U.S. DEPARTMENT OF THE INTERIOR
U. S. GEOLOGICAL SURVEY

GEOLOGIC ROAD GUIDE TO KINGS CANYON AND SEQUOIA NATIONAL PARKS, CENTRAL SIERRA NEVADA, CALIFORNIA

By
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Frontispiece The 1864 field party of the California Geological Survey. From left to right: James T. Gardiner, Richard D. Cotter, William H. Brewer, and Clarence King.

INTRODUCTION

This field trip guide includes road logs for the three principal roadways on the west slope of the Sierra Nevada that are adjacent to, or pass through, parts of Sequoia and Kings Canyon National Parks (Figs. 1, 2, 3). The roads include State Route 180 from Fresno to Cedar Grove in Kings Canyon Park (the Kings Canyon Highway), State Route 198 from Visalia to Sequoia Park ending near Grant Grove (the Generals Highway) and the Mineral King road (county route 375) from State Route 198 near Three Rivers to Mineral King. These roads provide a good overview of this part of the Sierra Nevada which lies in the middle of a 250 km span over which no roads completely cross the range. The Kings Canyon highway penetrates about three-quarters of the distance across the range and the State Route 198--Mineral King road traverses about one-half the distance (Figs. 1, 2). These two roads are connected by the Generals Highway.

The road logs are based largely on geologic mapping and attendant studies by the U. S Geological Survey over the last few decades since modern 15-minute quadrangle topographic maps became available (Fig. 4 and table 1). Geologic maps of fourteen 15-minute quadrangles that are adjacent to, or include parts of, Kings Canyon and Sequoia National Parks have been completed, and two others are in progress. In addition, theses and other studies have been combined with reconnaissance mapping to compile the geologic map of Sequoia and Kings Canyon National Parks (Moore and Sisson, 1987).

KINGS CANYON HIGHWAY, STATE ROUTE 180

The Kings Canyon Highway, California State Highway 180, provides a 85-mile-long geologic traverse nearly across the southern Sierra Nevada (Fig. 1). Only the highest part of the range is not crossed. Proceeding 13 miles east from Fresno, the route crosses to the south side of the Kings River, and then climbs 40 miles up the west flank of the range to Grant Grove at 6,500 ft. elevation. For the next 15 miles, the route drops into the Kings Canyon near the confluence of the Middle and South Forks of the Kings River, and ends about 20 miles further east at the head of the Yosemite-like canyon of the South Fork of the Kings River. The road's end is only about 15 miles from the road head on the east side of the Sierra west of the town of Independence. The eastern part of the Kings Canyon Highway route is shown on Figure 3 which is an oblique physiographic map of the central Sierra Nevada, viewed from the southwest (Alpha, 1977).

This route follows rather closely parts of the trail of the first scientific expedition into this part of the Sierra Nevada, the 1864 Whitney Survey of the Geological Survey of California (Frontispiece). The survey field party included William Brewer, party chief, Charles Hoffman, topographer, James Gardiner, geologist, Clarence King, geologist (later to become the first

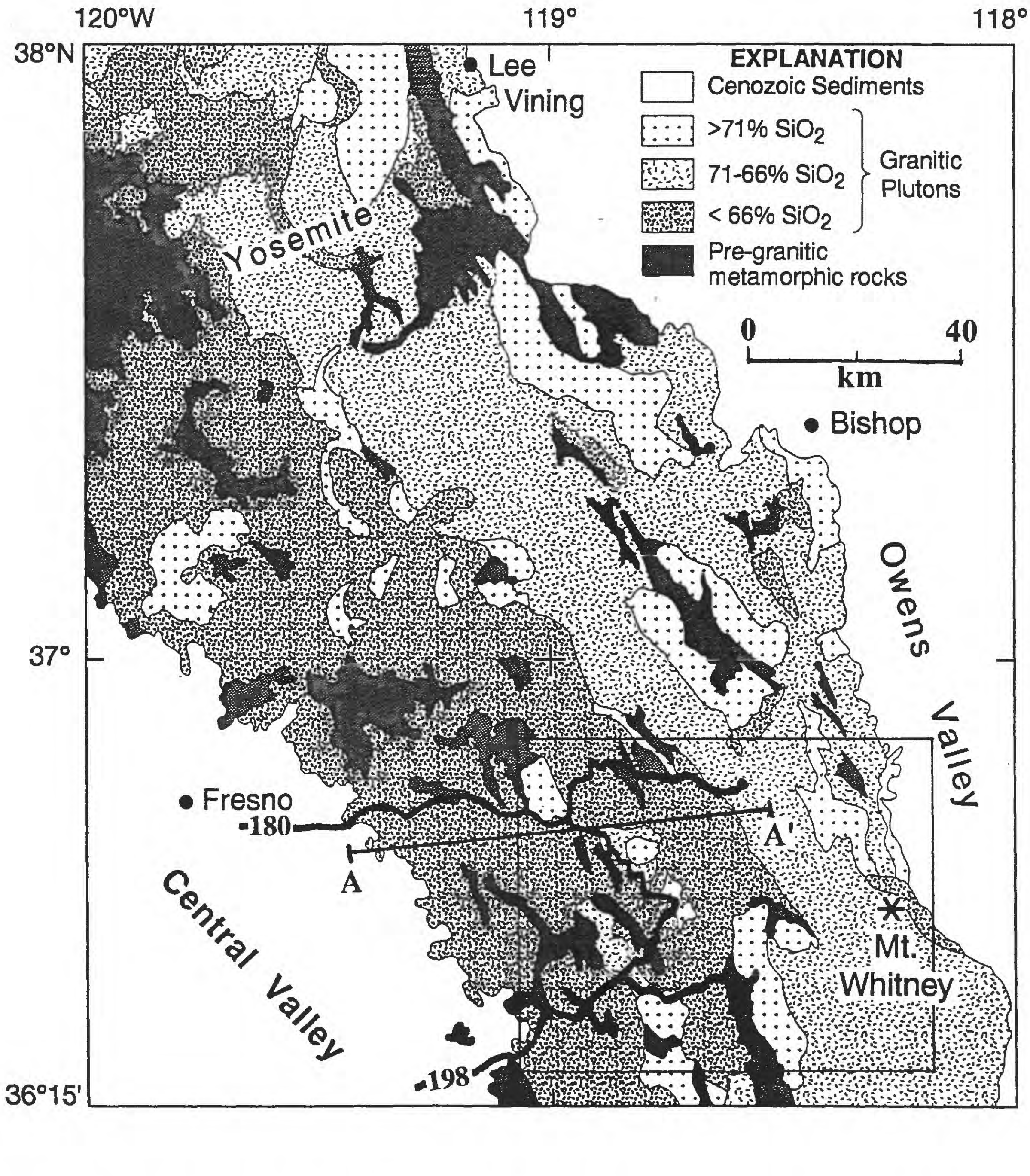

Figure 1. Geologic map of the central Sierra Nevada area showing composition of average granitic rock, and field trip routes (heavy lines) on highways 180 and 198, with the Gererals Highway connecting. The line of projection for figure 6 is shown as line A-A', and area of figure 7 is shown by box.

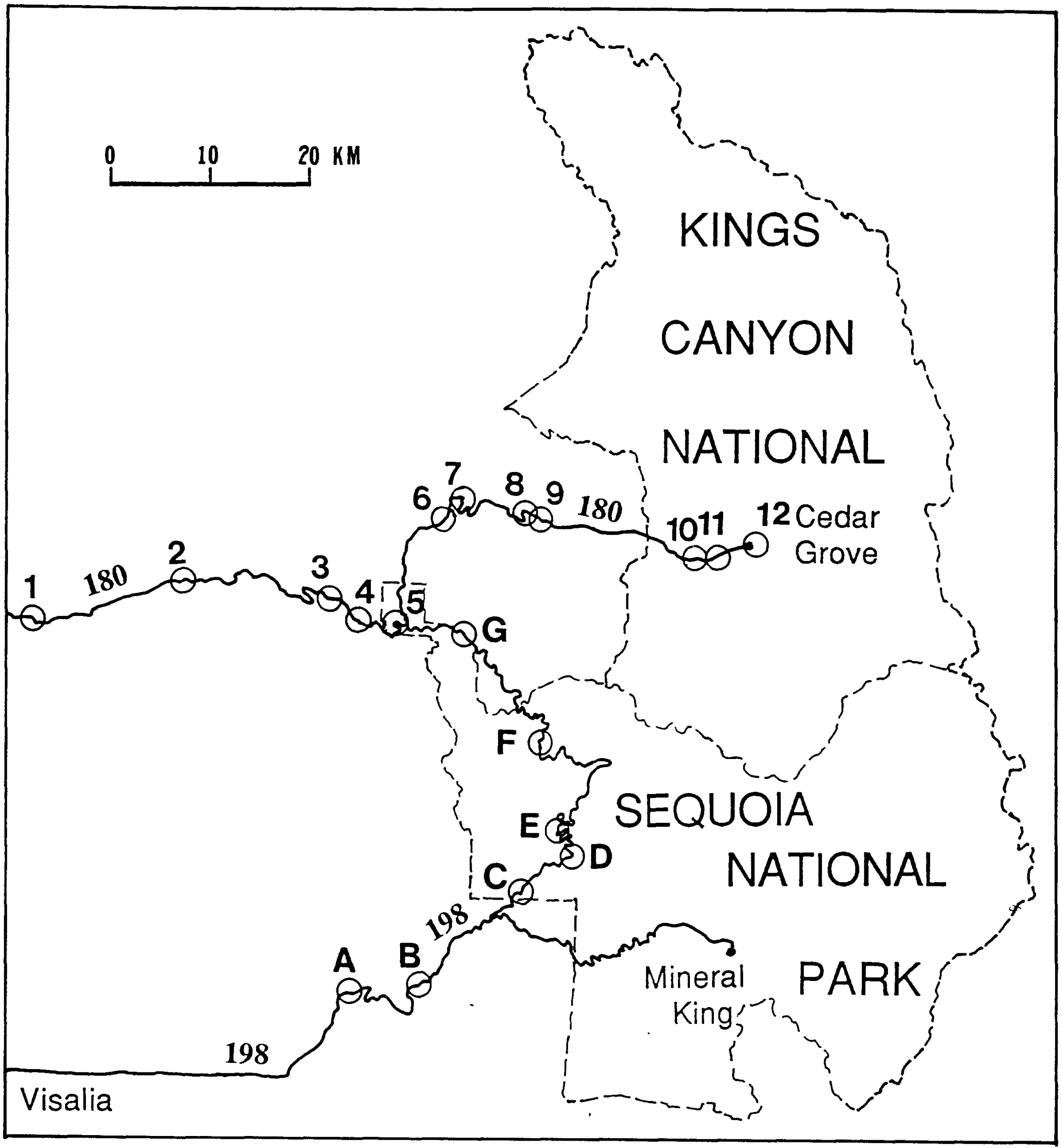

Figure 2. Map of the field trip routes and stops. The 12 stops on highway 180 are designated with numbers and the 7 stops on highway 198-Generals Highway are designated by letters.

Director of the U.S. Geological Survey), and Dick Cotter, packer. During the 1864 expedition, the party explored much of the southern Sierra Nevada and discovered and named many of the loftier peaks in the range, including Mt. Brewer, Mt. Gardiner, Mt. Clarence King, Mt. Williamson, Mt. Tyndall, and Mt. Whitney.

Field trip stops, points of interest, and reference points for the road log are given: (1) in bold type as distance in miles from the beginning (west end) of each of the field trip routes; and (2) in regular type as mile notations of selected Department of Highway roadside mile markers. All of the field trip stops are shown in figure 2. Stops on route 180 are shown by numbers and those on route 198 are shown by letters.

The geology of most of the field trip area is shown on Figure 5, which is an updated version of part of a generalized geologic map of Sequoia and Kings Canyon National Parks (Moore and Sisson, 1987). In addition to the various geologic studies cited in this geologic field trip guide, geologic maps for the region have been published by Krauskopf (1953), Macdonald (1941), Ross (1958), and Moore and Nokleberg (1992). Matthews and Burnett (1965) list all of the published and unpublished geologic maps as of 1965 for the California Division of Mines and Geology Fresno 2° Sheet in which Sequoia and Kings Canyon National Parks are locatead. Figure 4 outlines the mapping utilized in compiling the National Parks map.

The field trip route provides a close look at parts of the Kings-Kaweah ophiolite belt on the west (Saleeby, 1975, 1978), remnants of pre-batholithic metasedimentary and metavolcanic rocks within the Sierra Nevada batholith (Saleeby and others, 1978; Girty, 1977a, b; Moore and Marks, 1972, Moore and Nokleberg, 1992), compositional changes in the granitic rocks of the Sierra Nevada batholith (Figs. 1, 6) which occur systematically from west to east (Moore, 1959; Moore, 1978; Chen, 1977; Chen and Tilton, 1978; Chen and Moore, 1982), and various aspects of the youngest eastern part of the Sierra Nevada batholith near Cedar Grove and Roads End (Moore, 1978; Moore and du Bray, 1978). In addition, the Kings Canyon Highway provides an opportunity to study small remnants of late Cenozoic potassic alkalic basaltic lava flows (Moore and Dodge, 1980), and the effects of river and glacial erosion on a giant scale along the Kings Canyon.

Various belts of wall rocks are traversed by the field trip route. From west to east these belts are: (1) Kings River ophiolite (Permian and Triassic) consisting of peridotite, serpentinite, gabbro, basalt, pillow lava, mafic dikes, and chert (Mile 30); (2) Kings sequence (Late Triassic, Early Jurassic, and possibly older) consisting of intercalalated schist, quartzite, calc-silicate hornfels, marble, metachert, and sparse metavolcanic rocks (Mile 70); (3) Mesozoic metavolcanic rocks in the central part of the Sierra Nevada batholith, consisting chiefly of siliceous pyroclastic rocks and interbedded volcaniclastic rocks (Mile 73); and (4) Paleozoic metasedimentary rocks of

