Stratigraphy and Structure of Part of the Western Sierra Nevada Metamorphic Belt, California

GEOLOGICAL SURVEY PROFESSIONAL PAPER 410

Prepared in cooperation with the State of California, Department of Conservation, Division of Mines and Geology

Stratigraphy and Structure of Part of the Western Sierra Nevada Metamorphic Belt, California

By LORIN D. CLARK

GEOLOGICAL SURVEY PROFESSIONAL PAPER 410

Prepared in cooperation with the State of California, Department of Conservation, Division of Mines and Geology

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1964

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

The U.S. Geological Survey Library has cataloged this publication as follows:

Clark, Lorin Delbert, 1918–
Stratigraphy and structure of part of the western Sierra Nevada metamorphic belt, California. Washington, U.S. Govt. Print. Off., 1964.

iv, 70 p. illus., maps (7 col.) diagrs. (1 col.) tables. 30 cm. (U.S. Geological Survey. Professional paper 410).
Part of illustrative matter fold. in pocket.
Prepared in cooperation with the State of California Dept. of Natural Resources, Division of Mines and Geology.
Bibliography: p. 58–59.

(Continued on next card)

Clark, Lorin Delbert, 1918– Stratigraphy and structure of part of the western Sierra Nevada metamorphic belt, California. 1964.
(Card 2)

1. Geology, Stratigraphic. 2. Geology—California—Sierra Nevada Mountains. I. California. Division of Mines and Geology. II. Title. III. Title: Sierra Nevada metamorphic belt, California. (Series)

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

CONTENTS

ILLUSTRATIONS

[Plates 1–11 in map case]

TABLES

STRATIGRAPHY AND STRUCTURE OF PART OF THE WESTERN SIERRA NEVADA METAMORPHIC BELT, CALIFORNIA

By LORIN D. CLARK

ABSTRACT

The area described in this report lies on the lower western slopes of the Sierra Nevada due east of San Francisco Bay and northwest of Yosemite National Park. It is about 90 miles long and 30 miles wide and is underlain by steeply dipping metamorphic rocks of Paleozoic and Mesozoic age lying between the Sierra Nevada batholith on the east and overlapping Tertiary deposits of the Central Valley of California on the west. The historically famous Mother Lode gold belt extends northwestward through the center of the area.

Distribution of the different units of metamorphic rocks is profoundly influenced by two nearly vertical major fault zones that divide the region into three structural blocks. The orientation and amount of net slip along the fault zones have not been definitely established but the horizontal component is probably much greater than the vertical component; the apparent vertical component of movement amounts to many thousands of feet.

Rocks of Paleozoic age constitute the eastern fault block, which lies east of the Mother Lode. All the Paleozoic rocks have previously been assigned to the Calaveras formation, and this usage is retained. The upper part of the Calaveras formation is of Permian age, but the formation is perhaps tens of thousands of feet thick, and the age of lower parts is unknown. Five lithologic members have been distinguished within the Calaveras formation, but no revision of the nomenclature is proposed. The Calaveras formation consists largely of originally argillaceous rocks and chert and is notable for a paucity of detrital material as coarse as sand, except in the lowermost part. Volcanic rocks form lenses in most of the formation and thick, extensive sequences in some places. Limestone also forms widespread lenses, but is prominent only in the east-central part of the area.

Mesozoic rocks constitute the western fault block and most of the central block. Paleontologically dated Mesozoic rocks are of Late Jurassic age. They are divisible in a general way into sequences of epiclastic rocks, largely slate, graywacke and conglomerate, and volcanic rocks, although epiclastic and volcanic rocks are commonly interbedded and in some places intertongue. The graywacke and conglomerate of all the formations are similar in composition. The most abundant clastic fragments are of volcanic rocks, slate, and chert, but fragments of metamorphic rocks, plutonic rocks, and quartzite are widespread. The various volcanic formations also have many features in common; most are composed largely of tuff and volcanic breccia, but lavas, in part having pillow structure, form thick sequences locally. Felsic volcanic rocks are common in one of the volcanic formations, but lacking in the others. Type localities of previously named formations are within the central fault block, and because of the difficulty of correlating between the two fault blocks new names are proposed for formations of the western fault block.

