Wallrocks of the Central Sierra Nevada Batholith, California: A Collage of Accreted Tectono-Stratigraphic Terranes

GEOLOGICAL SURVEY PROFESSIONAL PAPER 1255

Wallrocks of the Central Sierra Nevada Batholith, California: A Collage of Accreted Tectono-Stratigraphic Terranes

By WARREN J. NOKLEBERG

GEOLOGICAL SURVEY PROFESSIONAL PAPER 1255

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1983

UNITED STATES DEPARTMENT OF THE INTERIOR

JAMES G. WATT, *Secretary*

GEOLOGICAL SURVEY

Dallas L. Peck, *Director*

Library of Congress Cataloging in Publication Data
Nokleberg, Warren J.
Wallrocks of the central Sierra Nevada batholith, California.
(Geological Survey Professional Paper 1255)
Bibliography: 28 p.
Supt. of Docs. No.: I 19.16:1255
1. Batholiths—Sierra Nevada Mountains (Calif. and Nev.)
I. Title. II. Series.
QE461.N64 552'.3 81-607153 AACR2

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

CONTENTS

ILLUSTRATIONS

TABLES

WALLROCKS OF THE CENTRAL SIERRA NEVADA BATHOLITH, CALIFORNIA: A COLLAGE OF ACCRETED TECTONO-STRATIGRAPHIC TERRANES

By WARREN J. NOKLEBERG

ABSTRACT

Structural and stratigraphic analysis of the wallrocks of the central Sierra Nevada batholith, California, supports the hypothesis that the wallrocks constitute a collage of tectono-stratigraphic terranes that were accreted along an actively deformed continental margin. The terranes, represented by well-known pre-middle Cretaceous belts of wallrocks, with north-northwest trends, were successively accreted during Triassic and Jurassic time. Successive pulses of magmatism were interspersed with successive accretions of terranes and with successive deformations and movements along interarc faults. From east to west, the terranes consist of: (1) early Paleozoic metasedimentary rocks (Owens terrane); (2) late Paleozoic metasedimentary and unconformably overlying Permian and Triassic metavolcanic rocks (High Sierra terrane); (3) Jurassic metavolcanic rocks (Goddard terrane); (4) Late Triassic and Early Jurassic miogeosynclinal metasedimentary rocks and sparse metavolcanic rocks of the Kings sequence (Kings terrane); (5) late Paleozoic slate, marble, and metaquartzite of the Calaveras Formation and rocks similar to the Shoo Fly Formation—and underlying late Paleozoic ophiolite (Merced River terrane); and (6) Jurassic andesite and basalt flows, breccias, epiclastic mudstone, siltstone, volcanic graywacke, and conglomerate representing a volcanic arc suite and underlying Jurassic and older ophiolite west of the Melones fault (Foothills terrane). Each terrane generally has: (1) a distinct stratigraphic sequence with a narrow age range; (2) no nearby sediment source; (3) bounding thrust, reverse, or strike-slip faults; and (4) a distinct structural history. After accretion, adjacent terranes were welded together and their boundaries locally obliterated by episodic intrusion of granitic magmas.

Major thrust, reverse, or strike-slip faults representing accretionary sutures separate the various terranes. The Owens Valley fault, a vertical, predominantly right lateral strike-slip fault, separates the Owens terrane from bedrock units to the east in the White–Inyo Mountains. The Laurel–Convict fault, an originally west dipping thrust, separates the Owens and High Sierra terranes. Triassic accretion and deformation along this suture defines the Sonoman orogeny in the eastern Sierra Nevada. The San Joaquin River fault, a major strike-slip fault, separates the High Sierra and Goddard terranes. The Kings River fault, a major right-lateral strike-slip fault, separates the Goddard and Kings terranes. Late Jurassic accretion and deformation along the Kings River and San Joaquin River faults between the High Sierra, Goddard, and Kings terranes defines the Nevadan orogeny in the eastern part of the central Sierra Nevada. The Foothill suture, originally a major left-lateral strike-slip fault, separates the Kings and Merced River terranes. Middle Jurassic accretion along this suture marks the accretion of the Tethyan-derived Merced River terrane to the western margin of North America. The collision of the Merced River terrane with the western margin of North America may have caused the contemporaneous left-lateral offset of Precambrian crystalline terranes from southeastern California to Sonora, Mexico. The Foothill suture may be the continuation of the left-lateral megashear in the central Sierra Nevada. The Melones fault separates the Merced River and Foothills terranes. Late Jurassic accretion and deformation along this suture, along with reactivation of the Foothill suture, defines the Nevadan orogeny in the western metamorphic belt. Comparison of the tectonics of the Mesozoic Sierra Nevada with that of Cenozoic southern Alaska reveals many similarities. The Mesozoic Sierra Nevada may represent an Alaskan-type volcanic and plutonic arc that formed along a tectonically active continental margin.

INTRODUCTION

The geology of the wallrocks of the Sierra Nevada is a key to understanding the geology of the North American Cordillera and the relations between the Paleozoic and Mesozoic rocks of the Great Basin, Great Valley, and California Coast Range provinces. However, the tectonic framework of the wallrocks of the Sierra Nevada is still very controversial. Currently, there are several major interpretations. A complex, faulted synclinorium is proposed by Bateman and others (1963), Bateman and Eaton (1967), and Bateman and Clark (1974). Inward-facing top directions and stratigraphic sequences that are progressively younger toward the center of the batholith and symmetrical with its long axis are cited as evidence for the synclinorium. Accretion of Mesozoic country rocks onto the west side of the range against an Andean-type arc is proposed by Hamilton (1969, 1978), Schweickert and Cowan (1975), Davis and others (1978), and Schweickert (1978). East of the Melones fault, the Calaveras Formation and underlying ophiolite are cited by some of these authors as one example of an accreted terrane. Local occurrences of Tethyan fossils in tectonic fragments of the Calaveras Formation indicate an exotic origin for at least parts of this unit. West of the Melones fault, the Jurassic wallrocks and underlying ophiolite, possibly representing an island-arc system, are also cited by some of these authors as another example of an accreted terrane. An anticlinorium that formed as a result of multiple deformations is proposed by Kistler and others (1971). The multiply deformed and nearly vertical strata forming the wallrocks are cited as evidence for the anticlinorium.

This paper analyzes the well-known belts of wall rocks in the central Sierra Nevada and proposes the hypothesis that the pre-middle Cretaceous belts constitute a collage of tectono-stratigraphic terranes that were accreted during volcanism and plutonism along a tectonically active continental margin. This analysis lists the depositional, structural, metamorphic, and magmatic histories for each terrane and shows the unique geologic history of each terrane and that large-scale tectonic movements are required for juxtaposition of terranes. Terranes are analyzed from east to west. Because most of the faults bounding terranes and the bulk of the study area is underlain by Mesozoic granitic rocks (pl. 1), emphasis is placed on the contact relations between wallrock sequences. Finally, this paper compares and shows that the stratigraphy, structure, and tectonics of the Mesozoic Sierra Nevada is extremely similar to that of southern Alaska in Cenozoic time. The Mesozoic Sierra Nevada may represent an Alaskan-type volcanic and plutonic arc that formed along a tectonically active continental margin.

This paper represents the first attempt to analyze all of the wallrocks of the central Sierra Nevada batholith as a collage of accreted terranes. Because of considerable stratigraphic and structural complexity, future investigations may show that some terranes, particularly the Goddard, Kings, Merced River, and Foothills terranes, may each be a composite of several terranes.

DEFINITIONS

"Tectono-stratigraphic terrane" is defined as a fault-bounded geologic entity with distinct geologic history, stratigraphy, structure, and mineral deposits differing markedly from those of adjoining neighbors (Jones and Silberling, 1979; Beck and others, 1980). Each terrane is characterized by one or more distinctive, internally coherent stratigraphic sequences (Jones and Silberling, 1979). "Accretion" is defined as the juxtapositioning of a terrane into its present position. "Amalgamation" is defined as the juxtapositioning of two terranes in a location with subsequent drift and accretion at a site far removed from the site of amalgamation. "Arc" is defined as a linear belt of contemporaneous volcanic and plutonic rocks and adjacent wall rocks. "Suture" is defined as a major fault between tectono-stratigraphic terranes. A key factor in terrane analysis is determining the timing of accretion and amalgamation by defining the oldest units that weld together two adjacent terranes. In the central Sierra Nevada, such welding consists of either younger units that unconformably overlie adjacent terranes or plutonic rocks that intrude adjacent terranes.

ACKNOWLEDGMENTS

I am grateful for the many discussions of this topic with D. L. Jones, R. W. Kistler, J. B. Saleeby, R. S. Schweickert, N. J. Silberling, R. C. Speed, and J. H. Stewart. I thank David L. Jones and Edwin D. McKee for their constructive reviews, and the numerous colleagues with whom I have had so many exciting discussions of Sierra Nevada and Alaskan geology over the last several years.

RELATION OF MULTIPLE REGIONAL DEFORMATION TO TERRANE ACCRETION

In a detailed study of regional deformations of the central Sierra Nevada, Nokleberg and Kistler (1980) show that (1) each generation of structures is characterized by folds of a particular style and orientation, with related cleavages, schistosities, lineations, and faults and (2) each generation of structures was formed during a regional deformation. The recognition of multiple generations of structures is based principally on superposition relations, especially the warping or refolding of an earlier fold, schistosity, lineation, or cleavage by a later fold. Other criteria used for distinguishing between generations include: (1) differences in the style of folding for a generation—generally more open for successively younger fold sets; (2) different orientations of axial planes, schistosities, and cleavages; and (3) crossing of an older axial plane, cleavage, or schistosity by a younger structure. Associated with each regional deformation of this terrane and of other terranes to the west was a period of regional metamorphism (Nokleberg and Kistler, 1980). Usually the interiors of the larger roof pendants show the remnants of greenschist-facies regional metamorphism with development of penetrative fabric and extensive recrystallization along axial plane schistosities and fold axes formed during a particular deformation. Adjacent to granitic plutons, the margins of most roof pendants are contact metamorphosed to the albite-epidote or hornblende-hornfels facies of contact metamorphism, and the contact metamorphism has masked the earlier regional metamorphism and deformation. In the western metamorphic belt, greenschist-facies regional metamorphism generally prevails along with local areas of amphibolite-facies regional metamorphism (Behrman, 1978; Saleeby and others, 1978; Nokleberg and Kistler, 1980). In this study, each period of regional deformation and metamorphism is related to accretion, amalgamation, and (or) transport of terranes along sutures.

RELATION OF TERRANES TO INTRUSIVE EPOCHS OF GRANITE ROCKS

The oldest geologic units that weld together terranes in the Sierra Nevada are mainly individual granitic plutons, or age groups of plutons that define intrusive epochs (Evernden and Kistler, 1970). The intrusive epochs of granitic rocks occur along various linear age belts (Evernden and Kistler, 1970; Kistler and others, 1971). From oldest to youngest, the intrusive epochs (Evernden and Kistler, 1970) are: Lee Vining of Late Triassic and Early Jurassic age (210 to 195) m.y.); Inyo Mountains of Early and Middle Jurassic age (180 to 160 m.y.); Yosemite of Late Jurassic and Early Cretaceous age (148 to 132 m.y.); Huntington Lake of Early Cretaceous age (121 to 104 m.y.); and Cathedral Range of Late Cretaceous age (90 to 79 m.y.). Relative age assignments of radiometric dates are from Sohl and Wright (1980).

If each age belt of granitic rock is continous at depth, then the distribution of each belt could be analyzed to place limits on timing of terrane accretion. However, this analysis has inherent pitfalls. Sutures or major faults may occur within a volcanic and plutonic arc with immense strike slip displacement. Such displacement could result in alinement of coeval fragments of a composite batholith that originally formed in widely separated places. And in some areas of the central Sierra Nevada batholith major fragments are faulted against wallrocks; some of the faults may represent sutures. Examples of such sutures are the White Mountains fault zone (Crowder and Sheridan, 1972) and portions of the Melones fault in the western Sierra Nevada (Duffield and Sharp, 1975). The welding of adjacent terranes by granitic rocks can only be demonstrated where individual plutons, or series of plutons, are observed in the field to intrude adjacent terranes. In the bulk of the batholith, the granitic rocks are considerably younger than the ages of movement on sutures. This relation allows that substantial movement on sutures was possible before intrusion by granitic magmas.

OWENS TERRANE

OCCURRENCE

The Owens terrane consists of early Paleozoic metasedimentary rocks that are exposed discontinuously in roof pendants in the eastern Sierra Nevada for about 140 km in a northwest-trending belt that ranges from about 20 to 25 km in width (pl. 1; table 1). This terrane, the oldest in the range, is best exposed in the Log Cabin mine and the eastern part of the Mount Morrison roof pendants. To the east, it is either intruded by Late Triassic and Early and Middle Jurassic granitic plutons of the Lee Vining and Inyo Mountains intrusive epochs (Evernden and Kistler, 1970) or bounded by the Owens Valley fault discussed below. To the west, this terrane is either intruded by Late Triassic; Early Jurassic, and Late Cretaceous granitic plutons of the Lee Vining and Cathedral Range intrusive epochs or faulted against the High Sierra terrane along the Laurel-Convict fault (Pl. 1). The Laurel-Convict fault in the Mount Morrison roof pendant, and the extension of this fault northward in the Gull Lake and Saddlebag Lake roof pendants (Brook and others, 1979; Kistler and Nokleberg, 1980), forms a suture between the High Sierra and Owens terranes (pl. 1). In the Gull Lake roof pendant, the fault occurs at the base of a thin Carboniferous marble unit, mapped by Kistler (1966b), about 0.8 km east of the east shore of Silver Lake (W. J. Nokleberg, unpub. data, 1975). In the Saddlebag Lake roof pendant, the western trace of the fault occurs at the base of a highly deformed, thin section of Carboniferous rocks on the slopes about 0.4 km west of the southwest shore of Saddlebag Lake (Brook, 1977; Brook and others, 1979).

STRATIGRAPHY

The dominant protoliths in the Owens terrane are calcareous sandstone, shale, and chert, with minor marl, limestone, and dolomite (table 1). These rocks are dated (pl. 1; table 1) by the occurrence of Ordovician graptolites in the Log Cabin mine roof pendant (J. H. Stewart, written commun., 1979), Ordovician to Silurian(?) graptolites in the Mount Morrison roof pendant (Rinehart and Ross, 1964), Cambrian *Skolithos*(?) and *Cruziana*(?) in the Big Pine Creek roof pendant (Moore and Foster, 1980). The nonfossilerous rocks of the eastern parts of the Saddlebag Lake and Gull Lake roof pendants are correlated with the lower Paleozoic rocks of the Mount Morrison roof pendant on the basis of distinctive metamorphosed crossbedded quartzite and shale occuring in all three (Kistler, 1966a, b; Brook, 1977; Brook and others, 1979; W. J. Nokleberg, unpub. data, 1977). Rocks of this terrane are interpreted as slope-rise deposits in the Mount Morrison roof pendant (J. H. Stewart, oral commun., 1979), as near-shelf deposits in the Bishop Creek roof pendant and as shelf deposits in the Big Pine Creek roof pendant (Moore and Foster, 1980). There appears to have been a facies change from shelf to slope deposition in the area now

TABLE 1.—*Principal occurrences, original lithologies, fossils and ages, and investigators of wallrocks and roof pendants constituting tectonostratigraphic terranes in the central Sierra Nevada*