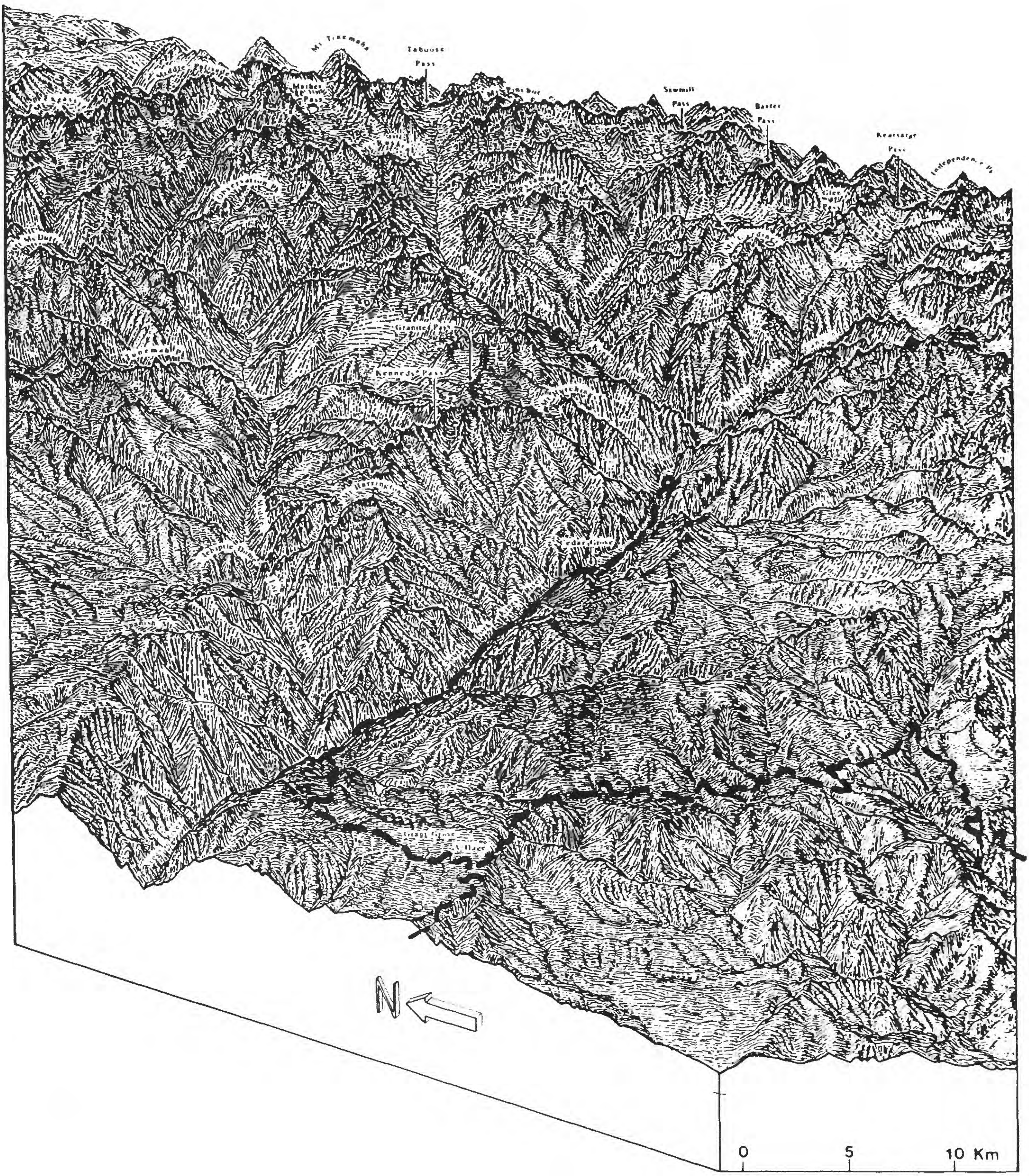

Figure 3 Oblique physiographic map of the upper Kings River Drainage as viewed 30 degrees above the horizontal from the southwest (after Alpha, 1977). Highway 180 extends east up Kings Canyon in center, and Generals Highway contours around to right (south).

the Sierra Nevada crest consisting mostly of pelitic and calc-silicate schist and hornfels (not seen on this traverse). The various age belts of wall rocks are interpreted by Nokleberg (1983) as a series of tectonostratigraphic terranes that were tectonically accreted along major thrust faults or sutures during the Mesozoic. The Kings River ophiolite is interpreted by Saleeby (1975, 1978), Saleeby, others (1978), and Nokleberg (1983) as oceanic crust and upper mantle that was tectonically accreted onto the continental margin during the Mesozoic.

The generalized geologic map of the Kings Canyon and adjacent area (Fig. 5) shows a regional relationship between age the belts of wall rocks and belts of granitic rocks. The plutons generally become younger eastward in the Sierra Nevada batholith (Fig. 6). Surrounding the Kings River ophiolite in the western foothills are mostly Early Cretaceous and some Jurassic granitic plutons. Associated with the Kings sequence are granitic plutons of mainly mid-Cretaceous age. In the central part of the batholith to the east of the Kings sequence are the Mesozoic metavolcanic rocks that comprise in part the youngest wall rocks of the Sierra Nevada batholith; they are associated with the youngest and largest granitic plutons (Late Cretaceous) of the entire batholith. Paleozoic metasedimentary rocks adjacent to the Sierra Nevada crest are associated with older granitic rocks of Jurassic age. Scattered plutons of Early and Late Cretaceous age also occur in this area.

Modal analyses of granitic rocks at various localities are listed in the Road Log part of this geologic guide. The analyses were measured by Oleg Polovtzoff on cut slabs of granitic rock, usually about 8 by 14 cm, which were stained for plagioclase and K-feldspar. All mafic minerals (pyroxene, hornblende, biotite, iron-titanium oxides) are grouped together. Modes are listed in volume percent for each mineral. The following abbreviations are used in the reporting of modal analyses: Pl - plagioclase; Kf - K-feldspar; Q - quartz; and Mf - mafic minerals. The bedrock geology of the Boyden Cave roof pendant and adjacent area is shown in Figure 7, a generalized geologic map modified from Moore and Nokleberg (1992).

CHEMICAL VARIATIONS IN GRANITIC ROCKS

The granitic rocks of the Sierra Nevada batholith become more posassic, more continental, and younger from west to east. This geographic change can be demonstrated by examination of modal K-feldspar content, initial strontium isotope ratios, and U-Pb zircon ages (Fig. 6). K-feldspar is not abundant in the western Sierran granitic rocks. Thirty km east along the traverse (Fig. 6A), the most undifferentiated rocks begin to show a steady increase of K-feldspar that attains about 10 percent 80 km east at Roads End. This systematic eastward change in the dominant type of granitic rock from diorite and quartz diorite to granodiorite was first defined by locating a "quartz diorite line" about one-third of the way across the batholith near mile 38 (Moore, 1959).

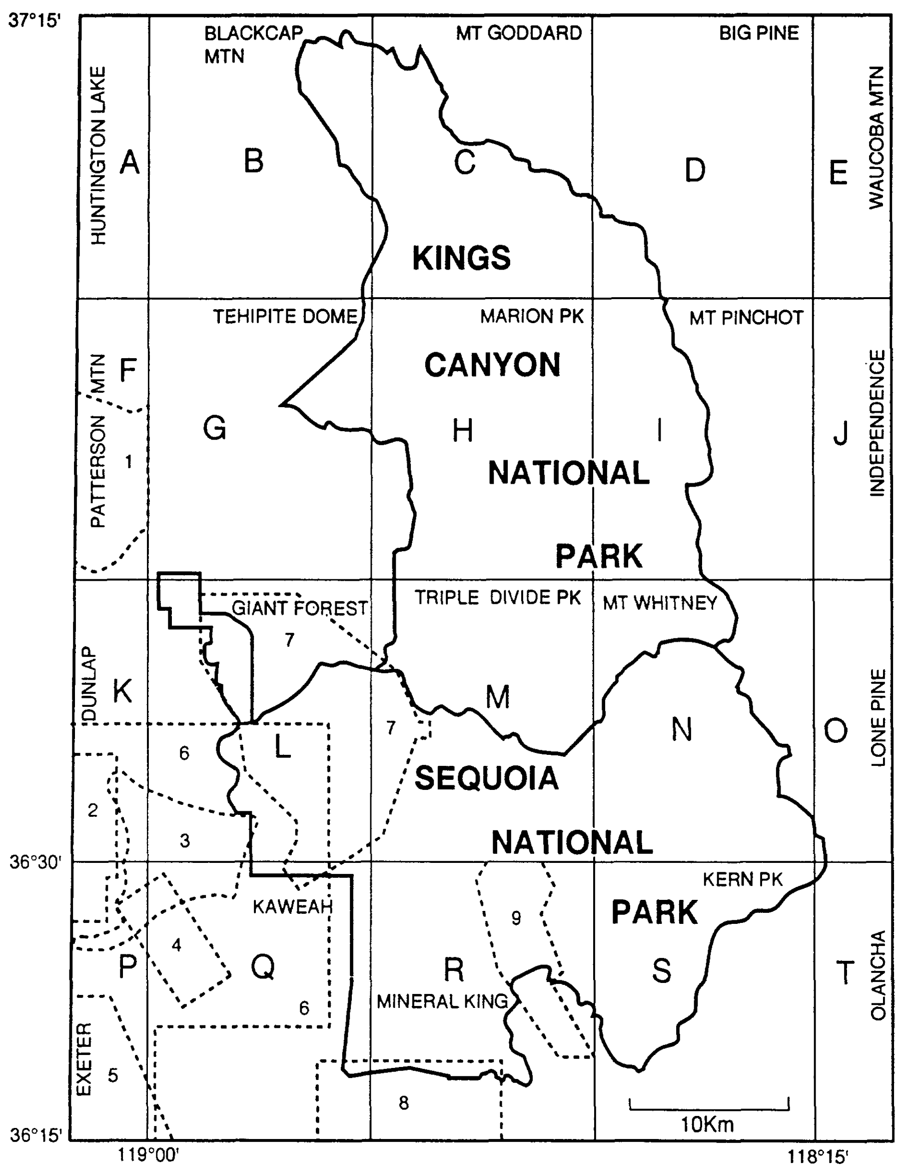

Figure 4 Outline map of Kings Canyon and Sequoia National Parks showing areas of geologic mapping utilized in compiling the geologic map of the parks (fig. 5). Quadrangles (letters) and special mapped areas (numbers) refer to references listed in table 1.

The sparse, more differentiated granitic rocks show an irregular, rapid increase eastward to more than 40 percent K-feldspar at Roads End.

The increase in K-feldspar (and K_2O) from west to east across the Sierra Nevada batholith is also accompanied by a general increase in average SiO_2 content. The specific gravity of samples of granitic rocks can provide a reliable estimate of the SiO_2 content because of the rather good correlation between the specific gravity of samples for which the SiO_2 content has been analyzed (Fig. 6D). The specific gravity is commonly available for many more samples than silica content because of the ease of determining the specific gravity.

The initial $^{87}Sr/^{86}Sr$ ratios increase regularly to the east, reaching 0.704 at 20 km, 0.706 at 50 km, and about 0.707 east of 55 km (Fig. 6B). This variation in initial strontium isotope ratios has been attributed to the derivation of plutons in the western Sierra Nevada batholith from upper mantle material of oceanic character, whereas plutons in the eastern Sierra Nevada batholith were derived from lower continental crust of Precambrian age (Kistler and Peterman, 1978; Chen, 1977; Chen and Tilton, 1978; Chen and Moore, 1982).

A detailed look at Pb, Sr, and Nd isotopic trends on a traverse across the Sierra Nevada close to the route of this field trip indicate: (1) along the western margin pluton sources have substantial mantle components, (2) toward the central part of the batholith an increasing component from aged continental crustal material is present, and (3) from the central part toward the eastern margin of the batholith, sources change from granitic to granulitic components (although an enriched subcontinental lithosphere instead of a granulitic source cannot be eliminated) (Chen and Tilton, 1991; Chen and Moore, 1982). Lead isotopic data indicate an average age of the crustal source materials of about 1,900 Ma.

The U-Pb zircon ages of most granitic samples (Fig. 6C) remain rather constant at 110 Ma from 15 km east to 60 km along the field trip route. East of 60 km, the rocks generally become younger and their age is about 85 Ma near Roads End and the Sierra Nevada crest (Chen, 1977; Chen and Tilton, 1978; Chen and Moore, 1982). The isotopic ages reveal a pattern of northwest-trending age belts of granitic plutons. This pattern was first discerned by Evernden and Kistler (1970) with K-Ar and Rb-Sr dating techniques and subsequently was documented in more detail with U-Pb zircon dating techniques by Chen (1977), Stern and others (1981), Chen and Tilton (1978), and Chen and Moore (1982).

BOYDEN CAVE ROOF PENDANT

Granitic rocks of the composite Sierra Nevada batholith are the most abundant bedrock materials of the region, but remnants of pre-batholithic metamorphosed sedimentary and volcanic rocks occur as isolated screens or roof pendants that separate individual masses of granitic rocks. One of the largest areas of metamorphic rocks in the region is the Boyden Cave roof pendant (Fig.

- PAGE 12 FOLLOWS -

7). The metamorphic rocks of the roof pendant comprise two major terranes--the Kings terrane to the west composed mainly of metasedimentary rocks, and the Goddard terrane to the east composed mainly of metavolcanic and metamorphosed hypabyssal rocks (Nokleberg, 1983; Moore and Nokleberg, 1992). A continuation of the roof pendant extends northwest across both forks of the Kings River to Spanish Mountain and Rodgers Ridge on the north canyon rim. Topical studies of the metamorphic rocks of the Boyden Cave roof pendant and of the Paleozoic and Mesozoic tectonics of the central and southern Sierra Nevada are subjects of reports by Moore and Dodge (1962), Jones and Moore (1973), Bateman and Clark (1974), Girty (1977a, b), Saleeby and others (1978), Nokleberg and Kistler (1980), Chen and Moore (1982), Nokleberg (1983), Girty (1985), Saleeby and others (1978), Schweickert and Lahren (1991, 1993), Kistler (1993), and Saleeby and Busby (1993).

Kings Terrane

The Kings terrane, first called the Kings sequence by Bateman and Clark (1974), was extended to include similar strata in the southern Sierra Nevada, including the Kaweah River, Yokohl Valley, Tule River, Kern Canyon, Isabella, and Tehachapi pendants by Saleeby and others (1978), and to include the metasedimentary rocks of the Strawberry mine roof pendant by Nokleberg (1983). The metasedimentary rocks, best exposed in the central and western parts of the Boyden Cave roof pendant, consist of highly deformed and regionally metamorphosed quartzite, arkose, marl, mudstone, calcareous sandstone, and limestone transformed into metaquartzite, meta-arkose, biotite-quartz schist, andalusite-biotite schist, calc-schist, and marble.

Exposures of the metasedimentary rocks of the Kings terrane are spectacular in the southern part of the Boyden Cave roof pendant along the South Fork of the Kings River (Fig. 8). In this area, the major metasedimentary rock types are marble, phyllite, biotite schist, calc-schist, and quartzite. Prominent ridges of marble underlie Windy Cliffs and form impressive exposures on Monarch Divide to the north. Metaquartzite forms the prominent ridge south of Horseshoe Bend. Sparse fossils, mainly crinoids and ammonites found near the mouth of Boulder Creek in the quartz and biotite mylonitic phyllite unit (Fig. 7), indicate an Early Jurassic age for that unit (Moore and Dodge, 1962; Jones and Moore, 1973; Saleeby and others, 1978). Available paleontologic evidence from other areas indicates a Late Triassic to Early Jurassic age for other parts of the Kings terrane to the north and south (Saleeby and others, 1978; Nokleberg, 1981, 1983; Saleeby and Busby, 1993) which is interpreted as a submarine-fan system containing craton-derived sands and, farther to the south, silicic volcanic tuffs and breccias (Saleeby and others, 1978; Saleeby and Busby, 1993). The base and top of the Kings terrane are either faulted or intruded by granitic plutons. Minimum stratigraphic thickness is estimated at a few thousand meters.