Formations exposed in the central block are conformable and include the Cosumnes formation, of probable Late Jurassic age, consisting largely of epiclastic rocks; the Logtown Ridge formation, ranging from Callovian to late Oxfordian or early Kimmeridgian in age, and consisting of volcanic, chiefly pyroclastic rocks; the Peñon Blanco volcanics, of Late Jurassic age, consisting of lava and pyroclastic rocks; and the Mariposa formation, of late Oxfordian or early Kimmeridgian age or both, consisting chiefly of epiclastic rocks. Conglomerate is very abundant in the Cosumnes formation and part of the Mariposa formation and contains many pebbles and boulders of limestone derived from the Calaveras formation. Coarse, poorly sorted conglomerates, previously thought to be tillite, are probably of mudflow origin. The section is everywhere truncated by faults or erosion, but the total thickness of the Jurassic strata is in excess of 15,000 feet.

In the western fault block, a lower formation of volcanic rocks, a middle formation of epiclastic rocks, and an upper formation of volcanic rocks can be distinguished. Names here proposed for these formations are, respectively, the Gopher Ridge volcanics, the Salt Spring slate, and the Copper Hill volcanics. These units form a conformable and, in part, intertonguing, sequence. Fossils have been described from only one locality; these are from the Salt Spring slate and indicate late Oxfordian or early Kimmeridgian age. The Salt Spring slate is therefore about equivalent to the Mariposa formation, and the Gopher Ridge volcanics are presumably about equivalent to the Logtown Ridge formation. The youngest unit, or Copper Hill volcanics, may be equivalent to the upper exposed part of the Mariposa formation but may be younger. Two other formations, here named the Peaslee Creek volcanics and the Merced Falls slate, of probable Late Jurassic age, have been distinguished in part of the block.

The metamorphic rocks are on the west limb of a faulted synclinorium, the axial part of which is occupied by the Sierra Nevada batholith. Large folds having essentially horizontal axes were formed during development of the synclinorium but wide homoclinal belts also occur. Axial planes of the folds dip steeply eastward or are vertical, and most beds dip eastward more steeply than 60°. The folds and homoclinal sections are truncated by the two major fault zones, which strike nearly parallel to bedding and are parts of a fault system that extends throughout and beyond the western Sierra Nevada metamorphic belt. The fault zones are characterized by mappable belts of cataclastically deformed and in part recrystallized rocks and by thin elongate pods of serpentine. The general sequence of strata within each fault block is from older on the west to younger on the east. This sequence was reversed by movements on the major fault zones, so that the youngest exposed strata are in the western fault block and the oldest in the eastern fault block. Pervasive shearing that accompanied the faulting resulted in the development of steeply plunging

minor folds and *b*-lineations, particularly in the fault zones and the eastern fault block.

Whether extensive deformation accompanied emplacement of the Sierra Nevada batholith during middle Cretaceous time has been neither established nor disproved. Most of the deformation apparently took place during part of Late Jurassic time as major folds involving upper Jurassic strata are truncated by the major faults, some of which are in turn cut by a Late Jurassic pluton.

INTRODUCTION

LOCATION, CULTURE, AND ACCESSIBILITY

The area covered by this report lies on the lower western slope of the Sierra Nevada in California (fig. 1). It extends from a short distance south of the Merced River to a short distance north of the Cosumnes River, or from north latitude 37°30′ to about north latitude 38°35′. The area is bisected by the historically famous Mother Lode gold mining belt and the towns and villages of the region were established as centers of mining activity during the 19th Century. The largest town is Sonora, with 2,500 people. The population of the region has decreased markedly since the days of active mining. The road and highway network is still much the same as shown on topographic maps published in 1900 and before, but grades and surfaces of the highways have been modernized and most