Principal occurrences	Original lithologies	Fossils and ages	Investigators
	Owens terrane		
Log Cabin mine, eastern part of Saddlebag Lake, eastern part of Gull Lake, eastern part of Mount Morrison, Bishop Creek, Big Pine Creek, Casa Diablo, and Dinkey Creek roof pendants.	Calcareous sandstone, shale, and chert; minor marl, limestone, and dolomite.	Ordovician to Silurian(?) graptolites in Mount Morrison and Bishop Creek roof pendants. Cambrian Skolithos(?) and Cruziana(?) in Big Pine Creek roof pendant. Ordovician graptolites in Log Cabin mine roof pendant.	Rinehart and Ross (1957, 1964), Bateman (1965), Kistler (1966a, b), Crowder and Sheridan (1972), Brook (1977), Brook and others (1979), Russell and Nokleberg (1977), W. J. Nokleberg (unpub. data, 1977), Moore and Foster (1980), J. H. Stewart (oral commun., 1980).
	High Sierra terrane		
Western part of Saddlebag Lake, western part of Mount Dana, northern part of Ritter Range, western part of Gull Lake, eastern part of central Ritter Range, Oak Creek, western part of Mount Morrison, and Big Pine Creek roof pendants.	Volcanic rocks: andesite to rhyodacite tuff, ash-flow tuff, and flows, conglomerate, volcanic breccia, andesite sills; minor marl, volcanic sandstone, and basalt flows. Sedimentary rocks: siliceous and calcareous mudstone; minor limestone, marl, conglomerate, quartz-sandstone, and chert.	Volcanic rocks: 240 m.y. by Rb-Sr whole-rock isochron. Sedimentary rocks: Pennsylvanian conodonts, Mississippian(?), Pennsylvanian, and Permian(?) crinoids, corals, brachiopods, and pelecypods.	Rinehart and Ross (1964), Bateman (1965), Huber and Rinehart (1965), Kister (1966a, b), Morgan and Rankin (1972), Brook and others (1974), Chesterman (1975), Russell (1976), Tobisch and Fiske (1976), Brook (1977), Russell and Nokleberg (1977), Tobisch and others (1977), Fiske and Tobisch (1978), C. H. Stevens, W. J. Nokleberg, and A. H. Harris (unpub. data, 1978), Brook and others (1979), Kistler and Nokleberg (1980).
	Goddard terrane		
Central and western part of Ritter Range, eastern part of Boyden Cave, Mount Goddard, and Alabama Hills roof pendants.	Andesite to dacite, ash-flow tuff, lava flows, tuff-breccia, tuff, lapilli tuff; minor basalt and rhyolite flows and tuff, limestone, and limy tuff.	Early Jurassic pelecypod. 168 m.y. by Rb-Sr whole-rock isochron. 153 to 186 m.y. by U-Pb zircon techniques.	Rinehart and Ross (1964), Bateman (1965), Bateman and Moore (1965), Moore and Marks (1972), Moore (1973), Lockwood and Lydon (1975), Tobisch and Fiske (1976), Girty (1977a, b), Russell and Nokleberg (1977), Schweickert and others (1977), Tobisch and others (1977), Moore (1978), Fiske and Tobisch (1978), Saleeby and others (1978), and Moore and others (1979).
	Kings terrane		
Metasedimentary rocks of Strawberry mine, western part of Boyden Cave, eastern part of lower Kings River, eastern part of Kaweah River, Tule River, Mineral King, eastern part of Yokohl Valley, and Kern Canyon roof pendants.	Quartzite, arkose, limestone, marl mudstone, and calcareous sandstone; minor dacite to rhyodacite tuff, ash-flow tuff, breccia, and volcanic sandstone. Very minor andesite and basalt tuff and breccia.	Early Jurassic(?) pelecypod, Late Triassic and Early Jurassic ammonites and pelecypods. 168 and 210 m.y. by U-Pb zircon techniques.	Durrell (1940), Macdonald (1941), Krauskopf (1953), Ross (1958), Moore and Dodge (1962), Christensen (1963), Nokleberg (1970, 1980), Moore and Marks (1972), Jones and Moore (1973), Girty (1977a, b), Schweickert and others (1977), Saleeby and others (1978), Moore and others (1979), Busby-Spera and others (1980), Saleeby and Sharp (1980).
	Merced River terrane		
Metasedimentary rocks and underlying ophiolite of the western metamorphic belt east of the Melones fault. Similar rocks in northeastern part of Oakhurst, western part of lower Kings River, western part of Kaweah River, and western part of Yokohl Valley roof pendants. Similar rocks in fault-bounded lenses within Bear Mountain fault.	Sedimentary rocks: shale, quartzite, and limestone; minor marl, quartz-siltstone, chert, and conglomerate. Ophiolite: serpentinite, serpentinized peridotite and dunite, gabbro, diabase, basaltic pillow lava, pillow breccia, tuff-breccia, and tuff.	Sedimentary rocks: Carboniferous and Permian fusulinids, part with Tethyan origin; Carboniferous or Permian coral; Carboniferous brachiopod. Ophiolite: 270 to 305 m.y. by U-Pb zircon techniques on plagiogranite.	Durrell (1940), Macdonald (1941), Taliaferro and Solari (1948), Clark (1954), Eric and others (1955), Clark (1960), Baird (1962), Clark (1964), Douglass (1967), Clark (1970), Nockleberg (1975), Duffield and Sharp (1975), Morgan (1976), Wetzel and Nokleberg (1976), Morgan and Stern (1977), Russell and Cebull (1977), Schweikert and others (1977), Behrman (1978), W. J. Nockleberg (unpub. data, 1978), Saleeby (1978, 1979), Saleeby and others (1978), Sharp and Saleeby (1979), Saleeby and Sharp (1980).
	Foothills terrane		
Metamorphosed volcanic arc rocks and underlying ophiolite of the western metamorphic belt west of the Melones fault. Similar rocks in southwestern part of Oakhurst roof pendant.	Volcanic arc rocks: epiclastic mudstone, siltstone, and volcanic graywacke and conglomerate. Predominately basaltic with lesser andesitic flows, pillow lava, and breccia. Ophiolite: serpentinite, serpentinized peridotite and dunite, gabbro, diabase, basaltic pillow lava and tuff-breccia, and chert.	Volcanic arc rocks: Callovian and Kimmeridgian (Middle and Late Jurassic) ammonites and pelecypods. Ophiolite: 182 to 190 m.y. or older for possibly syngenetic diorites dated by U-Pb zircon techniques (Morgan, 1976); 200 to 300 m.y. by U-Pb zircon techniques on plagiogranite (Saleeby and others, 1979).	Taliaferro and Solari (1948), Eric and others (1955), Clark (1960), Mannion (1960), Imlay (1961), Best (1963), Clark (1964, 1970), Duffield and Sharp (1975), Morgan (1976), Wetzel and Nokleberg (1976), Morgan and Stern (1977), Russell and Cebull (1977), Behrman and Parkinson (1978), Schweikert (1978), Saleeby and Moores (1979), Saleeby and others (1979).

represented by the metasedimentary rocks of the Bishop Creek roof pendant (Moore and Foster, 1980).

The stratigraphic section of rocks forming the Owens terrane is fault bounded. Because of intense, multiple deformation, stratigraphic thicknesses are not well known. The minimum stratigraphic thicknesses of these rocks are estimated at about 2,500 to 5,150 m in the Mount Morrison roof pendant by Rinehart and Ross (1964). However, Russell and Nokleberg (1977) found that intense isoclinal folding caused considerable repetition of strata and estimated the stratigraphic thickness as a few hundred meters. Minimum stratigraphic thicknesses are estimated at about 1,500 m in the Bishop Creek roof pendant and at about 250 m in the Big Pine Creek roof pendant (Moore and Foster, 1980).

STRUCTURE

Most of the Owens terrane is thrice deformed (table 2). The principal, and first, generation of structures in the Owens terrane was formed in a Devonian or Mississippian regional deformation, possibly the Antler orogeny (Russell and Nokleberg, 1977). Structures of this generation consist of appressed to isoclinal folds, parallel thrust and reverse faults, cleavage and schistosity parallel to faults and axial planes of folds, and lineations parallel to fold axes (Russell and Nokleberg, 1977; Nokleberg and Kistler, 1980). The style of folding is predominantly flexural slip with a minor component of slip. Where bedding is developed in relatively incompetent rocks, such as marble, it is commonly thinned on limbs and thickened in hinges, indicating flowage during folding. In areas relatively unaffected by later deformations, axial planes of major and minor folds and parallel schistosities have average strikes of north to N. 10° W. and nearly vertical dips (table 2). Most major and minor fold axes plunges gently north or south and indicate a first or near-first deformation of these rocks (Nokleberg and Kistler, 1980).

The Devonian or Mississippian age of this regional deformation is best established in the Mount Morrison roof pendant where first-generation north-trending structures are restricted to the lower Paleozoic metasedimentary rocks (Russell and Nokleberg, 1977). Later (Mesozoic) structures occur in both the Owens terrane and other, younger terranes containing Mississippian(?) and Pennsylvanian rocks to the west, thereby limiting the first deformation of the Owens terrane to the Devonian or Mississippian (Russell and Nokleberg, 1977). The Laurel-Convict fault, which separates the Owens terrane from the High Sierra terrane to the west, forms a suture between a thrice-deformed terrane to the east and a twice-deformed terrane to the west. The Devonian or Mississippian age of deformation coincides with the Antler orogeny of the Great Basin (Russell and Nokleberg, 1977). Asymmetric folds and thrust faults of the Log Cabin mine roof pendant and the steeply west dipping Laurel-Convict fault indicate tectonic transport from west to east, analogous to the Antler orogeny (Burchfiel and Davis, 1972). The Laurel-Convict fault has been considerably steepened by Mesozoic deformations (Russell and Nokleberg, 1977).

Two younger deformations also occurred in the Owens terrane (table 2) (Nokleberg and Kistler, 1980). The second, the Late Jurassic Nevadan orogeny, occurred along N. 20° to 40° W. trends in all roof pendants of this terrane except the Log Cabin mine and Bishop Creek roof pendants, which were apparently shielded by Late Triassic granitic rocks of the Lee Vining intrusive epoch. This deformation occurred during accretion of terranes to the west along the coeval Laurel-Convict fault, as discussed below. The third deformation occurred along N. 50° to 80° W. trends in the middle Cretaceous in this terrane and other terranes to the west (table 2). This generation of structures refolded and offset older structures formed in the Late Jurassic Nevadan orogeny and in older deformations in the central Sierra Nevada (table 2) (Nokleberg and Kistler, 1980).

EVIDENCE FOR OWENS VALLEY FAULT BOUNDING EASTERN MARGIN

The eastern limit of the Owens terrane appears to be a Cretaceous or Tertiary suture, herein named the Owens Valley fault, that strikes north-south from Benton Valley in the north through Owens Valley in the south. In the northern part of the area, the Owens Valley fault separates the lower Paleozoic terrane in the eastern Sierra Nevada from the Permian to Jurassic metavolcanic rocks in the White Mountains to the east. Further south, the Owens Valley fault separates the Owens terrane of the eastern Sierra Nevada from the late Precambrian and Cambrian metasedimentary rocks in the White-Inyo Mountains.

In the north, the evidence for the Owens Valley fault is that although highly deformed, the younger Permian to Jurassic metavolcanic rocks are nowhere observed, either east or west of the fault, to unconformably overlie the late Precambrian and Cambrian metasedimentary rocks (Rinehart and Ross, 1957; Crowder and Sheridan, 1972). This relation indicates that the Permian to Jurassic metavolcanic rocks are bordered on their margin by major faults. In the south, the evidence for the fault is the lack of detailed correlation of Cambrian units between the Sierra Nevada and White-Inyo Mountains. General correlation of stratotypes has been made by Moore and Foster (1980) between the Cambrian to Silurian(?) metasedimentary rocks in the Bishop Creek and Big Pine Creek roof pendants with late Precambrian and Cambrian metasedimentary rocks in the White-Inyo Mountains. However, Moore and Foster (1980) were not able to correlate formations across Owens Valley, despite extremely well established

TABLE 2.—*Regional deformations recorded in tectono-stratigraphic terranes in the central Sierra Nevada*

[Age of deformation includes average strike of fold axial planes, rock types, and age of rocks for each area. Ages of roof pendants or wallrocks, when known with some certainty, are given; for areas in which younger generations of structures are absent, age of adjacent granitic rocks is given]

Area	Devonian or Mississippian deformation Antler orogeny	Triassic deformation Sonoman orogeny	Early and Middle Jurassic deformation	Late Jurassic Nevadan orogeny	Middle Cretaceous deformation
		Owens terrane			
Log Cabin mine roof pendant (Kistler, 1966; W. J. Nockleberg, unpub. data, 1975).	N.; metasedimentary rocks; Ordovician(?) and Silurian(?).	N. 25° W.; same rocks.	Bordered by--------	Late Triassic granite-	----------------
Eastern part of Saddlebag Lake roof pendant (Brook, 1972, 1974, 1977; Brook and others, 1979).	N. 8° W.; metasedimentary rocks; Ordovician(?) and Silurian(?).	N. 20° to 30° W.; same rocks.	-------------------	---------------------	N. 50° to 60° W.; same rocks.
Eastern part of Mount Morrison roof pendant (Russell and Nockleberg, 1974, 1977).	N. 8° W.; metasedimentary rocks; Ordovician and Silurian(?).	---------------------	-------------------	N. 23° W.; same rocks.	N. 58° W.; same rocks.
Bishop Creek roof pendant (Bateman, 1965; Moore and Foster, 1980).	N.; metasedimentary rocks; Ordovician(?) and Silurian(?).	---------------------	Bordered by--------	Late Triassic granite-	----------------
Dinkey Creek roof pendant (Kistler and Bateman, 1966)	N. 5° E.; metasedimentary rocks; Paleozoic(?).	---------------------	-------------------	N. 25° W.; same rocks.	N. 60° W.; same rocks.
		High Sierra terrane			
Western part of Saddlebag Lake roof pendant (Brook, 1972, 1974, 1977; Brook and others, 1979).	-------------------------	N. 20° to 30° W.; metasedimentary rocks, Mississippian(?); metavolcanic rocks, Permian and Triassic.	-------------------	---------------------	N. 61° W.; same rocks.
Western part of Mount Dana roof pendant (Kistler, 1966a, b; Russell, 1976).	-------------------------	N. 25° W.; metavolcanic rocks; Permian and Triassic isochron.	-------------------	---------------------	N. 60° to 65° W.; same rocks.
Northern part of Ritter Range roof pendant (Kistler, 1966a).	-------------------------	N. 25° W.; metavolcanic rocks; Permian and Triassic isochron.	-------------------	---------------------	N. 50° W.; same rocks.
Eastern part of central Ritter Range roof pendant (Kistler, 1966a, b; Huber and Rinehart, 1965; Fiske and Tobisch, 1978).	-------------------------	N. 30° W.; metavolcanic rocks; Permian and Triassic isochron and Triassic U-Pb zircon age.	-------------------	N. 30° W.; same rocks.	N. 50° to 70° W.; same rocks.
Central part of Mount Morrison roof pendant (Rinehart and Ross, 1964; Russell and Nokleberg, 1977).	-------------------------	N. 30° W.; metasedimentary rocks; Pennsylvanian and Permian(?).	-------------------	N. 30° W.; metasedimentary rocks; Pennsylvanian and Permian; metavolcanic rocks; Permian to Jurassic.	N. 62° W.; same rocks.
Pine Creek roof pendant (Bateman, 1965).	-------------------------	N. 22° W.; metasedimentary rocks; Pennsylvanian(?) and Permian(?).	Bordered by--------	Late Triassic granite-	----------------
		Goddard terrane			
Central and western parts of Ritter Range roof pendant (Kistler, 1966a, b; Huber and Rinehart, 1965; Fiske and Tobisch, 1978).	-------------------------	---------------------	-------------------	N. 30° W.; metavolcanic rocks; Permian, Triassic, and Early Jurassic isochrons and Pb-U zircon ages.	N. 50° to 70° W.; same rocks.
Mount Goddard roof pendant (Bateman and Moore, 1965; Chen and Moore, 1979).	-------------------------	---------------------	-------------------	N. 20° to 40° W.; metavolcanic rocks; pre-Late Jurassic.	N. 50° to 70° W.; same rocks.
Eastern part of Boyden Cave roof pendant (Moore and Marks, 1972; Girty, 1977a, b; Saleeby and others, 1978).	-------------------------	---------------------	-------------------	N. 15° to 20° W.; metavolcanic rocks; pre-Early Cretaceous.	Encircled by Early Cretaceous granite.

TABLE 2.—*Regional deformations recorded in tectons-stratigraphic terranes in the central Sierra Nevada*—Continued

Area	Devonian or Mississippian deformation Antler orogeny	Triassic deformation Sonoman orogeny	Early and Middle Jurassic deformation	Late Jurassic Nevadan orogeny	Middle Cretaceous deformation
			Kings terrane		
Strawberry mine roof pendant (Nockleberg, 1970, 1980).	-------------------------	---------------------	N.E.; metasedimentary rocks; Early Jurassic(?).	---------------------	N. 20° to 30° W. and N. 55° to 60° W.; same rocks.
Western part of Boyden Cave roof pendant (Moore and Marks, 1972; Girty, 1977a, b; Saleeby and others, 1978).	-------------------------	---------------------	N. 60° E.; metasedimentary rocks; Late Triassic and Early Jurassic.	N. 20° W.; same rocks.	Encircled by Early Cretaceous granite.
Mineral King roof pendant (Christensen, 1963).	-------------------------	---------------------	---------------------	N. 30° W.; metasedimentary rocks; Late Triassic.	Encircled by Early Cretaceous granite.
			Merced River terrane		
Stanislaus River near Camp 9 (Baird, 1962).	-------------------------	---------------------	N. 55° to 65° E.; Calaveras Formation, quartzite; Late Paleozoic(?).	N. 20° to 30° W.	----------------
Stanislaus River near Melones (Baird, 1962).	-------------------------	---------------------	N. 30° to 50° E.; Calaveras Formation, argillite; Late Paleozoic(?).	N. 20° to 30° W.; same rocks.	----------------
Merced River (W. J. Nokleberg, unpub. data, 1972).	-------------------------	---------------------	N. 30° to 40° E.; Calaveras Formation, quartzite; Late Paleozoic(?).	N. 20° W.; same rocks.	----------------
Merced River (W. J. Nokleberg, unpub. data, 1977).	-------------------------	---------------------	N. 45° to 55° E.; Calaveras Formation, argillite; Late Paleozoic(?).	N. 20° to 30° W.; same rocks.	----------------
			Foothills terrane		
San Andreas (Duffield and Sharp, 1975).	-------------------------	---------------------	---------------------	N. 15° to 25° W.; Mariposa Formation, Slate and Logtown Ridge Formation; Late Jurassic.	----------------
Angels Camp and Sonora quadrangles (Eric and others, 1955).	-------------------------	---------------------	---------------------	N. 30° to 40° W.; Mariposa Formation, Slate and Brower Creek Volcanic Member; Late Jurassic.	----------------
Mariposa (Best, 1963)-------	-------------------------	---------------------	---------------------	N. 15° to 30° W.; Mariposa Formation, slate; Late Jurassic.	----------------
San Andreas (Clark, 1970)---	-------------------------	---------------------	---------------------	N. 20° to 30° W.; Salt Spring Slate and Copper Hill Volcanics, slate and volcanic rocks; Late Jurassic.	----------------
Stanislaus River, east of Knights Ferry (Clark, 1964).	-------------------------	---------------------	---------------------	N. 20° to 35° W.; Salt Spring Slate and Gopher Ridge Volcanics, slate and volcanic rocks; Late Jurassic.	----------------

stratigraphic relations in shelf deposits in the White-Inyo Mountains and a distance of only 13 km between the metasedimentary rocks on opposite sides of the valley. Also, there is a transition from shelf deposits in the Big Pine Creek roof pendant to slope deposits in the Mount Morrison roof pendant which does not occur in the White-Inyo Mountains to the east and which appears to be truncated by the Owens Valley fault.