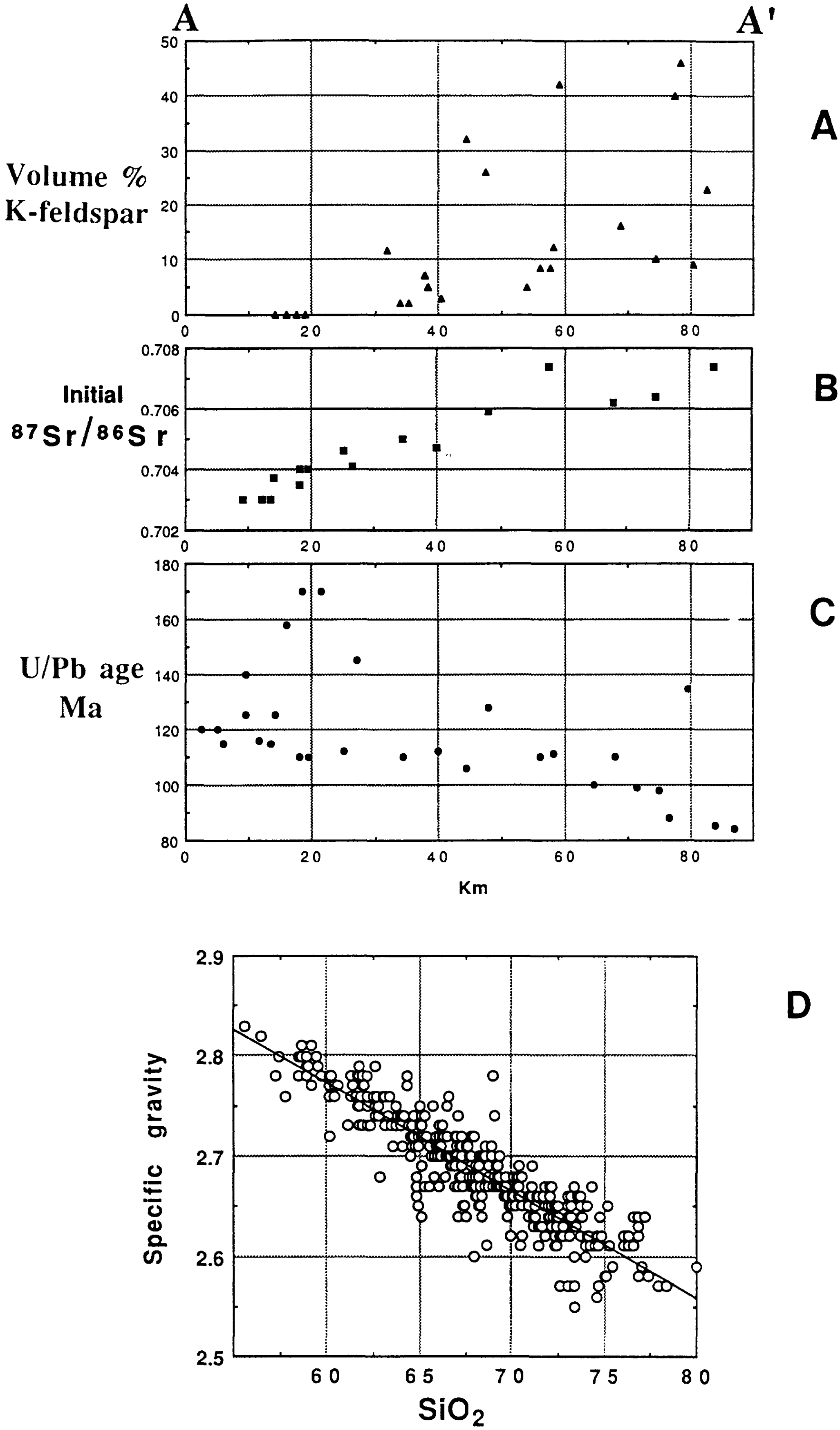

Figure 6. A. Analytical data on granitic rocks projected onto line A-A' of figure 1. A, volume percent of K-feldspar; **B**, initial strontium 87/86 ratios; **C**, U-Pb zircon ages of granitic and mafic rocks in millions of years; **D**. Relation between specific gravity and weight percent SiO_2 of granitic rocks.

Some units in the metasedimentary rocks of the Boyden Cave roof pendant are correlated with similar strata in the Death Valley region by Schweickert and Lahren (1991, 1993). However, these correlations are based on the interpretation that a continuous stratigraphic sequence, younging to the east, occurs in the metasedimentary rocks of the roof pendant. As discussed below, our detailed mapping and structural analysis indicates that the metasedimentary rocks in the roof pendant occur in a stack of folded thrust slices or nappes. In addition, the search for units correlative with the metasedimentary rocks should be along structural and tectonic strike to the southeast (Saleeby and others, 1978; Nokleberg, 1983; Saleeby and Busby, 1993), not across structural and tectonic strike to the east.

Structural Geology of Metasedimentary Rocks in the Boyden Cave Roof Pendant

The rocks of the Kings terrane present in the Boyden Cave roof pendant are intensely, multiply deformed and regionally metamorphosed (Girty, 1977a, b; Nokleberg and Kistler, 1980; Moore and Nokleberg, 1992). Multiple deformations are indicated by two generations of superposed minor and major structures, mainly refolded folds with axial-plane schistosity, and by local younger shear and mylonite zones. In addition, the margins of the Boyden Cave roof pendant have been recrystallized to hornfels by the heat of adjacent granitic plutons. Bedding has generally been transposed to a series of parallel tectonic lenses or foliations by penetrative deformation.

The older set of structures, termed *first-generation structures*, strikes east-northeast and dips moderately to steeply north. Minor first-generation structures are well exposed in the quartz and biotite mylonitic phyllite unit along the north side of the paved road east of Boyden Cave where minor folds and parallel axial plane schistosity strike northeast. The first-generation schistosity contains an upper greenschist- to lower amphibolite-facies mineral assemblage composed of varying proportions of clinopyroxene, garnet, hornblende, wollastonite, carbonate, and biotite (Girty, 1977a, b). Major first-generation structures consist of stacks of refolded thrust sheets or nappes and folded intervening faults that are best preserved in the cores of major antiforms and synforms (Fig. 7).

The younger set of structures, termed *second-generation structures*, strikes north-northwest and dips steeply to vertically. These structures consist of major and minor folds and faults, and schistosity that occur in both the metasedimentary rocks of the Kings terrane to the west, and in the metavolcanic rocks to the east. Associated minor folds generally plunge east-southeast, but locally plunge north-northwest. The second-generation structures are superposed on the first-generation structures (Girty, 1977a, b; Nokleberg and Kistler, 1980). The second-generation schistosity also contains an upper greenschist to amphibolite mineral assemblage. The diagnostic minerals are hornblende, clinopyroxene, wollastonite, garnet, and biotite. Local retrograde metamorphism to greenschist facies is indicated by replacement of hornblende, clinopyroxene, garnet, and biotite by

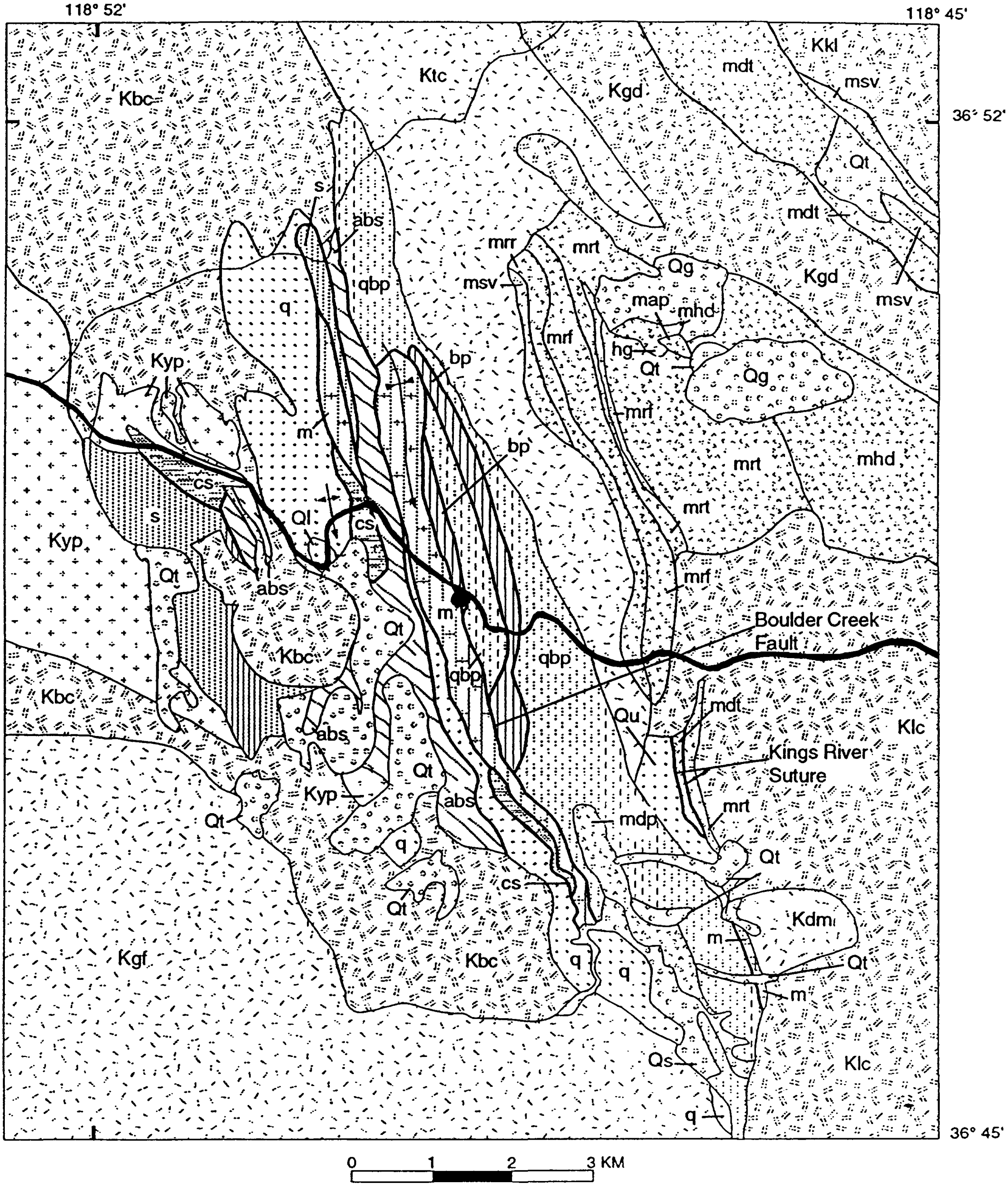

Figure 7. Generalized geologic map of the Boyden Cave roof pendant. Adapted from Moore and Nokleberg (1992). Heavy line crossing the roof pendant from west to east is the South Fork of the Kings River; Horseshoe Bend is the prominant convex north curve in the river. Closed circle along South Fork of Kings River indicates geologic stop at parking lot for Boyden Cave near bridge across river(Mile 71.3).

chlorite. Second-generation structures also include a widely distributed mylonitic schistosity that in places is concentrated in mylonite zones as wide as a few centimeters, particularly in the quartz and biotite mylonitic phyllite unit, and in the granite of Grand Dike. Local and regional comparisons of major and minor structures indicate that the first-generation structures formed in a regional deformation during the Early or Middle Jurassic, and that the second-generation structures formed during the Late Jurassic through the mid-Cretaceous (Moore and Nokleberg, 1992).

Boulder Creek Fault

The metasedimentary rocks of the Boyden Cave roof pendant comprise two distinct sequences of rocks that are interpreted to be juxtaposed by large-scale movement on a shear zone or major fault, named the Boulder Creek fault (Fig. 7). This fault occurs as a tectonic breccia zone at the western margin of the quartz and biotite mylonitic phyllite unit, adjacent to the thick marble unit to the west (Nokleberg, 1983; Moore and Nokleberg, 1992; Kistler, 1993). Evidence for this fault includes: (1) Highly-deformed rocks in the shear zone display considerable shearing flattening, granulization, and small scale folding along N. 20-40° W. trends. Locally, shearing and granulization produced mylonites (Girty, 1977a, b; Moore and Nokleberg, 1992); (2) Map units in the quartz and biotite mylonitic phyllite unit strike obliquely into the marble unit to the west, south of the Kings River (Fig. 7); (3) An intense mylonitic schistosity occurs within the tectonic breccia. This schistosity is part of the second generation structures and parallels the contact with the marble unit to the west; and (4) the tectonic breccia contains abundant fragments that are regionally deformed and metamorphosed with a strong, first-generation, east-northeast-striking schistosity that parallels axial planes of minor folds in the fragments. Superposed on these fragments and their older penetrative structures is the younger, north-northwest-trending, second generation schistosity that parallels the fault between the marble unit to the west and the quartz and biotite mylonitic phyllite unit to the east. The second-generation structures associated with the Boulder Creek fault were clearly superposed on previously metamorphosed and deformed metasedimentary rocks and were not formed during soft-sediment deformation. As a second-generation structure, the Boulder Creek fault is interpreted as forming as a companion structure to the Kings River suture, discussed below.

Goddard Terrane

Metavolcanic and metamorphosed hypabyssal intrusive rocks form the northeastern third of the Boyden Cave roof pendant (Fig. 7). These rocks consist mainly of metarhyolite and metadacite tuffs and flows, as well as a distinctive metamorphosed hypersthene dacite intrusion. Nokleberg (1983) assigned the metavolcanic rocks of the Boyden Cave roof pendant to the Jurassic Goddard terrane. New Rb-Sr whole rock and U-Pb zircon isotopic dating of the metavolcanic and

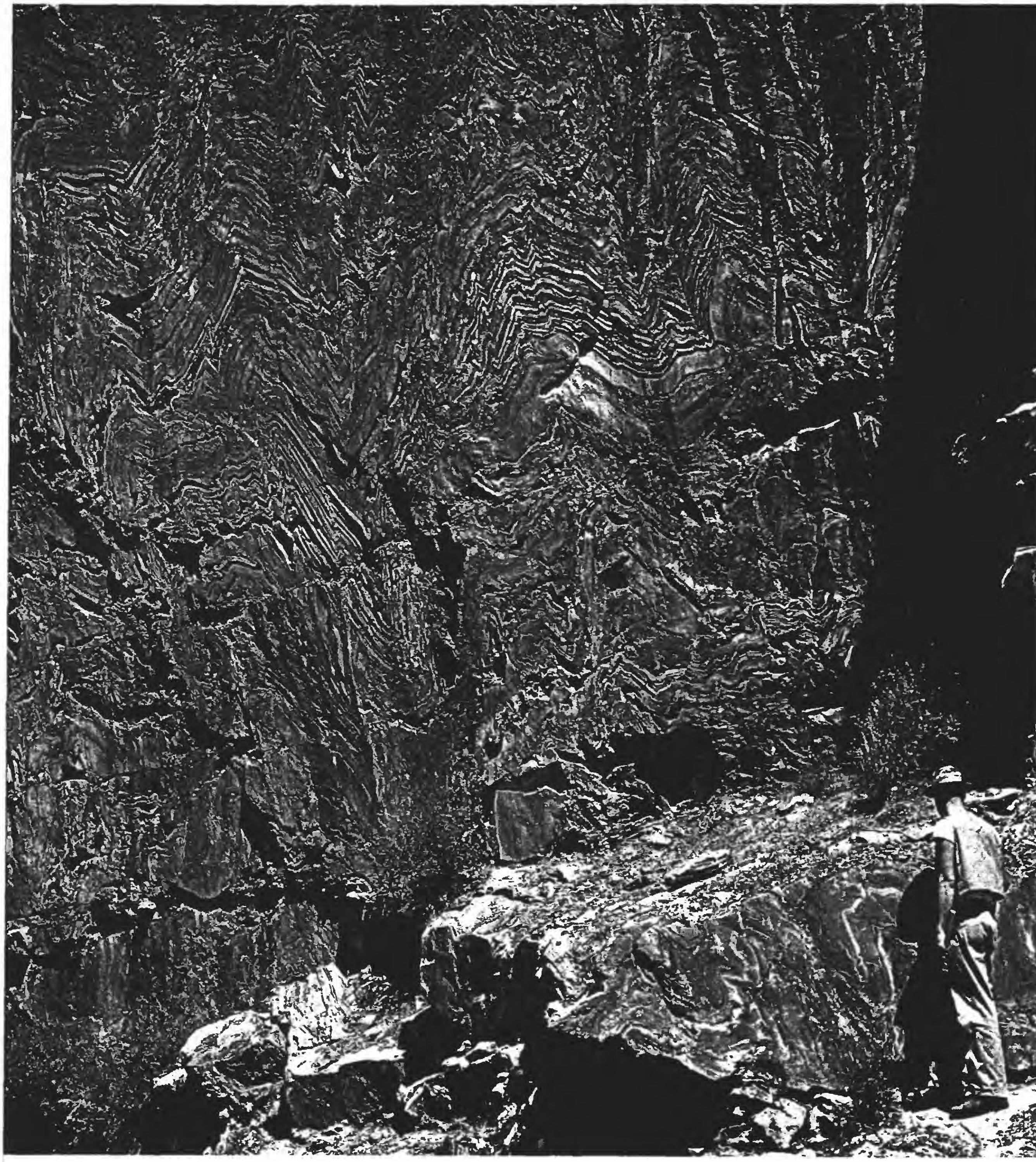

Figure 8. Chevron-folded metasiltstone in Kings Canyon slightly east of Boyden Cave bridge on north side of highway at Mile 71.9.

metaintrusive rocks yield ages of 102-105 Ma or mid-Cretaceous (Saleeby and others, 1990). Thus, the metavolcanic rocks of the Boyden Cave roof pendant are younger than the Goddard terrane as originally defined. Nevertheless, the metavolcanic rocks of the Boyden Cave roof pendant form the easternmost limit of metamorphic rocks of the Kings terrane at this latitude and still appear to represent a major terrane boundary. We, therefore, continue to include the metavolcanic rocksof the Boyden Cave roof pendant within the Goddard terrane. This part of the Goddard terrane is interpreted as a fault-bounded fragment of the upper part of a mid-Cretaceous Andean-type arc that formed on the Jurassic to mid-Cretaceous margin of western North America (Nokleberg, 1983). Intrusive into west-dipping metavolcanic rocks are coeval, locally metamorphosed granitic rocks, such as the granodiorite of Tombstone Creek and the granite of Grand Dike, that have zircon U-Pb intrusive ages of 99 to 103 Ma (Saleeby and others, 1990). The granodiorite of Tombstone Creek also intrudes the metasedimentary rocks of the Kings terrane to the west (Fig.7).