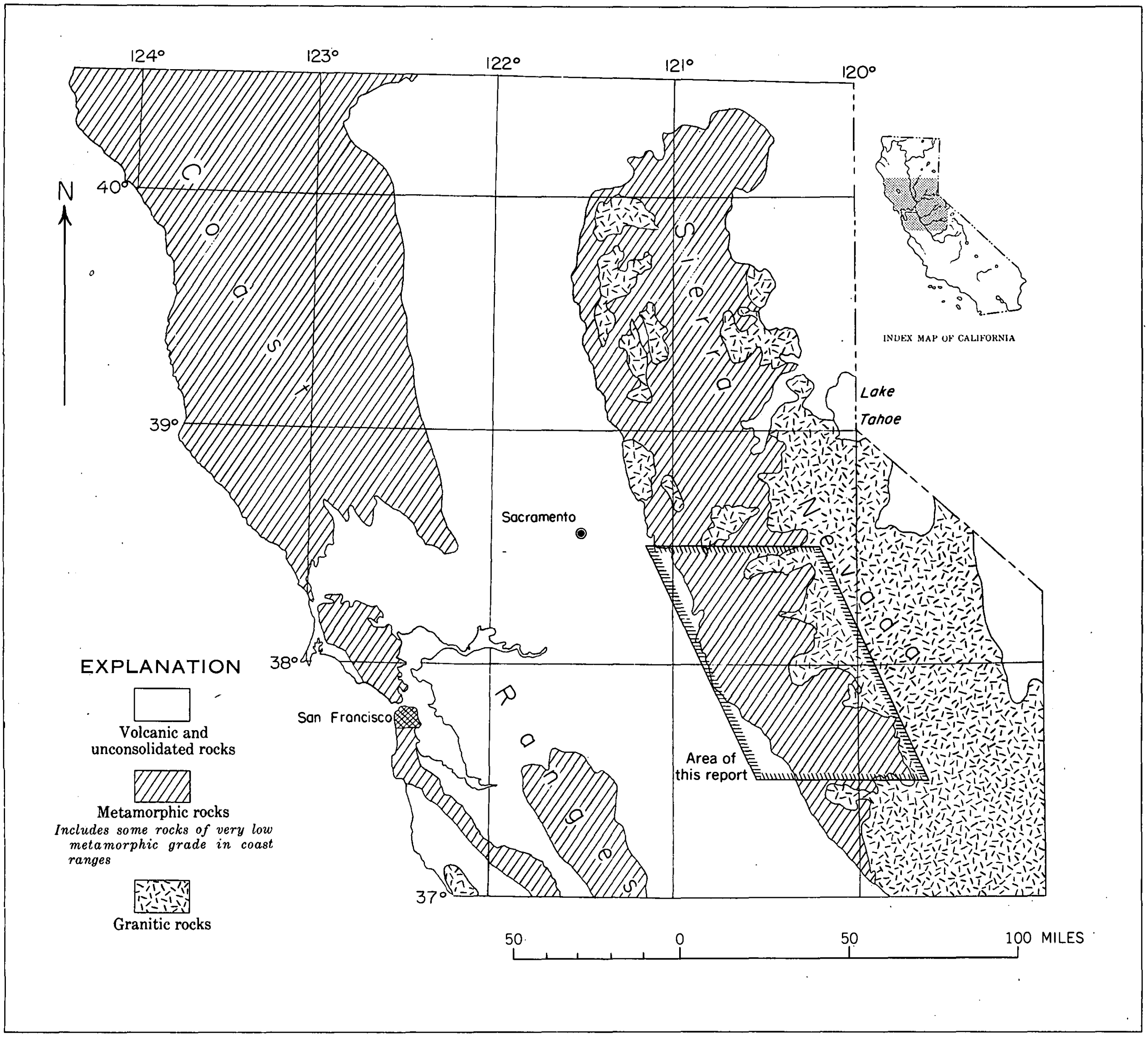

Figure 1.—Index map showing location of area studied.