CRITICAL DIFFERENCES BETWEEN OWENS TERRANE AND METASEDIMENTARY ROCKS OF WHITE-INYO MOUNTAINS

Substantial differences exist between the metasedimentary rocks of the Owens terrane and the late Precambrian and Cambrian metasedimentary rocks in the White-Inyo Mountains. Sparse fossils indicate

Cambrian, Ordovician, and Silurian(?) ages for the Owens terrane, whereas abundant fossils indicate late Precambrian and Cambrian ages for the sedimentary rocks in the White-Inyo Mountains. In addition, the metasedimentary rocks of the Owens terrane consist of both shelf and slope deposits, but the late Precambrian and Cambrian metasedimentary rocks of the White-Inyo Mountains consist predominatly of shelf deposits, Also, the metasedimentary rocks of the Owens terrane are multiply deformed and metamorphosed, whereas the late Precambrian and Cambrian metasedimentary rocks of the White-Inyo Mountains are barely metamorphosed and less intensely deformed (Dunne and others, 1978). These differences and the evidence for the Owens Valley fault indicate the Owens terrane is displaced, may be allochtonous, and has been accreted to units to the east.

ACCRETION OF OWENS TERRANE

The timing of accretion of the Owens terrane can only be determined by the age of crosscutting units that weld the Owens terrane to terranes to the east. There is no known area where individual plutons of any Mesozoic intrusive epoch can be observed in the field to intrude and weld the Owens terrane to the Permian to Jurassic metavolcanic rocks or the late Precambrian and Cambrian metasedimentary rocks of the White-Inyo Mountains (Evernden and Kistler, 1970). The only other Mesozoic constraint on timing of accretion of the Owens terrane is the Late Jurassic Independence dike swarm, dated by U-Pb techniques as 148 m.y., which crosses Owens Valley near Independence (Moore and Hopson, 1961; Chen and Moore, 1979). Moore and Hopson (1961) suggest that this occurrence of the dike swarm across Owens Valley limits movement on any fault in the valley to less than a few tens of kilometers. However, recently discovered exposures of the dikes greatly enlarge the width and length of the dike swarm (Chen and Moore, 1979). These new data shows the dike swarm is up to 60 km wide and strikes almost parallel to Owens Valley. Thus, major fault with several hundreds of kilometers of movement could readily occur in Owens Valley, strike subparallel to the dike swarm, and easily offset portions of the dike swarm to form the present-day pattern.

The above analysis indicates accretion of the Owens terrane in the interval between the deposition of the Permian to Jurassic metavolcanic rocks in the White-Inyo Mountains and the inception of Tertiary volcanism in Owens Valley. To narrow this time interval, more data are needed on the ages of the metavolcanic rocks and on critical geologic relations in similar rocks further south in the Mojave Desert. These relations indicate the Owens Valley fault is a major tectonic boundary, possibly a suture, between two allochthonous terranes, the Owens terrane to the west and the late Precambrian and Cambrian metasedimentary rocks of the White-Inyo Mountains to the east. The Owens Valley fault may be a major right-lateral strike-slip fault of Cenozoic age, possibly related to movement on the San Andreas fault system, the Death Valley fault of Cenozoic age, and the Las Vegas shear zone. Of considerable note is the inability of various workers to extend the Roberts Mountain thrust, formed during the Antler orogeny, and the vast differences in structures produced in the Antler orogeny in central Nevada and the Sierra Nevada (Burchfiel and Davis, 1972; Russell and Nokleberg, 1977; Davis and others, 1978); these relations indicate considerable movement on the Owens Valley fault, thereby causing offset of the Roberts Mountain thrust as well as juxtaposition of different terranes.

HIGH SIERRA TERRANE

OCCURRENCE

The High Sierra terrane consists of metamorphosed late Paleozoic metasedimentary rocks and unconformably overlying Permian and Triassic metavolcanic rocks that are exposed discontinuously in roof pendants along the crest of the Sierra Nevada for about 140 km in a northwest-trending belt that averages about 5 km in width (pl. 1) (Kistler and Nokleberg, 1980). This terrane is best exposed in the Saddlebag Lake, Mount Morrison, and Pine Creek roof pendants. To the east, this terrane is either intruded by Late Triassic to Middle Jurassic and Late Cretaceous granitic plutons of the Lee Vining, Inyo Mountains, and Cathedral Range intrusive epochs (Evernden and Kistler, 1970) or faulted against the Owens terrane along the Laurel-Convict fault (pl. 1). To the west, this terrane is either faulted against the Goddard terrane along the San Joaquin River fault (pl. 1) or intruded by Late Cretaceous granitic plutons of the Cathedral Range intrusive epoch (Evernden and Kistler, 1970). The stratified Permian and Triassic metavolcanic rocks forming the western part of this terrane are faulted against the Jurassic metavolcanic rocks of the Goddard terrane in the central part of the Ritter Range roof pendant (Huber and Rinehart, 1965; Fiske and Tobisch, 1978; W. J. Nokleberg, unpub. data, 1976).

STRATIGRAPHY

The dominant protoliths in the late Paleozoic metasedimentary rocks are siliceous and calcareous mudstone, with minor limestone, marl, conglomerate, quartz-sandstone, and chert (Kistler and Nokleberg,

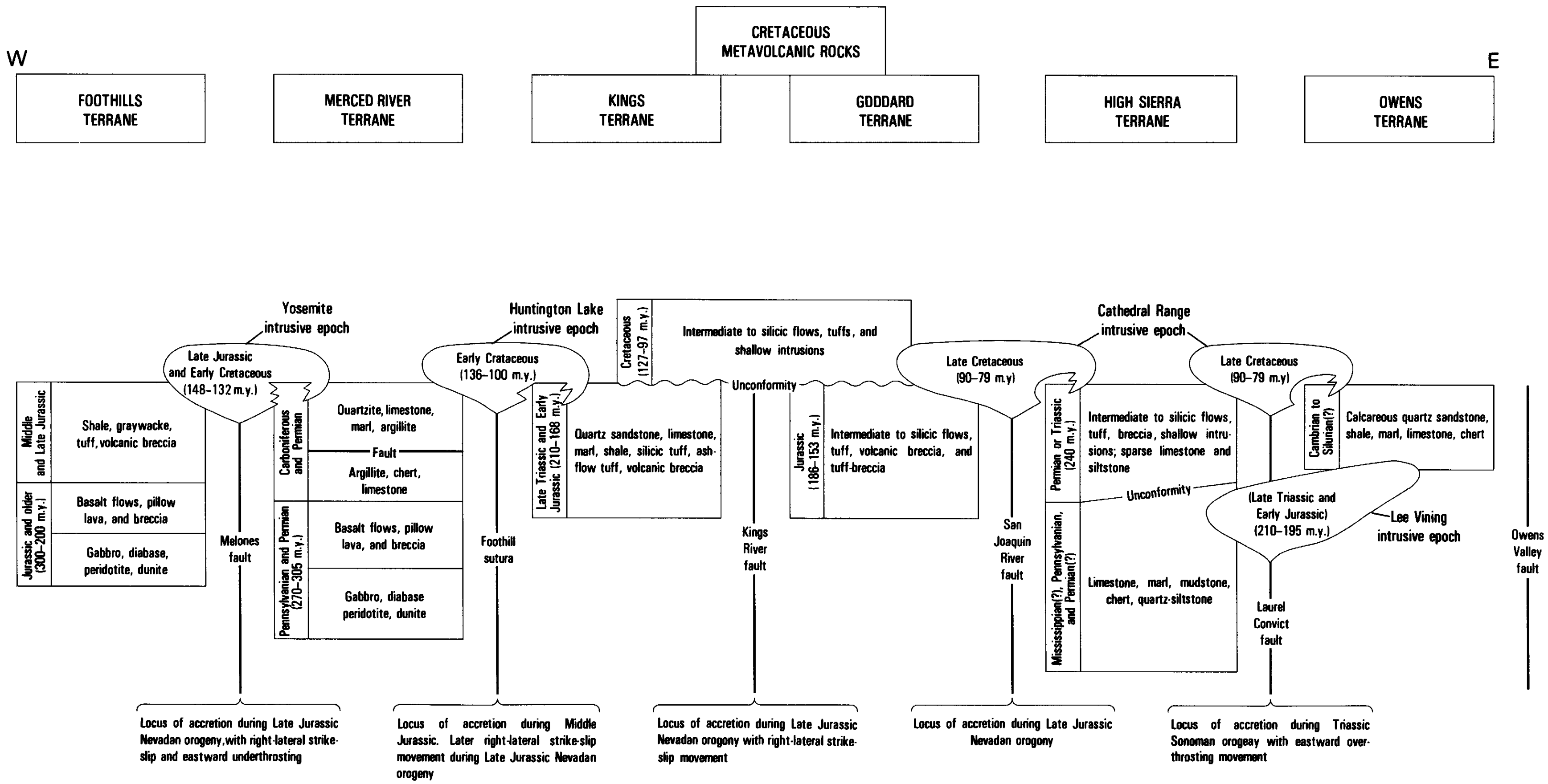

FIGURE 1.—Generalized stratigraphic columns for Paleozoic and Mesozoic tectonostratigraphic terranes, central Sierra Nevada. Solid lines between adjacent columns represent major thrust, reverse, or strike-slip sutures separating terranes. Age of accretion and movement on suture given at bottom of suture line. Units marked by "+" are the oldest granitic rocks known to weld together two adjacent terranes. Oldest stratigraphic units overlying adjacent terranes shown in overlapping box. Sources of data on lithologies given in text. Sources of radiometric and fossil ages given in table 1.

1980). The metasedimentary rocks of the High Sierra terrane contain (pl. 1; table 1) Pennsylvanian conodonts in an unnamed roof pendant northeast of Saddlebag Lake (W. J. Nokleberg and A. H. Harris, unpub. data, 1978); Mississippian(?) crinoid fragments and corals in the Saddlebag Lake roof pendant (Brook and others, 1979); Mississippian(?) brachiopods and pelecypods in the northern Ritter Range roof pendant (Brook and others, 1979); and abundant brachiopods, corals, and bryozoans of Pennsylvanian and Permian(?) age in the Mount Morrison roof pendant (Rinehart and Ross, 1964). The unfossiliferous metasedimentary rocks of other roof pendants in this terrane are correlated with the upper Paleozoic rocks of the Mount Morrison roof pendant on the basis of lithologic similarity. The stratigraphic section is bounded by a fault at its base and by an angular unconformity at its top. Because of intense, multiple deformation, the stratigraphic thickness of the late Paleozoic metasedimentary rocks of this terrane is not well known but is estimated at about 1,600 m in the Mount Morrison roof pendant (Rinehart and Ross, 1964; Morgan and Rankin, 1972) and at about 1,600 m in the Pine Creek roof pendant (Bateman, 1965). In the western part of the Saddlebag Lake roof pendant, transposition of bedding into foliation by intense, penetrative deformation has made estimation of stratigraphic thicknesses impossible (Brook, 1977). The metasedimentary rocks of this terrane are interpreted as having originally been deposited in a shelf or slope environment (Kistler and Nokleberg, 1980).

The dominant protoliths in the Permian and Triassic metavolcanic rocks are andesite to rhyodacite tuff, ash-flow tuff, and flows, conglomerate, volcanic breccia, and andesite sills, with minor marl, volcanic sandstone, and basalt flows (table 1) (Brook, 1977; Kistler, 1966a). In the Saddlebag Lake roof pendant, the sequence consists of a basal conglomerate, a thick rhyolite ash-flow tuff, andesite sills and tuff, and an upper unit of volcaniclastic rocks, tuff, and marl (Brook, 1977). The very distinctive basal conglomerate and overlying ash-flow tuff can be traced for 70 km from the Saddlebag Lake roof pendant in the north to the Mount Dana, Ritter Range, and Mount Morrison roof pendants in the south (Russell, 1976; Kistler, 1966b; W. J. Nokleberg, unpub. data, 1976). Although identifiable fossils have not been found in the Permian and Triassic metavolcanic rocks, the rocks are dated Permian and Triassic (240 m.y.) by a Rb/Sr whole-rock isochron (Kistler, 1966a; Brook, 1977; Fiske and Tobisch, 1978; Nokleberg and Kistler, 1980). Because of intense, multiple deformation, the stratigraphic thickness of the Permian and Triassic metavolcanic rocks is unknown but is estimated at about 500 m in the Saddlebag Lake roof pendant (Brook, 1977) and at about 2,000 m in the Ritter roof pendant (Fiske and Tobisch, 1978). The metavolcanic and limy metasedimentary rocks of this terrane are interpreted as having formed in a shallow marine environment.

A major regional angular unconformity separates the late Paleozoic metasedimentary rocks from the overlying Permian and Triassic metavolcanic rocks. This unconformity occurs along a 75-km stretch of the Sierra Nevada crest that includes the Saddlebag Lake, Mount Dana, Ritter Range, and Mount Morrison roof pendants (Kistler, 1966a, b; Russell, 1976; Brook, 1977; Russell and Nokleberg, 1977; Fiske and Tobisch, 1978). Interpretation of the contact between these two sequences as an angular unconformity rather than a fault is discussed by Brook and others (1974) and Morgan and Rankin (1972). The angular unconformity separating the two rock sequences is manifested by (1) a marked change in lithologies, (2) the basal conglomerate in the Permian and Triassic metavolcanic rocks containing clasts similar to the underlying late Paleozoic metasedimentary rocks, and (3) truncation of layers in the late Paleozoic metasedimentary rocks with no indication of shearing along the contact (Brook and others, 1974). The time hiatus represented by the unconformity may be quite short because of the Mississippian(?), Pennsylvanian, and Permian(?) age of the underlying metasedimentary rocks and the Permian and Triassic age of the overlying metavolcanic rocks. In the southern part of the Mount Morrison roof pendant, local faulting may occur along the unconformity (Morgan and Rankin, 1972). This unconformity represents a great change in the stratigraphy of the wallrocks and marks not only Permian and Triassic uplift and erosion, but also the cessation of marine sedimentation in the Paleozoic, and the inception of Andean-type arc volcanism in the latest Paleozoic and Mesozoic (Brook and others, 1974).

STRUCTURE

Most of the High Sierra terrane is either twice or thrice deformed (table 2). The principal, and first, deformation of this terrane occurred in a Triassic regional deformation, possibly the Sonoman orogeny (Nokleberg, 1979; Nokleberg and Kistler, 1980). Structures produced during this deformation consist of the north-northwest-trending Laurel-Convict fault (pl. 1), parallel-trending isoclinal folds and faults, and schistosity. Axial planes of major and minor folds and parallel schistosities have average attitudes of N. 20° to 30° W. with vertical dips (table 2). Major and minor fold axes plunge moderately to steeply northwest (Nokleberg and Kistler, 1980).

The Triassic age of this regional deformation is best established in the Saddlebag Lake and northern Ritter

Range roof pendants where structures, including the northern extension of the Laurel-Convict fault, are intruded by Late Triassic granitic rocks of the Lee Vining intrusive epoch (Evernden and Kistler, 1970; Nokleberg and Kistler, 1980). A similar age of deformation is also determined from the Pine Creek roof pendant where N. 20° to 30° W.-trending structures in Pennsylvanian(?) and Permian(?) metasedimentary rocks are crosscut by relatively undeformed Late Triassic granitic rocks of the Lee Vining intrusive epoch, which restricts the deformation to Late Permian or Triassic. In both the Saddlebag Lake and northern Ritter Range roof pendants, the upright nature of folds and the nearly vertical dip of associated faults indicate mainly compression during this deformation. The moderately plunging fold axes in the Saddlebag Lake roof pendant (Brook, 1977; Nokleberg and Kistler, 1980) may indicate a component of strike-slip movement.

Critical geologic data on structural history are lacking in the western part of the Mount Dana, and northern part of the Ritter Range roof pendants, and only a Triassic or Jurassic age of deformation can be determined for the N. 20° to 40° W.-trending structures (table 2) (Nokleberg and Kistler, 1980). Later, intense deformation occurred during accretion of the Goddard terrane to the west during the Late Jurassic Nevadan orogeny, as discussed below (table 2). Coaxial, multiple deformations along N. 20° to 40° W. trends may have occurred in both the Triassic and Late Jurassic in the High Sierra terrane (Nokleberg and Kistler, 1980) (table 2). A third deformation occurred along N. 50° to 80° W. trends in the middle Cretaceous (table 2).

EVIDENCE FOR LAUREL-CONVICT FAULT

The evidence for the Laurel-Convict fault is: (1) in the Mount Morrison roof pendant, juxtaposition of upper Paleozoic sedimentary rocks over lower Paleozoic sedimentary rocks along a steeply west dipping surface of shearing and intense deformation (Rinehart and Ross, 1964; Russell and Nokleberg, 1977); (2) in the Gull Lake roof pendant, juxtaposition of upper Paleozoic sedimentary rocks against lower Paleozoic sedimentary rocks along a vertically dipping surface of tectonic imbrication and shearing located at the east side of a mapable unit about 1 km east of Silver Lake (Kistler, 1966b; W. J. Nokleberg, unpub. data, 1975); and (3), in the Saddlebag Lake roof pendant, juxtaposition of twice-deformed upper Paleozoic sedimentary rocks over thrice-deformed lower Paleozoic sedimentary rocks along a folded shear surface (Brook, 1977; Brook and others, 1979).

In the Mount Morrison roof pendant, the Laurel-Convict fault dips steeply westward (Rinehart and Ross, 1964). The Laurel-Convict fault was originally interpreted by Rinehart and Ross (1964) as a faulted angular unconformity between lower Paleozoic rocks to the east (Owens terrane) and upper Paleozoic rocks to the west (High Sierra terrane). In this study, the concept of the Laurel-Convict fault representing a former unconformity is rejected because nowhere in the eastern Sierra Nevada is the unconformity ever observed. Instead, a surface of intense deformation and shearing is generally observed. This fault has probably been rotated to steeper angles by the Nevadan orogeny, dicussed subsequently, and was originally a moderate to shallowly west dipping thrust fault.

