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Stratigraphy and Structure of the Strawberry Mine Roof Pendant Central Sierra Nevada, California

GEOLOGICAL SURVEY PROFESSIONAL PAPER 1154

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By WARREN J. NOKLEBERG

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Miogeosynclinal sedimentation, contemporaneous volcanism and plutonism, and multiple deformation in metasedimentary and metaigneous rocks of the central Sierra Nevada

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STRATIGRAPHY AND STRUCTURE OF THE STRAWBERRY MINE ROOF PENDANT CENTRAL SIERRA NEVADA, CALIFORNIA

By WARREN J. NOKLEBERG

ABSTRACT

The Strawberry mine roof pendant, 90 km northeast of Fresno, Calif., is composed of a sequence of metasedimentary rocks of probable Early Jurassic age and a sequence of metaigneous rocks of middle Cretaceous age. The metasedimentary rocks are a former miogeosynclinal sequence of marl and limestone now metamorphosed to calc-silicate hornfels and marble. A pelecypod found in the calc-silicate hornfels has been tentatively identified as a Mesozoic bivalve, possibly *Inoceramus pseudomytiloides* of Early Jurassic age. These metasedimentary rocks are similar in lithology, structure, and gross age to the metasedimentary rocks of the Boyden Cave roof pendant and are assigned to the Lower Jurassic Kings sequence. The younger metaigneous rocks are metamorphosed shallow-intrusive rocks that range in composition from granodiorite to rhyolite. These rocks are similar in composition and age to the metavolcanic rocks of the surrounding Merced Peak quadrangle and nearby Ritter Range, and probably represent necks or dikes that were one source for the metavolcanic rocks. The roof pendant is intruded by several plutons, ranging in composition from dioritic to highly felsic, that constitute part of the granodiorite of Jackass Lakes, also of middle Cretaceous age. The contemporaneous suites of metaigneous, metavolcanic, and plutonic rocks in the region represent a middle Cretaceous period of calc-alkalic volcanism and plutonism in the central Sierra Nevada and are interpreted as part of an Andean-type volcanic-plutonic arc.

Three deformations are documented in the roof pendant. The first deformation is reflected only in the metasedimentary rocks and consists of northeast- to east-west-trending folds. Similar structures occur in the Boyden Cave roof pendant and in the Calaveras Formation and represent a Middle Jurassic regional deformation. Evidence of the second deformation occurs in the metasedimentary and metaigneous rocks and consists of folds, faults, minor structures, and regional metamorphism along N. 25° W. trends. Crosscutting of these structures by the contemporaneous granodiorite of Jackass Lakes indicates that this deformation occurred simultaneously with volcanism and plutonism during the middle Cretaceous. The third deformation involved both the roof pendant and adjacent plutonic rocks and consists of folds, faults, schistosities, and regional metamorphism along N. 65°-90° W. trends. Crosscutting of similar structures in other middle Cretaceous plutonic rocks of the Merced Peak quadrangle by undeformed late Cretaceous plutonic rocks indicates a regional deformation of middle to late Cretaceous age. Structures of similar style, orientation, and age occur elsewhere in metavolcanic and plutonic rocks throughout the central Sierra Nevada.

INTRODUCTION

The Strawberry mine roof pendant in the central Sierra Nevada, Calif., is part of a discontinuous belt of metamorphic rocks of the Sierra Nevada batholith between the Ritter Range roof pendant and the western metamorphic belt (fig. 1). In this discontinuous belt, the roof pendants generally contain miogeosynclinal assemblages of contact-metamorphosed shale, marble, marl, and siltstone of Paleozoic and Mesozoic age, and (or) eugeosynclinal assemblages of metamorphosed andesitic to rhyolitic flows, tuff, breccia, shallow-intrusive bodies, and occasional interlayers of graywacke and shale, all of Mesozoic age. The Strawberry mine roof pendant, however, contains metasedimentary rocks of probable Jurassic age as well as metaigneous rocks of middle Cretaceous age.

In this report I present a detailed description of the stratigraphy and structure of the Strawberry mine roof pendant and compare the geologic features of the roof pendant with those of other roof pendants in the central Sierra Nevada and the western metamorphic belt to obtain a better understanding of the regional geology of wallrocks of the Sierra Nevada batholith. Finally, this report partly tests the regional-deformation hypothesis of Kistler and Bateman (1966) and Kistler (1966a) that was extended by Brook (1974, 1977), Russell and Nokleberg (1974, 1977), and Nokleberg and Kistler (1977). This hypothesis proposes that several superposed regional deformations are recorded in the wallrocks of the central Sierra Nevada batholith and that these deformations can be correlated between widely separated roof pendants.

The Strawberry mine roof pendant is 90 km northeast of Fresno, Calif., in the southeast corner of the Merced Peak 15-minute quadrangle, at an elevation of about 2,300 m (fig. 1). For this study, a 5-km^2 area

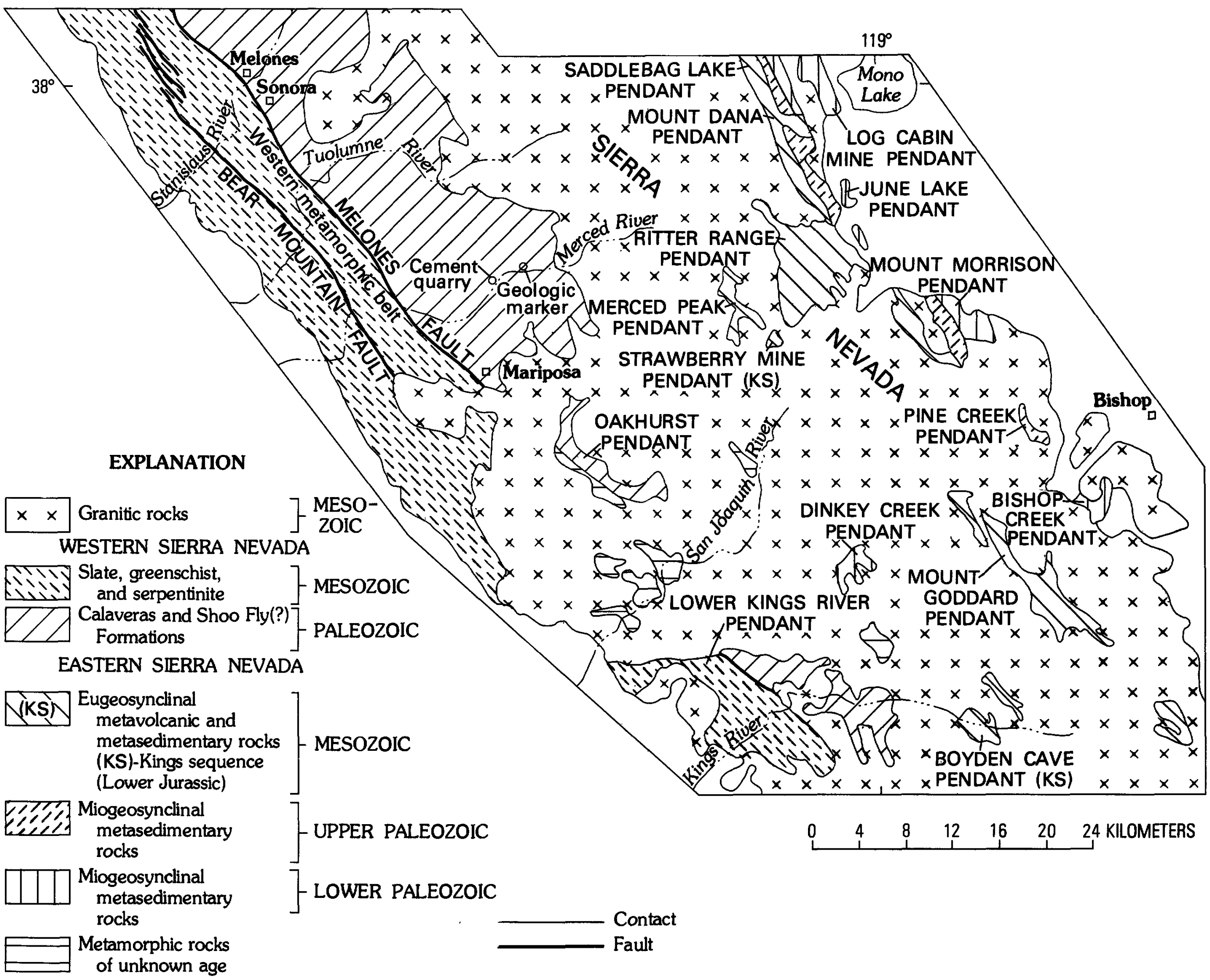


FIGURE 1.—Generalized geologic map of central Sierra Nevada, Calif., showing location of various roof pendants and areas in western metamorphic belt. Cenozoic rocks and faults are omitted.

was mapped by planetable survey at a scale of 1:3,600 (pl. 1). Most of the area lies on a series of unpatented mining claims owned by J. A. McDougald and J. E. Cobb of O'Neals, Calif., and is currently leased to the Teledyne Tungsten Corp. Contact-metasomatic tungsten deposits on the margins of the roof pendant were studied by Krauskopf (1953) and Nokleberg (1970a, b; 1980), and the surrounding Merced Peak quadrangle was mapped by Peck (1964). Earlier versons of this study have been presented by Nokleberg (1970a, b; 1971).

Acknowledgments.--The study of the Strawberry mine area was suggested by D. L. Peck and P. C. Bateman. The company operating the tungsten mine at the time of this study, the New Idria Mining and Chemical Co., gave me complete access to their files, maps, and workings. I benefited considerably from discussions with mine managers M. C. Richardson and D. J. Beauregard and geologists R. Lynn, M. Ward, and K. Rank. I also enjoyed discussions with D. L. Peck, P. C. Bateman, W. S. Wise, C. A. Hopson, A. G. Sylvester, R. W. Kistler, and O. T. Tobisch.

