc is not clear.

The trace of the accretionary suture in the Sierra Nevada is markedly different than that of the Klamath Mountains. A SW-NE cross section, drawn just N of the Guadalupe complex by Schweickert and others (1999, Fig. 4A), shows the Jurassic volcanic and sedimentary strata between the Sonora fault and alluvial edge of the Great Valley as an imbricate series of steeply east-dipping west-vergent folds and thrusts. The terrane boundary sutures also are shown as steeply east-dipping thrusts. The fold structures are intruded by the 151 Ma Guadalupe Complex. The accretionary suture is along the eastern boundary of the Mother Lode terrane, generally coinciding with the Melones Fault. The Mariposa Fm. (black stipple pattern) of the Mother Lode terrane is exposed almost continuously along the west side of the Melones fault, from the south end of exposure near Mariposa to more than 100 miles northwest to near the latitude of Auburn where it disappears beneath the older rocks of the American River, Cool Quarry, and Mount Ararat terranes, a few miles south of the latitude of the Yuba Rivers pluton. There, the Central belt is10 miles wide and is separated from the Calaveras terrane by the Melones fault. As shown in cross section at that latitude by Graymer and Jones (1994, Fig. 7) the Central belt is mainly a series of imbricate steeply east-dipping thrust slabs of Logtown Ridge and Mariposa Fms (Mother Lode terrane) that are upwardly truncated and overlain by deformed thrust slices of Permian,Triassic, and Early to Middle Jurassic rocks of the American River, Cool Quarry, and Mount Ararat terranes. The Mother Lode terrane and overlying assemblage of older rocks are cut by the 143 Ma Coloma pluton which is truncated on the east by the Melones fault. The structure in both cross sections indicates an E-W strongly compressional environment following deposition of the Mariposa Fm. (post early Kimmeridgian). The presence of Mariposa and Logtown Ridge Fms. lying structurally beneath an assemblage of substantially older rocks of the Central belt is reminiscent of the Galice and Rogue Fms. lying beneath Rattlesnake Creek terrane in the Klamath Mountains and leads to speculation as to how far northward in the Central belt this structural relationship extends. This boundary between the Mother Lode terrane and overlying older rocks is herein considered part of the accretionary suture. From the north end of the Mother Lode terrane the accretionary suture trends irregularly southward to join the Bear Mountains Fault. There it abruptly trends northward along the Bear Mountains-Wolf Creek-Big Bend fault system, cutting the Yuba Rivers pluton and forming the eastern accretionary boundary of the Smartville Complex with its abundant preaccretionary ~160 Ma plutons, sheeted dikes, and associated Jurassic volcanic and sedimentary rocks. The extent to which the postaccretionary movements on the Melones Fault may have modified the map pattern of the accretionary suture is not clear. A few generally small ~150 Ma plutons intrude rocks of the accreting terrane young as Late Jurassic (Mariposa Fm.) as in the Klamath Mountains, and one pluton cuts the Calaveras-Shoo Fly Fault. Volcanic equivalents of the ~150 Ma plutons are not evident.

SEPARATION (aka PICKETT PEAK) EPISODE

Many regional tectonic elements relating to this time frame are complex and controversial (see Dickinson and others, 1996; and Godfrey and Klemperer, 1998) and the cause of the ~140 Ma plutonism is not clear. Perhaps the plutonism is evidence of a subduction zone now buried in the Great Valley or ever further west along the Coast Range Ophiolite-Franciscan boundary. The ~140 Ma plutons of the Klamath Mountains were more closely aligned N-S with those of the Sierra Nevada prior to separation of the two provinces. The Klamath Mountains block moved westerly along the trend of the Cold Fork fault (see Blake and others, 1999). During this left-lateral movement, the Great Valley overlap sequence was deposited on the Klamath block. The southwestern part of the sequence on the Klamath block is as old as Valanginian. To the northeast, where it unconformably overlies the erosional surface of the 136 Ma Shasta Bally Batholith, it is Hauterivian. In contrast, the south side of the Cold Fork fault is the Elder Creek terrane which consists of the north-trending Coast Range ophiolite and the overlying strata of the Great Valley sequence on the east. The lower part of the Great Valley sequence a few miles south of the fault is Upper Jurassic and is clearly much older than the ~140 Ma plutons. On both sides of the fault, the strata of the Great Valley sequence are successively younger up-section to the east until they are Turonian in age on both sides of the fault and are concealed to the east by Tehama Fm. (Pliocene). On the west, Franciscan rocks were subducted beneath the Western Klamath and Elder Creek terranes, developing the blueschist facies Pickett Peak terrane as a metamorphic selvage along the Western Klamath terrane and Coast Range ophiolite, spanning the Elder Creek fault. The South Fork Mountains Schist of the Pickett Peak terrane yields isotopic ages (mainly K-Ar) of ~120 Ma (Lanphere and others,1978), but early more deeply subducted parts of the terrane may well be older.