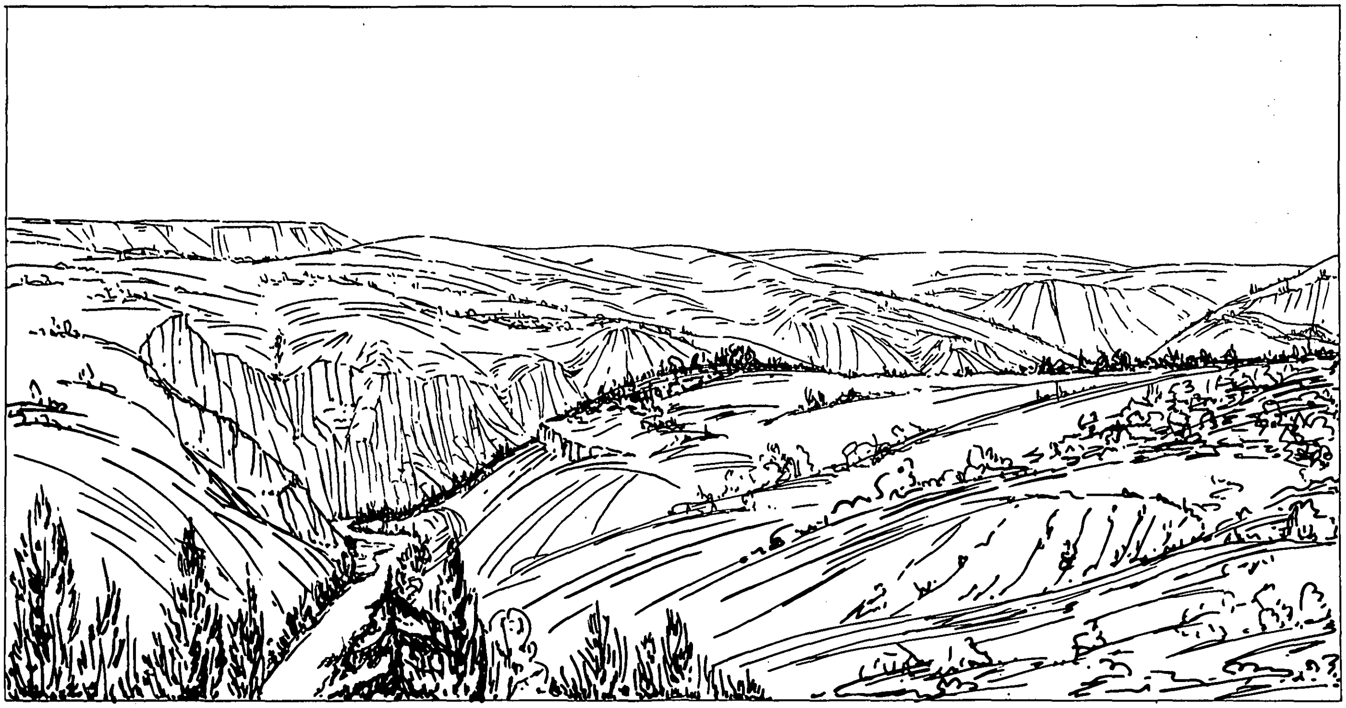

FIGURE 2.—Canyon of the Stanislaus River about two miles northeast of Parrotts Ferry bridge, looking northeast. The canyon is cut into a rolling upland surface underlain by the Calaveras formation of Paleozoic age. The cliffs are formed in limestone. Flat-topped ridge in left background is part of Table Mountain, which is composed of river-channel deposits of Tertiary age. These deposits consist of alluvial gravels and rhyolite tuffs capped by latite lava.

of the secondary roads also have hard surfaces. Houses are sparse between towns.

At the lower altitudes near the western edge of the area are extensive treeless semiarid grasslands. With increasing altitude, evergreen and deciduous oaks occur, and near the Mother Lode belt open oak forests are interspersed with grasslands dotted by scattered trees and by dense thickets of manzanita and chamise covering areas of poor, thin soil. At altitudes of about 2,000 feet, oaks give way to a conifer forest in which pines predominate. Little of the land is tilled, and most of the nontimbered land is used for grazing.

Precipitation is directly proportional to elevation, so that the annual rainfall increases from about 20 inches at the west edge of the area, to 30 inches or more on the Mother Lode, and to 40 inches farther east. It occurs mostly during the fall, winter, and spring months—rain is rare between about the first of June and the middle of September. Snow seldom whitens the ground west of the Mother Lode.