STRATIGRAPHY

METASEDIMENTARY ROCKS

The metasedimentary rocks of probable Early Jurassic age, the oldest exposed rocks of the Strawberry mine roof pendant, are a sequence of calc-silicate hornfels, marble, and biotite hornfels derived from marl, limestone, and calcareous shale, respectively. These metasedimentary rocks are divided into six stratigraphic units, from youngest to oldest: upper biotite hornfels, upper quartz-plagioclase hornfels, lower biotite hornfels, middle quartz-plagioclase hornfels, diopside-plagioclase hornfels and marble, and lower quartz-plagioclase hornfels. Except for the quartz-plagioclase hornfels units, the units are lithologically distinct, and contacts between units are sharp. Table 1 summarizes the field and petrologic characteristics of each unit; thicknesses are approximate and were estimated in areas where bedding is more or less continuous and has not been transposed to foliation.

Top directions are indicated by relict graded beds in the lower biotite hornfels unit. These graded beds are defined by light-colored quartz-rich bases grading upward into dark-colored biotite-rich tops (fig. 2); thicknesses of the graded beds range from a few millimeters to a few centimeters. The graded bedding consists of former quartz-rich silt grading upward into iron-rich clay that contains only sparse amounts of quartz silt. Top directions in the sedimentary sequence are plotted on the geologic map (pl. 1). In determining these top directions, several graded beds in each outcrop were checked; local reversals in top directions, although they exist, are uncommon.

Generally, the quartz-plagioclase, diopside-plagioclase, and biotite hornfels units are thin-bedded fine-grained aggregates containing varying proportions

TABLE 1.—*Metasedimentary rock units of the Strawberry mine roof pendant, listed in order of increasing age*

Unit and approximate thickness (meters)	Minerals--major ± minor	Average grain size, texture, and structure	Comments
Upper biotite hornfels; min 50 (upper contact unexposed).	Quartz, biotite, muscovite, plagioclase; ± magnetite, zircon.	0.1 mm; relict subangular quartz grains; thin bedded.	Interbeds of diopside-plagioclase hornfels; intruded by metadacite dikes.
Upper quartz-plagioclase hornfels; 235.	Quartz, diopside, plagioclase, K-feldspar; ± pyrite, sphene.	0.05 mm; thin bedded	Very uniform lithology; intruded by metarhyolite dikes.
Lower biotite hornfels; gray-green; 140.	Quartz, biotite, plagioclase, diopside, hornblende; ± opaque materials, zircon, rutile.	0.05 mm; thin bedded; relict graded bedding.	Thin to thick interbeds of diopside-plagioclase hornfels; abundant minor folds; intruded by metarhyolite dikes.
Middle-quartz plagioclase hornfels; 235.	Quartz, plagioclase, diopside, biotite; ± pyrite, zircon.	0.07 mm; thin to thick bedded	Two 3- to 8-m-thick interbeds of diopside-plagioclase hornfels and marble near top of unit; some biotite hornfels near base; intruded by metarhyolite dikes.
Diopside-plagioclase hornfels and marble; 27.	Hornfels: plagioclase, diopside, orthoclase; ± zircon, opaque materials. Marble: calcite; ± wollastonite, diopside.	Hornfels: 0.2 mm; thin bedded Marble: 0.5 mm; thin to thick bedded.	Marble beds metasomatized near granodiorite; four thick marble beds, 1 to 3 m thick, equally spaced through unit.
Lower quartz-plagioclase hornfels; min 200 (lower contact unexposed).	Quartz, plagioclase, diopside; ± pyrite, scapolite, zircon.	0.7 mm; thin to thick bedded; relict graded bedding.	A few 25- to 50-cm-thick beds of biotite hornfels; one 2- to 5-m-thick marble bed near top of unit.

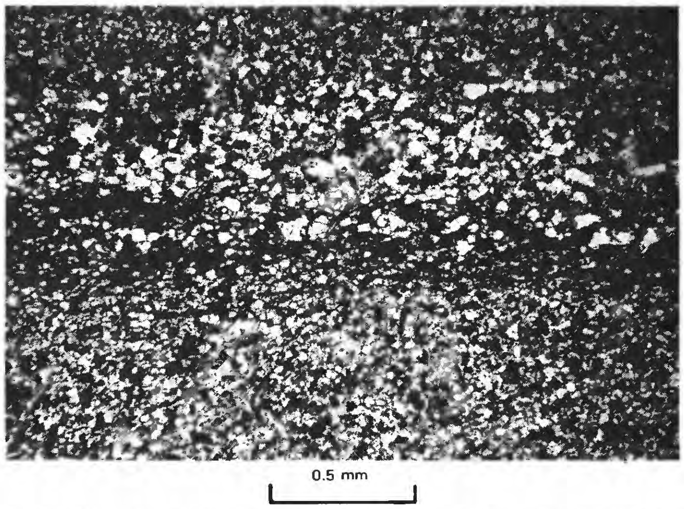


FIGURE 2.—Graded beds in lower biotite hornfels unit. Quartz-rich bases grade upward into biotite-rich tops.

of quartz, diopside, plagioclase, and biotite; wollastonite and muscovite are much less common (table 1). The average grain size is 0.1 mm. The various hornfels units are mostly distinguished by their varying proportions of quartz, biotite, and such calc-silicate minerals as plagioclase, diopside, and wollastonite. Differences in the relative proportions of these major minerals cause striking contrasts in color, a feature that was the chief field characteristic used in mapping the metasedimentary rocks. Accessory pyrite in the quartz-plagioclase hornfels units imparts a red-brown, weathered appearance to them. The biotite hornfels units are marked by prominent graded bedding, generally 1 or 2 mm thick.

The diopside-plagioclase hornfels and marble unit consists of equal proportions of green-gray hornfels and light-gray marble; commonly, bedding is a few centimeters thick. Within this map unit are five or six thicker beds of marble 1 to 3 m thick. The marble is generally coarse grained, massive, and contains accessory wollastonite and diopside. Locally, thin and thick marble beds pinch out owing to severe deformation. Along strike in such areas, sparse boudins of marble occur. Adjacent to the granodiorite in the areas of the No. 1 and No. 4 mines, the marble layers are extensively metasomatized to varieties of hornblende, pyroxene, garnet, and wollastonite skarns, some of which contain significant amounts of scheelite. Skarn replaces marble layers as far as 100 m from the intrusive contact. Within a few meters of the contact, the diopside-plagioclase hornfels is locally metasomatized to a hedenbergite-quartz skarn; none of the other metasedimentary units show any significant metasomatism. Genesis of the skarn has been studied by Nokleberg (1971, 1980).

The quartz-plagioclase, diopside-plagioclase, and biotite hornfels units were derived from marl that varied in the relative proportions of quartz, calcite, dolomite, and clay. The marble was derived from a fairly pure calcite limestone containing accessory quartz, dolomite, and clay. Because of the absence of interbedded volcanic rocks and the presence of a thin-bedded calcareous section in which individual beds are persistent, the metasedimentary rocks are interpreted as a miogeosynclinal sequence of marl and limestone.

FOSSIL, AGE, AND REGIONAL CORRELATIONS

In 1975, a poorly preserved pelecypod was found by Frank J. Maglio in float from the quartz-plagioclase hornfels unit on the side of a hill at about 7,600 feet elevation in an area about 310 m north-northwest of the No. 1 mine (pl. 1; fig. 3). R. W. Imlay (oral commun., 1978) identified the fossil as a Mesozoic bivalve, possibly *Inoceramus pseudomytiloides* of Early Jurassic age.

The metasedimentary rocks of the Strawberry mine roof pendant resemble those of other roof pendants included in the Upper Triassic and Lower Jurassic Kings sequence of Bateman and Clark (1974); this sequence includes the Boyden Cave, Dinkey Creek, and Mineral King roof pendants. In each roof pendant, miogeosynclinal calc-silicate hornfels, pelitic hornfels, and marble occur (Christensen, 1963; Moore and Marks, 1972; Girty, 1977). The metasedimentary rocks of each pendant contain fossils of Late Triassic and (or) Early Jurassic age, except for the Dinkey Creek roof pendant (Bateman and Clark, 1974). Considerable debate

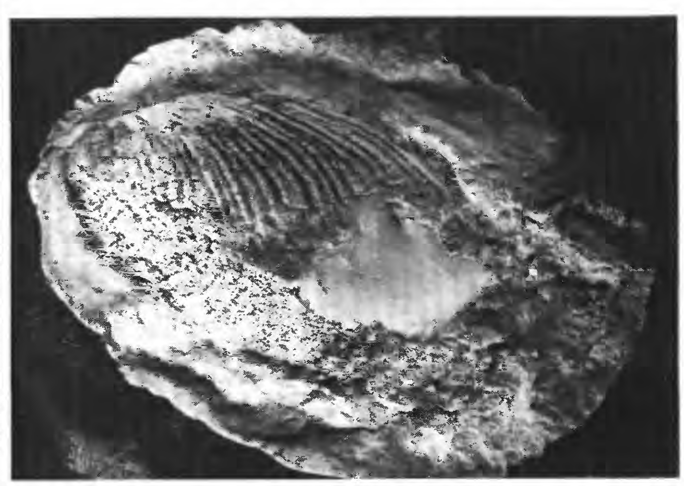


FIGURE 3.—Plaster cast showing imprint of Mesozoic bivalve, possibly *Inoceramus pseudomytiloides* of Early Jurassic age, from metasedimentary rocks of Strawberry mine roof pendant. Cast is 7.62 cm long.

persists concerning the age of the unfossiliferous Dinkey Creek roof pendant, which Kistler and Bateman (1966) and Russell and Nokleberg (1977) considered probably Paleozoic on the basis of its lithologic and structural similarities to the Mount Morrison roof pendant (Rinehart and Ross, 1964); Bateman and Clark (1974), however, determined an Early Jurassic age on the basis of its lithologic similarity to the Boyden Cave roof pendant. Although the Dinkey Creek and Boyden Cave roof pendants both contain thick quartzite units (Kistler and Bateman, 1966; Moore and Marks, 1972; Girty, 1977), the quartzite of the Dinkey Creek roof pendant is a relatively pure orthoquartzite, whereas the quartzite of the Boyden Cave roof pendant contains abundant potassium feldspar (Moore and Marks, 1972; Girty, 1977). In any case, the metasedimentary rocks of the Strawberry mine and Boyden Cave roof pendants have similar lithologies and ages, and the metasedimentary rocks of the Strawberry mine roof pendant should be considered part of the Lower Jurassic Kings sequence of Bateman and Clark (1974).