CRITICAL DIFFERENCES FROM OWENS TERRANE

The main differences between the High Sierra and Owens terranes are (tables 1, 2): (1) a late Paleozoic and Early Triassic age for the High Sierra terrane compared to an early Paleozoic age for the Owens terrane; (2) the occurrence of predominantly siliceous and calcareous mudstone and marble in the former sedimentary rocks of the High Sierra terrane compared to the predominantly calcareous sandstone and shale in the former sedimentary rocks of the Owens terrane; (3) the occurrence of former volcanic rocks generated in an Andean-type arc setting in the High Sierra terrane compared to no volcanic rocks in the Owens terrane; and (4) the occurrence of three generations of structures in the Owens terrane compared to only the younger two generations of structures in the High Sierra terrane. These differences and the evidence for the Laurel-Convict fault between the High Sierra and Owens terranes indicate that the High Sierra terrane has been either amalgamated or accreted to the Owens terrane.

AMALGAMATION AND ACCRETION OF HIGH SIERRA TERRANE

The Laurel-Convict fault is the locus of the Triassic overthrusting of the Owens terrane by the High Sierra terrane. The age of this overthrusting is generally similar to the emplacement of the Golconda allochthon in western Nevada during the Sonoman orogeny as described by Speed (1979). However, units in the Golconda allochthon or autochthon cannot be correlated with the High Sierra and Owens terranes, respectively (R. C. Speed, oral commun., 1979). Consequently, the Laurel-Convict fault is only a similar-age thrust fault or suture which, together with the other structures of the Triassic deformation, may represent the equivalent of the Sonoman orogeny in the eastern Sierra Nevada.

This deformation and overthrusting defines the amalgamation of the High Sierra terrane onto the Owens terrane. To the north in Nevada, a late Paleozoic island arc was amalgamated onto the North American margin (Silberling and Roberts, 1962; Speed, 1979), whereas to the south, a Permian or Triassic Andean-type arc was amalgamated to the North American margin. The amalgamation also was the major tectonic event just prior to development of the Mesozoic volcanic and plutonic arc of the Sierra Nevada. Subsequently, the High Sierra and Owens terranes were welded together in the northern part of the study area by Late Triassic granitic plutons of the Lee Vining intrusive epoch (pl. 1; fig. 1) (Evernden and Kistler, 1970). Preliminary data on the offset of initial strontium isotope contours in eastern California suggest reactivation of the southern part of the Laurel-Convict fault with right-lateral displacement in the Jurassic (Kistler and others, 1980). Subsequently, the High Sierra and Owens terranes were welded together during intrusion of the Late Cretaceous granitic plutons of the Cathedral Range intrusive epoch (fig. 1).

GODDARD TERRANE

OCCURRENCE

The Goddard terrane consists of metamorphosed volcanic rocks of Jurassic age that are exposed discontinuously in roof pendants along and just west of the crest of the Sierra Nevada for about 190 km in a north-northwest-trending belt that ranges from about 6 to 33 km in width (pl. 1; table 1). This terrane is best exposed in the Ritter Range and Mount Goddard roof pendants. However, the metavolcanic rocks of this terrane in the Goddard, eastern part of the Boyden Cave, and Alabama Hills roof pendants have not been extensively studied. Much additional work, particularly on obtaining radiometric age data, is needed in these roof pendants. To the east, this terrane is either intruded by Late Cretaceous granitic plutons of the Cathedral Range intrusive epoch (Evernden and Kistler, 1970) or faulted against the High Sierra terrane along the herein named San Joaquin River fault (pl. 1). To the west, this terrane is (1) intruded by Early Cretaceous and Late Cretaceous granitic plutons of the Huntington Lake and Cathedral Range intrusive epochs (Evernden and Kistler, 1970), (2) faulted against Kings terrane along the Kings River fault (pl. 1), or (3) unconformably overlain by Middle Cretaceous metavolcanic rocks (pl. 1). In the central and western parts of the Ritter Range roof pendant, a major angular unconformity separates twice-deformed predominantly Jurassic metavolcanic rocks from overlying once-deformed middle Cretaceous metavolcanic rocks (Huber and Rinehart, 1965; Fiske and Tobisch, 1978; Nokleberg and Kistler, 1980).

STRATIGRAPHY

The dominant protoliths in the Goddard terrane are andesite to dacite lava flows, tuff-breccia, tuff and lapilli tuff, ash-flow tuff, and minor basalt and rhyolite flows and tuff, limestone, and limy tuff (table 1). Abundant specimens of the bivalve genus *Weyla* at one locality in the Ritter Range roof pendant (Huber and Rinehart, 1965) and radiometric determinations of 153 to 186 m.y. in the Ritter Range roof pendant (Fiske and Tobisch, 1978) indicate an Early and Late Jurassic age (pl. 1; table 1). At the eastern margin of the Goddard terrane in the Ritter Range roof pendant, U-Pb zircon ages range from 186 to 214 m.y. (Fiske and Tobisch, 1978); however, these older ages are from samples near the San Joaquin River fault between the Goddard and High Sierra terranes where there is considerable tectonic mixing of the two terranes (W. J. Nokleberg, unpub. data, 1976). The Goddard terrane in the northern part of the Mount Goddard roof pendant is dated as pre-Late Jurassic. These rocks are intruded by a sheared granodiorite which is dated by U-Pb zircon techniques as 158 m.y. (Chen and Moore, 1979). The Goddard terrane in the eastern part of the Boyden Cave roof pendant is dated as pre-Early Cretaceous (>140 m.y.). These rocks are intruded by Early Cretaceous granitic plutons of the Huntington Lake intrusive epoch (Evernden and Kistler, 1970; Moore and others, 1979). The metavolcanic rocks of the Goddard terrane are either fault bounded or unconformably overlain by the middle Cretaceous metavolcanic rocks. A minimum thickness of a highly deformed section in the Ritter Range roof pendant is about 5,000 m (Fiske and Tobisch, 1978). The metavolcanic rocks of the Goddard terrane are interpreted as having formed in a shallow, but continually subsiding, marine basin in which volcanic arc flows, tuff, and breccia were being deposited during repeated marine transgressions and regressions (Fiske and Tobisch, 1978).

STRUCTURE

The Goddard terrane is twice deformed (table 2). The principal, and first, generation of structures was formed in the Late Jurassic Nevadan orogeny (Nokleberg and Kistler, 1980). Structures of this generation consist of north- northwest-trending faults, including the bounding San Joaquin River fault (pl. 1), moderately appressed to isoclinal folds, schistosity, and lineations (Nokleberg and Kistler, 1980). Axial planes of major and minor folds and parallel schistosities show average strikes of N. 20° to 40° W. (table 2). Major and minor fold axes have moderate to steep plunges. In the Ritter Range roof pendant, several fault zones show extreme cataclasis occurring parallel to the strike of major units and axial planes of major folds (W. J. Nokleberg, unpub. data, 1976).

The Late Jurassic age of the Nevadan orogeny in the roof pendant near the crest of the Sierra Nevada is best established in the Ritter Range roof pendant. The rocks of the central part of the roof pendant contain N. 20° to 40° W.-trending structures with Early Jurassic fossils and Jurassic radiometric ages and are unconformably overlain by Early Cretaceous metavolcanic rocks containing only younger structures (Fiske and Tobisch, 1978; Nokleberg and Kistler, 1980). These relations bracket the deformation as Late Jurassic. In late Paleozoic and Mesozoic metavolcanic rocks (probably Permian through Jurassic) of the Mount Morrison roof pendant, intrusions by Late Cretaceous granitic rocks of the Cathedral Range intrusive epoch (Evernden and Kistler, 1970) indicate the deformation probably was between Jurassic and Early Cretaceous time. In other roof pendants in this area, critical data are lacking and only a Mesozoic age of deformation can be inferred for the N. 20° to 40° W.-trending structures (Nokleberg and Kistler, 1980). The upright nature of folds and the nearly vertical dip of axial planes and fold limbs indicate mainly compression during this deformation, and the gentle to steep plunges of major and minor fold axes indicate compressional as well as strike-slip components of movement.

A later deformation occurred along N. 50° to 80° W. trends in the middle Cretaceous (table 2) (Nokleberg and Kistler, 1980). Structures of this middle Cretaceous deformation are the only ones to occur in the middle Cretaceous metavolcanic rocks that unconformably overlie the Jurassic metavolcanic rocks in the Ritter Range roof pendant (Tobisch and Fiske, 1976, Fiske and Tobisch, 1978).

EVIDENCE FOR SAN JOAQUIN RIVER FAULT

The San Joaquin River fault forms a suture between the Goddard and the High Sierra terranes. This fault is best exposed in the central part of the Ritter Range roof pendant (pl. 1). This fault occurs at the western limit of the Permian and Triassic metavolcanic rocks, along the piedmontite-bearing zone of Huber and Rinehart (1965), located about 0.5 km west of the headwaters of the San Joaquin River. The evidence for the San Joaquin River fault is: (1) intense shearing and cataclasis in the metavolcanic rocks in and adjacent to the piedmontite-bearing zone (W. J. Nokleberg, unpub. data, 1975); (2) truncation of units in both terranes along the contact (Fiske and Tobisch, 1978); and (3) juxtaposition of stratigraphic units of highly different ages, stratigraphy, and structure (tables 1, 2). Considerable tectonic mixing of the two terranes may occur along the San Joaquin River fault.

CRITICAL DIFFERENCES FROM THE HIGH SIERRA TERRANE

The stratigraphy, structure, and geologic history of the Goddard terrane differ greatly from those of the High Sierra terrane to the east. The main differences (tables 1, 2) are: (1) a Jurassic age for the Goddard terrane compared to a late Paleozoic and Early Triassic age for the High Sierra terrane; (2) greatly different stratigraphy for the former sedimentary rocks of the two terranes with abundant siliceous and calcareous mudstone, limestone, and marl in the High Sierra terrane compared to sparse limestone and limy tuff in the Goddard terrane; and (3) greatly different structural histories for the two terranes. The High Sierra terrane generally was thrice deformed: twice along N. 20° to 40° W. trends, in the Triassic Sonoman orogeny and in the Late Jurassic Nevadan orogeny, and once along N. 50° to 80° W. trends during the middle Cretaceous; whereas the Goddard terrane was twice deformed, during the later two periods (table 2). In addition, the High Sierra terrane is intruded by Late Triassic plutons of the Lee Vining intrusive epoch, whereas the Goddard terrane is intruded only by plutons of younger intrusive epochs. These differences and the evidence for the San Joaquin River fault between the Goddard and High Sierra terranes indicate that the Goddard terrane is allochthonous and has been amalgamated or accreted to the High Sierra terrane.

AMALGAMATION AND ACCRETION OF GODDARD TERRANE

The San Joaquin River fault, formed during the Late Jurassic Nevadan orogeny, is the locus of accretion of the Goddard and High Sierra terranes. Portions of the Early and Middle Jurassic granitic rocks of the Inyo Mountains intrusive epoch may have been also displaced along the San Joaquin River fault. These relations indicate the Late Jurassic Nevadan orogeny was an intense and widespread deformation that not only included accretion of terranes in the western metamorphic belt along the Melones fault (Davis and others, 1978) but also accretion of terranes to the east along major faults such as the San Joaquin River fault. Like the Melones fault, the San Joaquin River fault represents a suture along which there was major displacement and juxtaposition of diverse terranes within and during formation of the volcanic and plutonic arc of the Mesozoic Sierra Nevada. The Goddard terrane is welded to the High Sierra terrane by Late Cretaceous granitic plutons of the Cathedral Range intrusive epoch (fig. 1) (Evernden and Kistler, 1970). This relation allows that additional relative movement between the two terranes was possible in the middle Cretaceous.

CRETACEOUS METAVOLCANIC ROCKS

OCCURRENCE

The Cretaceous metavolcanic rocks do not form a terrane, but instead unconformably overlie or intrude, and thereby weld together, the Kings and Goddard terranes (pl. 1; fig. 1). The Cretaceous metavolcanic rocks consisting mainly of metamorphosed andesite to rhyodacite lava, tuff, breccia, and sparse limy metasedimentary rocks are exposed in the Mount Dana, western part of the Ritter Range, Merced Peak, and Strawberry mine roof pendants (pl. 1). The Cretaceous metavolcanic rocks have been studied by Kistler (1966a), Russell (1976), Tobisch and Fiske (1976), Fiske and Tobisch (1978), and Nokleberg (1981).

In the western part of the Ritter Range roof pendant, Early and middle Cretaceous metavolcanic rocks unconformably overlie the Early and Middle Jurassic rocks of the Goddard terrane. To the west, metamorphosed shallow intrusions of middle Cretaceous age intrude metasedimentary rocks of the Kings sequence in the Strawberry mine roof pendant (Nokleberg, 1980). These shallow intrusions are part of the Cretaceous metavolcanic rocks of the Merced Peak and adjacent roof pendants (pl. 1). The shallow intrusions and metavolcanic rocks form a magmatic sequence with the granodiorite of Jackass Lake and related plutonic rocks of middle Cretaceous age (Peck and others, 1977; Nokleberg, 1980). The Cretaceous metavolcanic rocks of the Mount Dana roof pendant unconformably overlie the late Paleozoic and Triassic metasedimentary and metavolcanic rocks of the High Sierra terrane (Kistler, 1966a, b; Russell, 1976).

STRATIGRAPHY AND STRUCTURE

The dominant protoliths of the Cretaceous metavolcanic rocks are volcanic tuff, flows, breccia, ash-flow tuff, shallow intrusions, volcanic graywacke, and minor limestone, marl, shale, and conglomerate. Igneous rock composition ranges from basalt to rhyolite, with andesite and dacite being most prevalent (Kistler, 1966a, b; Russell, 1976; Fiske and Tobisch, 1978; Nokleberg, 1981). The Cretaceous metavolcanic rocks are dated by Rb-Sr whole-rock and U-Pb zircon techniques as 97 to 100 m.y. in the Strawberry mine and Merced Peak roof pendants (Peck and others, 1977; Nokleberg, 1981), as 98 to 127 m.y. in the Ritter Range roof pendant (Fiske and Tobisch, 1978), and as Early Cretaceous in the Mount Dana roof pendant (Nokleberg and Kistler, 1980). In the Ritter Range roof pendant, these rocks are interpreted as a portion of an Andean-type arc in which there was mainly subaerial and local lacustrine deposition of volcanic material (Fiske and Tobisch, 1978), or as a portion of an Andean-type arc deposited in shallow marine basins in the Mount Dana roof pendant (Kistler, 1966a; Russell, 1976).

The Cretaceous metavolcanic rocks are generally once deformed. The deformation occurred in the middle to Late Cretaceous along mainly N. 50° to 70° W. trends (Nokleberg and Kistler, 1980). Structures consist of west-northwest-trending major and minor faults and folds, schistosity, and lineation. Fold axes and lineations generally plunge gently west-northwest. Conjugate folding along northeast trends is also associated with the west-northwest-trending structures in parts of the Ritter Range roof pendant (Tobisch and Fiske, 1976) and in the Strawberry mine roof pendant (Nokleberg, 1980). Regional metamorphism of the greenschist facies and penetrative deformation are slight to moderate.

KINGS TERRANE

OCCURRENCE

The Kings terrane consists of abundant Triassic and Jurassic metamorphosed sedimentary rocks and sparse intermediate to silicic metavolcanic rocks. These rocks have been included in the Kings sequence by Bateman and Clark (1974), Schweickert and others (1977), Saleeby and others (1978), and Nokleberg (1980). In this paper, the Kings sequence is defined as the metasedimentary rocks and sparse metavolcanic rocks that are discontinuously exposed from the Strawberry mine roof pendant in the north to the Isabella roof pendant in the extreme southern Sierra Nevada. These exposures form a north-northwest-trending belt about 210 km long and from 25 to 50 km wide between the crest and western foothills of the Sierra Nevada (pl. 1; table 1). This terrane is best exposed in the Strawberry mine, western part of the Boyden Cave, and Mineral King roof pendants.

The Dinkey Creek roof pendant is here excluded from the Kings sequence (pl. 1) because of stratigraphy and structure that differs markedly from the Kings sequence. The Dinkey Creek roof pendant contains former mudstones, marls, limestone, and particularly orthoquartzite, as well as three generations of superposed structures that are nearly identical to similar features in the early Paleozoic terrane to the east (Kistler and Bateman, 1966; Russell and Nokleberg; 1977; Bateman and Clark, 1974; Nokleberg, 1981). The Dinkey Creek roof pendant is interpreted as a small slice of the Owens terrane that has been displaced and accreted against the Kings terrane (pl. 1). However, such tectonic juxtaposition of the Dinkey Creek roof pendant presents a major unsolved problem in Mesozoic Sierra Nevada tectonics.

To the east, the Kings terrane is (1) intruded by Early Cretaceous and Late Cretaceous granitic plutons of the Huntington Lake and Cathedral Range intrusive epochs (Evernden and Kistler, 1970), (2) faulted against the Goddard terrane along the herein named Kings River fault (pl. 1), or (3) intruded by middle Cretaceous dikes and sills of andesite to rhyolite composition in the Strawberry mine roof pendant (pl. 1) (Nokleberg, 1970, 1981). To the west, this terrane is either intruded by Early Cretaceous granitic plutons of the Huntington Lake intrusive epoch (Evernden and Kistler, 1970) or faulted against the Merced River terrane along the Foothill suture (pl. 1). In the central part of the Boyden Cave roof pendant, the Kings River fault separates the less deformed metavolcanic rocks of the Goddard terrane to the east from the more higly deformed metasedimentary rocks of the Kings sequence and terrane to the west (Girty, 1977a, b; Moore and others, 1979). This fault occurs within and at the eastern margin of the highly deformed chaotic unit (Saleeby and others, 1978; Moore and others, 1979).