ACKNOWLEDGMENT

Thanks to R.W. Graymer, R.W. Kistler, and J.G. Moore, for helpful suggestions that improved this report.

REFERENCES CITED

Barrow, Wendy, and Metcalf, R.V., 2002, Central Metamorphic terrane, northern California: Geochemical evidence of a mid-ocean ridge origin: Geological Society of America, Abstracts with Programs, v. 34, no. 5, p. 43.
Bateman, P.C., Harris, A.G., Kistler, R.W., and Krauskopf, K.B., 1985, Calaveras reversed: Westward younging is indicated: Geology, v. 13, no. 5, p. 338-341.
Blake, M.C., Jr., Harwood, D.S., Helly, E.J., Irwin, W.P., Jayko, A.S., and Jones, D.L., 1999, Geologic map of the Red Bluff 30' x 60' quadrangle, California: U.S. Geological Survey, Geologic Investigations Map I-2542, scale 1;100,000, with text 15 p.
Blome, C.D. and Irwin, W.P., 1983, Tectonioc significance of Late Paleozoic to Jurassic radiolarians in the North Fork terrane, Klamath Mountains, California, *in* C.H. Stevens, ed., Pre-Jurassic rocks in western North American suspect terranes: Society of Economic Paleontologists and Mineralogists, Pacific section, p. 77-89.
Bond, G.C., and Devay, J.C., 1980, Pre-Upper Devonian quartzose sandstones in the Shoo Fly Formation, Northern California; Petrology, provenance, and implications for regional tectonics: Journal of Geology, v. 88, p. 285-308.
D'Allura, J.A., Moores, E.M., and Robinson, L., 1977, Paleozoic rocks of the northern Sierra Nevada, in Stewart, J.H., Stevens, C.H., and Fritsche, A.E., eds., Paleozoic paleogeography of the western United States: Society of Economic Paleontologists and Mineralogists, Pacific Section, Pacific Coast Paleogeography Symposium 1, p. 395-408.
Dickinson, W.R., Hopson, C.A., and Saleeby, J.B., 1996, Alternate origins of the Coast Range Ophiolite (California): Introduction and implications, *in* GSA Today: Geological Society of America, v. 6, no. 2, p. 1-10.
Diller, J.S., 1907, The Mesozoic sediments of southwestern Oregon: American Journal of Science, ser. 4, v. 23, p. 401-421.
Edelman, S.H., and Sharp, W.D., 1989, Terranes, early faults, and pre-Late Jurassic amalgamation of the western Sierra Nevada metamorphic belt, California: Geological Society of America Bull., v. 101, p. 1420-1433.
Edelman, S.H., Day, H.W., and Bickford, M.E., 1989, Implications of U-Pb zircon ages for the tectonic settings of the Smartville and Slate Creek complexes, northern Sierra Nevada, California: Geology, v. 17, p. 1032-1035.
Godfrey, N.J. , and Klemperer, S.L., 1998, Ophiolitic basement to a forearc basin and imiplications for continental growth: The Coast Range/Great Valley ophiolite, California: Tectonics, v. 17, no. 4, p. 558-570.
Graymer, R.W. and Jones, D.L., 1994, Tectonic implications of radiolarian chert from the Placerville Belt, Sierra Nevada Foothills, California: Nevadan-age continental growth by accretion of multiple terranes: Geological Society of America Bull., v. 106, p. 531-540.
Hacker,B.R., and Peacock, S.M., 1990, Comparison of the Central Metamorphic Belt and Trinity terrane of the Klamath Mountains with the Feather River terrane of the Sierra Nevada, *in* Harwood, D. S., and Miller, M. M., eds., Paleozoic and early Mesozoic paleogeographic relations; Sierra Nevada, Klamath Mountains , and related terranes: Geological Society of America Special Paper 255, p. 75-92.
Harwood, D.S., 1992, Stratigraphy of Paleozoic and lower Mesozoic rocks of the Northern Sierra terrane, California: U.S. Geological Survey Bull., 1957, 78 p.
Hinds, N.E.A., 1933, Geologic formations of the Redding-Weaverville districts, northern California: California Journal of Mines and Geology, v. 29, no. 1-2, p. 77-122.
Hotz, P.E., Lanphere, M.A., and Swanson, D.A., 1977, Triassic blueschist from northern California and north-central Oregon: Geology, v. 5, no. 11, p. 659-663.
Imlay, R.W., 1959, Succession and speciation of the Pelecypod Aucella *in* Shorter Contributions to Regional Geology: U.S. Geological Survey Professional Paper 314-G,, p. 155-169, 19 plates.
Imlay, R.W., 1961, Late Jurassic ammonites from the western Sierra Nevada, California *in* Shorter Contributions to Regional Geology: U.S. Geological Survey Professional Paper 374-D, , 28 p.
Irwin, W.P., 1994, Geologic map of the Klamath Mountains, California and Oregon: U.S. Geological Survey, Miscellaneous Investigations Map I–2148, scale 1:500000.