The Kings sequence was tentatively identified as the upper, younger part of rocks designated the Calaveras Complex by Schweickert, Saleeby, Tobisch, and Wright (1977). This broader use of the name "Calaveras" to include the Calaveras Formation, the Kings sequence, and other similar metasedimentary rocks of the Sierra Nevada foothills is inappropriate because (1) each named formation, sequence, and (or) complex should be defined to include rocks of a unique type and narrow age range rather than be so broad as to include lithologically dissimilar rocks of greatly diverse ages; and (2) the Kings sequence, which includes the metasedimentary rocks of the Strawberry mine roof pendant, differs greatly in age, geographic position, and lithology from the Calaveras Formation. For these reasons, I consider the assignment of the Kings sequence to the Calaveras Complex by Schweickert, Saleeby, Tobisch, and Wright (1977) to be invalid.

METAIGNEOUS ROCKS

The metaigneous rocks of the Strawberry mine roof pendant are a sequence of fine-grained blastoporphyritic quartz-biotite hornfels units derived from shallow-intrusive rocks. These metaigneous rocks are divided into six intrusive units, from youngest to oldest: metagranodiorite, metarhyolite, metarhyolite breccia, metadacite, and metadacite breccia and metabreccia. Because of the similar mineralogies of the various metaigneous rocks, genetic instead of metamorphic names are used; all units are lithologically distinct and have sharp contacts. Table 2 summarizes the field and petrographic characteristics of each unit; this age sequence was determined from contact relations. Locally, postintrusive shearing and faulting along contacts tend to resemble stoping relations; therefore, correct observation of field relations was required.

The suite of metaigneous rocks is younger than the suite of metasedimentary rocks. The metabreccia and metadacite breccia units contain inclusions of metasedimentary rocks, as do the younger metaigneous units. In addition, the metarhyolite and metagranodiorite units also intrude the metasedimentary rocks (fig. 4).

Generally, the metaigneous rocks are fine- to medium-grained aggregates of metamorphic quartz,

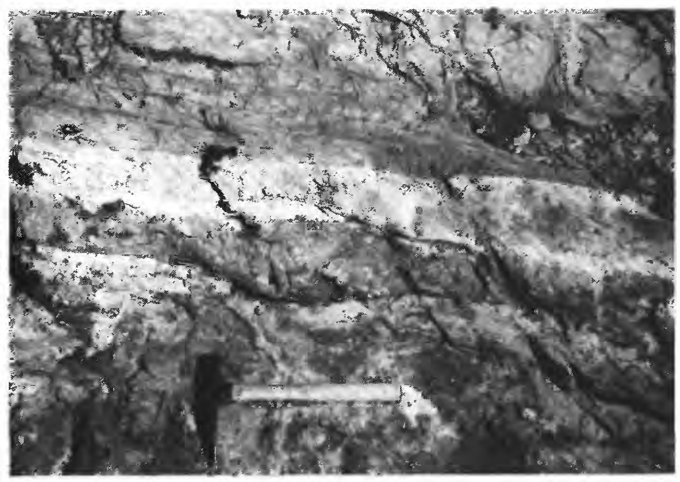


FIGURE 4.—Metarhyolite dike crosscutting folded metasedimentary rocks.

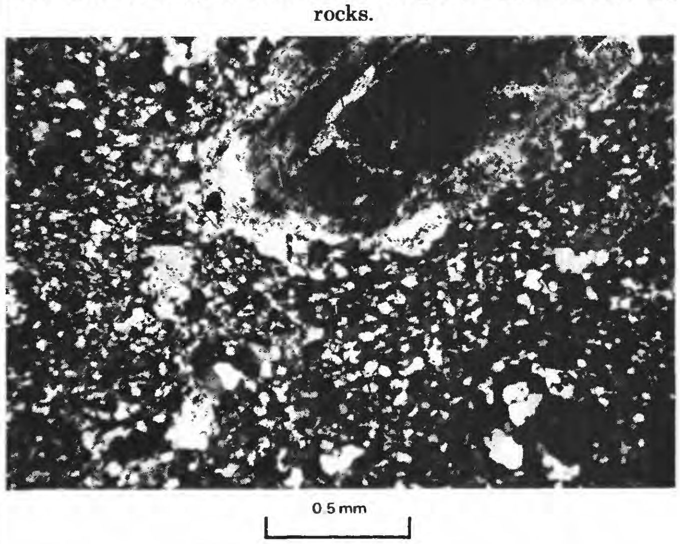


FIGURE 5.—Photomicrograph of metadacite, showing porphyroclast of plagioclase derived from a microphenocryst in recrystallized matrix of quartz, feldspar, and biotite. Crossed nicols.

TABLE 2.—*Metaigneous rock units of the Strawberry mine roof pendant, listed in order of increasing age*

Name	Minerals--major; ± minor	Texture	Comments
Metagranodiorite	Plagioclase (An_{15-30}), quartz, biotite, orthoclase, hornblende; ± apatite, zircon, epidote, opaque materials.	Plagioclase porphyryoclasts (An_{30}); a few orthoclase porphyroclasts; matrix of quartz, plagioclase (An_{15}), biotite, orthoclase, and hornblende.	Contains inclusions of metarhyolite intrusive rocks and metasedimentary rocks mostly bounded by faults.
Metarhyolite	Orthoclase, quartz, albite (An_{0-10}), biotite; ± muscovite, zircon, opaque materials.	Albite porphyroclasts (An_{0-5}) and orthoclase porphyroclasts; matrix of quartz, orthoclase, albite (An_5), and biotite; some albite porphyroclasts zone outward to antiperthite or perthite; a few glomeroporphyroclastic feldspar clots.	Contains inclusions of metarhyolite breccia and metasedimentary rocks; dikes of metadacite, metarhyolite breccia, and metasedimentary rocks.
Metarhyolite breccia	Orthoclase, quartz, albite (An_5), biotite; ± muscovite, epidote, zircon, opaque materials.	Sparse to locally abundant orthoclase porphyroclasts; matrix of quartz, orthoclase, albite (An_5), and biotite; abundant biotite streaks.	Contains inclusions of metadacite intrusive rocks and metadacite breccia; dikes of metadacite breccia.
Metadacite	Plagioclase (An_{30-60}), biotite, quartz; ± hornblende, muscovite, epidote, chlorite, opaque materials.	Plagioclase porphyroclasts (An_{40-60}); matrix of biotite, plagioclase (An_{30}), and quartz.	Contains inclusions of metabreccia, metadacite breccia, and metasedimentary rocks; dikes of metadacite breccia and metarhyolite dikes in metadacite breccia; relict flow banding.
Metadacite breccia	Plagioclase (An_{25-40}), quartz, orthoclase, biotite, hornblende; ± sphene, opaque materials, chlorite, zircon, apatite.	Plagioclase (An_{25-40}) porphyroclasts; a few hornblende porphyroclasts; matrix of quartz, orthoclase, biotite, and plagioclase (An_{25}).	Grades from massive to brecciated; breccia consists of massive metadacite intrusive rocks in very fine grained metadacite matrix; age relative to metabreccia unit unknown.
Metabreccia	Quartz, biotite, plagioclase, orthoclase; ± hornblende, rutile, sphene, opaque materials.	Sparse porphyroclasts of orthoclase, quartz, and plagioclase (An_{30}); matrix grades from one similar to lower biotite hornfels unit to one similar to matrix in metadacite breccia unit; plagioclase porphyroclasts probably relict phenocrysts; subangular quartz porphyroclasts probably relict detrital grains.	Contains abundant inclusions of metasedimentary rocks and metarhyolite; age relative to metadacite breccia unit unknown; mostly bounded by faults.

feldspar, biotite, and hornblende containing sparse to abundant relict microphenocrysts of plagioclase and (or) orthoclase (fig. 5). The relative proportions of relict microphenocrysts and groundmass minerals were used to determine the genetic names. The more mafic metaigneous rocks, such as the metagranodiorite unit, contain abundant hornblende and relict plagioclase microphenocrysts and less quartz, whereas the more siliceous metaigneous rocks, such as the metarhyolite unit, contain abundant biotite, quartz, and orthoclase microphenocrysts.

Table 3 shows the results of chemical analyses of five specimens of the metaigneous rocks. Samples with a wide compositional variation were chosen to yield a rubidium-strontium isochron with the longest possible slope.

Chemical analyses of the metaigneous rocks fall along smooth trends on a silica-variation diagram (fig. 6). These regular variations suggest a common source for the metaigneous rocks, and the Peacock index of 60-61 indicates a calc-alkalic suite. Chemical analyses of metavolcanic rocks from nearby roof pendants in the Merced Peak quarangle, reported by Peck, Stern, and Kistler (1977), also fall on the same calc-alkalic trend.