STRATIGRAPHY

The dominant protoliths in the Kings terrane are quartzite, arkose, limestone, marl, mudstone, calcareous sandstone, and sparse dacite to rhyodacite tuff, ash-flow tuff, breccia, and volcanic sandstone (table 1). Precambrian zircons in the thick quartzites (Moore and others, 1979) indicate a cratonal derivation. The volcanic rock and detritus composition is predominantly dacite with minor rhyodacite (table 1). These metasedimentary rocks of the Kings terrane are dated (pl. 1; table 1) by the occurrence of a late Mesozoic bivalve, most likely *Inoceramus pseudomytiloides* of Early Jurassic age, in the Strawberry mine roof pendant (Nokleberg, 1980) and pelecypods and ammonites of Late Triassic and Early Jurassic age in the Boyden Cave and Mineral King roof pendants (Christensen, 1963; Moore and Dodge, 1962; Jones and Moore, 1973; Saleeby and others, 1978). The metavolcanic rocks of the Kings terrane are dated (pl. 1; table 1) by U-Pb zircon ages of 210 and 168 m.y. in the Mineral King and Yokohl Valley roof pendants, respectively (Early to Middle Jurassic) (Busby-Spera and others, 1980; Saleeby and Sharp, 1980). The stratigraphy of the Kings sequence is interpreted by Saleeby and others (1978) and by J. S. Saleeby in Moore and others (1979) as a submarine fan system containing craton-derived sand, silicic volcaniclastic units, silicic tuff, and ash-flow tuff, all interbedded with mudstone, carbonate, and marl. Submarine fan facies include massive channel deposits, midfan to basin plane deposits, shallow-water slide blocks, and olistostromes of limestone and sandstone. The submarine fan system was dispersed off the shelf of western North America and westward onto accreted ocean floor represented by the Kings-Kaweah ophiolite belt (Saleeby, 1978). Because of intense multiple deformation, the stratigraphic thickness of the strata forming the Kings terrane is not well known. The base and top of the stratigraphic sections are either faulted or intruded by granitic plutons. The minimum stratigraphic thickness of these rocks is estimated at 887 m in the Strawberry mine roof pendant (Nokleberg, 1970, 1981) and at thousands of meters for the entire sequence by Saleeby and others (1978).

STRUCTURE

Most of the Kings terrane is twice or thrice deformed (table 2). The first generation of structures was formed in a Middle Jurassic deformation (Nokleberg and Kistler, 1980). Structures of this generation consist of northeast-trending open to isoclinal major and minor folds, parallel major and minor faults, axial plane schistosity, lineation, and areas of melange, broken formation, and cataclasite. Axial planes of major and minor folds and parallel schistosities have average strikes of northeast to N. 60° E. (Girty, 1977a, b) (table 2). Major and minor fold axes have gentle to moderate plunges (Nokleberg and Kistler, 1980). A maximum age for this Middle Jurassic deformation of the Kings terrane is determined by the structures occuring in Early Jurassic rocks in the Strawberry mine and western parts of the Boyden Cave roof pendants. A minimum age for this deformation is determined by the occurrence of superposed structures formed in the Late Jurassic Nevadan orogeny in (1) the western part of the Boyden Cave roof pendant (table 2) and (2) the Merced River terrane, which also contains the older, northeast-trending structures (table 2) (Nokleberg and Kistler, 1980). These relations bracket the deformation occurring along northeast trends as Middle Jurassic. The generally upright nature of folds and the nearly vertical dip of axial planes and fold limbs indicate mainly compression during this deformation. The gentle to moderate plunges of major and minor fold axes indicate that this was the first deformation of the Kings terrane.

Two younger deformations also occurred in portions of the Kings terrane (table 2). The second deformation occurred along N. 20° to 40° W. trends in the Late Jurassic Nevadan orogeny in the western part of the Boyden Cave and the Mineral King roof pendants (table 2). These Nevadan structures refolded and offset structures formed in the Middle Jurassic deformation (Girty, 1977a, b); they are very similar in the Kings and Goddard terranes (table 2) (Nokleberg and Kistler, 1980).

The Nevadan structures consist of north-northwest-trending faults, including the Kings River fault (pl. 1), moderately appressed to isoclinal major and minor folds, schistosity, and lineations (Girty, 1977a, b; Moore and others, 1979; Nokleberg and Kistler, 1980). Axial planes of major and minor folds and parallel schistosities have average strikes of N. 20° to 30° W. (table 2), and major and minor fold axes generally have vertical to steep southeast plunges. The major contacts between units of the western part of the Boyden Cave roof pendant strike north-northwest, parallel to the the deformational fabric of the rocks, and represent mostly tectonic contacts (Girty, 1977a, b; Moore and others, 1979). The timing of this deformation in the Kings terrane is bracketed by the earlier, Middle Jurassic deformation and by the crosscutting of all structures by the Early Cretaceous granitic rocks of the Huntington Lake intrusive epoch. The steep plunges of major and minor fold axes formed in the Late Jurassic Nevadan orogeny in the Kings terrane indicate mostly a strike-slip component of movement.

The third deformation occurred along N. 55° to 60° W. trends in the Strawberry mine roof pendant in the middle Cretaceous (Nokleberg, 1970, 1980). The Boyden Cave and Mineral King roof pendants were apparently shielded from this deformation by the Early Cretaceous granitic rocks of the Huntington Lake intrusive epoch (table 2).

EVIDENCE FOR KINGS RIVER FAULT

The Kings River fault forms a suture between the Goddard and Kings terranes (pl. 1) (Girty, 1977a, b; Saleeby and others, 1978; Moore and others, 1979). This predominantly strike slip fault occurs in the eastern part of the chaotic unit of the Boyden Cave roof pendant (pl. 1), just west of the quartz sandstone or flysch unit of Saleeby and others (1978). The critical evidence for the Kings River fault is: (1) intense penetrative deformation in the chaotic unit adjacent to the fault (Girty, 1977a, b; Moore and others, 1979); (2) juxtaposition of units with greatly different ages and stratigraphy (table 1); and (3) juxtaposition of strata with greatly different structural histories (table 2).

CRITICAL DIFFERENCES FROM GODDARD TERRANE

The stratigraphy, stucture, and geologic history of the Kings terrane differ greatly from those of the Goddard terrane to the east (tables 1, 2). The critical differences are (tables 1, 2): (1) a Late Triassic and Early Jurassic age for the Kings terrane compared to a pre-Cretaceous, most likely Jurassic, age for the Goddard terrane; (2) the occurrence of predominantly former quartzite, arkose, limestone, and marl, and sparse intermediate to silicic flows, tuff, and epiclastic rocks in the Kings terrane compared to predominantly former andesitic to rhyodacitic volcanic flows and tuff in the Goddard terrane; and (3) a greatly different structural history, including an older, northeast to N. 60° E.-trending set of folds, faults, and schistosity in the Kings terrane. In addition, there is no gradation between the massive metamorphosed flows of the Goddard terrane and the metasedimentary rocks and sparse metamorphosed volcanic and tuffaceous rocks of the Kings sequence (Girty, 1977a, b; Saleeby and others, 1978). The pre-Cambrian zircons in the quartzites of the Kings terrane (Moore and others, 1979) require a cratonal sources that does not exist adjacent to the Kings sequence. The above differences and the evidence for the Kings River fault between the Goddard and Kings terranes indicate the Kings terrane is allochthonous and has been accreted to the Goddard terrane.

ACCRETION OF KINGS TERRANE

The Kings River fault, formed in the Nevadan orogeny, is the locus of accretion of the Kings terrane to the Goddard terrane. Accretion consisted predominantly of right-lateral strike-slip movement and caused displacement of the Kings terrane from the Mojave region to its present position (Saleeby and others, 1978). Prior to movement on the fault, the Kings terrane formed an important spatial and temporal tie between major sedimentation patterns of the southwest Cordillera in the Mojave region and the continental margin of western North America (Saleeby and others, 1978). Movement of the submarine fan complex of the Kings sequence along strike-slip faults dissipated the strikes-slip component of oblique subduction (Saleeby and others, 1978). The Kings River fault represents a suture, along which there was major displacement and juxtaposition of diverse terranes within and during formation of the volcanic and plutonic arc of the Mesozoic Sierra Nevada. After accretion, the Kings terrane was welded to the Goddard terrane by Early Cretaceous granitic plutons of the Huntington Lake intrusive epoch (fig. 1) (Evernden and Kistler, 1970). In the Strawberry mine roof pendant, the Kings terrane is intruded by shallow dikes and sills of middle Cretaceous age (Nokleberg, 1981) that are the subsurface equivalent of the middle Cretaceous metavolcanic rocks of the Goddard terrane.

MERCED RIVER TERRANE

OCCURRENCE

The Merced River terrane consists of metamorphosed Carboniferous and Permian sedimentary rocks—the Calaveras Formation—and underlying ophiolite that are exposed either continously in the western metamorphic belt east of the Melones fault or discontinuously in roof pendants in the western Sierra Nevada in the area south of Mariposa (pl. 1). Within the study area, this terrane forms a north-northwest-trending belt about 310 km long and about 5 to 25 km wide (pl. 1). This terrane is best exposed along the Stanislaus and Merced Rivers in the western metamorphic belt, and in the lower Kings River, Kaweah Peaks, and Yokohl Valley roof pendants. To the east, this terrane is either intruded by various granitic plutons of Early Jurassic to Early Cretaceous age of the Inyo Mountains, Yosemite, or Huntington Lake intrusive epochs (Evernden and Kistler, 1970; Sharp and Saleeby, 1979; Saleeby and Sharp, 1980) or faulted against the Kings terrane along the Foothill suture (pl. 1). To the west, this terrane is either intruded by various granitic plutons of the same intrusive epochs as to the east or faulted against the Foothills terrane along the Melones fault (pl. 1). In the northern part of the study area, the eastern part of the Calaveras Formation (map unit mq, pl. l) in the western metamorphic belt may be the southward continuation of the lower Paleozoic Shoo Fly Formation (Schweickert, 1978). Further north in the northern Sierra Nevada, the Calaveras Formation is thrust under the Shoo Fly Formation (Clark, 1976), and the fault between the two formations has been traced to the south end of the western metamorphic belt by Schweickert (1978). In this study, rocks similar to the Shoo Fly Formation are included in the Merced River terrane. In the central Sierra Nevada, rocks called Kings sequence, as defined by Bateman and Clark (1974), were assigned by Schweickeret and others (1977) to the upper part of their Calaveras Complex which includes rocks formerly assigned to both the Calaveras Formation and the Kings sequence. In this study, the Calaveras Formation and Kings sequence are interpreted as belonging to separate terranes.

STRATIGRAPHY

The dominant protliths in the metasedimentary rocks of the Merced River terrane are shale and quartzite with minor limestone, marl, quartz-siltstone, and chert (table 1). The dominant lithologies in the underlying ophiolite are peridotite and dunite, serpentinite, gabbro, diabase, and basaltic pillow lava, breccia, tuff, and chert (table 2). Although commonly in fault contact with the metasedimentary rocks of the Merced River terrane, the ophiolite is observed to underlie and be the basement for the Merced River terrane (Saleeby, 1978, 1979; Saleeby and others, 1978; Sharp and Saleeby, 1979; Saleeby and Sharp, 1980). In the southern part of the study area, this ophiolite has been termed the Kings-Kaweah ophiolite belt (Saleeby, 1978; Saleeby and others, 1978). The metasedimentary rocks of the Merced River terrane east of the melones fault are dated (pl. 1; table 1) by sparse Carboniferous and Permian fusulinids, brachiopods, corals, and pelecypods in the northern part of the study area (Clark, 1964; Schweickert and others, 1977). The metasedimentary rocks of the Merced River terrane in a tectonically detached block west of the Melones fault and west of San Andreas (pl. 1) are dated (pl. 1; table 1) by Permian Tethyan fusulinids (Clark, 1964; Douglass, 1967); the metasedimentary rocks of the Merced River terrane in the Yokohl Valley roof pendant are also dated (pl. 1; table 1) by Permian Tethyan fusulinids (Schweickert and others, 1977; Saleeby and others, 1978). A late Paleozoic age for the ophiolite underlying the metasedimentary rocks of the Merced River terrane is indicated by U-Pb radiometric ages of 270 to 305 m.y. on zircon from plagiogranite dikes in the ophiolite (Saleeby, 1978; Saleeby and Sharp, 1980).

Of considerable importance are the Permian Tethyan fusulinids found in a large tectonically detached block of the Calaveras Formation within the Bear Mountain fault and in highly deformed chert and argillite of the upper part of the Kings-Kaweah ophiolite in the Yokohl Valley roof pendant (Clark, 1964; Schweickert and others, 1977; Saleeby and others, 1978). On the basis of the sparse Permian Tethyan fusulinids and similar lithologies, the Merced River terrane is correlated with the Cache Creek terrane of British Columbia and similar groups of rocks in northeastern Oregon and the Klamath Mountains containing Permian Tethyan fusulinids (Davis and others, 1978).

There are conflicting interpretations of the stratigraphy of the former sedimentary rocks of the Merced River terrane. Schweickert and others (1977) interpret the strata as a series of numerous shale and chert olistoliths that accumulated on oceanic lithosphere in a marginal basin. The quartzites represent progradation of mature sands derived from the North American continent to the east that were deposited across the basin margin. In this study, the strata are interpreted as a series of highly deformed fault-bounded tectonic blocks and lenses that are part of an accreted terrane. The strata may have been deposited in a marginal basin, however, but in the warm-water, equatorial Tethys region of the late Paleozoic. Because of intense, multiple deformation, and bounding of the stratigraphic section by faults, the stratigraphic thickness of the Merced River terrane is not known. A rough estimate of the stratigraphic thickness of the sedimentary rocks is thousands of meters (Schweickert and others, 1977). The base of the ophiolite and the top of the sedimentary units of the terrane are fault bounded (Schweickert and others, 1977; Saleeby and others, 1978).

STRUCTURE

Most of the Merced River terrane is thrice deformed (table 2). The second generation of structures was formed in a Middle Jurassic deformation (Nokleberg and Kistler, 1980). Structures of this generation consist of northeast- trending moderately appressed to isoclinal major and minor folds, parallel major and minor faults, axial plane schistosity, lineation, and zones of melange, broken formation, and cataclasite. Axial planes of major and minor folds and parallel schistosities have average strikes of N. 30° to 65° E. (table 2). Major and minor fold axes plunge moderately to steeply northeast and east (Nokleberg and Kistler, 1980). This deformation is related to formation of the Foothill suture (Nokleberg and Kistler, 1980). A minimum age for this deformation is indicated by the occurrence of superposed structures formed in the Late Jurassic Nevadan orogeny (table 2). A maximum age for this deformation is indicated by the occurrence of nearly identical and similar-trending structures in the Late Triassic and Early Jurassic Kings terrane (table 2). These relations bracket the deformation along northeast trends as Early and Middle Jurassic. A concordant U-Pb zircon age of 170 m.y. on a syntectonic pluton that intrudes the Calaveras Formation along the Stanislaus River (Baird, 1962) and that contains the northeast-trending structures also indicates a Middle Jurassic age of deformation (Sharp and Saleeby, 1979). The generally upright nature of folds and the nearly vertical dip of axial planes and fold limbs indicate mainly compression during this deformation. The uniform regional moderate to steep northeast plunges of major and minor fold axes indicate that the Merced River terrane was first deformed into north-northwest-trending isoclinal folds that dipped moderately east (Baird, 1962).

The third major deformation recognized in the Merced River terrane is attributed to the Late Jurassic Nevadan orogeny (table 2). This deformation produced structures with N. 20° to 30° W. trends and comprises north-northwest-trending isoclinal folds, cataclasite zones, and faults, including reactivation of the Foothill suture. Major and minor fold axes plunge steeply to vertically. The timing of the Nevadan deformation in the Merced River terrane is determined by superposition of the Nevadan structures on the northeast-trending structures formed in the Middle Jurassic and by the crosscutting of the Nevadan structures by the Late Jurassic granitic rocks of the Yosemite intrusive epoch (Nokleberg and Kistler, 1980) The Jurassic deformational histories of the Merced River and Kings terranes are very similar (table 2). The similar trend, style, and age of the Middle Jurassic and Late Jurassic structures in the two terranes indicate co-deformation during the Middle Jurassic deformation and the Late Jurassic Nevadan orogeny.

EVIDENCE FOR FOOTHILL SUTURE

A major fault, named the Foothill suture by Saleeby and others (1978), separates the Merced River and Kings terranes in the lower Kings River, Kaweah River, and Yokohl Valley roof pendants. In this study, the fault is just east of the chert unit which occurs just east of the Kings-Kaweah ophiolite belt (pl. 1). This location is at a major and highly deformed lithologic break between the sedimentary rocks of the Merced River and the Kings terranes (Nokleberg, 1975). The evidence for the Foothills suture is the juxtaposition of strata with different ages and stratigraphy (pl. 1; table 1) and the intense penetrative deformation and tectonic imbrication of units of the Merced River and Kings terranes along the suture (Nokleberg, 1975). In the area from the lower Kings River roof pendant to the Yokohl Valley roof pendant, this fault occurs in an area of extensive submarine slide blocks and olistostromes which were derived from the Kings terrane to the east and which are intermixed with chert and argillite of the Merced River terrane (Saleeby and others, 1978). In the Yokohl Valley roof pendant, the fault is placed in this study immediately west of the site of the 168-m.y. age determined by Saleeby and Sharp (1980) for the Kings sequence and immediately east of the Permian Tethyan fusulinid locality of Saleeby and others (1978) (pl. 1). Saleeby and others (1978) place the Foothill suture a few kilometers further east than shown in plate 1, in the area of extensive olistostromes.