Structural Geology of Metavolcanic Rocks in the Boyden Cave Roof Pendant

The metamorphosed volcanic, hypabyssal, and granitic rocks in the northeastern part of the Boyden Cave roof pendant contain only the second-generation, north-northwest-trending structures. Absence of first-generation structures in the metamorphosed volcanic and shallow intrusive rocks of the Goddard terrane indicates that these rocks formed after the deformation that produced the first-generation structures in the Kings terrane to the west, or else that the terrane was tectonically transported to its present position after formation of first-generation structures in the Kings terrane.

Second-generation structures include a widely distributed mylonitic schistosity that in places is concentrated in mylonite zones as wide as a few centimeters. Such zones occur in mid-Cretaceous metavolcanic rocks and in the mid-Cretaceous granitic rocks bordering the Boyden Cave roof pendant, such as the granite of Grand Dike, indicating that granitic intrusion occurred during, or prior to, regional deformation and metamorphism. The second-generation schistosity contains an upper greenschist to amphibolite mineral assemblage with hornblende, clinopyroxene, garnet, and biotite. Local retrograde metamorphism to greenschist facies is indicated by partial replacement of hornblende, garnet, and biotite by chlorite. As discussed below, the second-generation structures are interpreted to have formed during the mid-Cretaceous, immediately after extrusion and deposition of the mid-Cretaceous metavolcanic rocks and during intrusion of the mid-Cretaceous granitic rocks.

Kings River Suture

The Kings and Goddard terranes are separated by a major pre-granitic fault named the Kings River suture (Nokleberg, 1983; Moore and Nokleberg, 1992) (Fig. 7). The evidence for the fault consists of narrow slivers of fault-bounded and deformed metasedimentary and metavolcanic rocks that strike obliquely into one another on the east-central side of the Boyden Cave roof pendant, south of the South Fork of the Kings River and east of upper Boulder Creek. Intense shears and mylonite zones, part of the second generation structures, also occur in the eastern part of the quartz and biotite mylonitic phyllite unit near the fault. The parallelism of the Kings River suture to the second-generation structures indicates that the suture probably formed along with these structures. The occurrence of second-generation structures in the mid-Cretaceous metamorphosed volcanic and hypabyssal rocks of the Goddard terrane, and in adjacent mid-Cretaceous granitic rocks indicates that second-generation structures, along with major movement on the Kings River suture, probably formed in the mid-Cretaceous during granitic intrusion, regional deformation, and faulting. The Kings River suture or fault is interpreted as the Inter-Batholithic Break 2 by Kistler (1993) and as the only exposed trace of the Mojave-Snow Lake fault by Schweickert and Lahren (1991, 1993).

The occurrence of Proterozoic zircons in the quartzite unit of the Boyden Cave roof pendant (Chen, 1977; Chen and Moore, 1982) provides additional support for tectonic transport of the metasedimentary rocks into their present structural position west of the metavolcanic rocks. The zircons probably had a cratonal source, yet no nearby craton exists, except along structural strike to the southeast. Therefore, the metasedimentary rocks of the roof pendant are interpreted by most workers (Saleeby and others, 1978; Nokleberg, 1983; Saleeby and Busby, 1993; Schweickert and Lahren, 1991, 1993) as having been tectonically transported into their present position by, in part, strike-slip movement on major faults bounding the pendant, and occurring within the pendant from a source region to the southeast in southeastern California. Because Proterozoic inherited or xenocrystic zircons are also present in the metavolcanic rocks of the Goddard terrane (Tobisch and others, 1986; Saleeby and others, 1990), it is likely that the unexposed basement of the Goddard terrane was also tectonically transported to its present location. The tectonic migration and accretion of the Kings terrane against the mid-Cretaceous meta-igneous rocks of the Goddard terrane to the east is interpreted to have occurred during, or just after the mid-Cretaceous igneous activity.

STATE ROUTE 198 AND GENERALS HIGHWAY

This part of the field trip begins in the San Joaquin Valley in eastern Visalia on California Route 198 at Country Center Drive. The road goes east into the Sierra Nevada foothills, past Lake Kaweah and the town of Three Rivers and enters Sequoia National Park at the Ash Mountain

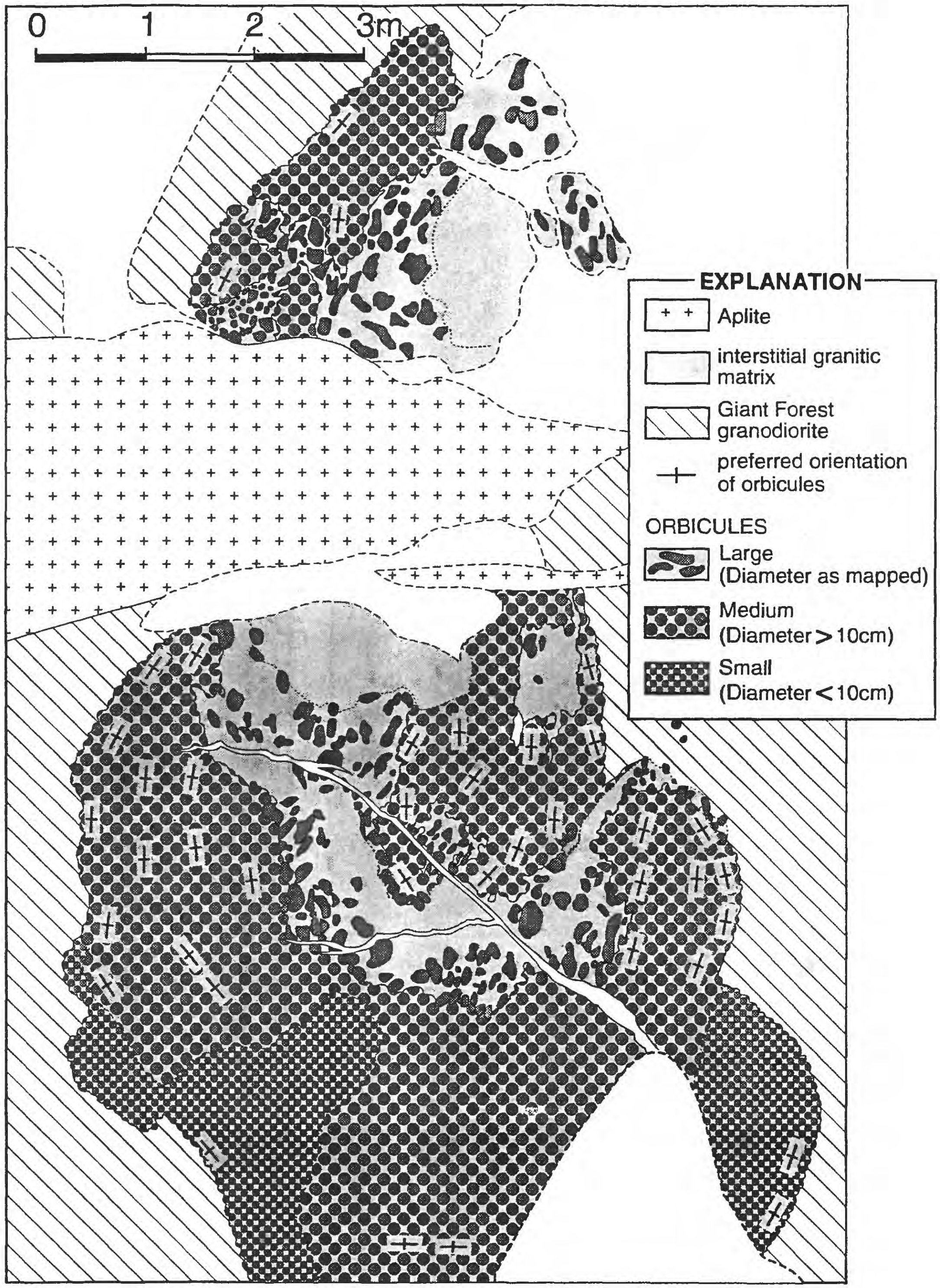

Figure 9. Orbicular pipe at Little Baldy Saddle just west of Generals Highway cutting the Giant Forest Granodiorite. Note concentric arrangement of orbicles and tendency toward larger orbicles occurring in central part of pipe. Unpublished geologic mapping by Kazuya Kubo (1986). North is to the top.

Entrance 36.5 miles from Visalia. From the park entrance the road, now designated the Generals Highway, continues up the canyon of the Middle Fork of the Kaweah River, then generally northwest up steep switchbacks on the north wall of the canyon to Giant Forest (campground, store, gas, food). Continuing northwest, the road passes the park campground and store at Lodgepole on the Marble Fork of the Kaweah River and continues across the drainage of the North Fork of the Kaweah River to join with highway 180 near Grant Grove for a total of 81 miles from Visalia.

The first half of the route traverses the Kings-Kaweah ophiolite belt, then across dark granodiorite and associated mafic plutonic rocks of the western Sierra Nevada batholith. Near Lake Kaweah and continuing to Three Rivers two major roof pendants of metasedimentary rocks are crossed. The second half traverses the outer part of the exposure area of the 99-Ma Giant Forest Granodiorite.

MINERAL KING ROAD

The Mineral King Road extends 25 miles east from highway 198 near Hammond east of the town of Three Rivers to the mountain hamlet of Mineral King at an elevation of 7600 feet. The narrow road is steep and curvy, and is closed in the winter.

Most of the road is in dark granodiorite cut by large, irregularly-shaped, light-colored sills and apophyses of the younger granite of Case Mountain.

ACKNOWLEDGMENTS

This geologic guide is expanded and updated from an earlier guidebook which included only highway 180 (Moore and others, 1979), and we hope that we have suitably credited our two previous co-authors Jason Saleeby and Gary Girty for their many contributions both before and after the writing of that guidebook. In addition, the authors appreciate the many discussions of the bedrock geology and tectonics of the central Sierra Nevada with P.C. Bateman, J.H. Chen, F.C.W. Dodge, G.H. Girty, C.A. Hopson, D.L. Jones, R.W. Kistler, H.W. Oliver, J.B. Saleeby, and O.T. Tobisch.

ROAD LOGS

LOG OF STATE ROUTE 180 FROM FRESNO TO ROADS END AT CEDAR GROVE

Road signs are designated FRE180

Miles	Signs	Comments
0.0		Intersection of Kings Canyon Highway (California State Highway 180) and Clovis Boulevard, east Fresno, California, at Sunnyside Square shopping center. Check and set your odometer here.
0.5	64.0	
12.6	76.0	
12.9		Kings River. *Historical note.* A group of Spanish explorers camped near here on January 6 (Day of Epiphany), 1806. To commemorate the day, they named the River "El rio de los Santos Reyes" or the river of the Holy Kings, from which is derived Kings River.
13.6	77.0	
16.2		The western margin of the Sierra Nevada batholith includes Early Cretaceous intrusions of gabbro, norite, diorite, tonalite and granodiorite. U-Pb zircon ages on norite and more siliceous compositions and K-Ar hornblende ages on gabbros range between 110 and 126 Ma (Sharp 1988). Campbell Mountain and Jesse Morrow Mountains to the south and north, respectively, consist primarily of olivine-hornblende gabbro and hornblende norite cumulates. Note the subdued landslide topography on the north side of Campbell Mountain.
19.8	83.0	
20.0	**Stop 1**	Large exfoliated boulders. Isolated outcrop of dark-colored quartz diorite with characteristic large poikilitic biotite crystals. Mode: Pl - 52.4; Kf - 0; Q - 22.8; Mf - 24.8. Uranium-lead zircon age, 114 Ma (Chen and Moore, 1982).
21.1		Dark quartz diorite. Mode: Pl - 48.9, Kf - 0; Q - 22.2; Mf - 28.9.
22.1		Dark quartz diorite. Mode: Pl - 59.2; Kf - 0; Q - 19.2; Mf - 21.6.
21.7	85.0	
22.2		1000-foot elevation.
25.7	89.0	
26.8		Squaw Valley store

28.2 Fine-grained, light-colored, migmatitic quartz diorite. Mode: Pl - 57.4; Kf - 1.0; Q - 33.5; Mf - 8.1.

29.0 Bridge over Mill Creek

29.8 93.0

30.1 Stop 2 Large gravel turnout. Walk back (west) about 80 m to see blocks of pillow lava on north side of highway that have rolled down from Bald Mountain to the north. They are part of the Permian and Triassic Kings River ophiolite that consists of several large blocks composed of peridotite, gabbro, mafic dikes, pillow lava, rare chert, and zones of serpentinite-matrix melange all metamorphosed to hornblende hornfels facies (Saleeby, 1978). The rocks are recrystallized to granoblastic sodic plagioclase and hornblende, and are intruded by Jurassic and Cretaceous plutons. The southernmost Bald Mountain slab consists of well-preserved mafic dikes at its northern end which grade into well-preserved pillow lavas to the south. Excellent exposures of pillow lava can be observed along Mill Creek about 1 km north of the Kings Canyon Highway.

The Kings Canyon Highway crosses over the southern end of a Jurassic plutonic complex in the vicinity of Bald Mountain. This complex consists of clinopyroxenite, gabbro, diorite, and quartz diorite with U-Pb zircon ages of both Middle and Late Jurassic (Chen, 1977; Chen and Tilton, 1978; Chen and Moore, 1982: Sharp, 1988). This plutonic complex intrudes the Kings River ophiolite along a 20 km length and is cut by younger Cretaceous plutonic rocks. The Jurassic plutonic rocks show a complex deformational history in contrast to the younger, relatively undeformed granitic rocks (Nokleberg and Kistler, 1980; Sharp, 1988). The observation that the Jurassic plutonic complex crosscuts a family of Triassic and possibly younger structures of the Kings River ophiolite, and that deformation occurred during the emplacement of the Jurassic complex leads to the conclusion that they are syntectonic intrusions. In the area south of Bald Mountain, Jurassic diorite can be observed with a variety of penetrative deformational features, including flattened and sheared igneous textures, and schistosities along which greenschist- to amphibolite-facies metamorphism has occurred. Some of these deformed and metamorphosed plutonic rocks are well exposed in roadcuts adjacent to the pillow lavas.