PHYSICAL FEATURES

The western slope of the Sierra Nevada in this region is for the most part a gently rolling upland with occasional scattered higher hills. This surface largely was developed prior to Eocene time, and is deeply weathered. It is buried in some places by younger deposits, which, in the western part of the area, project as buttes and cuestas. The upland surface is dissected by the rivers and their larger tributaries, which have cut deep, youthful canyons. In many of these the average slope of the walls from bottom to top is more than 40°, and the bottoms are little wider than the stream itself at intermediate water levels. The Calaveras River is an exception, as it flows in a broader valley inherited from an earlier erosion cycle, except for a few miles above the point where it leaves the bedrock. Part of the upland surface and canyon of the Stanislaus River are shown in figure 2. The western edge of the area stands about 300 feet above sea level, but near the eastern edge the upland surface stands 5,000 to 6,000 feet above sea level.

In the western part of the area long ridges carved from resistant parts of the bedrock extend parallel to the range front and project as much as 1,000 feet above the surrounding country. These are probably monadnocks on the upland surface (Eric, Stromquist, and Swinney, 1955, p. 5).

PREVIOUS WORK

Numerous publications on the geology of the western part of the Sierra Nevada have appeared, beginning shortly after the Gold Rush of 1849–50; the earlier of these were listed and summarized by J. P. Smith (1894). In the present account only those which bear on the subject of this investigation will be mentioned, but some others will be referred to later in the report.

The first comprehensive investigations were those of H. W. Turner, Waldemar Lindgren, and F. L. Ransome. The results were published between 1893 and 1900, in a series of geologic folios covering most of the western Sierra Nevada, and in separate papers dealing with specific areas or problems. The geologic maps of the folio series are shown by later work to have distinguished the various lithologic units with much accuracy. Besides the positions of intrusive rocks, these maps show that the western part of the area is underlain by northwest-striking alternating belts of volcanic rocks (diabase and porphyrite of the folio maps) and sedimentary rocks, and that the eastern part of the area is underlain largely by sedimentary rocks, among which only limestone is differentiated. Structural interpretations in the folios are diagrammatic, and bedded volcanic rocks are shown as massive igneous bodies, without stratigraphic significance.

Adolph Knopf (1929), in studying many of the gold mines of the Mother Lode region, found that the quartz veins with which the gold ore bodies are associated are in reverse faults. He also recognized that many of the volcanic rocks were bedded and that tuff was intimately interbedded with some of the sedimentary sequences. The results of N. L. Taliaferro's extensive investigations in the region are presented in a series of abstracts, papers, and a quadrangle geologic map published between 1942 and 1949. Taliaferro (1942, p. 96) treated the volcanic units as formations and has presented a concise summary of the sequence of major geologic events in the western Sierra Nevada. He has also summarized the regional aspects of the structure and stratigraphy (Taliaferro, 1942, p. 77–81, 89–105; 1943b, p. 280–286, 302–323), but his interpretations are supported by little specific locality data. During World War II, a number of copper mines in the region were mapped by G. R. Heyl, M. W. Cox, and J. H. Eric (*in* Jenkins, ed., 1948).

About 1946, the U.S. Geological Survey began a program of geologic mapping for the purpose of gathering the field data necessary to develop an understanding of the regional structure and stratigraphy. Results of this program appeared in the geologic maps and descriptions of the Sonora and Angels Camp (Eric, Stromquist, and Swinney, 1955) and Calaveritas (Clark, 1954) 7½ minute quadrangles. Although these maps contributed to the desired end, it became apparent that to approach the larger scale problems through standard mapping procedures would be very costly in time and manpower. At the same time the feasibility of a different approach to the regional geology was demonstrated.

PURPOSE AND SCOPE OF INVESTIGATION

The investigation described in this report is designed to supplement previous geologic mapping with new data for interpreting major features of the regional structure and stratigraphy of the metamorphic rocks (pls. 1 and 2). Plutonic rocks were not studied nor were the nearly flat lying Tertiary strata that locally cover the ancient surface. Field work consisted of detailed study of the geology along the major streams, which in general cross the regional structure at about right angles. The folio maps indicate the continuity of formations between the streams. This approach is reasonable not only because of the existing map coverage, but because of the physiographic and geologic features of the region.

Exposures, particularly of sedimentary rocks, are generally poor on the upland surface, and contacts between sedimentary rocks in the valleys and volcanic rocks in the ridges are commonly concealed beneath extensive surface debris. In contrast, the major stream canyons provide exposures that are continuous for considerable distances.