CRITICAL DIFFERENCES FROM KINGS TERRANE

The stratigraphy, structure, and geologic history of the Merced River terrane differ markedly from those of the Kings terrane to the east (tables 1, 2). The main differences are: (1) a late Paleozoic age for the metasedimentary rocks (the Calaveras Formation) and a late Paleozoic age for the underlying ophiolite in the Merced River terrane compared to a Late Triassic and

Early Jurassic age for the metasedimentary rocks and metavolcanic rocks of the Kings terrane; (2) the occurrence of sparse former dacite and rhyodacite ash-flow tuffs and epiclastic rocks in the Kings sequence, whereas such rocks are not present in the Merced River terrane; (3) the occurrence of an ophiolite basement, representing oceanic lithosphere, under the Merced River terrane, whereas no ophiolitic basement occurs under the Kings terrane; (4) the occurrence of Tethyan fusulinids in the sedimentary rocks of the Merced River terrane; and (5) the occurrence of an older generation of north-northwest-trending structures in the Merced River terrane.

The occurrence of Tethyan fusulinids in highly deformed blocks in the Merced River terrane indicates that these exotic blocks and probably the enclosing strata were formed in the warm-water, equatorial Tethys region of the late Paleozoic. Subsequently, this terrane moved toward and was accreted against the western margin of North America (Davis and others, 1978; Saleeby and others, 1978; this study). This interpretation strongly contrasts with previous interpretations of the Kings sequence as the upper part of the Calaveras Complex of Schweickert and others (1977). The preceding critical differences and the evidence for the Foothill suture between the Merced River and Kings terranes indicate the Merced River terrane is allochthonous and has been amalgamated or accreted to the Kings terrane.

AMALGAMATION AND ACCRETION OF THE MERCED RIVER TERRANE

The Foothill suture is the locus of amalgamation of the Merced River and Kings terranes (Nokleberg, 1975; Saleeby and others, 1978). The common deformation of the Merced River and Kings terranes along northeast trends (table 2) is interpreted as having formed during the amalgamation of the two terranes in the Middle Jurassic. The northeast-trending folds, shear and cataclasite zones, and schistosities that formed during this amalgamation probably represent northwest-southeast compression (Nokleberg and Kistler, 1980).

Amalgamation of the Merced River and Kings terranes appears to be contemporaneous with the left-lateral shear displacement along the western margin of North America (Silver and Anderson, 1974; Kistler and Peterman, 1978). This displacement is defined by offset along a left-lateral megashear of Precambrian crystalline terranes and Paleozoic depositional trends from southeastern California to Sonora, Mexico (Silver and Anderson, 1974). The Early and Middle Jurassic age and the left-lateral sense of displacement of Precambrian crystalline terranes and of Paleozoic depositional trends are very similar to those in the Middle Jurassic amalgamation and northwest-southeast compression of the Merced River and Kings terranes. The displacement of the crystalline terranes and depositional trends may have been caused by amalgamation of the Tethyan-derived Merced River terrane with the Kings River terrane on the western margin of North America. In the central Sierra Nevada, the Foothill suture may be the left-lateral megashear of Silver and Anderson (1974). The syntectonic Middle Jurassic granitic plutons within the Merced River terrane (Evernden and Kistler, 1970; Sharp and Saleeby, 1979) probably were intruded during this amalgamation and deformation.

Prior to, or at the inception of, the Middle Jurassic amalgamation, the ophiolite of the Merced River terrane underwest 190- to 200-m.y.-old amphibolite facies regional metamorphism and was intruded by syntectonic 200-m.y.-old gabbro (Saleeby and others, 1978; Saleeby and Sharp, 1980). This regional metamorphic and plutonic event may have occurred with the first deformation of the Merced River terrane along north-northwest trends. According to Saleeby and others (1979), this metamorphic event may represent the initial stage of amalgamation.

After the Middle Jurassic amalgamation, both the Merced River and Kings terranes and the Early and Middle Jurassic plutonic rocks intruding the Merced River terrane were displaced and accreted by right-lateral movement on the Kings River fault during the Late Jurassic Nevadan orogeny (Saleeby and others, 1978). During this movement and accretion, both terranes were penetratively deformed, resulting in the formation of the N. 20° to 30° W. structures (table 2) (Nokleberg and Kistler, 1980). Intense development of these Nevadan structures along and adjacent to the Foothill suture indicates that the Foothills suture was reactivated during the Nevadan orogeny. After this accretion, the Merced River and Kings terranes were welded together by Early Cretaceous granitic plutons of the Huntington Lake intrusive epoch (fig. 1).

FOOTHILLS TERRANE

OCCURRENCE

The Foothills terrane consists of metamorphosed Middle and Late Jurassic volcanic arc rocks, formed in either an Andean-type arc or island-arc environment, and underlying ophiolite that are exposed continuously in the western metamorphic belt west of the Melones fault and in the southwestern part of the Oakhurst roof pendant (pl. 1; table 1). Within the study area, this terrane forms a north-northwest-trending belt about 160 km long and about 25 km wide (pl. 1). It is best exposed along the Stanislaus and Merced Rivers in the western metamorphic belt (pl. 1). To the east, this terrane is either intruded by Late Jurassic and Early Cretaceous granitic plutons of the Yosemite intrusive epoch (Evernden and Kistler, 1970) or faulted against the Merced River terrane along the Melones fault (pl. 1). To the west, this terrane shows onlapping by the Mesozoic Great Valley sequence and Cenozoic sedimentary and volcanic rocks along the east edge of the Great Valley. The Melones fault is a northeast-dipping high-angle reverse fault along which the Foothills terrane is thrust under the Merced River terrane (pl. 1). The fault is marked by intense shearing and penetrative deformation, juxtaposition and tectonic imbrication of the diverse lithologies of the two terranes, and tectonically dismembered portions of the ophiolites underlying the Foothills and Merced River terranes (Clark, 1960; Schweickert and Cowan, 1975). West of the Melones fault, rocks of the Merced River terrane only occur as fault-bounded tectonic blocks (pl. 1).

STRATIGRAPHY

The dominant protoliths in the volcanic arc rocks of the Foothills terrane are epiclastic mudstone and siltstone, volcanic graywacke and conglomerate, basaltic with lesser andesitic flows, pillow lava, and breccia (table 1). Local abundant detritus, derived from rocks similar to those in the Calaveras Formation of the Merced River terrane, including fragments of argillite, quartzite, conglomerate, and quartz veins, form sparse but important constituents of the epiclastic rocks, graywacke and conglomerate (Clark, 1964; Behrman and Parkison, 1978). The major formations constituting the volcanic arc rocks are the Logtown Ridge, and Mariposa Formations, upper part of the Penon Blanco Volcanics, and the Salt Spring and Merced Falls Slates (Clark, 1964). The Mariposa Formation and Salt Spring and Merced Falls Slates are correlative units that occur in various fault blocks west of the Melones fault (Clark, 1964). The dominant lithologies in the underlying ophiolite are peridotite and dunite, gabbro, diabase, basaltic pillow lava and tuff-breccia, and chert (table 1). The major formations constituting the ophiolite are the Gopher Ridge, Copper Hill, and Peaslee Creek Volcanics, the lower part of the Penon Blanco Volcanics, and mostly unnamed bodies of peridotite, dunite, gabbro, and diabase, (Clark, 1964). The various volcanic rocks are correlative units that occur in various fault blocks west of the Melones fault (Clark, 1964).

The volcanic arc rocks of the Foothills terrane are dated (pl. 1; table 1) by the occurrence of Middle and Late Jurassic ammonites and pelecypods (Imlay, 1961; Clark, 1964) (table 1). The ophiolite has been dated as (1) 182 to 190 m.y. (Early Jurassic) or older by U-Pb zircon techniques on possibly syngenetic diorites that intrude the Penon Blanco Volcanics in the upper part of the ophiolite (Morgan, 1976; Morgan and Stern, 1977) and (2) about 200 to 300 m.y. (late Paleozoic and Triassic) by U-Pb zircon techniques on plagioclase granite in the ophiolite (Saleeby and others, 1979). Additional isotopic investigations are needed to determine the original age of this ophiolite. If the 200- to 300-m.y. age for the ophiolite is correct then the ophiolites at the bases of the Merced River and Foothills terranes would have identical ages and possibly the same origin (Saleeby and others, 1979). Because of intense deformation, the stratigraphic thickness of the volcanic arc rocks is not well known. The base of the ophiolite and the stratigraphic top of the Foothills terrane are fault bounded (Clark, 1964; Schweickert and Cowan, 1975). The minimum stratigraphic thickness of the volcanic arc rocks is 1,830 m; the minimum stratigraphic thickness of the stratified rocks forming the upper part of the ophiolite is 915 m (Clark, 1964)

The volcanic arc rocks forming the upper part of the Foothills terrane are interpreted as either Andean-type arc volcanic rocks shed from the Middle and Late Jurassic volcanic arc of the Sierra Nevada (Wetzel and Nokleberg, 1976; Saleeby and others, 1979) or island-arc rocks formed oceanward of North America (Schweickert and Cowan, 1975; Schweickert, 1978). The underlying ophiolite of the Foothills terrane with an Early Jurassic age is interpreted as oceanic lithosphere that formed during a Late Triassic to Middle Jurassic period of rifting that occurred either immediately adjacent to the volcanic arc of the Sierra Nevada (Wetzel and Nokleberg, 1976) or adjacent to an island arc forming oceanward of North American (Schweickert and Cowan, 1975; Schweickert, 1978). The underlying ophiolite of the Foothills terrane with a late Paleozoic and Triassic age can be most readily interpreted as older oceanic lithosphere upon which volcanic debris was shed from the Middle and Late Jurassic volcanic arc of the Sierra Nevada (Saleeby and others, 1979).

STRUCTURE

The only major deformation of most of the Foothills terrane was the Late Jurassic Nevadan orogeny (table 2). Structures of this deformation consist of the north-northwest-trending Melones and Bear Mountain faults, numerous other parallel faults, parallel-trending moderately appressed to isoclinal major and minor folds, axial plane schistosity, lineation, and zones of melange, broken formation, cataclasite, and mylonite (Duffield and Sharp, 1975; Behrman, 1978; Nokleberg and Kistler, 1980). The Bear Mountain fault is one of several major faults that trend parallel to the Melones fault within the Foothills terrane. The zones of melange, broken formation, cataclasite, and mylonite trend north-northwest, parallel to the major faults and folds. Axial planes of major and minor folds and parallel schistosities have average strikes of N. 15° to 40°′W. (table 2); major and minor fold axes generally plunge moderately southeast (Nokleberg and Kistler, 1980), and the folds are commonly asymmetric and have a clockwise or right-lateral sense of movement (Wetzel and Nokleberg, 1976; Nokleberg and Kistler, 1980). The age of the Nevadan orogeny in the western metamorphic belt is bracketed by the early Late Jurassic (Kimmeridgian) age of the volcanic arc epiclastic rocks and by the Late Jurassic and Early Cretaceous (148 to 132 m.y.) age of the granitic plutons of the Yosemite intrusive epoch that crosscut the major folds and faults, including the Melones fault, formed in this orogeny (Bateman and others, 1963; Bateman and Clark, 1974). A combination of right-lateral strike-slip and reverse dip-slip movement for this deformation is indicated by the southeast plunge of major and minor fold axes and by the clockwise asymmetry of the major and minor folds (Wetzel and Nokleberg, 1976; Nokleberg and Kistler, 1980).

The structures produced in the Late Jurassic Nevadan orogeny are almost identical to those in the Foothills, Merced River, and Kings terranes (table 2) Nokleberg and Kistler, 1980). In all three, major and minor faults and folds strike N. 20° to 40° W., parallel to the sutures. Major and minor fold axes plunge moderately to steeply southeast in the Kings and Merced River terranes and moderately southeast in the Foothills terrane. These relations indicate a large component of strike-slip movement on faults and penetrative slip surfaces in all three terranes, and a minor to moderate amount of reverse dip-slip movement on similar surfaces in the Foothills terrane.

EVIDENCE FOR MELONES FAULT

The evidence for the Foothills fault system, of which the Melones fault is the easternmost branch, is excellently discussed by Clark (1960, 1964). The main evidence for the Melones fault is: (1) mappable belts of cataclastically deformed rock; (2) thin elongate pods of highly deformed serpentine, and ultramafic and mafic igneous rocks; (3) pervasive shearing; and (4) juxtaposition of Upper Jurassic rocks of the Foothills terrane against the Calaveras Formation of the Merced River terrane. West of the Melones fault, the Calaveras Formation does not occur stratigraphically under the Foothills terrane, but only as fault-bounded slivers in the melange of the Foothills fault system (Clark, 1960, 1964; Duffield and Sharp, 1975; Schweickert, 1978). One such large tectonic sliver of the Calaveras Formation occurs west of the Melones fault in the area west of San Andreas (pl. 1).

CRITICAL DIFFERENCES FROM MERCED RIVER TERRANE

The main differences between the Foothills and Merced River terranes are (tables 1, 2): (1) a Middle and Late Jurassic age for the former volcanic and sedimentary rocks of the Foothills terrane compared to a late Paleozoic age for the former sedimentary rocks of the Merced River terrane; (2) the occurrence of mainly former volcanic and epiclastic rocks formed in an Andean-type arc environment in the Foothills terrane compared to mainly former shale, quartzite, limestone, and marl in the former sedimentary rocks of the Merced River terrane; (3) the occurrence of two older generations of structures in the Merced River terrane; and (4) the occurrence of a Tethyan fauna in the sedimentary rocks of the Merced River terrane. These differences and the evidence for the Melones fault between the Foothills and Merced River terranes indicate the Foothills terrane is allochthonous and has been accreted to the Merced River terrane.

ACCRETION OF FOOTHILLS TERRANE

The Melones fault, part of the structures formed in the Late Jurassic Nevadan orogeny, is the locus of accretion of the Foothills and Merced River terranes (pl. 1). Accretion and codeformation of both terranes occurred along north-northwest trends (Nokleberg, 1975; Schweickert and Cowan, 1975; Schweickert, 1978). Movement during accretion along the Melones fault consisted of predominantly right lateral strike slip with minor reverse dip slip (Nokleberg, 1975; Wetzel and Nokleberg, 1976; Nokleberg and Kistler, 1980). These data indicate the Foothills terrane, like the Merced River and Kings terranes, was migrating northward along the western margin of the volcanic arc of the Sierra Nevada before accretion. Intense deformation occurred during accretion with development of cataclasite, mylonite, broken formation, and severe tectonic dismemberment of both terranes along the Melones fault. The Melones and Bear Mountain faults were intruded immediately after formation by various Late Jurassic granitic plutons of the Yosemite intrusive epoch. These relations suggest the Melones fault represents a major accretionary suture between the Merced River and Foothills terranes and does not represent a former subduction zone as suggested by Schweickert and Cowan (1975), because the fault is intruded by nearly contemporaneous granitic magmas of the same deformational and magmatic cycle.

The Foothills terrane is interpreted as having formed during: (1) Middle and Late Jurassic island-arc volcanism that occurred over slightly older ophiolite (Schweickert and Cowan, 1975; Schweickert, 1978); or (2) shedding of volcanic debris from the Middle and Late Jurassic volcanic arc of the Sierra Nevada and from the Calaveras Formation in the Merced River terrane onto ophiolite formed in Late Triassic to Jurassic ocean-floor rifting (Wetzel and Nokleberg, 1976) or onto ophiolite formed in the late Paleozoic to Triassic (Saleeby and others, 1979). The occurrence of abundant detritus, derived from rocks similar to those in the Calaveras Formation in the Merced River terrane, in the epiclastic rocks of the Foothills terrane (Clark, 1964; Behrman and Parkison, 1978) is strong evidence that the ophiolite forming the base of the Foothills terrane was adjacent to some portion of the volcanic and plutonic arc of the Sierra Nevada during deposition of the epiclastic rocks. After deposition of the epiclastic rocks, the Foothills terrane was telescoped and accreted to the Merced River terrane during the Late Jurassic Nevadan orogeny. Considerable right-lateral movement may have occurred during accretion in the Nevadan orogeny (Saleeby and others 1978; Nokleberg and Kistler, 1980). During the waning stages of the orogeny, the Foothills and Merced River terranes were welded together along the accretionary suture of the Melones fault by various Late Jurassic and Early Cretaceous granitic plutons of the Yosemite intrusive epoch (fig. 1) (Evernden and Kistler, 1970; Bateman and Clark, 1974).

MESOZOIC AND CENOZOIC ACCRETIONARY TECTONICS ALONG THE WESTERN MARGIN OF NORTH AMERICA

One exciting area of geologic research in the last decade has been the development of the theory of microplate tectonics and the application of this theory to the tectonic evolution of the North American Cordillera during the Mesozoic and Cenozoic. Within the last few years several important articles have been published on the Mesozoic and Cenozoic accretionary tectonics of the North American Cordillera. These articles include studies of the accreted terrane of Wrangellia by Jones and others (1977), the collage of accreted terranes in the North American Cordillera from central British Columbia to central California by Davis and others (1978), the accretionary tectonics of the Western United States by Hamilton (1978), and the accreted terranes of the southern Sierra Nevada by Saleeby and others (1978). These papers stress that substantial portions of the western margin of the North American Cordillera consists of a collage of microplates or terranes that were accreted during the Mesozoic or Cenozoic.

In a similar manner, a major purpose of this paper is to list and discuss data for the hypothesis that the wall rocks of the central Sierra Nevada batholith constitute a collage of terranes that were accreted onto the margin of an active volcanic and plutonic arc in the Triassic and Jurassic. However, a secondary purpose of this paper is to show there is a Cenozoic, that is a young analog, to the Mesozoic Sierra Nevada. After a review of recent studies of the North American Cordillera, the region of southern Alaska was selected as the best-known example of a young analog.