30.9 94.0

31.7 Clingans Junction

32.5 2000-feet elevation

32.9 96.0

33.0 Dark granodiorite. Mode: Pl - 47.5; Kf - 11.7; Q - 25.3; Mf - 15.5.

34.4 Quartz diorite. Mode: Pl 55.2; Kf - 2.2; Q - 27.0; Mf -15.6

35.4 Quartz diorite. Mode: Pl - 53.7; Kf - 2.3; Q - 29.3; Mf - 14.7. U-Pb zircon age of 111 Ma (Chen and Moore, 1982).

36.0 3000-feet elevation.

38.3 Granodiorite. Mode: Pl - 50.2; Kf - 7.2; Q - 30.4; Mf - 12.2. The irregular increase of K-feldspar in the granitic rocks and the eastward predominance of granodiorite over quartz diorite or tonalite fixes the quartz diorite line of Moore (1959) at approximately this position.

39.5 Quartz diorite. Mode: Pl - 49.2; Kf - 5.1; Q - 30.9; Mf - 14.8.

39.8 4000-feet elevation.

40.5 Snowline Lodge. Quartz diorite Mode: Pl - 54.0; Kf - 3.4; Q - 22.8; Mf - 19.8. U-Pb zircon age of 112 Ma (Chen and Moore, 1982).

41.2 104.0

42.1 Stop 3 Large paved turnout. Walk west on highway 50 m to late Tertiary leucite phonolite in roadcut. This is one of many small lava flow remnants and associated vents of potassic basaltic rocks scattered about on the west slope of the Sierra Nevada (Moore and Dodge, 1980). Most of the volcanic remnants differ slightly in composition from one another and represent individual, small eruptive events related to the present topography. This lava contains phenocrysts of olivine, phlogopite, and augite and groundmass minerals of augite, biotite, leucite, K-feldspar, apatite, opaques, and pseudobrookite. The lava contains: SiO_2-49.3 wt. % , MgO-11.5 %, and K_2O-5.5 %. About 2 km south in Milk Ranch Canyon, a second late Cenozoic flow remnant of trachybasalt covers Stoney Flat. This lava contains phenocrysts of olivine and clinopyroxene as well as groundmass minerals of plagioclase, clinopyroxene, opaques, apatite, and minor biotite, and contains SiO_2- 55 %. The whole-rock K-Ar age of the lava at Stoney Flat is 3.4 Ma.

43.9 5000 ft. elevation

44.2 107.0

44.8 Stop 4 Large paved turnout where a biotite-muscovite-garnet-sillimanite alaskite crops out east of a thin screen of metasedimentary rocks. Mode: Pl - 36.3; Kf - 31.8; Q - 31.0; Mf - 0.6; Garnet - 0.3. The rocks contain: SiO_2-75.5 wt. %, MgO-0.06 %, Na_2O-4.5 %, and K_2O-3.9 %. The garnet-bearing facies occurs only in a marginal zone about 0.5 km thick within the pluton which is ~12 km long. The marginal alaskite has a high $^{87}Rb/^{86}Sr$ ratio of 42; a high $^{87}Sr/^{86}Sr$

value of 0.7673; a very small percentage of zircon with a low $^{206}Pb/^{204}Pb$ value (or a high content of common Pb); and shows a prominent negative Eu anomaly in a rare-earth element abundance plot. This rock yields a concordant U-Pb zircon age of 106 Ma (Chen and Moore, 1982).

Historical note During the summer of 1864, a party of the Whitney Survey made the first scientific expedition into the High Sierra Nevada in the drainages of the Kings, Kern, and San Joaquin Rivers adjacent to the region covered by this field trip. The party entered the mountains from Visalia, traveled through Millwood, 2 km northeast of this locality, and entered the giant sequoia trees at General Grant Grove (Farquhar, 1965).

45.3 108.0

47.3 110.0 6000-feet elevation

48.2 111.0

48.3 Park Entrance Station. Note that sampling and **collecting rocks is not allowed in the Park** without a collecting permit. Please contact the Superintendent of the Park in writing for a collecting permit.

48.9 **Stop 5** Big Stump Picnic Area; restrooms. Light-colored granite. Mode: Pl - 37.1; Kf - 26.1; Q - 31.4; Mf - 5.4.

49.9 The Wye. Intersection of highway 180 with the Generals Highway to Giant Forest and other parts of Sequoia National Park

51.3 Visitors' Center, Grant Grove. *Historical note.* The 1864 Whitney Survey party traveled from Grant Grove through Big Meadows, 10 km east of here, and climbed a peak on the Kings-Kaweah divide which they named Mount Silliman. From this point, they descended Sugarloaf Creek to Roaring River and ascended a high peak on the Great Western Divide which they named Mount Brewer after the party chief. From this vantage point, several high peaks on the main Sierra Nevada crest about 14 km to the east were mapped and named, including Mounts Whitney, Williamson, and Tyndall. King and Cotter then made a 5-day side trip over the Kings-Kern divide where they climbed Mount Tyndall on the main Sierra Nevada crest. After rejoining the main party near Mount Brewer, the group returned to Big Meadow and worked down the great canyon of the South Fork of the Kings River to near the present site of Cedar Grove (Farquhar, 1965).

52.6 112.09 Park boundary

54.3 Cherry Gap, 6897-feet elevation.

54.5 114.0

57.3 Hume Lake turnoff; 3 miles to lake. A small area of Tertiary basalt occurs near this turnoff. Two miles east on the Hume Lake road, and on the upper road to Camp Seven, one can obtain excellent views of Mount Clarence King and Tehipite Dome.

58.6 Dark facies of the Giant Forest Granodiorite . Mode: Pl - 49.8; Kf - 4.7; Q - 21.1; Mf - 24.4.

58.6 118.0 Views into Kings Canyon

58.8 **Stop 6** Olivine basalt lava flow in stream channel. Basalt rests on about 2 m of sediment composed of granitic sand, basaltic ash and lapilli, that in turn rest on weathered granodiorite. The basalt has phenocrysts of olivine, clinopyroxene, and plagioclase and groundmass minerals of olivine, clinopyroxene, plagioclase, sanidine, apatite, opaques, and rare biotite. The rock contains 47.2 percent SiO_2, 10.9 percent MgO, 2.45 percent Na_20, and 1.2 percent K_20. A basalt cropping out about 3 km to the south near Hume lake, is much more potassic with phenocrysts of biotite and clinopyroxene. The basalt near Hume Lake contains 51 percent SiO_2, with as much as 5.7 percent K_20. To the east from this point can be seen the Middle Palisade and University Peak on the main Sierra Nevada crest and Mounts Gardiner and Cotter on King Spur. Mount Clarence King is obscured by the Monarch Divide.

59.6 119.0

62.0 **Stop 7** Junction View. From here, one can look into both the Middle and South Forks of the Kings River which are Yosemite-like canyons separated by the Monarch Divide. Points visible from north to south (left to right) are: Deer Ridge, Spanish Mountain (10,051 ft), Tombstone Ridge, Tehipite Valley, Monarch Divide, Wren Peak (9,450 ft.), and University Peak (13,632 ft) on the main Sierra Crest to the southeast. The canyon below the junction is one of the deepest in the United States dropping 7890 feet from Spanish Mountain (10,051 ft), on the north, to the river. Much of the north wall of the canyon is carved in the granodiorite of Brush Canyon, recently dated by Ar-Ar isotopic analysis at about 90 Ma (Brent Turrin, written commun., 1993).

64.1 123.55 Bridge over Ten Mile Creek

64.2 Bartons Resort. Mafic granodiorite and the quartz diorite of Yucca Point (Moore and Marks, 1972). Mode: Pl - 48.4; Kf - 8.2; Q - 20.2; Mf - 23.2. The quartz diorite of Yucca Point is surrounded and overlain by the younger granodiorite of Brush Canyon in Kings Canyon (Fig. 4).

64.5 Mafic granodiorite and the quartz diorite of Yucca Point. Mode Pl - 43.2; Kf - 8.0; Q- 27.3; Mf - 21.5.

65.5 Mafic granodiorite and the quartz diorite of Yucca Point. Mode: Pl - 43.5; Kf - 11.1; Q - 27.3; Mf - 18.1. U-Pb zircon age of 110 Ma (Chen and Moore, 1982).

65.6 125.0

66.3 Fine-grained porphyritic granodiorite dike apparently related to the granodiorite of Brush Canyon (Moore and Nokleberg, 1992). Sub-horizontal dikes of this rock are visible across the canyon cutting the quartz diorite of Yucca Point on Monarch Divide. This unit contains 70-74 wt. % SiO_2, and here on the highway the mineral content is: Pl - 28.4; Kf - 41.1; Q - 29.0, Mf 1.5. This dike is among the youngest dated granitic rocks with an U-Pb zircon age of 86 Ma (Chen and Moore, 1982). The road passes through only small offshoots of the Brush Canyon unit, but across the river the pluton is more than 12 km wide and much of the canyon wall is carved in it. The main mass of the granodiorite of Brush Canyon has yielded Ar-Ar ages of about 90 Ma (B. Turrin, written comm., 1992)

67.2 This part of the highway obliquely cuts the contacts between the western units of metasedimentary rocks in the Boyden Cave roof pendant, the biotite-feldspar-quartz schist, the calc-silicate schist, and the andalusite-biotite schist units (Fig. 6). Local abundant north-northwest-striking, second-generation isoclinal folds with parallel schistosity also occur, along with locally abundant dikes and small masses of the granodiorite of Brush Canyon and garnet-bearing aplite-pegmatite dikes.

68.5 128.0

68.6 Redwood Creek with lacy, high waterfall in metamorphic rocks to south of highway.

69.3 Prisoner Camp Turnout. The anomalous flat and knob toward the river are produced by a landslide originating on the steep slope east of the highway. The Prisoner Camp was the area where convicts were housed during construction of this part of the Kings Canyon Highway during the 1930's.

Stop 8

69.5 129.0 Horseshoe Bend. This stop is near the central part of the well-bedded, well-sorted feldspathic quartzite unit of the Boyden Cave roof pendent (Fig. 6). Apparent cross-bedding and some graded bedding occurs in strata that are nearly vertical. The dominant lithology in the western block is a band of massive gray to white quartzite, with a maximum structural thickness of approximately 1,100 m. Petrographic studies of the quartzites show that quartz generally comprises more than 90 % of the rock, with as much as 15 % orthoclase (Jones and Moore, 1973; Girty, 1977a, 1977b, 1985). Field measurements indicate that the dominant top direction of the quartzite unit is toward the west (Moore and Marks, 1972), but care must be taken to separate intersecting schistosities from cross bedding in this unit (Saleeby and others, 1978; Girty, 1985).

The quartz-rich metasandstones in the western part of the Boyden Cave roof pendant are variously interpreted as forming in a shallow-water, tidal- and wave-influenced environment (Girty, 1985) or as the remnants of a large channel in the Kings sequence fan system (Saleeby and others, 1978; Saleeby and Busby, 1993) with the massive size of the unit along with local grading, cross-bedding and amalgamation being typical of young, well-documented channel deposits. The provenance most likely included Precambrian felsic plutonic and metamorphic rocks (Girty, 1985). Clastic, hyacinth-colored zircons occur in the feldspathic quartzite unit and yield discordant U-Pb ages of: 1511 Ma for Pb-206/U-238; 1727 Ma for Pb-207/U-235; and 2000 Ma for Pb-207/Pb-206. The ultimate source of these sediments, as determined from these age data for clastic zircons, was presumably a Precambrian craton (Chen, 1977; Chen and Moore, 1982).

Looking northwest from the turnout at Horseshoe Bend, the various units of the western part of the Boyden Cave roof pendant are spectacularly exposed on the southern slopes of Monarch Divide (Fig. 6). One prominent contact is between the quartzite unit on the west and a narrow interval of blue-gray marble and calc-silicate schist that occurs east of the quartzite unit. To the east of the calc-silicate schist on the southern slope of Monarch Divide, are the units of dark-brown andalusite hornfelsic schist, and farther east, blue-gray marble. Still farther east are exposures of the quartz and biotite mylonitic phyllite unit (Fig. 6). Along the south slope of Monarch Divide, the calc-silicate schist pinches out just before it reaches the South Fork of the Kings River in the canyon below.

Adjacent to the granodiorite of Brush Canyon, just west of Redwood Creek, the calc-schist is metasomatized to a chocolate-brown garnet skarn.

Two generations of structures occur in the metasedimentary rocks of the Boyden Cave roof pendant. First-generation structures in the metasedimentary rocks in the western part of the pendant are generally obscured by the intense second deformation which resulted in north-northwest-trending faults and major and minor nearly isoclinal foldsaxial plane schistosity that dominate the structural grain of the roof pendant. Where observed in outcrop, the first deformation structures form a series of dismembered quartzite beds that strike roughly east-west, as well as sparse east-west striking folds. Second-generation fold axes plunge moderately south-southeast, with a few plunging north-northwest, because of superposition of second-generation folds on the limbs of the east-west striking first-generation folds. These relations are best shown in the outcrops south of the turnout at Horseshoe Bend, where both the second-generation schistosity and the cross-beds occur. The schistosity trends N. 15° W. and dips 80° east. In the outcrops on the north-facing slope just west of Prisoner Canyon turnoff and east of Redwood Creek, dismembered quartzite beds strike generally east-west and are crosscut by the second-generation schistosity. These dismembered beds are probably first-generation fold limbs.

Major faults present between the various units of metasedimentary rocks in the Boyden Cave roof pendant (Fig. 6) are indicated by: (1) narrow lenses of lithologies that locally pinch out along strike; (2) an intense, north-northwest-trending schistosity and parallel-compositional layering; both structures occur parallel to enclosing contacts; (3) local acute striking of compositional layering in one unit into that of an adjacent unit; and, (4) sharp contrasts in metamorphic texture, grain size, and grade between units. These major faults are folded around south-southeast-plunging antiforms and synforms. This relation indicates that the major faults present between units are first-generation structures that were refolded during the second generation deformation.

In this area, the map pattern of the quartzite, calc-silicate schist, and andalusite-biotite schist and intervening faulted contacts defines a south-southeast-plunging antiform along the ridge extending south from Horseshoe Bend (Fig. 6). The quartzite unit occurs in the core of the plunging antiform, and is successively structurally overlain to the south-southeast by the calc-silicate schist unit and the andalusite-biotite schist unit (Fig. 6). This antiform is part of the second-generation structures, described below. North of the crest of

Monarch Divide, the marble unit occurs in the core of a major, south-southeast-plunging, isoclinal synform that is a companion second-generation structure to the antiform described above (Fig. 6). In the core of the synform, the marble unit is structurally underlain by the quartz and biotite mylonitic phyllite unit (Fig. 6). The south-southeast-plunging synform is defined by (Fig. 6): (1) a folded contact between the marble unit and the quartz and biotite mylonitic phyllite units; (2) folded compositional layering; (3) folded schistosity; and (4) the folded Boulder Creek fault. If bedding tops are predominantly to the east in the quartz and biotite mylonitic phyllite unit, as described below, then the quartz and biotite mylonitic phyllite unit is structurally inverted underneath the synformal termination of the marble unit north of Monarch Divide, and the major second-generation synform in this area formed on the inverted limb of a first-generation nappe.

Stop 9

70.7 130.13 Bridge over the South Fork of the Kings River. At the Boyden Cave parking area, west of the bridge, the most resistant unit developed in the metamorphic rocks is nearly vertically layered, massive, blue-gray marble with a maximum structural thickness of about 600 m. However, as mentioned above, the marble unit occupies the central part of a synform, and this unit thickness represents the doubling of a former structural layer. To the southeast, the marble unit is tectonically thinned and pinches out in the upper part of Boulder Creek (Fig. 6). Local, small- to moderate-sized caves lie within the marble unit, as at Boyden Cave. At river level, water entering small cave openings in marble are visible on the south flank of Monarch Divide. Efforts to extract conodonts from this and other marble units in the Boyden Cave roof pendant were unsuccessful.