TABLE 3.—*Chemical analyses of and normative minerals in metaigneous rocks of the Strawberry mine roof pendant*

[Rapid rock analyses in weight percent. Analyst: Lowell Artis]

Sample[1]	GC-50	GC-10	GC-41	GC-204	GC-62
Chemical analyses					
SiO_2	62.40	64.60	64.00	73.20	73.20
Al_2O_3	16.60	17.20	16.80	14.70	14.30
Fe_2O_3	1.20	1.00	1.60	.40	.71
FeO	4.60	4.30	3.10	1.60	.90
MgO	2.60	1.70	1.50	.38	.28
CaO	4.80	4.80	4.10	.92	.74
Na_2O	3.30	2.80	3.50	4.10	4.70
K_2O	2.40	1.40	2.40	3.90	4.50
H_2O	.96	1.10	1.30	.71	.54
TiO_2	.81	.98	.71	.26	.23
P_2O_5	.21	.26	.18	.05	.05
MnO	.11	.11	.14	.07	.07
CO_2	.02	.02	.04	.02	.02
Total	100.01	100.27	99.37	100.31	100.24
CIPW norms					
Q	17.62	28.28	22.62	30.93	26.39
C	.39	3.01	1.52	2.22	.51
or	14.18	8.25	14.27	22.97	26.52
ab	27.92	23.62	29.80	34.58	39.67
an	22.31	21.92	19.03	4.09	3.21
en	6.47	4.22	3.75	.94	.69
fs	6.32	5.64	3.48	2.30	.81
mt	1.74	1.44	2.33	.57	1.02
il	1.53	1.85	1.35	.49	.43
ap	.49	.61	.42	.11	.11
cc	.04	.04	.09	.04	.04
Total	99.05	98.91	98.70	99.29	99.46
Differentiation index	59.72	60.15	66.69	88.49	92.60

[1]Samples: GC-50, metagranodiorite; GC-10, metadacite; GC-41, metadacite breccia; GC-204, metarhyolite breccia; GC-62, metarhyolite.

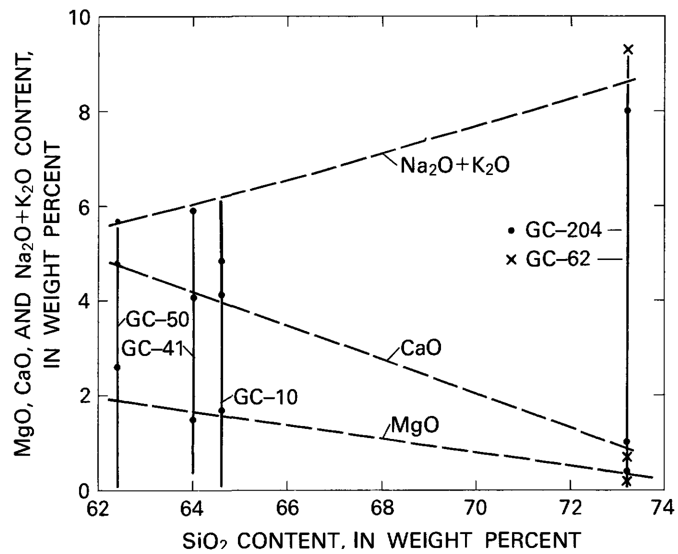
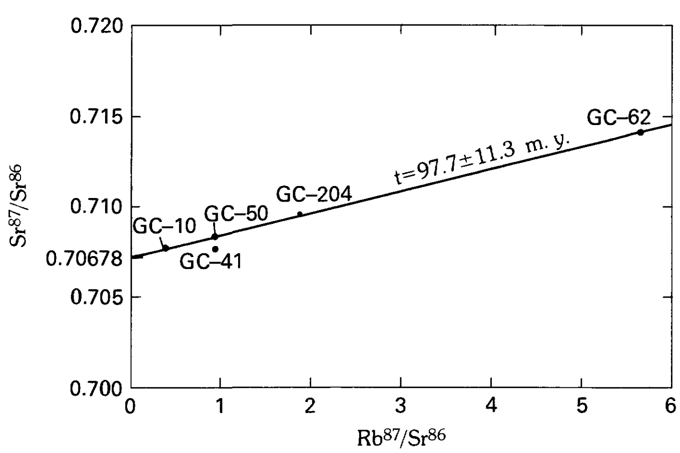


FIGURE 6.—Variation in silica content of metaigneous rocks of Strawberry mine roof pendant. Labeled samples refer to table 3. Data from sample GC-10 were omitted in drawing trends.



Rubidium-strontium analytical data

Sample	Rb (Parts per million)	Sr (Parts per million)	Rb^{87}/Sr^{86}	Sr^{87}/Sr^{86}
GC–10	59.0	504	0.339	0.7073
GC–41	122	387	.913	.7073
GC–50	115	366	.910	.7077
GC–62	189	96.9	5.64	.7142
GC–204	136	210	1.87	.7096

FIGURE 7.—Rubidium-strontium isochron-age determination and analytical data on five specimens of metaigneous rocks of Strawberry mine roof pendant. Isotope analyses and age determination by R. W. Kistler; rubidium and strontium analyses by Willis Doering. Decay constant $\gamma = 1.42\times10^{-11} yr^{-1}$. Whole-rock analytical data are given in table 3.

AGE AND REGIONAL CORRELATIONS

A whole-rock rubidium-strontium isochron for five metaigneous rock samples (fig. 7) indicates a middle Cretaceous age of 97.7 m.y. (R. W. Kistler, written commun., 1971). Seven other metavolcanic rock samples from nearby roof pendants in the Merced Peak quadrangle also fall on the same isochron (Peck and others, 1977). One metaigneous rock sample from the Merced Peak quadrangle yielded a lead-uranium zircon age of 100 m.y. (Peck and others, 1977). These data indicate that the metaigneous rocks of the Strawberry mine roof pendant and the nearby metavolcanic rocks of the Merced Peak quadrangle constitute part of a contemporaneous suite of volcanic and shallow-intrusive rocks that formed from 95 to 100 m.y. ago, that is, during the middle Cretaceous.

The metaigneous rocks exposed in the Strawberry mine roof pendant provide a unique insight into the volcanic and plutonic history of the Sierra Nevada during the middle Cretaceous. The metaigneous rocks, representing metamorphosed shallow-intrusive rocks, and the metavolcanic rocks of the Merced Peak quadrangle have similar chemical compositions and ages (Peck, 1964; Peck and others, 1977). These data strongly suggest that the two rock suites formed from a common magma(s) during the middle Cretaceous and that the metaigneous rocks of the Strawberry mine roof pendant represent necks or dikes which were one source of the metavolcanic rocks. As a composite suite, the metaigneous rocks of the Strawberry mine roof pendant and the metavolcanic rocks of the Merced Peak quadrangle document a calc-alkalic period of volcanism in the central Sierra Nevada during middle Cretaceous time.

Similar-age metavolcanic and metaigneous rocks occur in other areas of the central Sierra Nevada. Metamorphosed andesitic to rhyolitic flows, breccia, and tuffaceous sandstone of middle Cretaceous age occur in the Dana sequence on Mount Dana (Kistler, 1966a; Russell, 1976; R. W. Kistler, oral commun., 1977), and metamorphosed rhyolitic to rhyodacitic ash flows and breccia of middle Cretaceous age form the upper part of the Ritter Range roof pendant (Huber and Rinehart, 1965; Fiske and Tobisch, 1978). Metamorphosed shallow-intrusive rocks of middle Cretaceous age also form the granodiorite of Rush Creek and the quartz monzonite of Billy Lake in the central part of the Ritter Range roof pendant in the Mono Craters quadrangle (Kistler, 1966b; R. W. Kistler, oral commun., 1977). Regionally, these metamorphosed intermediate to siliceous shallow-intrusive rocks, flows, breccia, and tuffaceous sandstone of middle Cretaceous age form part of an Andean-type volcanic arc that existed on the west margin of the North American Continent during the middle Cretaceous; trough accumulations from the arc form part of the Great Valley sequence to the west (Hamilton, 1969; Ernst, 1970).

GRANITIC ROCKS

The Strawberry mine roof pendant is intruded by four granitic plutons (pl. 1); dikes of all four intrusive rocks crosscut the roof pendant. The sequence of granitic intrusion is: (1) quartz diorite, (2) hornblende granodiorite, (3) biotite quartz monzonite, and (4) alaskite and felsic dikes and masses. This sequence of granitic intrusive rocks—from older, more mafic to younger, more siliceous units—probably represents a differentiation series that crystallized from a single magma. During cooling and differentiation, the magma periodically broke through its rind of previously crystallized material to reintrude the country rock; these intrusive bodies extend as far as several kilometers from the roof pendant (Peck, 1964). The quartz diorite, granodiorite, and quartz monzonite are facies of the granodiorite of Jackass Lakes, a unit extending 9 km west and about 20 km north of the roof pendant. One large granitic pluton, the Mount Givens Granodiorite, intrudes to within 1 km of the southeast margin of the roof pendant. This Late Cretaceous pluton (Evernden and Kistler, 1970) extends 80 km south-southeastward along the strike of the Sierra Nevada (Bateman and others, 1963).

Contacts between the various granitic intrusive rocks forming the granodiorite of Jackass Lakes are sharp, regular, and clean. Several features, such as stoping, diking, or crosscutting of igneous foliation, were used with consistent results to determine the relative ages between units. The rock units are homogeneous except for local contamination adjacent to wallrocks. The granitic intrusive rocks exhibit a primary igneous foliation defined by schlieren, that is, parallel flattened inclusions (pl. 1). The foliation commonly parallels the intrusive contacts.