Irwin, W.P. and Mankinen, E.A., 1998, Rotational and accretionary evolution of the Klamath Mountains, California and Oregon, from Devonian to present time: U.S. Geological Survey, Open-File Report 98-114.
Irwin, W. P., and Wooden, J. L., 1999, Plutons and accretionary episodes of the Klamath Mountains, California and Oregon: U.S. Geological Survey, Open-File Report 99-374.
Irwin, W.P., and Wooden, J.L., 2001, Map showing plutons and accreted terranes of the Sierra Nevada, California, with a tabulation of U/Pb isotopic ages: U.S. Geological Survey, Open-File Report 01-299, scale 1/1,000,000.
Jayko, A.S., 1988, Paleozoic and Mesozoic rocks of the Almanor 15' quadrangle, Plumas County, California: U.S., Geological Survey Open-File Report 88-757, map scale 1:62,500, text 14 p.
Jennings, C.W., 1977, Geologic map of California: California Division of Mines and Geology, Geologic Data Map No. 2, scale 1:750,000.
Lanphere, M.A., Blake, M.C., Jr., and Irwin, W.P., 1978, Early Cretaceous metamorphic age of the South Fork Mountain Schist in the northern Coast Ranges of California: American Journal of Science, v. 278, p. 798-815.
Lindsley-Griffin, N., Farmer, J.D., and Griffin, J.R., 2002, Ediacaran cyclomedusids from an accreted terrane in the eastern Klamath Mountains, Ca: Geological Society of America, Abstracts with Programs, v. 34, no. 6, p. 272.
Mankinen, E.A,, Lindsley-Griffin, N., and Griffin, J.R., 2002, Concordant paleolatitudes for Neoproterozoic ophiolitic rocks of the Trinity Complex, Klamath Mountains, California: Journal of Geophysical Research, vol. 107, no. B10, EPM 11, p. 1-18.
Palmer, A.R., and Geissman, J.W., 1999, Geologic time scale: Geological Society of America, Product code CTS004.
Pessagno, E.A., Jr., and Blome, C.D., 1990, Implications of new Jurassic stratigraphic, geochronometric, and paleolatitudinal data from the western Klamath terrane (Smith River and Rogue Valley subterranes): Geology, v. 18, p. 665-668.
Renne, P.R., 1987, Permian to Jurassic tectonic evolution of the eastern Klamath Mountains, California: Berkeley, California University, Ph. D. dissertation, 127 p.
Saleeby, J.B., 1982, Polygenetic ophiolite belt of the California Sierra Nevada: Geochronological and tectonostratigraphic development: Journal of Geophysical Research, v. 87, no. B3, p. 1803-1824.
Saleeby, J.B., 1984, Pb/U zircon ages from the Rogue River area, western Jurassic belt, Klamath Mountains, Oregon: Geol;ogical Society of America, Abstracts with Programs, v. 16, p. 331.
Saleeby, J.B., 1987, Discordance patterns in Pb/U zircon ages of the Sierra Nevada and Klamath Mountains: Eos (American Geophysical Union Trans.), v.68, p. 1514-1515.
Saleeby, J.B., and Harper, G.D.,1993, Tectonic relations between the Galice Formation and the Condrey Mountain Schist, Klamath Mountains, northern California, *in* Dunn, G., and McDougall, K., eds., Mesozoic paleogeography of the western United States-II: Society of Economic Paleontologists and Mineralogists, Pacific Section, Book 71, p.61-80.
Saleeby, Jason, and Sharp, Warren, 1980, Chronology of the structural and petrologic development of the southwest Sierra Nevada foothills, California: Geological Society of America, Part II, p. 1416-1535, Doc. No. M00601.
Saleeby, J.B., Shaw, H.F., Sidney Niemeyer, Moores, E.M., and Edelman, S.H., 1989, U/Pb, Sm/Nd and Rb/Sr geochronological study of Northern Sierra Nevada ophiolitic assemblages, California; Contributions to Mineralogy and Petrology, v. 102, p. 205-220.
Saucedo, G.J., and Wagner, D.L., 1992, Geologic map of the Chico quadrangle, California: California Division of Mines and Geology, Regional Geologic Map Series, Map No. 7A, scale 1:250,000.
Schweickert, R. A., Hanson, R. E., and Girty, G. H., 1999, Accertionary tectonics of the Western Sierra Nevada Metamorphic Belt , *in* Wagner, D.L., and Graham, S.S., eds., Geologic Field Trips in Northern California: California Division of Mines and Geology, Special Publication SP-119, p. 33-79.
Wagner, D.L., Jennings, C.W., Bedrossian, T.L., and Bortugo, E.J., 1981, Geologic map of the Sacramento quadrangle: California Division of Mines and Geology, Regional Geologic Map Series, Map No. 1A, scale 1:250,000.
Wagner, D.L., Bortugno, E.J., and McJunkin, R.D., 1991, Geologic map of the San Franciscan-San Jose quadrangle, California: California Division of Mines and Geology, Regional Geologic Map Series, Map No, 5A, scale 1:250,000.