East of the marble unit is a unit of quartz and biotite mylonitic phyllite (Moore and Nokleberg, 1992) (Fig. 6) that contains a zone of tectonic breccia along its western margin. The westernmost exposures of this unit, previously called the *chaotic unit* (Saleeby and others, 1978; Girty, 1985; Saleeby and Busby, 1993) crop out a few meters east of the bridge over the South Fork of the Kings River. Looking towards the northeast from the concession stand at the parking area, blocks of marble and quartzite are visible that are lithologically similar to the marble and quartzite units to the west. The unit also contains irregular augen of calc-schist in a very fine-grained, schistose, pelitic matrix. East of the highway bridge, and to the south along the trail to Boulder Creek, the unit contains pebble- to boulder-sized augen of quartzite and calc-silicate schist in a highly schistose, pelitic matrix. The long dimensions of the augen are oriented parallel to the north-northwest-trending, second-generation schistosity, most evident in the pelitic matrix, that trends N. 15° W. and dips 80° east. Second-generation fold axes plunge moderately north-northwest or south-southeast, parallel to schistosity.

Early Jurassic fossils have been recovered from the quartz and biotite mylonitic phyllite unit along the trail along the lower reaches of Boulder Creek (Moore and Dodge, 1962; Jones and Moore, 1973), including an Early Jurassic ammonite found in an angular, out-of-place fragment of slate from the matrix, below the trail to Boyden Cave, about 25 m east of the marble unit of the Boyden Cave roof pendant (Saleeby and others, 1978). Despite complex multiple episodes of Mesozoic regional deformation of the southern Sierra Nevada region, strain was inhomogeneous enough to have provided pockets where delicate features such as fossils were preserved.

The quartz and biotite mylonitic phyllite unit, along its western boundary, is a tectonic breccia consisting of small to large, angular to flattened augen composed of quartz-biotite phyllite, quartzite, calc-silicate schist, and sparse marble, surrounded by a fine-grained, dark, foliated, pelitic phyllite matrix. Second-generation axial surfaces and schistosity occur within the larger and smaller blocks and fragments and are aligned parallel to the surrounding matrix schistosity, and crosscut a set of first-generation folds and schistosity that are preserved in some of the larger blocks, particularly north of the river and east of the bridge at Mile 71.9. The second-generation schistosity in the matrix generally conforms to the outlines of the blocks, but locally abuts or passes through the blocks. Granulation and shearing accompanied the second deformation, as indicated by occasional crush trails and finely comminuted, discontinuous lenticular to planar bands of isotropic material. Minute, acicular biotite is commonly aligned in parallel planes in the matrix. Slabs cut through large blocks of the tectonic breccia show angular to flattened fragments of folded quartz and biotite phyllite that contain a regional-grade metamorphic fabric, locally folded, now oriented at random angles, and upon which is superposed the intense, north-northwest-trending, second-generation schistosity.

These structures apparently formed during regional faulting with locally abundant fluids in a shear zone, thereby resulting in local formation of angular tectonic fragments. The shear zone apparently formed during juxtaposition of the metasedimentary rocks of the western part of the Boyden Cave roof pendant against the quartz and biotite mylonitic phyllite unit of the central part of the roof pendant.

An alternative interpretation for the tectonic breccia zone at the western margin of the quartz and biotite mylonitic phyllite unit is that the breccia is a large olistostrome or submarine slide deposit that was subsequently metamorphosed (Saleeby and others, 1978; Schweickert and Lahren, 1991; Saleeby and Busby, 1993; Girty, 1985). However, the occurrence of an older, amphibolite-facies, regional metamorphic fabric in the tectonic fragments and blocks in the shear zone, upon which is superposed the intense, north-northwest-trending, second-generation schistosity is strong evidence for the so-called *chaotic* features not having formed during submarine sliding, but having formed instead during the second-generation regional metamorphism and deformation.

71.3 **BEWARE OF DANGEROUS CANYON HIGHWAY TRAFFIC ALONG THIS PART OF THE KINGS CANYON HIGHWAY!**

A spectacular exposure of east-northeast-striking chevron minor folds is on the north side of highway in a large tectonic block of interlayered calc-silicate phyllite in the quartz and biotite mylonitic phyllite unit (Fig. 7). Note the second-generation folds and their chevron forms. An earlier set of first-generation folds can be seen on joint surfaces oriented at approximately right angles to the axial surfaces of the chevron folds. The earlier folds trend east-northeast and represent the easternmost occurrence of first-generation structures in the Boyden Cave roof pendant (Girty, 1977a, b; Nokleberg and Kistler, 1980). The diagnostic metamorphic minerals in the first-generation schistosity are clinopyroxene, hornblende, biotite, and garnet. In the highly deformed phyllite surrounding this block, and locally within the block, are second-generation folds with axial planes that strike north-northwest and dip steeply to vertically.

Toward the east, the highway crosses alternating units of quartz-rich and biotite-rich mylonitic phyllite that strike north-northeast and dip steeply to vertically (Fig. 6). To the south of the river, the contacts between these units strike obliquely into the marble unit to the west indicating a fault between the marble unit and the quartz and biotite mylonitic phyllite unit to the east.

Farther east, local east-facing, relict sedimentary top directions have been found in the quartz and biotite mylonitic phyllite unit interpreted as characteristic of a fine-grained flysch deposit (Saleeby and others, 1978). Tops are determined by: (1) Grading in cm-scale beds is defined by quartz-rich bases that grade upward to mica-rich tops. (2) Local, small-scale unconformities where small channels appear to truncate layering occur on the north side of the highway. (3) Local amalgamation, subtle grading, ripple marks, convolute bedding, and flame structures are visible in metamorphosed sub-arkosic sandstone.

Detrital zircons from the quartz and biotite mylonitic phyllite unit along this part of the highway yield the following discordant ages: 542 Ma for $^{206}Pb/^{238}U$; 717 Ma for $^{207}Pb/^{235}U$; and 1310 Ma for $^{207}Pb/^{206}Pb$. The $^{207}Pb/^{206}Pb$ age can be considered the minimum age of the source rock (Chen, 1977). The ultimate source for the zircons was probably a craton.

The easternmost part of the quartz and biotite mylonitic phyllite unit lacks first-generation structures, but contains uniformly south-southeast-plunging second-generation folds (Girty, 1977a, b). Also, the lateral continuity of individual beds within the eastern block is much greater than in the metasedimentary rocks to the west. These differences suggest that the easternmost part of the quartz and biotite mylonitic phyllite unit was only deformed during the second deformation event.

South of the canyon, the calcareous, quartzitic, and arkosic rocks in the central and western parts of the Boyden Cave roof pendant are faulted against the metavolcanic rocks of the Goddard terrane (Fig. 6). The two major metavolcanic masses south of the river are a metadacite tuff (mdt) and a metarhyolite tuff (mrr) that weathers a distinctive red color. Locally, thin marble layers are tectonically interspersed with these metavolcanic rocks (Fig. 6). This fault may define the Kings River suture (Nokleberg, 1983; Moore and Nokleberg, 1992), the postulated loci of accretion of the Kings terrane to the west against the Goddard terrane to the east (Nokleberg, 1983). Along the Kings River, these important relationships are obscured by an intervening granitic pluton, the granodiorite of Tombstone Creek.

72.5 132.0

72.6 Contact between the granodiorite of Tombstone Creek to the west and the metavolcanic rocks of the Goddard terrane to the east (Fig. 6). The granitic rocks adjacent to this intrusive contact locally exhibit a schistosity parallel to the intense schistosity in the red-weathering metarhyolite tuff unit to the east. These fabrics apparently formed during syntectonic intrusion of the granodiorite as movement along the Kings River suture was waning. The granodiorite of Tombstone Creek has a preferred U-Pb zircon ages of 99 to 102 Ma (Chen and Moore, 1982; Saleeby and others, 1990), and the metarhyolite tuff unit has a U-Pb zircon age of 106 Ma (Saleeby and others, 1990). These relations indicate a narrow time span for: (1) deposition of the metavolcanic rocks of the western part of the Goddard terrane at about 102 to 106 Ma; (2) regional tilting of the metavolcanic rocks to steep to vertical dips; (3) late-stage, syntectonic intrusion of the granodiorite of Tombstone Creek at about 99 to 102 Ma; and, (4) structural juxtaposition of the metasedimentary rocks of the Kings terrane to the west along the north-northwest trending Kings River suture.

To the northeast on Monarch Divide, the northeastern part of the Boyden Cave roof pendant consists of mid-Cretaceous metavolcanic and metamorphosed hypabyssal rocks with U-Pb zircon ages that range from 102 to 106 Ma (Saleeby and others, 1990) (Fig. 6). These metaigneous rocks are intruded by the granite of Grand Dike with a U-Pb zircon age of 103 Ma (Saleeby and others, 1990). The granite of Grand Dike is regionally metamorphosed and deformed at conditions of the upper greenschist or lower amphibolite facies, and locally contains zones of mylonite as much as 10 cm wide. These relations are similar to those for intrusion of the metavolcanic rocks by the granodiorite of Tombstone Creek to the west, and indicate eruption, deformation, and intrusion of the igneous rocks of the Goddard terrane during a major tectonic episode in the central and southern Sierra Nevada. This deformation apparently formed during tectonic migration of the Kings terrane from the southeast to the Kings Canyon region with simultaneous formation of the north-northwest-trending structures, including major and minor folds and faults, schistosity, and mylonite and tectonic breccia zones that occur parallel to the Kings River suture and to the schistosity in the metagranitic and metavolcanic rocks of the Goddard terrane (Nokleberg, 1983).

74.3 4000 ft. elevation.

75.6 135.0

75.9 Grizzly Creek. Granodiorite of Lightning Creek. Mode Pl - 46.3; Kf - 15.5; Q - 22.5; Mf - 15.7. Preferred U-Pb zircon age of 100 Ma (Saleeby and others, 1990). The granodiorite of Lightning Creek intrudes the eastern margin of the metamorphosed rhyodacites and dacites. The metavolcanic rocks contain a schistosity that strikes N. 10° W. and dips vertically, and adjacent to the metavolcanic rocks the granodiorite of Lightning Creek also contains a subparallel cataclastic schistosity (Girty, 1977a, b). Lying within the plane of the schistosity are ellipsoidal aggregates of biotite whose long axes plunge vertically. The uniform nature of the structure in the metavolcanic rocks suggests a single, homogeneous deformation.

The main trunk glacier which occupied the South Fork Canyon reached to about this point during its greatest advance in the Pleistocene.

79.2 Bridge across the South Fork of the Kings River. Granodiorite of Lookout Peak (Moore, 1978). Mode: Pl - 49.6; Kf - 9.7; Q - 21.5; Mf - 19.2; U-Pb zircon age of 97 Ma (Chen and Moore, 1982). Despite a low K-feldspar content, this rock generally has large K-feldspar phenocrysts. The granodiorite of Lookout Peak along with the correlative 98-Ma granodiorite of Castle Creek to the south form the outermost members of the zoned Mitchell Intrusive Suite (Moore and Sisson, 1987b). The Mitchell Intrusive Suite extends 58 km from the southern Marion Peak 15-minute quadrangle (Moore, 1978) to the southern Mineral King 15-minute quadrangle (T.W. Sisson and J.G. Moore, unpublished mapping).

80.3 Cedar Grove Village turnoff. Still in the granodiorite of Lookout Peak.

81.2 Stop 10 Canyon Viewpoint (5025 ft). Turnout on north side. Good view up valley of U-shaped glacial valley.

81.7 Turnout on north side of highway. Granite of North Mountain. Contact between the granite of North Mountain and the granodiorite of Lookout Peak is in swale behind knob to south.

82.3 Turnout on north side of highway. Float boulders of the granite of North Mountain. Mode: Pl - 30.4; Kf - 38.9; Q - 27.9; Mf - 2.8.

83.1 Stop 11 Roaring River turnout on east side of Roaring River across bridge. Short trail to Roaring River Falls. The granite of North Mountain which crops out near the falls comprises a small pluton about 5 km in diameter. The top of the pluton is exposed high on the canyon walls where it is mantled by a thin hood of metamorphic rocks. The granitic rocks of the North Mountain unit consist of a heterogeneous, fine-grained alaskitic granite with admixed dark granitic rocks and many aplite dikes. Average mode: Pl - 20.9; Kf - 44.9; Q - 33.2; Mf - 1.0. It has a high Rb-87 to Sr-86 ratio of 13, a high Sr 87/86 value of 0.7245, and very heterogeneous zircon populations which yield discordant U-Pb ages. The rocks were probably produced by partial melting of sedimentary parent rocks producing an S-type granite (Chen, 1977).

83.6 Turnout on north side of highway just across Kings River Bridge. Best place to see contact of the granite of North Mountain on south wall of canyon.

83.8 Turnout on south side of highway. Contact of the granite of North Mountain is visible on south wall. Best place to walk to contact on north canyon wall and see metamorphic screen between the Lookout Peak and North Mountain plutons.

84.6 Turnout on south side of canyon. Good float of the granodiorite of Lookout Peak showing large Carlsbad-twinned K-feldspar. Mode: Pl - 57.7; Kf - 8.6; Q - 16.7; Mf - 17.0.

84.8 Grand Sentinel Viewpoint on south side of highway. Glacial grooves and polish can be seen high on the canyon walls, indicating that the Pleistocene glaciers were hundreds of meters thick at this point.

Historical note. John Muir explored Kings Canyon during 1875-1877 and wrote of the Grand Sentinel: "Beyond the Gable Group, and separated slightly from it by the beautiful Avalanche Canyon and Cascades, stands the bold and majestic mass of the Grand Sentinel, 3300 feet high, with a split vertical front presented to the valley, as sheer and nearly as extensive as the front of the Yosemite Half Dome. Projecting out into the valley from the base of this sheer front is the Lower Sentinel, 2400 feet high; and on either side, the West and East Sentinels, about the same height, forming altogether the boldest and most massively sculptured group in the valley" (Muir, 1891).

85.5 Stop 12 Roads End turnout on north side of loop. Please note that sampling and collecting rocks in the Park is not allowed without a collecting permit. Please contact the Superintendent of the Park in writing for a collecting permit.

From here, a large copper stain can be seen at about the 6800-foot-elevation on the northeast face of Grand Sentinel. The copper occurs in minor sulfide mineralization with epidote and quartz in a system of left-lateral joints (shears) trending northeast. Passing through the Roads End loop is the contact with the porphyritic granodiorite of the Paradise pluton which extends east for about 10 km. This pluton is characterized by "camouflaged" K-feldspar phenocrysts filled with concentrically arranged inclusions of biotite, hornblende, and plagioclase. Float boulders of this rock are visible here. Average mode: Pl - 43.6; Kf - 22.0; Q - 22.5; Biotite - 6.7; Hornblende - 3.5; Accessory minerals - 1.8. U-Pb zircon age, 83-86 Ma (Chen and Moore, 1982).

The Paradise pluton forms the outer shell of one of the largest and youngest nested plutonic sequences in the Sierra Nevada batholith, with dimensions of 80 by 25 km, and an area of 1200 km^2. The pluton extends N 30° W from Olancha Peak on the Sierra Nevada crest to near Granite Pass on Monarch Divide. The core of the plutonic sequence is occupied by the younger Whitney pluton that is characterized by large (to 10-cm) K-feldspar megacrysts (Moore and du Bray, 1978). The Whitney pluton has a U-Pb zircon age of 83 Ma (Chen and Moore, 1982) and K-Ar ages of 79-82 Ma (Evernden and Kistler, 1970). This concentric plutonic sequence is similar in composition, age, size, structure and tectonic setting to the Tuolumne Intrusive Suite in Yosemite National Park about 140 km to the north-northwest.