CENOZOIC ACCRETIONARY TECTONICS OF SOUTHERN ALASKA

The tectonic synthesis of the geology of southern Alaska has been the subject of various summary studies. Plafker (1972), Csejtey (1976), Jones and others (1977, 1981), Jones and Silberling (1979), Beikman (1980), show that southern Alaska, along with much of the entire North American Cordillera, consists of a series of accreted terranes into which have been intruded granitic rocks of pre- and post-acretion ages. Periodic intrusion of granitic rocks in southern Alaska from late Paleozoic to late Tertiary is discussed by Smith and Lanphere (1971), Reed and Lanphere (1973), Richter and others (1975), and Hudson (1979). Hudson (1979) shows that many of the Mesozoic plutonic rocks of southern Alaska can be grouped into five calc-alkalic plutonic belts and further suggests that some of the plutonic belts may represent magmatic arcs that migrated or were rafted relatively northward to their present position in southern Alaska.

The important features of southern Alaska, as determined from the cited studies, are as follows (fig. 2). A collage of accreted terranes, such as the Wrangellia, Nixon fork, Chugach, Peninsular, and Prince William terranes, form the basement to the region. The best presently know terrane in southern Alaska is Wrangellia (fig. 2), which consists of late Paleozoic island-arc volcanic rocks and the overlying Triassic Nikolai Greenstone which initially formed near the Triassic equator and subsequently moved northward and was accreted onto North America in late Mesozoic or early Cenozoic time (Jones and others, 1977). The terranes are bounded by ancient and modern thrust and strike-slip faults or sutures such as the Denali, Castle Mountain, Border Ranges, and Contact faults. Volcanic and plutonic rocks of mainly Jurassic to Recent age have been intruded into or onto various terranes either before or after accretion. Andean-type arc volcanism and contemporaneous plutonism appears to have occurred simultaneously with accretion of terranes. Belts of nearly contemporaneous volcanic and plutonic rock appear to have been displaced along major faults and sutures within the volcanic and plutonic arc. Some of the older plutonic rocks may have been accreted along with enclosing terranes. Holocene volcanic rocks overlap adjacent terranes; locally, however, Quaternary volcanic rocks are offset by movement on sutures. Some sutures, such as the Denali, Border Ranges, and Contact faults, are presently active.

The modern sutures appear to be part of a complex system of faulting related to subduction and transform faulting south and east of southern Alaska. The Aleutian megathrust (fig. 2) is the surface projection of the subduction zone that dips gently northwestward under southern Alaska and separates the North American and Pacific plates (Pflaker, 1972). In the western part of southern Alaska, sutures trend northeast, parallel to the Aleutian megathrust, whereas in the eastern part, the sutures trend east-west or northwest, more parallel to the continental margin (fig. 2). Northwest-southeast convergence along the Aleutian megathrust appears to be the cause of right-lateral strike-slip movement along sutures, such as the Denali fault, in eastern Alaska. Convergence between two major plates along the Aleutian megathrust appears to be causing simultaneous formation of the late Cenozoic magmatic arc and displacement of terranes and volcanic and plutonic rocks. In summary, the above data and relations indicate that in Cenozoic time, a collage of tectono-stratigraphic terranes were accreted during volcanism and plutonism along an actively deformed continental margin in southern Alaska. This tectonic setting is herein defined as an Alaskan-type arc.

COMPARISON OF THE MESOZOIC SIERRA NEVADA AND SOUTHERN ALASKA

There are several similarities between the Mesozoic Sierra Nevada and southern Alaska. First, both consist of a series of terranes separated by sutures. Second, plutonism and volcanism were interspersed with accretion of terranes in both areas. Third, sutures in both areas are predominantly right lateral strike-slip faults. Fourth, some terranes in both areas are allochthonous with respect to North America. Fifth, some terranes in both areas formed along the continental margin of North America, but subsequently migrated along sutures into their present position. Sixth, some terranes are welded together by granitic and volcanic rocks. And seventh, in both areas, some granitic and volcanic rocks are displaced by movements on sutures.

There are also several contrasts between the Mesozoic Sierra Nevada and southern Alaska, mostly resulting from comparing a modern-day arc with a Mesozoic volcanic and plutonic arc. First, granitic rocks are much more extensive and wall rocks are much less extensive in the Sierra Nevada than in southern Alaska, probably because of a greater depth of erosion in the Sierra Nevada. Second, displacement is still occurring along sutures in southern Alaska, whereas movement has ceased along sutures in the Sierra Nevada. Third, terranes are commonly longer and wider in southern Alaska than in the Sierra Nevada (fig. 2); however, some Alaskan terranes, such as the Maclaren terrane, are of comparable size to terranes in the Sierra Nevada (pl. 1; fig. 2). And fourth, the geologic history of terranes in the two areas is very dissimilar.

In summary, there is a very great similarity between the tectonic frameworks of southern Alaska and the Mesozoic Sierra Nevada. This great similarity strongly suggests that the Mesozoic Sierra Nevada formed in a manner analogous to that of southern Alaska and that the Mesozoic Sierra Nevada probably represents an Alaskan-type arc in which a series of terranes were accreted during volcanism and plutonism along an actively deformed continental margin.

CONCLUSIONS

Stratigraphic and structural analysis of the age belts of wallrocks in the central Sierra Nevada indicates that the wall rocks constitute a collage of tectono-stratigraphic terranes that were accreted in an Alaskan-type arc setting similar to that of southern Alaska in Cenozoic time. Timing of accretions of the various terranes range from Triassic to Late Jurassic (fig. 1). Movement and accretion along the Owens Valley fault, which bounds the easternmost Owens terrane, may have ceased as late as late Tertiary. Available data indicate that the four eastern terranes, the Owens, High Sierra, Goddard, and Kings terranes, originated along the western margin of North America before detachment, movement, and accretion at their present loci. The two westernmost terranes, the Merced River and Foothills terranes, have origins far removed with respect to continental North America.

During the Triassic Sonoman orogeny, the High Sierra terrane was thrust over and accreted to the Owens terrane. The Goddard terrane was accreted to the High Sierra terrane during the Late Jurassic Nevadan orogeny. The Merced River terrane and the correlative Cache Creek terrane to the north in British Columbia are exotic with respect to North America and were formed in the warm-water, equatorial Tethys region of the late Paleozoic, before detachment, movement, and amalgamation along the western margin of North America. The Merced River terrane was amalgamated to the Kings terrane along the Foothill suture

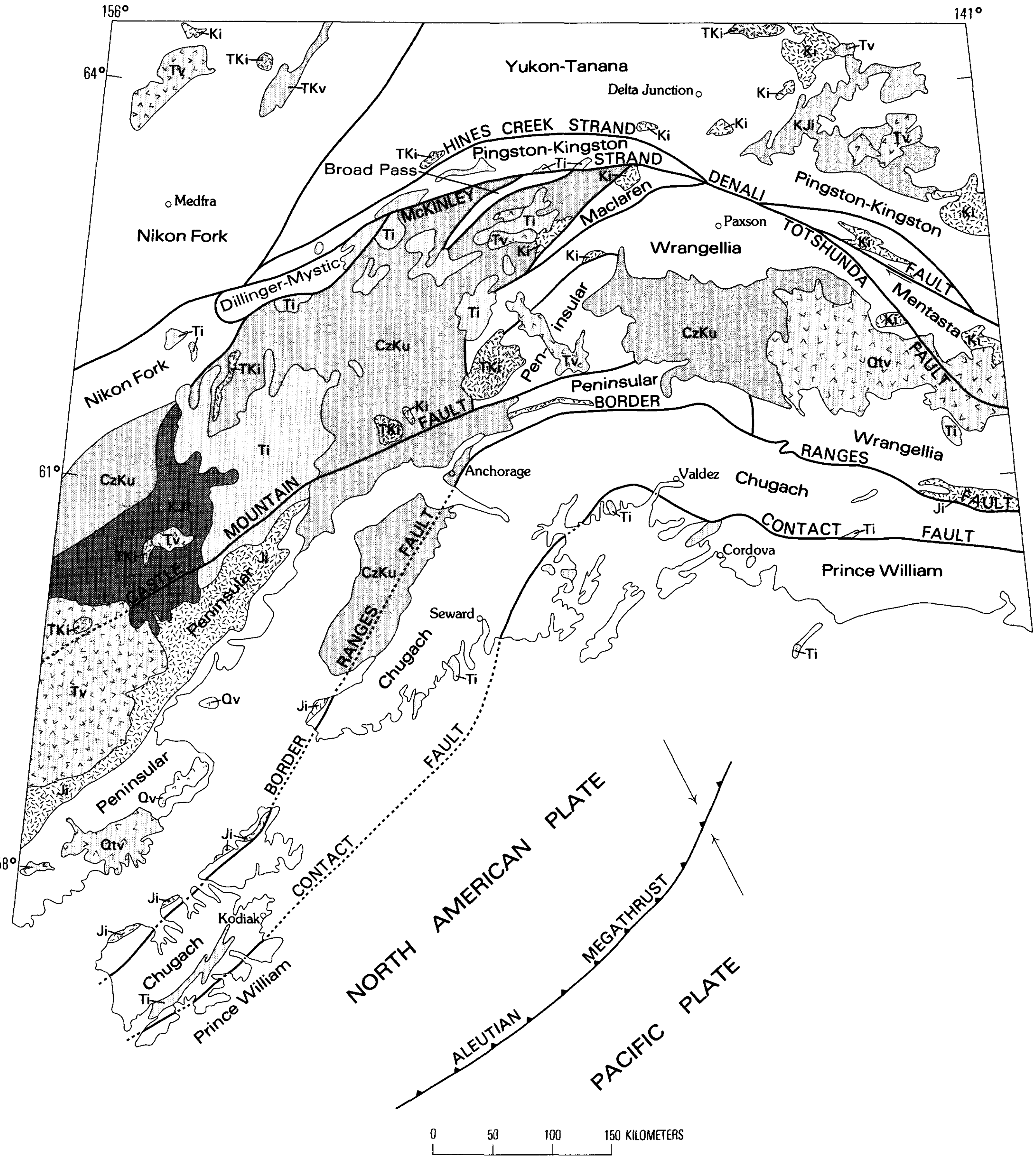

FIGURE 2.—Simplified geologic map of southern Alaska showing major features of tectono-stratigraphic terranes, faults, Mesozoic and Cenozoic igneous rocks, and Aleutian megathrust. Arrows indicate the present relative horizontal component of plate motion. Adapted from Plafker (1972), Jones and Silberling (1979), Beikman (1980), and Jones and others (1980).

during the Middle Jurassic. This amalgamation coincided with, and may have caused, the left-lateral offset of Precambrian crystalline terranes from southeastern California to Sonora, Mexico. In the central Sierra Nevada, the Foothill suture may be the left-lateral megashear of Silver and Anderson (1974). After amal-

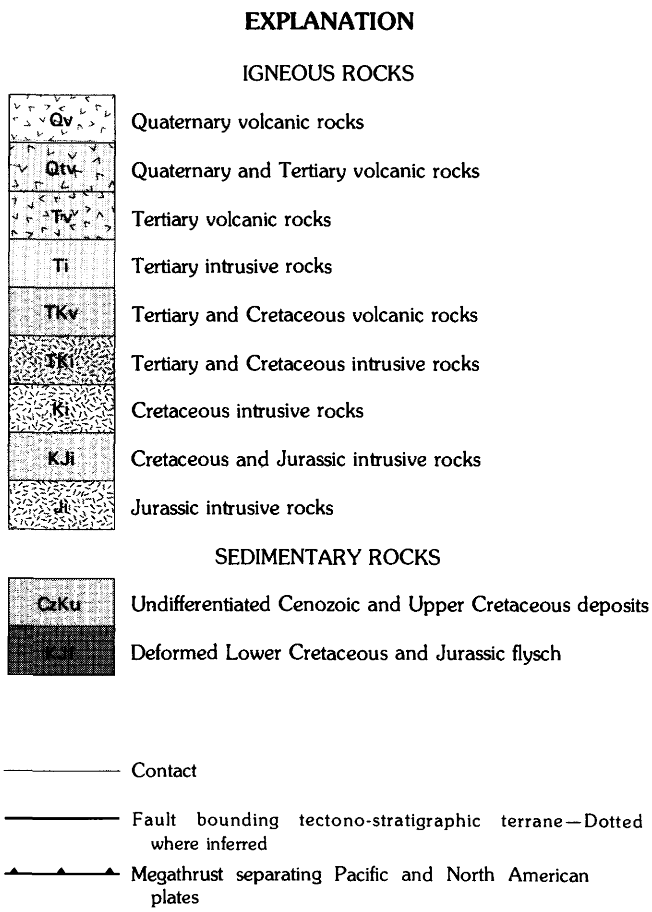

FIGURE 2.—Continued

gamation of the Merced River and Kings terranes, both terranes were offset by right-lateral strike-slip movement from the site of origin of the Kings terrane in the Mojave region to their present loci in the central Sierra Nevada. The westernmost, Foothills, terrane formed during a Middle to Late Jurassic period of Andean-type arc volcanism in the central Sierra Nevada. Debris and flows from the volcanic arc and detritus from rocks similar to those in the Calaveras Formation in the Merced River terrane were shed onto oceanic lithosphere of either Late Triassic to Middle Jurassic or late Paleozoic and Triassic age. Telescoping and accretion of the Foothills terrane and northward migration of the Foothills, Merced River, and Kings terranes occurred during the Late Jurassic Nevadan orogeny.

REFERENCES CITED

Baird, A. K., 1962, Superposed deformations in the central Sierra Nevada foothills east of the Mother Lode: California University Publications in Geological Sciences, v. 42, p. 1–70.

Bateman, P. C., 1965, Geology and tungsten mineralization of the Bishop district, California: U.S. Geological Survey Professional Paper 470, 208 p.

Bateman, P. C., and Clark, L. D. 1974, Stratigraphic and stuctural setting of the Sierra Nevada batholith, California: Pacific Geology, v. 8, p. 79–89.

Bateman, P. C., Clark, L. D., Huber, N. K., Moore, J. G., and Rinehart, C. D., 1963, The Sierra Nevada batholith—a synthesis of recent work across the central part: U.S. Geological Survey Professional Paper 414–D, p. D1–D46.

Bateman, P. C., and Eaton, J. P., 1967, Sierra Nevada batholith: Science, v. 158, p. 1407–1417.

Bateman, P. C., and Moore, J. G., 1965, Geologic map of the Mount Goddard quadrangle, Fresno and Inyo Counties, California: U.S. Geological Survey Geologic Quadrangle Map GQ–429, scale 1:62,500.

Beck, Myrl, Cox, Allan, and Jones, D. L., 1980, Mesozoic and Cenozoic microplate tectonics of western North American: Geology, v. 8, p. 454–456.

Behrman, P. G., 1978, Pre-Callovian rocks, west of the Melones fault zone, central Sierra Nevada foothills, *in* Howell, D. G., and McDougall, K. A., eds., Mesozoic paleogeography of the western United States: Society of Economic Paleontologists and Mineralogists Pacific Coast Paleogeography Symposium 2, p. 337–348.

Behrman, P. G., and Parkison, G. A., 1978, Paleogeographic significance of the Callovian to Kimmeridgian strata, central Sierra Nevada foothills, *in* Howell, D. G., and McDougall, K. A., eds., Mesozoic paleogeography of the western United States: Society of Economic Paleontologists and Mineralogists Pacific Coast Paleogeography Symposium 2, p. 349–360.

Beikman, H. M., 1980 Geologic map of Alaska: U.S. Geological Survey Map, scale 1:2,500,000.

Best, M. G., 1963, Petrology and structural analysis of metamorphic rocks in the southwestern Sierra Nevada foothills, California: California University Publications in Geological Sciences, v. 42, p. 111–158.

Brook, C. A., 1972, Stratigraphy and superposed deformations of parts of the Saddlebag Lake roof pendant, Sierra Nevada, California [M.A. thesis]: Fresno, California State University, 47 p.

——1974, Nature and significance of superposed folds in the Saddlebag Lake roof pendant, Sierra Nevada, California: Geological Society of America Abstracts with Programs, v. 6, pt. 3, p. 147–148.

——1977, Stratigraphy and structure of the Saddlebag Lake roof pendant, Sierra Nevada, California: Geological Society of America Bulletin, v. 88, p. 321–334.

Brook, C. A., Gordon, Mackenzie, Jr. Mackey, M. J., and Chetelat, G. F., 1979, Fossiliferous upper Paleozoic rocks and their structural setting in the Ritter Range and Saddlebag Lake roof pendants, central Sierra Nevada, California: Geological Society of America Abstracts with Programs, v. 11, p. 70.

Brook, C. A., Nokleberg, W. J., and Kistler, R. W., 1974, Nature of the angular unconformity between the Paleozoic metasedimentary rocks and the Mesozoic metavolcanic rocks in the eastern Sierra Nevada, California: Geological Society of America Bulletin, v. 85, p. 571–576.

Burchfiel, B. C., and Davis, G. A., 1972, Structural framework and evolution of the southern part of the Cordilleran orogen, western United States: American Journal of Sciences, v. 272, p. 97–118.

Busby-Spera, C. J., Goodin, S. E., and Saleeby, J. B., 1980, Early Mesozoic quartz, sandstone—volcanic arc associations in the Kaweah River area, southern Sierra Nevada, California: Geological Society of America Abstracts with Programs, v. 12, p. 99–100.

Chen, J. H., and Moore, J. G., 1979, Late Jurassic Independence dike swarm in eastern California: Geology, v. 7, p. 129–133

Chesterman, C. W., 1975, Geology of the Matterhorn Peak Quadrangle, Mono and Tuolumne Counties, California: California Division of Mines and Geology Map Sheet 22, scale 1:62,500.