A schistosity that is almost uniform in the various intrusive rocks forming the granodiorite of Jackass Lakes is defined by parallel crushed grains of mafic and felsic minerals, trains of crushed grains, and recrystallized biotite. The schistosity is fine grained but obvious in thin section, although it cannot be separated in outcrop from the igneous foliation. The schistosity reflects a period of penetrative deformation and metamorphism under conditions of amphibolite-facies metamorphism that postdated the intrusion of units of the granodiorite of Jackass Lakes.

In adjacent areas of the Merced Peak quadrangle, D. L. Peck (oral commun., 1977) defined a middle to Late Cretaceous period of regional deformation and metamorphism. Within the southern part of the quadrangle, Peck (1964) mapped shear zones in various plutonic rocks of middle Cretaceous age that include the granodiorite of Jackass Lakes. These shear zones are defined by schistose bands as wide as 1 m that contain partially recrystallized mafic and felsic minerals. The shear zones, which trend from east-west to N. 50° W. and generally have steep to vertical dips (Peck, 1964), do not occur in the Late Cretaceous Tuolumne Intrusive Series of granitic rocks but are cut off by the Tuolumne Intrusive Series (D. L. Peck, oral commun., 1978).

CONTEMPORANEOUS PLUTONISM AND VOLCANISM

According to Peck, Stern, and Kistler (1977), the granodiorite of Jackass Lakes, the metavolcanic rocks of the Merced Peak quadrangle, and the adjacent subvolcanic domes form a nearly contemporaneous plutonic to volcanic sequence of middle Cretaceous age. The granodiorite of Jackass Lakes has a lead-uranium zircon age of 98 m.y. and a potassium-argon hornblende age of 95 m.y. (Peck and others, 1977). These ages overlap those of the metaigneous rocks of the Strawberry mine roof pendant and those of the metavolcanic rocks of the Merced Peak quadrangle. In addition, the metavolcanic rocks are locally intruded by the granite porphyries of Red Peak and Post Peak (Peck, 1964). In turn, the porphyries and the metavolcanic rocks are complexly intruded over a large area by the granodiorite of Jackass Lakes (Peck, 1964). Peck, Stern, and Kistler (1977) interpreted these rocks as a volcanic sequence, in which the granite porphyries were formed from degassed magma that filled subvolcanic cupolas above a larger chamber now represented by the granodiorite of Jackass Lakes. The data on the metaigneous rocks of the Strawberry mine roof pendant further complicate the history of volcanic and plutonic activity in this region during the middle Cretaceous. From oldest to youngest, the sequence of intrusion would be: (1) nearly simultaneous extrusion of volcanic rocks, now represented by the metavolcanic rocks of the Merced Peak quadrangle, and intrusion of shallow magmas along feeder dikes, now represented by the metaigneous rocks of the Strawberry mine roof pendant; (2) formation of the granite porphyries from degassed magmas at shallow levels, now represented by the Red Peak and Post Peak plutons; and (3) intrusion of deeper plutonic rocks, now represented by the different units of the granodiorite of Jackass Lakes.

METAMORPHISM

Contact metamorphism and metasomatism are the most prevalent metamorphic effects in the Strawberry mine roof pendant. The various granitic rocks bordering the roof pendant thermally metamorphosed their wallrocks to the hornblende hornfels facies, as defined by Turner (1968). The common assemblage in the calc-silicate hornfels is diopside, plagioclase (An_{30-50}), quartz, and accessory tremolite or grossularite-rich garnet. In the more mafic metaigneous rocks, the common assemblage is hornblende, biotite, plagioclase (An_{30-60}), microcline, and quartz. No variation in the grade of contact metamorphism or in the degree of recrystallization across the roof pendant was observed. Both the metasedimentary rocks and the metaigneous rocks are fine grained and have mainly granoblastic textures. Contact metasomatism has been discussed elsewhere (Nokleberg, 1971, 1980).

A period of regional metamorphism affected the wallrocks before units of the granodiorite of Jackass Lakes were emplaced during the middle Cretaceous, and a later period of regional metamorphism occurred both in the wallrocks and in units of the granodiorite of Jackass Lakes during the middle to Late Cretaceous. The earlier regional metamorphism is defined (1) in the metasedimentary rocks by planar alinement of such platy minerals as biotite and sparse white mica, by a strongly preferred orientation of quartz, and by mineral-streak lineations of all minerals; and (2) in the metaigneous rocks by planar alinement of recrystallized biotite and hornblende, by sparse epidote, and by mineral-streak lineations of all minerals. These data indicate recrystallization and simultaneous deformation of the wallrocks under conditions approximating the upper greenschist or lower amphibolite facies, as defined by Turner (1968). This regional metamorphism occurred before intrusion of the various plutonic units because the regional metamorphic minerals and textures are overprinted by granoblastic minerals and textures that formed during contact metamorphism.

The later regional metamorphism is defined in the wallrocks by platy minerals, such as biotite and hornblende, that are recrystallized along a schistosity which parallels, and in a few places can be traced into, the weak schistosity in units of the granodiorite of Jackass Lakes. This schistosity trends N. 50°-80° W. and dips steeply to near vertically. This second period of regional metamorphism occurred after emplacement of the granodiorite of Jackass Lakes during the middle Cretaceous.

STRUCTURE

The strata in the roof pendant are complexly folded and faulted. Four generations of major and minor structures that formed in three widely spaced regional deformations are recognized; each generation of structures is characterized by a distinctive style and average strike of axial planes and faults. The structural fabric is inhomogeneous. Detailed mapping and analysis of minor structures indicate that the roof pendant is an area of intersecting fold-fault belts; in the areas of intersection, superposition relations exist between generations of major and minor structures. Major and minor structures were analyzed by grouping into syngenetic generations to establish the order of superposition between generations. Each generation of structures consists of folds, faults, cleavage, schistosity, and foliation, all formed in response to the same stress field. Relations between structures of different generations must be consistent for a valid analysis (Loney, 1965). Structural elements were plotted on equal-area lower-hemisphere diagrams according to a computer program developed by Charles Corbato and Theodore Theodore (written commun., 1969) that plots points for any contour interval by means of least-squares refinement.

In the metasedimentary rocks, minor folds are most useful for structural analysis because, unlike lineations and schistosity, they were not obscured by later metamorphism. Also, minor folds can be more easily grouped into generations than other structures by the style and orientations of axial planes. Grouping into generations according to the orientation of axial planes is based on the principle that axial planes of a given generation of folds are planar and parallel regardless of preexisting bedding attitudes (Weiss and McIntyre, 1957). Fold axes are less helpful than axial planes for grouping into generations because the orientation of a fold axis is partly controlled by the preexisting orientation of bedding or foliation (Weiss, 1959a, b) and may vary considerably in areas of refolded folds. Style, orientation of axial planes, and orientation of fold axes may change considerably with subsequent deformation.

Besides being readily grouped into generations, minor folds also show superposition features. The two most important superposition criteria are the refolding of minor folds and the refolding of limbs of a major fold by minor folds of a younger generation. Although areas of refolded minor folds are rare, superposition of the major and minor folds of different generations is abundant.

Other common structures in the metasedimentary rocks, less easily grouped into generations, are slip cleavages, lineations, and schistosities. Slip cleavages, which are planar surfaces along which the beds have been slightly displaced, sometimes, but not always, occur with minor folds and parallel or fan about minor-fold axial planes. When not associated with a fold, the generation of a slip cleavage is difficult to establish except on the basis of orientation. In a few areas, movement along slip cleavage has transposed the bedding into lenticular fragments. Lineations, commonly defined by biotite streaks, mostly parallel the axial planes.

FIRST-GENERATION STRUCTURES

Major structures.—First-generation structures are not readily apparent because they have been obscured by later deformations and initially were not extensively developed (fig. 8*A*). The hinge of the only major first-generation fold observed in the roof pendant is just north of the No. 1 mine (pl. 1) in an area now mostly underlain by granitic intrusive rocks. North of the No. 1 mine the metasedimentary rocks face north, whereas south of the No. 1 mine the metasedimentary rocks generally face south, as deter-

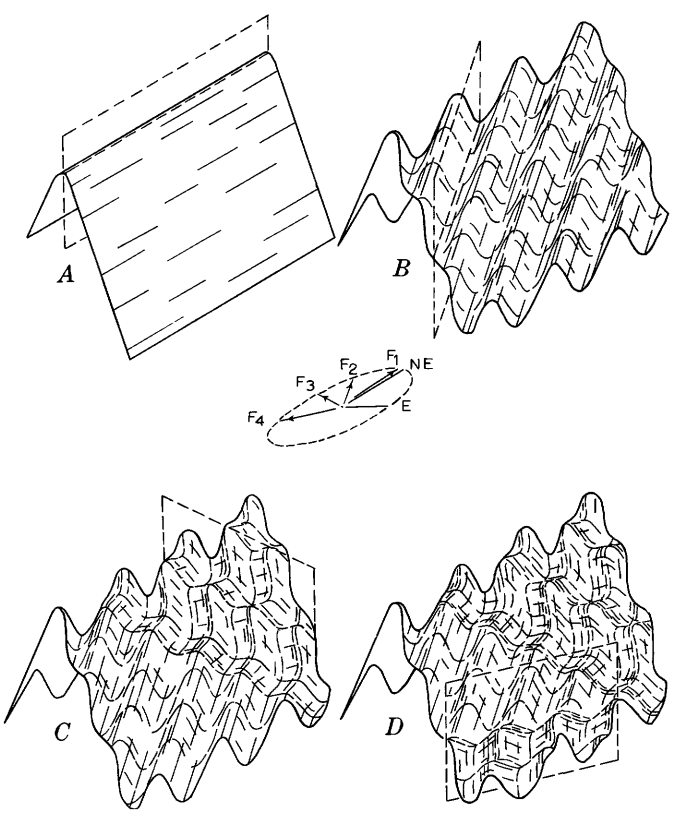


FIGURE 8.—Sequential development of major folds. Dashed rectangles indicate orientation of axial plane. *A*, First-generation fold (F_1). *B*, Second-generation folds (F_2). *C*, Third-generation folds (F_3). *D*, Fourth-generation folds (F_4).

mined from the graded bedding. The opposed facings and sequence of formations indicate that the area around the No. 1 mine represents the former hinge area of a northeast-to east-west-striking anticline. Superposition of major and minor structures of all younger generations on the limbs of a major first-generation fold indicates that this fold is the oldest major structure in the roof pendant. The exact initial orientation of this first-generation fold cannot be determined because the pendant is not extensive enough to permit the irregularities caused by younger folds to be smoothed out.