Historical note. The 1864 Whitney Survey party passed this spot and made several attempts to explore the region to the north. They made their way up Copper Creek to Granite Basin and from the crest of the divide near Granite Pass, (10673 ft or 3250 m elevation), found that their pack animals could not descend into the Middle Fork of the Kings River. From the crest, they mapped and named Mount Goddard on the San Joaquin-Kings divide, the Palisades on the main Sierra Nevada crest, and three nearby peaks on Kings Spur: Mounts Gardner, Cotter, and Clarence King. Returning to the South Fork Canyon, they worked their way east of this spot up Bubbs Creek to Kearsarge Pass and down to Owens Valley (Farquhar, 1965).

LOG OF STATE HIGHWAY 198 AND GENERALS HIGHWAY

Roadside signs are designated TUL198, but none are present in the parks

Miles	Signs	Comments
0.0	8.0	Junction of State Route 198 and Country Center Drive in Visalia. Shopping center south of highway includes Denny's, Albertson's, K-Mart, and Payless Drug. Reset odometer here.
1.0	9.0	
1.4	9.4	Highway 63 exit
10.0	18.0	
10.7		Highway 65 to Exeter and Porterville
11.0	19.0	
11.7		Route 245 to Woodlake on left. Homer's Nose is visible to the east from here to about mile 14. The 600-ft-high nearly vertical cliff is formed by exfoliation in the granite of Case Mountain which covers a broad area in the drainages of the East and South Forks of the Kaweah River.
13.0	21.0	
13.2		High Sierra Road (close to west edge of Sequoia and Kings Canyon National Parks and Vicinity special map, Moore and Sisson, 1987). The long low Badger Hill just to the south is underlain by serpentinite melange containing Permian and Carboniferous ophiolitic rocks.
13.8		Yokol Creek. Two miles south on the road that turns off beyond the creek is the Rocky Hill stock of granodiorite with K-Ar ages of 132 Ma (Putnam and Alfors, 1965), 114 and 115 Ma (Evernden and Kistler, 1970), and a Pb-U zircon age of 120 Ma (Saleeby and Sharp, 1980). A quartz diorite cropping out at the foot of the Sierra foothills six miles north yielded a discordant U-Pb zircon age of 116 Ma (Chen and Moore, 1982) *Historical note.* Just off highway is a bronze plaque commemorating the Jordan toll trail: "This monument is near the beginning of the Jordan trail laid out by John Jordan in the year 1861. The trail shortened the route to the silver mines in the Coso Range near Owens Lake east of the Sierra Nevada Mountains. The trail led up Yokohl Creek, across the south end of Blue Ridge,

up Bear Creek to near Balch Park, thence to Hossack Meadow, south side of Jordon Peak, Kern Flat on Kern River, and crossed the main summit of the Sierra via Jordon Hot Springs and Monache Meadows. The trail down the east slope was by Olancha Pass, down Walker Creek and to Owen's Lake. Portions of the trail are still in use."

14.0 22.0

15.1 23.0 Roadcut in tonalite with abundant mafic inclusions. Biotite K-Ar age 109 Ma (Putnam and Alfors, 1965).

19.2 Lemon Cove Post Office. Wutchumna Hill immediately northwest of town is underlain by hornblende hypersthene gabbro.

20.1 28.0

20.7 **Stop A** Road to left leads 1.3 miles to spillway of Kaweah Lake dam. Exposed in spillway is thin-bedded quartzite and calc-silicate hornfels showing chevron folding and marble layers. The distinctive thin-bedded quartzite (metachert?) is characteristic of the metamorphic rocks west of the Park. A one-foot-thick mafic dike dips gently west cutting metamorphic rocks.

21.0 29.00

21.2 Gently dipping dark dikes cutting tonalite are well-exposed in roadcuts on main highway. The majority of mafic dikes near Lake Kaweah have SiO_2 53-62 wt. % and MgO 5.2-2.6 wt. %; However, one dike at the west end of the roadcut is more primitive with SiO_2 48 wt. % and MgO 9.2 wt. %.

23.5 31.50

25.5 Horse Creek

27.0 35.00

27.4 **Stop B** Good exposures of the garnet-bearing, informally named Tharps Peak granodiorite of Liggett (1990) dated at 109 Ma by the Rb-Sr Method (Liggett, 1990). Turn off behind hump on lake side--BEWARE OF HIGHWAY TRAFFIC. The Tharps Peak granodiorite contains biotite and muscovite and the rock resembles S-type granitoids, but Liggett (1990) has shown that the garnet-bearing granodiorite and granite have low $^{87}Sr/^{86}Sr_i$ (0.7049) similar to the surrounding tonalites of clear I-type affinity. He suggests that the granodiorite gained its peraluminous character by extensive hornblende fractionation from a tonalitic parent. Silica content of the granodiorite is 72-74 wt. %, and associated felsic dikes attain 76 wt. %. The tonalite pluton east of the Tharps Peak granodiorite has been dated at 108 Ma (Pb-U zircon, Chen and Moore 1982), within the age-limits error for the Tharps Peak granodiorite.

27.6 35.50

27.7 Slick Rock turnout. The relatively dark granodiorite here yields a concordant zircon Pb-U age of 108 Ma (Chen and Moore, 1982).

28.0 36.00

28.9 37.00

29.4 West city limit of Three Rivers. The white pattern on the north face of Blossom Peak to the south is formed by a thin, light-colored granite dike about 1 ft thick cutting vertically-layered dark calc-hornfels rocks. The dike has split parallel to its walls giving an irregular white pattern on the grey metamorphic rocks. The metasedimentary rocks form a major roof pendant some 15 km long that crosses the Kaweah River.

30.0 38.00

30.5 North Fork Kaweah River Drive. *Historic Note.* Five miles up the North Fork of the River the Kaweah Colony established the camp of Advance in the late 1880's. This was the base camp for an ambitious effort to build a road to Giant Forest for the purpose of logging. The threat of logging the giant sequoias helped to marshall those that desired to protect the big trees and to create Sequoia National Park. The road that the colony built, though now in disrepair, was the only road access to Giant Forest for many years.

30.9 Chevron gas station

32.0 40.0

32.3 Marble layers forming Comb Peak of the Sheep Creek roof pendant are visible to the north. The $^{87}Sr/^{86}Sr_i$ granitoid isopleth of 0.706 lies near here.

33.0 41.0

34.1 42.0

34.4 Mineral King Road. A road log describing the geology along the 25-mile-long road to Mineral King follows this guide.

35.4 View of Moro Rock

36.0 43.94 Kaweah River Bridge.

36.4 Blasted roadcut in diorite followed by road on right (gate) that leads to gaging station on Middle Fork of the Kaweah River. Water-washed outcrops expose heterogeneous hornblende diorite, with SiO_2 55-59 wt. % and MgO 4-3 wt. %, typical of small mixed masses of dioritic rocks common near pluton-roof pendant contacts.

36.5 Entrance to Sequoia National Park-- note that collecting is not allowed in the park without a collecting permit. Sequoia National Park was the first national park in California. It was created by act of Congress on September 25, 1890. Five days later on October 1, 1890, a second act created Yosemite National Park and also enlarged Sequoia National Park to include Giant Forest and the General Grant Grove.

36.6 Sequoia National Park sign

37.4 Park Headquarters, Visitor's Center.

38.1 Stop C Coarse-grained marble within small metasedimentary pendant within the granite of Frys Point. Paved pullout on right.

38.8 Tunnel Rock

39.8 2000 ft.

40.2 Bridge over Marble Fork of Kaweah River

40.3 Potwisha Campground turnoff

40.6 Castle Rock spires and domes are visible. They are carved from the weakly gneissic, light-colored granite of Dome Creek.

41.8 Sign pointing out Mt. Stewart (12,205) just north of Kaweah Gap on the Great Western Divide. The peak, carved out of the granite of Eagle Scout Peak is named for George W. Stewart, a newspaper publisher in Visalia and a leader in the movement to establish Sequoia National Park.

42.6 Stop D Hospital Rock. Rest rooms, water. The parking lot is littered with large boulders up to several meters in diameter that were deposited during major rock falls and avalanches off Moro Rock 1.5 miles and 4000 feet above to the north. A large granodiorite boulder here has split after coming to rest, and Indian petroglyphs done in a red iron-oxide compound are painted on the flat joint face of this fracture. For the next 4.1 miles up the road from this point, numerous large boulders of the dark Giant Forest Granodiorite that are part of this avalanche, or series of avalanches, are visible adjacent to the road. Bedrock beneath the road is almost entirely composed of metasedimentary rocks of the Sequoia roof pendant.

A small road from here leads about 1.5 miles to Buckeye Flat campground on the Middle Fork of the Kaweah River. Here metasedimentary rocks of the Sequoia roof pendant are well exposed in waterworn outcrops. Megascopic andalusite is visible in the metamorphosed argillaceous rocks.

Historic Note: Hale Tharp, cattleman, was the first Caucasian visitor here in 1858, and at that time a year-round settlement of about 200 Indians was in residence at this site.

43.3 3,000 ft elevation.

44.2 Switchback on east side of the Sequoia roof pendant where the road barely enters the porphyritic marginal facies of the Giant Forest Granodiorite.

46.0 Big Fern Spring. Small trail leads up stream that flows across vertically layered, thin-bedded quartz-biotite schist, with quartzite layers. Metamorphic rocks collected here, apparently derived from aluminum-rich, quartz-poor argillacaeous rocks, contain: plagioclase, biotite, K-feldspar, minor quartz, andalusite, sillimanite, cordierite, corundum, and green spinel (Clifford Hopson, written commun., July, 1993). Two large granodiorite avalanche boulders here are about 7 m in diameter.

47.4 Amphitheater point (Phone) Good view of Moro Rock and Castle Rocks to the south across the canyon of the Kaweah River. Mt. Eisen, 12,160 ft., is visible on the Great Western Divide. The Sequoia roof pendant can be seen crossing Paradise Ridge in a saddle four miles to the southeast just east of the prominent Milk Ranch Peak. Brownish units are quartzite that are much thicker bedded than those that lie west of the park; lighter-colored, blue-gray units are marble on which yucca plants commonly grow.

48.3 Granite Spring on east side of the Sequoia roof pendant just inside the outcrop area of the Giant Forest Granodiorite. The sharp vertical contact with metasedimentary rocks is visible slightly uphill in highway roadcut.

48.5 Highest granodiorite boulders in avalanches from Moro Rock

49.0 Stop F Deer Ridge lookout (Phone). Switchback Peak to west with blue-gray marble below. Walk to northeast side of viewpoint to see several marble units to north that are discontinuous and folded in places and join in other places. These marble units form thin sheet-like bodies that can be traced for as much as five miles. Chamise, manzanita, buckeye, deerbrush, blue oak, and poison oak thrive on Deer Ridge and lower slopes.

49.5 5000 ft elevation.

49.9 Eleven Range overlook. Note marble ridges crossing canyon below. The highway has just entered the Giant Forest Granodiorite (U-Pb zircon age of 99 Ma, Chen and Moore, 1982) in which it will remain, except for short excursions into the granodiorite of Big Meadows, for the next 28 miles to mile 78. The Giant Forest Granodiorite is the oldest unit of the zoned Sequoia Intrusive Suite, a series of granodiorite and granite plutons in a roughly concentric arrangement centered at Shell Mountain in the Giant Forest Quadrangle. The composition and texture of the Giant Forest Granodiorite, as well as its abundance of mafic inclusions, are quite typical of the large hornblende granodiorite plutons of the Sierra Nevada batholith. Silica contents fall in the range 60.5-69 wt.%, but most are 62-65 wt. %; K_2O lies in the range 2.3-4.2 wt. %, but most are near 3.0 wt. %; and, MgO lies in the range 1-2 wt. %. Note the prominent sphene, uncommon in the tonalitic rocks of the western foothills.

Sign discusses the problems of air pollution--here graphically displayed since small conifer pictured in middle of plaque has died.

50.5 Crystal Cave road turnoff. The cave, 3.5 air miles northwest, is in a marble layer within the Sequoia roof pendant.

53.1 Giant Forest store. Road to the right leads to Moro Rock in the Giant Forest Granodiorite. A short steep trail leads to the summit where good views may be had of the 12-14,000 ft. peaks of the Great Western Divide (east), Castle Rocks (south), and the western foothills and Central Valley (west).

55.2 General Sherman Tree turnoff.

55.8 Wolverton turnoff. Slightly more than a mile east on this road is a small ski area developed at Long Meadow. The meadow is formed behind south lateral moraines of the Tahoe and Tioga glaciations deposited by a major glacier that flowed west down the U-shaped Tokopah Valley of the Marble Fork of the Kaweah River.

57.4 Lodgepole turnoff. The main glacier of the Tahoe glaciation in Tokopah Valley terminated about 1 mile west of the highway at an elevation of 6000 feet. About one-half mile east of the highway in Tokopah Valley is the east contact (concealed) of the Giant Forest Granodiorite where it intrudes the overlying older granite of Lodgepole, a pale-orange coarse-grained granite (72-76 wt. % SiO_2) that underlies many of the neighboring domes and peaks, including Mt. Silliman (11,188 ft) and Alta Peak (11,204 ft).

57.5 Marble Fork bridge
58.3 Clover Creek Bridge
59.1 7000 ft. Wuksachi site
61.1 Halstead Creek
62.5 Suwanee Creek
64.2 **Stop F** Little Baldy Saddle (7335 ft)--BEWARE OF DANGER FROM TRAFFIC. A multiple granitoid pipe containing orbicules cuts the Giant Forest Granodiorite about 150 yds west of the road at the saddle turnout (Fig. 8). Note that orbicles are elongate parallel to walls of pipe and are notably smaller at edge than in center of pipe. Mafic minerals define an internal contact between orbicular pipes. The pipe was originally about 6 m in diameter, before it was cut and offset by an aplite dike

On the other side of the highway (east), a trail leads to the summit of Little Baldy, a typical Sierra granitic dome in the Giant Forest Granodiorite where good views can be had from the summit. The round trip trail is 3.4 miles with walking time of 2-3 hours.

Internal contacts within the Giant Forest Granodiorite that are defined by changes in hornblende abundance and habit are well displayed in the blasted roadcuts to the south of Little Baldy Saddle.

65.7 Dorst Creek Campground entrance.

66.4 Dorst Creek,

67.1 Cabin Creek,

68.4 Lost Grove.

69.1 Sequoia National Forest--Sequoia National Park Boundary (National Forest on northwest).

70.2 Stony Creek. Campground turnoff. About one-quarter mile downstream from lower part of campground metamorphosed rhyolite tuffs of Cretaceous age (Pb-U zircon age 110 Ma, J. Saleeby, written comm., 1991) are well exposed.

This turnoff is within the granite of Big Meadows. Interesting contact relations of the granite of Big Meadows with the granite of Weaver Lake can be viewed by hiking upstream (northeast) along Stony Creek.

70.7 Stony Creek Village.

75.4 Big Meadow road turnoff. The road to Big Meadows and a hike up Shell Mountain afford an opportunity to examine the Sequoia Intrusive Suite in the northeastern part of the Giant Forest 15-minute quadrangle. This concentric plutonic complex, about 12 by 42 km in size, consists of the Giant Forest Granodiorite (oldest) and several younger and smaller granitic masses--the granite of Big Meadows, the granodiorite of Clover Creek, and the granite of Weaver Lake (youngest), and tentatively the granite of Chimney Rock. These units were emplaced sequentially, generally toward the central part of the intrusive suite in the order listed. They also generally become lighter colored and more silicic with time, except for the granodiorite of Clover Creek which is more mafic than the older granite of Big Meadows. The youngest unit, the granite of Weaver Lake, forms a central funnel-shaped mass about 7 km in diameter which sent out numerous upward-dipping sills intrusive into the granite of Big Meadows. Tabular masses and blocks of the granite of Big Meadows are isolated between these intrusive sheets. The units of the Sequoia

Intrusive Suite were emplaced and cooled at about 99 Ma. The nested succession and chemical coherence of the units indicate that they are genetically related and formed from a common magma through successive intrusions as temperatures systematically decreased.