Christensen, M. N., 1963, Structure of metamorphic rocks at Mineral King, California: California University Publications in Geological Sciences, v. 42, p. 159–198.

Clark, L. D., 1954, Geology and mineral deposits of Calaveritas quadrangle, Calaveras County, California: California Division of Mines and Geology Special Report 40, 23 p.

———1960, Foothills fault system, western Sierra Nevada, California: Geological Society of America Bulletin, v. 71, p. 483–496.

———1964, Stratigraphy and structure of part of the western Sierra Nevada metamorphic belt, California: U.S. Geological Survey Professional Paper 410, 70 p.

———1970, Geology of the San Andreas 15-minute quadrangle, Calaveras County, California: California Division of Mines and Geology Bulletin 195, 23 p.

———1976, Stratigraphy of the north half of the western Sierra Nevada metamorphic belt, California: U.S. Geological Survey Professional Paper 923, 26 p.

Crowder, D. F., and Sheridan, M. F., 1972, Geologic map of the White Mountain Peak quadrangle, Mono County, California: U.S. Geological Survey Geologic Quadrangle Map GQ–1012, scale 1:62,500.

Csejtey, Bela, Jr., 1976, Tectonic implications of a late Paleozoic volcanic arc in the Talkeetna Mountains, south-central Alaska: Geology, v. 4, p. 49–52.

Davis, G. A., Monger, J. W. H., and Burchfiel, B. C., 1978, Mesozoic construction of the Cordilleran "collage," central British Columbia to central California, *in* Howell, D. G., and McDougall, K. A., eds., Mesozoic paleogeography of the western United States: Society of Economic Paleontologists and Mineralogists Pacific Coast Paleogeography Symposium 2, p. 1–32.

Douglass, R. C., 1967, Permian Tethyan fusulinids from California: U.S. Geological Survey Professional Paper 593–A, p. A1–A13.

Duffield, W. A., and Sharp, R. V., 1975, Geology of the Sierra foothills melange and adjacent areas, Amador County, California: U.S. Geological Survey Professional Paper 827, 30 p.

Dunne, G. C., Gulliver, R. M., and Sylvester, A. G., 1978, Mesozoic evolution of rocks of the White, Inyo, Argus, and Slate Ranges, eastern California, *in* Howell, D. G., and McDougall, K. A., eds., Mesozoic paleogeography of the western United States: Society of Economic Paleontologists and Mineralogists Pacific Coast Paleogeography Symposium 2, p. 189–208.

Durrell, Cordell, 1940, Metamorphism in the southern Sierra Nevada northeast of Visalia, California: California University Publications in Geological Sciences, v. 25, p. 1–118.

Eric, J. H., Stromquist, A. A., and Swinney, C. M., 1955, Geology and mineral deposits of the Angels Camp and Sonora quadrangles, Calaveras and Tuolumne Counties, California: California Division of Mines and Geology Special Report 41, 55 p.

Evernden, J. F., and Kistler, R. W., 1970, Chronology of emplacement of Mesozoic batholithic complexes in California and western Nevada: U.S. Geological Survey Professional Paper 623, 42 p.

Fiske, R. S., and Tobisch, O. T., 1978, Paleogeographic significance of volcanic rocks of the Ritter Range pendant, central Sierra Nevada, California, *in* Howell, D. G., and McDougall, K. A., eds., Mesozoic paleogeography of the western United States: Society of Economic Paleontologists and Mineralogists Pacific Coast Paleogeography Symposium 2, p. 209–222.

Girty, G. H., 1977a, Cataclastic rocks in the Boyden Cave roof pendant, central Sierra Nevada, California: Geological Society of America Abstracts with Programs, v. 9, p. 423.

———1977b, Multiple regional deformation and metamorphism of the Boyden Cave roof pendant, central Sierra Nevada, California [M.A. thesis]: Fresno, California State University, 82 p.

Hamilton, Warren, 1969, Mesozoic California and underflow of Pacific mantle: Geological Society of America Bulletin, v. 80, p. 2409–2430.

———1978, Mesozoic tectonics of the western United States, *in* Howell, D. G., and McDougall, K. A., eds., Mesozoic paleogeography of the western United States: Society of Economic Paleontologists and Mineralogists Pacific Coast Paleogeography Symposium 2, p. 33–70.

Huber, N. K., and Rinehart, C. D., 1965, Geologic map of the Devils Postpile quadrangle, California: U.S. Geological Survey Quadrangle Map GQ–437.

Hudson, Travis, 1979, Mesozoic plutonic belts of southern Alaska: Geology v. 7., p. 230–234.

Imlay, R. W., 1961, Late Jurassic ammonites from the western Sierra Nevada, California: U.S. Geological Survey Professional Paper 374–D, p. D1–D30

Jones, D. L., and Moore, J. G., 1973, Lower Jurassic ammonite from the south-central Sierra Nevada, California: U.S. Geological Survey Journal of Research, v. 1, p. 453–458.

Jones, D. L., and Silberling, N. J., 1979, Mesozoic stratigraphy—The key to tectonic analysis of southern and central Alaska: U.S. Geological Survey Open-File Report 79–1200, 37 p.

Jones, D. L., Silberling, N. J., and Hillhouse, J., 1977, Wrangellia—A displaced terrane in northwestern North America: Canadian Journal of Earth Sciences, v. 14, p. 2565–2577.

Jones, D. L., Silberling, N. J., Plafker, George, and Berg, H. C., 1981, Tectono-stratigraphic terranes of Alaska: U.S. Geological Survey Open-File Report 81–792, 20 p.

Koenig, J. B., 1963, Geologic Map of California—Walker Lake Sheet (1:250,000): California Division of Mines and Geology.

Kistler, R. W., 1966a, Structure and metamorphism in the Mono Craters quadrangle, Sierra Nevada, California: U.S. Geological Survey Bulletin 1221–E, p. E1–E53.

———1966b, Geologic map of the Mono Craters quadrangle, Mono and Tuolumne Counties, California: U.S. Geological Survey Geologic Quadrangle Map GQ–462, scale 1:62,500.

Kistler, R. W., and Bateman, P. C., 1966, Stratigraphy and structure of the Dinkey Creek roof pendant in the central Sierra Nevada, California: U.S. Geological Survey Professional Paper 524–B, p. B1–B14.

Kistler, R. W., Evernden, J. F., and Shaw, H. R., 1971, Sierra Nevada plutonic cycle; Part 1, Origin of composite granitic batholiths: Geological Society of America Bulletin, v. 82, p. 853–868.

Kistler, R. W., and Nokleberg, W. J., 1980, Carboniferous rocks of the eastern Sierra Nevada: U.S. Geological Survey Professional Paper 1110–CC, p. CC21 to CC26.

Kistler, R. W., and Peterman, Z. E., 1978, Reconstruction of crustal blocks in California on the basis of initial strontium isotopic composition of Mesozoic granitic rocks: U.S. Geological Survey Professional Paper 1071, 17 p.

Kistler, R. W., Robinson, A. C., and Fleck, R. J., 1980, Mesozoic right-lateral fault in eastern California: Geological Society of America Abstracts with Programs, v. 12, p. 115.

Krauskopf, K. B., 1953, Tungsten deposits of Madera, Fresno and Tulare Counties, California: California Division of Mines and Geology Special Report 35, 83 p.

Lockwood, J. P., and Lydon, P. A., 1975, Geologic map of the Mount Abbot quadrangle, central Sierra Nevada, California: U.S. Geological Survey Geologic Quadrangle Map GQ–1155, scale 1:62,500.

MacDonald, G. A., 1941, Geology of the western Sierra Nevada between the Kings and San Joaquin Rivers, California: California University Publications in Geological Sciences, v. 26, p. 215–286.

Mannion, L. E., 1960, Geology of the La Grange quadrangle, California [Ph. D. thesis]: Stanford, Stanford, Univ., 173 p.

Matthews, R. A., and Burnett, J. L., 1965, Geologic Map of California—Fresno Sheet: California Division of Mines and Geology, scale 1:250,000.

Moore, J. G., 1973, Geology of the Mount Pinchot quadrangle, southern Sierra Nevada, California: U.S. Geological Survey Bulletin 1130, 152 p.

———1978, Geologic Map of the Marion Peak quadrangle, Fresno County, California: U.S. Geological Survey Quadrangle Map GQ–1399, scale 1:62,500

Moore, J. G., and Dodge, F. C., 1962, Mesozoic age of metamorphic rocks in the Kings River area, southern Sierra Nevada, California: U.S. Geological Survey Professional Paper 450–B, p. B19–21.

Moore, J. G., and Hopson, C. A., 1961, The Independence dike swarm in eastern California: American Journal of Science, v. 259, p. 241–259.

Moore, J. G., and Marks, L. Y., 1972, Mineral Resources of the High Sierra Primitive Area. Callifornia, *with a section on* Aeromagnetic interpretation, by H. W. Oliver: U.S. Geological Survey Bulletin 1371–A, p. A1–A40.

Moore, J. G., Nokleberg, W. J., Chen, J. H., Girty, G. H., and Saleeby, J. B., 1979, Geologic guide to the Kings Canyon Highway: Geological Society of America, Cordilleran Section Meeting, 33 p.

Moore, J. N., and Foster, C. T., Jr., 1980, Lower Paleozoic metasedimentary rocks in the east-central Sierra, California: Correlation with Great Basin formations: Geological Society of America Bulletin, v. 91, p. 37–43.

Morgan, B. A., 1976, Geologic map of the Chinese Camp and Moccasin quadrangles, Tuolumne County, California: U.S. Geological Survey Geologic Quadrangle Map MF–840, scale 1:24,000.

Morgan, B. A., and Rankin, D. W., 1972, Major structural break between Paleozoic and Mesozoic rocks in the eastern Sierra Nevada, California: Geological Society of America Bulletin, v. 83, p. 3739–3744.

Morgan, B. A., and Stern, T. W., 1977, Chronology of tectonic and plutonic events in the western Sierra Nevada, between Sonora and Mariposa, California: Geological Society of America Abstracts with Programs, v. 9, p. 471–472.

Nokleberg, W. J., 1970, Geology of the Strawberry mine roof pendant, central Sierra Nevada, California [Ph. D. thesis]: Santa Barbara, University California, 156 p.

———1975, Structural analysis of a collision between an oceanic plate and a continental plate preserved along the lower Kings River in the Sierra Nevada: Geological Society of America Abstracts with Programs, v. 7, pt. 3, p. 357–358.

———1979, Accreted microplates in the central Sierra Nevada, California: Geological Society of America Abstracts with Programs, v. 11, p. 120.

———1981, Stratigraphy and structure of the Strawberry mine roof pendant, central Sierra Nevada, California: U.S. Geological Survey Professional Paper 1154, 18 p.

Nokleberg. W. J., and Kistler, R. W., 1980, Paleozoic and Mesozoic deformations in the central Sierra Nevada, California: U.S. Geological Survey Professional Paper 1145, 24 p.

Peck, D. L., Stern, T., and Kistler, R. W., 1977, Penecontemporaneous volcanism and intrusion in the Sierra Nevada batholith, California: IASPEI/IAVCEI Joint Assembly, Durham, Abstracts.

Plafker, George, 1972, Alaskan earthquake of 1964 and Chilean earthquake of 1960: Implications for arc tectonics: Journal of Geophysical Research, v. 77, p. 901–925.

Reed, B. L., and Lanphere, M. A., 1973, Alaska–Aleutian Range batholith: Geochronology, chemistry, and relation to circum-Pacific plutomism: Geological Society of America Bulletin, v. 84, p. 2583–2610.

Richter, D. H., Lanphere, M. A., and Matson, N. A., Jr., 1975, Granitic plutonism and metamorphism, eastern Alaska Range, Alaska: Geological Society of America Bulletin, v. 86, p. 819–829.

Rinehart, C. D., and Ross, D. C., 1957, Geologic map of the Casa Diablo Mountain quadrangle, California: U.S. Geological Survey Geologic Quadrangle Map GQ–99.

———1964, Geology and mineral deposits of the Mount Morrison quadrangle, Sierra Nevada, California: U.S. Geological Survey Professional Paper 385, 106 p.

Ross, D. C., 1958, Igneous and metamorphic rocks of parts of Sequoia and Kings Canyon National Parks, California: California Division of Mines and Geology Special Report 53, 24 p.

Russell, L. R., and Cebull, S. E., 1977, Structural-metamorphic chronology in a roof pendant near Oakhurst, California: Implications for the tectonics of the western Sierra Nevada: Geological Society of America Bulletin, v. 88, p. 1530–1534.

Russell, S. J., 1976, Geology of the Mount Dana roof pendant, central Sierra Nevada, California [M.A. thesis]: Fresno, California State University, 71 p.

Russell, S. J., and Nokleberg, W. J., 1974, The relation of superposed deformations in the Mount Morrison roof pendant to the regional tectonics of the Sierra Nevada: Geological Society of America Abstracts with Programs, v. 6, p. 245.

Russell, S. R., and Nokleberg, W. J., 1977, Superimposition and timing of deformations in the Mount Morrison roof pendant in the central Sierra Nevada, California: Geological Society of America Bulletin, v. 88, p. 335–345.

Saleeby, J. B., 1978, Kings River ophiolite, southwest Sierra Nevada foothills, California: Geological Society of American Bulletin, v. 89, p. 617–636.

———1979, Kaweah serpentinite melange, southwest Sierra Nevada foothills, California: Geological Society of America Bulletin, v. 90, p. 29–46.

Saleeby, J. B., Goodin, S. E., Sharp, W. D., and Busby, C. J., 1978, Early Mesozoic paleotectonic-paleogeographic reconstruction of the southern Sierra Nevada region, *in* Howell, D. G., and McDougall, K. A., eds., Mesozoic paleogeography of the western United States: Society of Economic Paleontologists and Mineralogists Pacific Coast Paleogeography Symposium 2, p. 311–336.

Saleeby, J. B., Mattinson, J. M., and Wright, J. E., 1979, Regional ophiolite terranes of California-Vestiges of two complex ocean floor assemblages: Geological Society of America Abstracts with Programs, v. 11, p. 509.

Saleeby, J. B., and Moores, E. M., 1979, Zircon ages on northern Sierra Nevada ophiolite remnants and some possible regional correlations: Geological Society of America Abstracts with Programs, v. 11, p. 125.

Saleeby, Jason, and Sharp, Warren, 1980, Chronology of the structural and petrologic development of the southwest Sierra Nevada foothills: Geological Society of America Bulletin, Part II, v. 91, p. 1416–1535.

Schweickert, R. A., 1978, Triassic and Jurassic paleogeography of the Sierra Nevada and adjacent regions, California and western Nevada, *in* Howell, D. G., and McDougall, K. A., eds., Mesozoic palegeography of the western United States: Society of Economic Paleontologists and Mineralogists Pacific Coast Paleogeography Symposium 2, p. 361–384.

Schweickert, R. A., and Cowan, D. S., 1975, Early Mesozoic tectonic evolution of the western Sierra Nevada, California: Geological Society of America Bulletin, v. 86, p. 1329–1336.

Schweickert, R. A., Saleeby, J. B., Tobisch, O. T., and Wright, W. H., III, 1977, Paleotectonic and paleogeographic significance of the Calaveras Complex, western Sierra Nevada, California, *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 Coast Paleogeography Symposium 1, p. 381–394.

Sharp, W. D., and Saleeby, J. B., 1979, The Calaveras Formation and syntectonic Middle Jurassic plutons between the Stanislaus and Tuolumne Rivers, California: Geological Society of America Abstracts with Programs, v. 11, p. 127.

Silberling, N. J., and Roberts, R. J., 1962, Pre-Tertiary stratigaphy and structure of northwestern Nevada: Geological Society of America Special Paper 72, 58 p.

Silver, L. T., and Anderson, T. H., 1974, Possible left-lateral early to middle Mesozoic disruption of the southwestern North America craton margin: Geological Society of America Abstracts with Programs, v. 6, p. 955–956.

Smith, A. R., 1964, Geologic Map of California—Bakersfield Sheet (1:250,000): California Division of Mines and Geology.

Smith, T. E., and Lanphere, M. A., 1971, Age of sedimentation, plutonism, and regional metamorphism in the Clearwater Mountains region, central Alaska: Isochron West, no. 2, p. 17–20.

Sohl, N. F., and Wright, W. B., 1980, Changes in stratigraphic nomenclature by the U.S. Geological Survey, 1979: U.S. Geological Survey Bulletin 1502–A, p. A1–A2.

Speed, R. C., 1979, Collided Paleozoic microplate in the western United States: Journal of Geology, v. 87, p. 279–292.

Strand, R. G., 1967, Geologic Map of California—Mariposa Sheet: California Division of Mines and Geology, scale 1:250,000.

Strand, R. G., and Koenig, J. B., 1965, Geologic Map of California—Sacramento Sheet: California Division of Mines and Geology, scale 1:250,000.

Taliaferro, N. L., and Solari, A. J., 1948, Geology of the Copperopolis quadrangle, California: California Division of Mines and Geology Bulletin, v. 145, 64 p.

Tobisch, O. T., and Fiske, R. S., 1976, Significance of conjugate folds and crenulations in the central Sierra Nevada, California: Geological Society of America Bulletin, v. 87, p. 1411–1420.

Tobisch, O. T., Fiske, R. S., Sacks, S., and Taniguchi, D., 1977, Strain in metamorphosed volcaniclastic rocks and its bearing on the evolution of orogenic belts: Geologic Society of America Bulletin, v. 88, p. 23–40.

Wetzel, N., and Nokleberg, W. J., 1976, Plate tectonic and structural relations for the origin and deformation of the western metamorphic belt along the margin of the central Sierra Nevada batholith: Geological Society of America Abstracts with Programs, v. 8, p. 420.

U.S. GOVERNMENT PRINTING OFFICE: 676-041/31—1983