Metaigneous rocks are not deformed by the major first-generation fold. On the hill north of the No. 1 mine, however, an extensive area underlain by metaigneous rocks appears to be related to a belt of third-generation folds and faults that trends N. 65° W. along the northeast margin of the roof pendant. No major faults are related to structures of the first generation.

Minor structures.—First-generation folds are observed only in the hinge areas of major second-generation folds, and the style of first-generation folds is altered by the formation of younger structures. First-generation folds have tightly appressed limbs and thickened hinges (fig. 9). The limbs of first-generation folds are commonly transposed by movement along slip cleavage into a mosaic of subparallel lenticular fragments. Most minor first-generation folds are of about the same scale and style as that shown in figure 9 and resemble the passive-flow folds of Donath and Parker (1964). No consistent asymmetry of minor first-generation folds was observed.

The orientations of first-generation folds were altered by the formation of younger structures. Statistically, where recognized, the axial planes of first-generation folds are not subparallel, and the poles to axial planes do not form a tight maximum on a lower-hemisphere diagram. Instead, poles to first-generation–fold-axial planes form a small-circle girdle with an 85° angular radius around β_2, the major second-generation–fold axis (diagrams 1b, 2a, pl. 2). First-generation–fold axes in the same areas do not exhibit a tight maximum but rather a diffuse concentration around point L_1 (diagram 1c, pl. 7). These data show that first-generation folds are rotated by second-generation structures. This conclusion agrees with the field observation that the axial planes of first-generation folds are bent around the hinges of major second-generation folds. Accordingly, the superposition of major second-generation on minor first-generation folds can be clearly established. The initial orientation of minor first-generation folds, however, cannot be directly estimated from the field data. No minor structures of the first generation were observed in the metaigneous rocks. Metaigneous rocks crosscut the metasedimentary rocks in areas of second-generation–fold hinges, but in these areas the metaigneous rocks contain structures only of the second and (or) younger generations.

FIGURE 9.—First-generation fold (F_1) in middle quartz-plagioclase hornfels unit. Wedges of bedding parallel to axial plane of first-generation fold are probably detached limbs of first-generation folds.

In the metaigneous rocks, the most common minor structure is a parallel alinement of flattened inclusions in the metasedimentary rocks; in a few areas, schistosity can be discerned. Both structures are grouped together as a tectonic foliation on the geologic map (pl. 1). Throughout the roof pendant, the foliation in the metaigneous rocks parallels the axial surfaces of the most dominant generation of minor folds in nearby metasedimentary rocks. An example occurs between the areas labeled "main hill" and "open pit" (pl. 1), where the axial planes of minor second-generation folds strike N. 25° W. and dip steeply east; the foliation in the adjacent metaigneous rocks is parallel. No superpositional relations were observed between generations of minor structures in the metaigneous rocks across the roof pendant because metaigneous rocks of this type do not show much detail.

SECOND-GENERATION STRUCTURES

Major structures.—Major second-generation folds, which are most apparent in the central part of the roof pendant (pl. 1), form a series of upright to overturned anticlines and synclines whose vertical-axial planes strike N. 25° W. and whose fold axes plunge at moderate angles toward azimuth 155°. The major second-generation folds are also delineated by reversals in top directions on opposite sides of the axial planes. The uniform bearing and plunge of major second-generation–fold axes is consistent with the concept of second-generation folds forming on the south-dipping limb of a larger older fold (fig. 8*B*).

Major second-generation folds are also delineated by composite diagrams of bedding attitudes. The diagram of poles to bedding in areas of second-generation folds (diagram 2a, pl. 2) shows a great-circle girdle whose center statistically defines a major-fold axis, termed β_2, that plunges 55° toward azimuth 155°. The fact that the set of poles to bedding is statistically homoaxial about a rectilinear axis indicates cylindroidal folding; parallelism between β_2 and point L_2, the center of concentration of minor second-generation–fold axes (diagrams 2a, 2c, pl. 2), most likely indicates that the mechanism of folding was flexural slip rather than slip (Weiss, 1959a, b).

Major second-generation folds may also have affected the metaigneous rocks. Because of the random occurrence of the metaigneous rocks, this pattern is not so apparent here as in the metasedimentary rocks. Major faults parallel the axial planes of major second-generation folds, as clearly displayed on the west side of main hill (pl. 1). These faults probably reflect extreme strain during the later stages of folding. Several lines of evidence for faulting are found west of main hill. First, the metaigneous rocks, which in other areas intrude the metasedimentary rocks, show no intrusive relations along faults. Second, in an area of the fault zone about 200 m west-southwest of bridge, in the southern part of the roof pendant, various metasedimentary and metaigneous rock units are transposed into a tectonic breccia in which flattened fragments parallel the strike of the fault zone. Third, on long ridge, the bedding in one metasedimentary rock unit strikes into the bedding in another metasedimentary rock unit across the fault. The sense of movement or extent of displacement on these faults cannot be determined with certainty.

Minor structures.—Minor second-generation structures are most common in the central part of the roof pendant, an area relatively unaffected by later deformations. Most second-generation folds are open with simple hinges (fig. 10) and have the characteristics of folds formed by flexural slip or flexural flow (Donath and Parker, 1964). In a few areas, second-generation folds are tightly appressed with complex hinges and have characteristics that are transitional between folds formed by flexural flow and by passive flow or slip, a relation suggesting a change from flexural to slip folding with continued deformation.

The axial planes of second-generation folds strike N. 25° W. and dip vertically (diagram 2b, pl. 2), and fold axes plunge 55° toward azimuth 154° (diagram 2c, pl. 2) in areas unaffected by later deformations. Other minor second-generation structures are: (1) slip cleavage that parallels second-generation–fold axial planes (diagrams 2b, 2d, pl. 2); (2) lineation that parallels fold axes; and (3) foliation in the metaigneous rocks that parallels second-generation–fold axial planes (diagrams 2b, 2e, pl. 2).

THIRD-GENERATION STRUCTURES

Major structures.—The largest major third-generation fold is in an area extending from north of the No. 4 mine to northeast of the summit of main hill (pl. 1). The fold, whose axial plane strikes N. 65° W. and dips steeply south, is outlined by a conspicuous marker bed and by top directions. On the surface of and underground in the No. 4 mine, several metasedimentary rock units can be traced around the nearly vertical hinge of the fold, which is superposed on the limb of a second-generation anticline (pl. 1). The wavelengths of third-generation folds are considerably less than those of second-generation folds. Major third-generation folds are mostly confined to the northeast margin of the roof pendant (pl. 2; fig. 8*C*).

Major third-generation folds are also delineated by composite diagrams of bedding attitudes. A plot of poles to bedding in areas of third-generation folds (diagram 3a, pl. 2) contains a girdle whose center defines a rectilinear major-fold axis, β_3, that differs considerably in orientation from β_2. Diagram 3a (pl. 2) also shows a strong maximum subparallel to the axial planes of major third-generation folds, which have an average strike of N. 65° W. and a dip of 85° N.

Superposition of fault generations is best shown on the summit of main hill, where a third-generation

FIGURE 10.—Second-generation fold in lower biotite hornfels unit.

fault crosscuts the second-generation fault zone west of main hill. The third-generation fault strikes east-west and dips steeply south; if extended eastward along strike, this fault would coincide with the axial plane of the major third-generation fold north of the No. 4 mine.

Minor structures.—Minor third-generation folds are most common along the northeast margin of the roof pendant. These folds are generally open with simple hinges and have the characteristics of folds formed by flexural flow (Donath and Parker, 1964). The axial planes of third-generation folds strike approximately N. 65° W. and dip vertically (diagram 3b, pl. 2); fold axes plunge 69° toward azimuth 138° (diagram 3c, pl. 2). In places showing abundant second- and third-generation folds, such as the hill north of the No. 1 mine, third-generation folds are superposed on second-generation folds (fig. 11). Other minor third-generation structures are: (1) slip cleavage that parallels axial planes, (2) foliation in the metaigneous rocks that parallels axial planes (diagrams 3b, 3e, pl. 2), and (3) mineral segregations along slip cleavage in the hilltop area.

FOURTH-GENERATION STRUCTURES

Major structures.—Major fourth-generation folds and faults occur only on the east margin of the roof pendant, around hilltop (pl. 1). The axial planes of fourth-generation folds strike about N. 55° E. and dip vertically. Major fourth-generation folds have wavelengths considerably less than the wavelength of the major third-generation fold north of the No. 4 mine. Restriction of major fourth-generation folds to the hilltop area precludes any determination of superposition between major third- and fourth-generation folds. The area between hilltop and the No. 4 mine, in which major third- and fourth-generation folds would intersect, is underlain by hornblende granodiorite. Major fourth-generation folds are superposed on the east limb of a southeast-plunging second-generation anticline in the hilltop area (pl. 1; fig. 8*D*).