75.6 Big Baldy trailhead. A ridge crest walk of about 2 miles to Big Baldy provides good exposures of metasedimentary rocks of the Big Baldy roof pendant.

77.6 Stop G Sierra View overlook. Peaks visible are from left (north to south): Spanish Mtn. (10,051 ft), Obelisk (9,970 ft), Tombstone Ridge, Mt. McGee (12,604 ft, 31 air miles), Mt. Reinstein (12,604 ft), Mt. Goddard (13,568 ft), Kettle Dome (9,446 ft), Finger Peak (12,404 ft), Burnt Mtn (10,602 ft), Mt. McDuffie (13,271 ft), and Tunemah Pk. (11,894 ft, 23 air miles). None of these peaks are on the main Sierra crest which is five miles beyond Mts. Goddard and McDuffie. On the right can be seen Buck Rock lookout which lies on the outer margin of the granite of Big Meadows of the Sequoia Intrusive Suite (U-Pb zircon age, 99 Ma, Chen and Moore, 1982).

77.7 Quail Flat. Hume Lake road.

78.6 Park-Forest boundary. Grant Grove section, Kings Canyon National Park on west.

81.3 The Wye--End of Generals Highway and intersection with State route 180.

LOG OF MINERAL KING ROAD FROM HIGHWAY 198 TO END OF ROAD AT MINERAL KING

Roadside signs designated MTN375

Miles	Sign	Comments
0.0		Beginning of Mineral King road (designated MTN375 on road signs) at highway 198 just above Hammond. The granodiorite of Three Rivers (U-Pb zircon age of 104 Ma, Chen and Moore, 1982), a relatively dark granodiorite carrying abundant mafic inclusions, occurs from the beginning of the road to mile 3.5. The rocks are cut by many dikes, including a lighter-colored granitic rock-unit probably related to the granite of Case Mountain exposed to the east.
1.0	1.00	
3.0	3.00	
3.5	3.50	The granite of Case Mountain extends from here to mile 16.2, although a rock-unit of older granodiorite occurs within this span. The granite of Case Mountain is light-colored, relatively coarse-grained, commonly porphyritic, and intrudes the granodioritic masses that border it on the east and west. Its margins are commonly irregular because of many dikes and sills sent out by the main body. K-Ar ages are 83-90 Ma uncorrected (Everenden and Kistler, 1970). Samples of the granite of Case Mountain contain 73-75 wt. % SiO_2 and 3.4-4.3 wt. % K_2O. The rocks are unusually enriched in some trace elements compared to most Sierran granites: La up to 260 x chondritic, Zr to 345 ppm, Th to 65 ppm, and U to 20 ppm. Average concentrations for Sierran granites with similar silica contents are La 100 x chondritic, Zr 190 ppm, Th 24 ppm, U 7 ppm.
4.0	4.00	
5.1		Nearly horizontal 1-m-thick pegmatite dike in road cut.
6.2		Begin the dark granodiorite of Three Rivers containing abundant mafic inclusions. This rock-unit is exposed along road to mile 9.5.
6.6		Bridge over East Fork of Kaweah River.

7.0	7.0	Settlement of Oak Grove (phone)
8.5		Grunigen creek
9.0	9.0	
9.5		Sequoia National Park boundary. Reenter the granite of Case Mountain which extends to mile 16.2
9.7		Coldspring--cement water trough at 3200 ft elevation.
10.0		A large pegmatite dike about 30 feet thick that cuts the granite of Case Mountain crops out as a white knob almost hidden behind brush on the south side of the road.
10.4		Park entrance station. Note that sample collecting is not allowed within the Park without a permit.
10.9		Overhanging cliff made up of the granite of Case Mountain .
13.0	13.04	
15.7	15.76	
16.2		Redwood Creek and cement water trough (5706 ft). Contact of the granite of Case Mountain with the granodiorite of Castle Creek (U-Pb zircon age of 98 Ma; Busby-Spera and Saleeby, 1987, refer to rocks comprising this pluton as their informally named Eagle Lake quartz monzodiorite). The granodiorite of Castle Creek is the outermost and oldest unit of the Mitchell Intrusive Suite, a series of granodiorite and granite plutons 58 km long (north-south) that are arranged in a roughly concentric pattern centered to the north in the Triple Divide Peak quadrangle. The granodiorite of Castle Creek is lighter colored than, but otherwise resembles, the granodiorite of Giant Forest, the oldest unit of the zoned Sequoia Intrusive Suite exposed along the Generals Highway. The granodiorite of Castle Creek has SiO_2 averaging 67 wt.% and K_2O averaging 3.4 wt. %.
17.7	17.68	Small stream.
19.2		Atwell Mill ranger station.

19.4 Atwell Mill campground.

19.9 Deadwood Creek.

20.1 20.21

20.5 Cabin Cove--Seventh Heaven sign over road.

21.1 Silver City store.

22.0 Highbridge Creek.

23.8 Mineral King ranger station, 7580 ft. The western margin of the Mineral King roof pendant is not exposed on the road, but passes close to the ranger station. From ranger station to roads end, the road traverses metarhyolite tuff, calc-silicate rocks, and slate.

Metavolcanic rocks in the Mineral King roof pendant have yielded U-Pb zircon ages of 217 Ma (Late Triassic) and 190 Ma (Early Jurassic), and the metasedimentary rocks have yielded Late Triassic and Early Jurassic marine fossils.

24.2 Travertine terrace 30 m north of road is apparently a post-glacial mineral spring deposit.

23.9 23.94

24.6 Trailhead to Sawtooth Pass (parking, phone)

24.7 Bridge over Monarch Creek

25.0 Corral, roads end.

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TITLES TO FIGURES

Frontispiece. The 1864 field party of the California Geological Survey. From left to right: James T. Gardiner, Richard D. Cotter, William H. Brewer, and Clarence King.

Figure 1. Geologic map of the central Sierra Nevada area showing composition of average granitic rock, and field trip routes (heavy lines) on highways 180 and 198, with the Gererals Highway connecting. The line of projection for figure 6 is shown as line A-A', and area of figure 7 is shown by box.

Figure 2. Map of the field trip routes and stops. The 12 stops on highway 180 are designated with numbers and the 7 stops on highway 198-Generals Highway are designated by letters.

Figure 3. Oblique physiographic map of the upper Kings River Drainage as viewed 30 degrees above the horizontal from the southwest (after Alpha, 1977). Highway 180 extends east up Kings Canyon in center, and Generals Highway contours around to right (south).

Figure 4 Outline map of Kings Canyon and Sequoia National Parks showing areas of geologic mapping utilized in compiling the geologic map of the parks (fig. 5). Quadrangles (letters) and special mapped areas (numbers) refer to references listed in table 1.

Figure 5. Generalized geologic map of the Kings Canyon and adjacent area. Modified from Moore and Sisson (1987). Field trip routes shown by heavy dashed lines.

Figure 6. **A**. Analytical data on granitic rocks projected onto line A-A' of figure 1. A, volume percent of K-feldspar; **B**, initial strontium 87/86 ratios; **C**, U-Pb zircon ages of granitic and mafic rocks in millions of years; **D**. Relation between specific gravity and weight percent SiO_2 of granitic rocks.

Figure 7. Generalized geologic map of the Boyden Cave roof pendant. Adapted from Moore and Nokleberg (1992). Heavy line crossing the roof pendant from west to east is the South Fork of the Kings River; Horseshoe Bend is the prominant convex north curve in the river. Closed circle along South Fork of Kings River indicates geologic stop at parking lot for Boyden Cave near bridge across river(Mile 71.3).

Figure 8. Chevron-folded metasiltstone in Kings Canyon slightly east of Boyden Cave bridge on north side of highway at Mile 71.9.

Figure 9. Orbicular pipe at Little Baldy Saddle just west of Generals Highway cutting the Giant Forest Granodiorite. Note concentric arrangement of orbicles and tendency toward larger orbicles occurring in central part of pipe. Unpublished geologic mapping by Kazuya Kubo (1986). North is to the top.

To accompany figure 7.

DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

Ql **Landslide deposit (Quaternary)**

Qt **Talus and colluvium (Quaternary)**

Qg **Glacial deposits, undifferentiated (Quaternary)**

GRANITIC ROCKS

[Rock names from classification of Streckeisen, 1973]

Dark-colored rocks

[Generally more than 10 percent dark minerals]

Kgf **Giant Forest Granodiorite** (Cretaceous)—Medium-grained equigranular, hornblende-rich granodiorite with abundant mafic inclusions. Contains ~17 percent mafic minerals. Mafic inclusions are variable in size, shape, and texture. Zircon U-Pb age, 97-102 Ma (Chen and Moore, 1982)

Ktc **Granodiorite of Tombstone Creek** (Cretaceous)—Medium-grained, dark-colored granodiorite with ~19 percent mafic minerals. Zircon U-Pb ages are 99 Ma (Chen and Moore, 1982) and 102 Ma (J.B. Saleeby, and others, 1990)

Klc **Granodiorite of Lighting Creek** (Cretaceous)—Medium-grained, dark-colored granodiorite with ~19 percent mafic minerals.. Zircon U-Pb ages are 108 Ma (Chen and Moore, 1982) and 100 Ma (J.B. Saleeby, and others, 1990)

Kyp **Quartz diorite of Yucca Point** (Cretaceous)—Medium-grained granodiorite and quartz diorite with prominent hornblende crystals, abundant mafic inclusions, and ~21 percent dark minerals Zircon U-Pb age of 110 Ma (Chen and Moore, 1982).

Medium-colored rocks

[Generally 6-10 percent dark minerals]

Kbc **Granodiorite of Brush Canyon** (Cretaceous)—Porphyritic granodiorite and granite averaging about 6 percent mafic minerals and containing 1-2-cm-long potassium-feldspar phenocrysts in a medium-to fine-grained groundmass. Zircon U-Pb age of 86 Ma (Chen and Moore, 1982).

Light-colored rocks

[Generally less than 6 percent dark minerals]

Kdm **Granite of Deer Meadow Grove** (Cretaceous)—Chiefly medium-grained biotite-hornblende granite with ~5-7 percent dark minerals.

Kkl **Granite of Kennedy Lakes** (Cretaceous)—Generally coarse-grained, heterogeneous, light-colored granite with admixed darker granitic rocks. Coarse-grained rock produces crags and spires

Kgd **Granite of Grand Dike** (Cretaceous)—Sheared and gneissic granite commonly coarse-grained and resistant. Contains local mylonite zones up to 10 cm thick. Zircon U-Pb age of103 Ma (J.B. Saleeby and others, 1990)

METAMORPHOSED HYPABYSSAL INTRUSIVE ROCKS

mhd **Hypersthene-bearing metadacite** (Cretaceous)—Subvolcanic intrusion of massive to weakly schistose hypersthene-bearing, homogeneous metadacite containing small spindle-shaped mafic inclusions. Zircon U-Pb age of 102 Ma (Saleeby and others, 1990)

hg Hypabyssal granodiorite stock (Cretaceous)—Medium-grained, weakly schistose, hornblende-biotite granodiorite. Forms small intrusion associated with metadacite subvolcanic mass (mhd) on north side of Monarch Divide. Zircon U-Pb age of 103 Ma (Saleeby and others, 1990)

mdp Metadacite porphyry (Cretaceous)—Chiefly metamorphosed, schistose, hornblende-biotite dacite porphyry. Contains plagioclase phenocrysts as long as 4 mm. Forms hyabyssal intrusion in metasedimentary rocks along upper Boulder Creek. Zircon U-Pb age of 105 Ma (Saleeby and others, 1990)

METAVOLCANIC ROCKS

mrt Metarhyolite tuff (Cretaceous)—Chiefly metamorphosed rhyolite and dacite tuff. Zircon U-Pb age of 106 Ma (Saleeby and others, 1990)

mrf Metarhyolite lava (Cretaceous)—Chiefly metamorphosed massive, sheared, silicic volcanic rocks. Predominantly lava flows

msv Metavolcanic sedimentary rocks (Cretaceous)—Metamorphosed water-laid volcaniclastic sediments and airfall ash

mdt Metadacite and metarhyolite tuff (Cretaceous)—Metamorphosed tuff and volcaniiclastic sedimentary rocks. Also contains meta-andesitic tuffaceous rocks

mrr Metarhyolite (Cretaceous)—(Cretaceous)—Red-weathering, fine-grained, metamorphosed lapilli tuff and tuff breccia. Zircon U-Pb age of 104 Ma (Saleeby and others, 1990)

map Metarhyolite airfall ash (Cretaceous)—Fine-grained, commonly well-bedded, airfall ash with well-preserved accretionary lapilli 2-20 mm in diameter

METASEDIMENTARY ROCKS

s Biotite-feldspar-quartz schist (Jurassic or older)—Reddish-brown weathering, biotite-feldspar-quartz schist with thin (10 cm or less) layers of micaceous quartzite. Includes minor calc-silicate schist and sparse marble. Thin to medium layered

m Marble (Jurassic or older)—Coarsely crystalline, schistose to gneissose, white to light-gray, marble. Commonly cavernous and dolomitic in some places

q Quartzite (Jurassic or older)—Fine- and medium-grained, schistose, white, micaceous, quartzite, arkosic quartzite, and lesser quartz-biotite schist. Medium to massive bedded, locally exhibiting cross-bedding

cs Calc-silicate schist (Jurassic or older)—Calc-silicate schist and minor calc-hornfels adjacent to granitic plutons. Includes quartz-biotite schist and minor tactite and marble. Thin to medium layered

qbp Quartz and biotite mylonitic phyllite (Jurassic)— Chiefly thin-layered to medium-layered, fine-grained quartz-, feldspar-, and biotite-rich mylonitic phyllite and mylonitic calc-phyllite. Local mylonite and tectonic breccia zones near western contact with marble unit. Contains Lower Jurassic fossils near lower Boulder Creek

bp Biotite mylonitic phyllite (Jurassic)—Chiefly thin-layered to medium-layered, fine-grained biotite-quartz mylonitic phyllite with lesser quartz-feldspar mylonitic phyllite

abs Andalusite-biotite schist (Jurassic or older)—Dark-gray, thin- to medium-layered, fine- to medium-grained, quartz-muscovite-biotite-andalusite schist

MAP SYMBOLS

Contact

Fault

Antiform, showing plunge of axis

Synform, showing plunge of axis

Table 1--To accompany figure 3

References used in compiling geologic map of Kings Canyon and Sequoia National Parks

Fifteen-minute quadrangles

A. Bateman, P. C. and D. R. Wones, 1972, Geologic map of the Huntington Lake Quadrangle, central Sierra Nevada, California: U.S. Geological Survey Geologic Quadrangle Map GQ-987.

B. Bateman, P. C., 1965, Geologic map of the Blackcap Mountain Quadrangle, Fresno County, California: U.S. Geological Survey Geologic Quadrangle Map GQ-428.

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D. Big Pine Quadrangle: Bateman, P. C. et. al., 1965, Geology and Tungsten Mineralization of the Bishop District, California: U.S. Geological Survey Professional Paper 470.

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F. Patterson Mountain Quadrangle: indicated references and reconnaissance mapping by the authors

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K. Dunlap Quadrangle: indicated references and reconnaissance mapping by the authors

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O. Lone Pine Quadrangle; indicated references and reconnaissance mapping by the authors

P. Exeter Quadrangle: indicated references and reconnaissance mapping by the authors

Q. Kaweah Quadrangle: indicated references and reconnaissance mapping by the authors

R. Mineral King Quadrangle: indicated references and reconnaissance mapping by the authors

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