Major fourth-generation folds are also delineated by composite diagrams of poles to bedding. The plot of poles to bedding for the hilltop area (diagram 4a, pl. 2) contains a girdle of poles to bedding that defines a fold axis, β_4, differing in orientation from other major-fold axes. The parallelism between β_4 and point L_4, the average orientation of minor fourth-generation-fold axes (diagrams 4a, 4c, pl. 2), suggests flexural folding. However, a transition toward slip folding is indicated by fourth-generation-fold axes spreading along a great circle parallel to the axial planes of fourth-generation folds.

Several faults in the hilltop area parallel the axial planes of fourth-generation folds. Near the south margin of the roof pendant, south of lowlands and hilltop, a fault is inferred because second-generation folds and faults on long ridge do not extend the length of the ridge and because the bedding in the various metasedimentary rock units strikes into the bedding of other units across the fault.

Minor structures.—Minor fourth-generation structures are most common in the hilltop area, where fourth-generation folds are generally open and symmetrical (fig. 12). The folds commonly have simple hinges and the characteristics of flexural-slip folds (Donath and Parker, 1964). The axial planes of fourth-generation folds strike about N. 60° E. and dip steeply south (diagram 4b, pl. 2); fold axes plunge 75° toward azimuth 105° (diagram 4c, pl. 2). Minor fourth-generation folds are superposed on minor

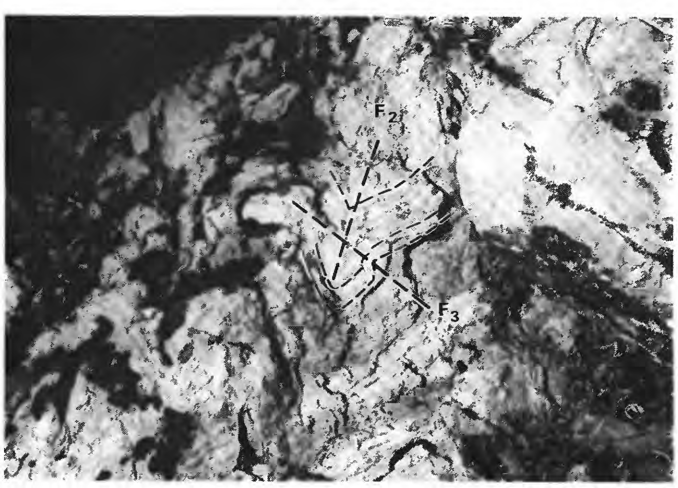


FIGURE 11.—Third-generation fold (F_3) crosscutting second-generation fold (F_2) in lower biotite hornfels unit. Axial plane of second-generation fold (F_2) is nearly vertical. Axial plane of third-generation fold (F_3) runs from lower right to upper left.

FIGURE 12.—Fourth-generation fold in lower biotite hornfels unit.

third-generation folds in the hilltop area.

RELATION OF MAJOR TO MINOR STRUCTURES

A high positive correlation exists between the orientations of axial planes of major and minor folds of each generation for which comparisons can be made. The average strikes of major and minor folds of each generation are: (1st) northeast to east-west for major folds, unknown for minor folds; (2d) N. 20° W. for both major and minor folds; (3d) N. 65° W. for both major and minor folds; and (4th) N. 60°–65° E. for both major and minor folds. A high positive correlation also exists between the orientations of fold axes of major and minor folds of each generation for which comparisons can be made. The average orientations of major and minor fold axes of each generation are: (1st) unknown for major folds, 47° toward azimuth 176° for minor folds; (2d) 55° toward azimuth 155° for both major and minor folds; (3d) 70°–80° toward azimuth 160° for both major and minor folds; and (4th) 80° toward azimuth 152° for major folds, 75° toward azimuth 105° for minor folds. Besides the parallelism between major- and minor-fold axes, a progressive steepening of successively younger major- and minor-fold axes was observed.

Superposition relations between a major second-generation fold and minor folds of all generations are illustrated in figure 13. Minor first-generation folds, which occur in the hinge areas of major second-generation folds, have axial planes that are folded around major second-generation folds. Although minor second-generation folds reflect the orientation and style of major second-generation folds, they change sense on opposite sides of major second-generation folds. The fact that minor third- and fourth-generation folds do not change orientation or sense on opposite sides of major second-generation folds indicates that minor third- and fourth-generation folds are superposed on the limbs of a major second-generation fold. Careful study of the orientation and sense of each generation of minor or major folds shows a consistent superposition similar to those described above, and so a high positive correlation exists between major and minor structures of each generation.

TIMING AND CAUSE OF STRUCTURES

The metasedimentary rocks, presumably of Early Jurassic age, contain all four generations of structures, whereas the metaigneous rocks, of middle Cretaceous age, contain only the younger three. These relations indicate that the first generation of structures formed during a Middle Jurassic through Early Cretaceous deformation. This deformation, which I designate the "first deformation," consisted of moderately appressed to isoclinal major and minor folds originally striking probably northeast to east-west. The first-generation structures could not have formed from forceful emplacement of plutonic rocks because no plutonic rocks were emplaced at that time.

The metasedimentary and metaigneous rocks contain second- through fourth-generation structures, whereas the granodiorite of Jackass Lakes contains third-generation structures and crosscuts second-generation structures in the roof pendant. These relations indicate that the second-generation struc-

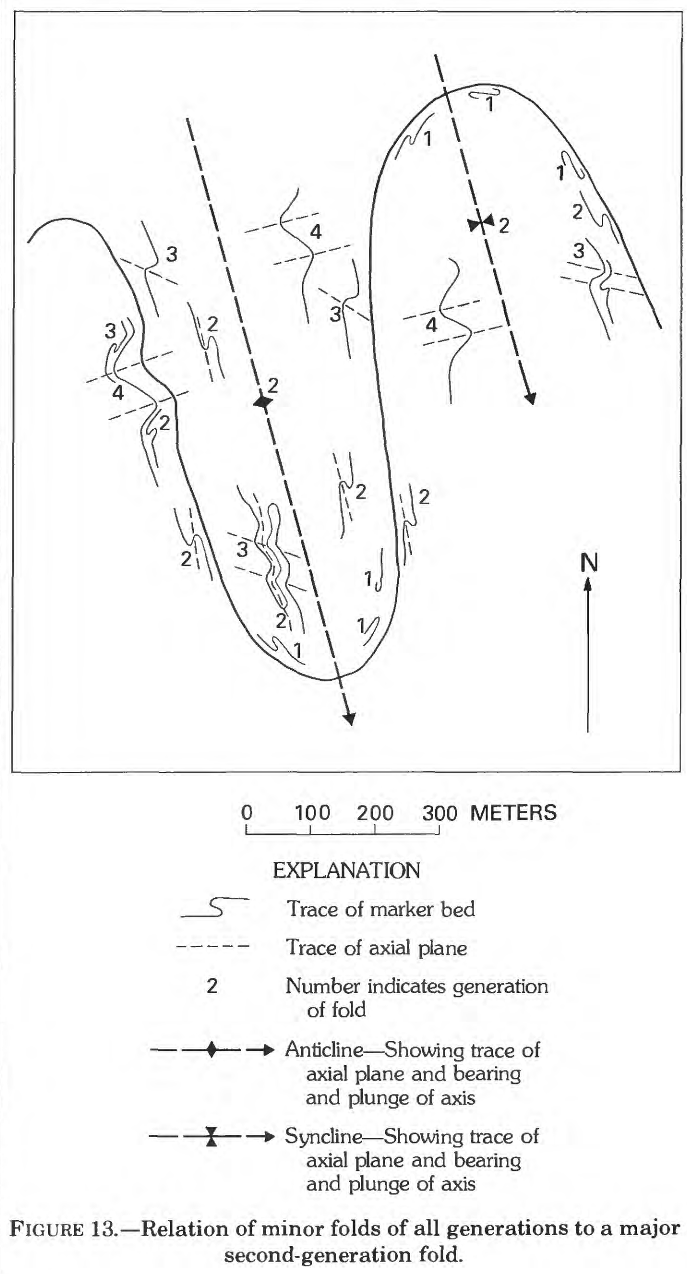


FIGURE 13.—Relation of minor folds of all generations to a major second-generation fold.

tures formed during a middle Cretaceous deformation, which I designate the "second deformation." This deformation consisted of moderately appressed to isoclinal folding, faulting, and regional metamorphism under conditions approximating the upper greenschist to amphibolite facies; folding and faulting had average trends of N. 25° W. Because the metaigneous rocks and the granodiorite of Jackass Lakes have nearly identical radiometric ages, the second deformation was contemporaneous with volcanism, shallow intrusion, and batholithic intrusion.

Third-generation structures occur in both the roof pendant and the granodiorite of Jackass Lakes and also in other middle Cretaceous plutonic rocks of the Merced Peak quadrangle, but not in the Late Cretaceous plutonic rocks (D. L. Peck, oral commun., 1977). These relations indicate that these third-generation structures formed during a middle to Late Cretaceous deformation between two periods of batholithic intrusion. This deformation, which I designate the "third deformation," consisted of folding, faulting, and regional-grade metamorphism under conditions approximating the amphibolite facies; folding and faulting had average trends of N. 65°-90° W. This deformation cannot be related to forceful emplacement of younger plutonic rocks because the structures crosscut large older plutonic rocks many kilometers from younger rocks.

Fourth-generation structures are rare and occur only on the east margin of the roof pendant, in an area of abundant third-generation folds. The fourth-generation folds have average strikes of N. 60°-65° E. that cross the average strikes of third-generation folds at a high angle. Thus, these fourth-generation structures may be a conjugate set of folds and faults that formed simultaneously with or just after the third-generation structures. Tobisch and Fiske (1976) described conjugate folds with similar trends and styles in the central Sierra Nevada and pointed out the possibility of conjugate folding in the Strawberry mine roof pendant. Accordingly, the fourth-generation structures are here assigned to the third deformation.

In summary, the four generations of structures in wallrocks and adjacent granitic plutonic rocks of the Strawberry mine roof pendant probably formed from three deformations during Middle Jurassic to Early Cretaceous, middle Cretaceous, and middle to Late Cretaceous time. No evidence that any generation of structures formed from forceful emplacement of plutons was observed. The second deformation occurred during the middle Cretaceous, contemporaneously with volcanism, shallow intrusion, and batholitic intrusion, and denotes simultaneous orogeny and magmatism. The first and third deformations appear to be related to widespread regional deformations recorded elsewhere in the central Sierra Nevada.

JURASSIC AND CRETACEOUS REGIONAL DEFORMATIONS

The first, Middle Jurassic through Early Cretaeous deformation in the Strawberry mine roof pendant is recognized in other roof pendants and in parts of the western metamorphic belt in the central Sierra Nevada. An Early or Middle Jurassic regional deformation was identified in the upper Paleozoic Calaveras Formation and in the Boyden Cave roof pendant (Girty, 1977; Nokleberg and Kistler, 1977). The Calaveras Formation (fig. 1) is intensely deformed along N. 30°-50° E. trends in a large area from the Stanislaus to Merced Rivers (fig. 1), with the development of melange, broken formation, cataclasites, and isoclinal to open folds. This generation of structures, with fold axes that commonly plunge steeply northeast, is superposed on older northwest-trending structures that formed during the Triassic and was redeformed by the Late Jurassic Nevadan orogeny. The Boyden Cave roof pendant along the Kings River (fig. 1) contains an older generation of structures nearly identical in style, geometry, and orientation to those in the Calaveras Formation and the Strawberry mine roof pendant. Calc-silicate hornfels is intensely deformed along N. 60° E. trends with the development of open to isoclinal folds, schistosities, and melange (Girty, 1977). The fold axial planes strike N. 60° E., and the fold axes plunge gently toward azimuth 060° (Girty, 1977). The age of this deformation in the Boyden Cave roof pendant is bracketed by the Early Jurassic age of the calc-silicate hornfels and slate (Jones and Moore, 1973; Girty, 1977) and by the redeformation of this generation of structures by structures formed during the Late Jurassic Nevadan orogeny (Girty, 1977). The overall similar style of folds, orientations of fold axial planes, and timing of deformations in the Calaveras Formation, in the metasedimentary rocks of the Strawberry mine roof pendant, and in the calc-silicate hornfels of the Boyden Cave roof pendant are strong evidence of a regional deformation of wallrocks of the central Sierra Nevada batholith during Middle Jurassic time.

Similarities in lithology, age, structure, and age of deformation between the Strawberry mine and Boyden Cave roof pendants strongly suggest that these two pendants were part of a once-continuous sequence. As previously mentioned, Bateman and

Clark (1974) grouped the Boyden Cave, Mineral King, and Dinkey Creek roof pendants into the Kings sequence of Late Triassic and Early Jurassic age. The Strawberry mine and Boyden Cave roof pendants have similar lithologies, ages, and structural histories, and so the metasedimentary rocks of the Strawberry mine roof pendant should be considered part of the Kings sequence of Bateman and Clark (1974). Although these two roof pendants share a common Middle Jurassic deformation with the Calaveras Formation, the lithologies, ages, and geographic positions of the Kings sequence and the Calaveras Formation strongly differ. Because of these differences, the Kings sequence should not be included with the Calaveras Complex of Schweickert, Saleeby, Tobisch, and Wright (1977). The Kings sequence and the Calaveras Formation have in common only a Middle Jurassic regional deformation, which may have resulted from tectonic juxtaposition of the two belts of rocks.

The second, middle Cretaceous deformation in the Strawberry mine roof pendant has not yet been recognized in other areas of the central Sierra Nevada; second-generation structures, however, are nearly identical in style, orientation, and regional metamorphism to structures formed during the Late Jurassic Nevadan orogeny in several roof pendants and in the western metamorphic belt. Structures formed during this orogeny in the Ritter Range roof pendant, the Mineral King roof pendant, and the western metamorphic belt generally consist of N. 20°-40° W.-trending folds and faults associated with greenschist- to amphibolite-facies metamorphism (Christensen, 1963; Huber and Rinehart, 1965; Wetzel and Nokleberg, 1976; Nokleberg and Kistler, 1977). Both major and minor folds commonly plunge moderately southeast toward azimuth 155°. The similarity between structures of the Strawberry mine roof pendant and those of other wallrocks of the central Sierra Nevada suggests, but does not prove, that in the Strawberry mine roof pendant the Nevadan orogeny continued into the middle Cretaceous. On the other hand, the second, middle Cretaceous deformation in the Strawberry mine roof pendant may have resulted from a local pulse of contemporaneous orogeny, volcanism, and plutonism.

The third, middle to Late Cretaceous deformation in the Strawberry mine roof pendant is also recognized in other roof pendants and in parts of the western metamorphic belt. A period of intense folding, cataclasis, and regional metamorphism along N. 50°-80° W. trends can be identified in the Ritter Range, Mount Morrison, Mount Dana, Saddlebag Lake, and lower Kings River roof pendants (fig. 1) (Nokleberg, 1975; O. T. Tobisch, oral commun., 1976; Nokleberg and Kistler, 1977). The similarity in style, age, and orientation of structures in these areas is evidence of a regional deformation in the central Sierra Nevada during middle to Late Cretaceous time. Tobisch and Fiske (1976) concluded that the east-west- and north-south-trending conjugate folding in the western metamorphic belt and Ritter Range roof pendant occurred during the Late Jurassic in response to a relaxation of stress after the Nevadan orogeny. On the other hand, data from the Strawberry mine roof pendant, the Ritter Range roof pendant (Nokleberg and Kistler, 1977), and the lower Kings River roof pendant (Nokleberg, 1975) indicate that this generation of conjugate folds and associated structures formed during the middle to Late Cretaceous.

SUMMARY AND CONCLUSIONS

The oldest rocks of the Strawberry mine roof pendant are a miogeosynclinal sequence of marl and limestone, now metamorphosed to calc-silicate hornfels and marble. A pelecypod found in float from calc-silicate hornfels has been tentatively identified as a Mesozoic bivalve, possibly *Inoceramus pseudomytiloides* of Early Jurassic age. These metasedimentary rocks of the Strawberry mine roof pendant are probably Early Jurassic because of their lithologic, structural, and gross age similarities to the metasedimentary rocks of the Boyden Cave roof pendant, and they are here accordingly assigned to the Kings sequence of Bateman and Clark (1974). I consider the assignment of the Kings sequence to the Calaveras Complex by Schweickert, Saleeby, Tobisch, and Wright (1977) to be invalid.

A middle Cretaceous sequence of metaigneous rocks derived from shallow-intrusive rocks, ranging in composition from granodiorite to rhyolite, is the next younger suite. The metaigneous rocks, which are similar in composition and age to the metavolcanic rocks of the surrounding Merced Peak quadrangle, probably represent necks or dikes that were a source of the metavolcanic rocks. The suites of metaigneous and metavolcanic rocks represent a middle Cretaceous calc-alkalic period of volcanism in the central Sierra Nevada. Similar metaigneous and metavolcanic rocks occur to the north and east in the central Sierra Nevada and represent part of a middle Cretaceous Andean-type volcanic arc.

The Strawberry mine roof pendant is intruded by several plutons that range in composition from diorite to felsic dikes and masses. These plutonic rocks constitute part of the granodiorite of Jackass Lakes and the leucogranite of Timber Knob (Peck, 1964), which have the same general radiometric ages as the metaigneous and metavolcanic rocks of the surrounding area. According to Peck, Stern, and Kistler (1977), these metavolcanic, metaigneous, and plutonic rocks represent a major volcanic-plutonic center of middle Cretaceous age.

Three superposed deformations affected the Strawberry mine roof pendant and adjacent plutonic rocks. Structures of the first deformation occur only in the metasedimentary rocks and consist of northeast- to east-west-trending folds. Folds of similar style and orientation as well as other structures, which occur in both the Boyden Cave roof pendant and the Calaveras Formation, represent a regional deformation of Middle Jurassic age. Structures of the second deformation occur in both the metasedimentary and metaigneous rocks and consist of folds, faults, and minor structures that trend about N. 25° W.; regional metamorphism was coeval with this deformation. Crosscutting of these structures by the granodiorite of Jackass Lakes, which has the same radiometric age as the metaigneous rocks, indicates that the second deformation occurred simultaneously with volcanism and plutonism during the middle Cretaceous. This second deformation may be a distinct event that followed the same trends as the earlier Nevadan orogeny. Structures of the third deformation occur in wallrocks and granitic rocks adjacent to the roof pendant and consist of folds, faults, and schistosities trending from N. 65° to 90° W.; regional metamorphism was coeval with this deformation. Although similarly oriented shear zones crosscut the middle Cretaceous plutonic rocks of the Merced Peak quadrangle, these shear zones are in turn crosscut by undeformed Late Cretaceous plutonic rocks (D. L. Peck, oral commun., 1977). Similar structures also occur in other areas of the central Sierra Nevada and represent a regional deformation along N. 65°-90° W. trends during the middle to Late Cretaceous.

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