Fossils are so sparsely and unevenly distributed in the region that stratigraphic sequences must be worked out by systematic observation of structures showing the direction of tops of beds; such structures are abundant in the region. They are readily observed on stream-polished surfaces but in many places where exposures are weathered and covered with lichens they can be discovered only after tedious search. Similar field methods have been used for many years in areas of Precambrian rocks, particularly in the Lake Superior region, but have been little used in California.

In the field, the metamorphic rocks were mapped and described in terms of the numbered map units shown on plates 3 through 8, and the basic rock descriptions in tables 1 through 7 (p. 59 to 66) are independent of structural and stratigraphic interpretations. During compilation each unit was assigned a number in sequence from west to east and the units were grouped into formations. The rock descriptions do not represent columnar sections, for each outcrop belt resulting from repetition of a unit by a fold or fault is described separately.

This investigation is limited to the metamorphic rocks of the region—rocks of Tertiary age and the plutonic rocks are not considered. This is a preliminary report on a continuing study, and some of the interpretations may be changed as a result of further work. At present, only some of the sedimentary rocks have been studied petrographically, and these not fully. Petrography of the volcanic rocks probably has less bearing on the stratigraphy and has not yet been studied.

FIELD WORK AND ACKNOWLEDGMENTS

Field work covered a total period of 5½ months during 1953 and 1954. Field mapping was done on aerial photographs and topographic maps at a scale of 1/24,000. The data were compiled at 1/48,000 for publication at 1/62,500 scale. In addition, short sections have been mapped by plane table at a scale of one inch to 500 feet. The investigation was performed in cooperation with the California Division of Mines and Geology. In compiling the map and cross section along the Calaveras River free use was made of an unpublished map and report on the San Andreas northwest quadrangle prepared by A. A. Stromquist and C. M. Swinney. A detailed map of the type section of the Amador group in the Cosumnes River area prepared by G. R. Heyl, J. H. Eric and M. W. Cox is incorporated in this report. Richard Pack assisted in the field work during the early part of the 1953 field season, and E. H. Pampeyan later in that season. C. D. Rinehart participated in mapping the shores of the reservoirs in the area. The East Bay Municipal Water District granted permission to enter the closed area around the Pardee Reservoir.

TERMINOLOGY

Discussion of some of the terminology used in this report is necessary for clarity. All the sedimentary and volcanic rocks in the region are metamorphosed, but original structures and textures are commonly well preserved, and the emphasis of this study is on their structure and stratigraphy. For this reason the rocks are generally designated by such names as chert and tuff rather than metachert and metatuff. Lack of consistency will be apparent, however, for originally argillaceous rocks are referred to as slate, phyllite, and schist, and some volcanic rocks in which original textures are destroyed are distinguished by the term "metavolcanic." This nomenclature has proved convenient and understandable to geologists of my acquaintance.

In this region, original textures and structures of pyroclastic rocks forming much of the volcanic formations are indistinguishable from those of rocks of similar grain size composing the "sedimentary" formations. This similarity indicates that both sandstone and tuff, for example, were introduced to the area of deposition and were deposited in the same manner—they are both sedimentary rocks. The significant difference between them is the origin and manner of comminution of the fragments. In recognition of this, shale, sandstone, conglomerate, and the like will be designated "epiclastic" rocks to indicate that the component debris was formed by weathering of pre-existing rocks.

The term "graywacke" designates poorly sorted sandstone with a matrix of silt-size and originally clay-size material (Pettijohn, 1954; 1957, p. 290–292). Sand grains are mostly chert or other lithic fragments, but various amounts are mineral grains, most commonly quartz. Rocks in which the sand-size fraction consists entirely of volcanic rock and mineral detritus are called tuff, but those containing even widely scattered grains of nonvolcanic material are called graywackes. No fundamentally important aspect of the interpretation of geologic history of the region is masked by this usage, as sequences of definite volcanic material alternate with sequences of definite epiclastic material on both the regional scale and the scale of a single formation. The term "tuffaceous sandstone" is not appropriate unless the rock contains both grains formed by epiclastic processes and first-cycle grains formed by pyroclastic processes.

In the absence of a purely descriptive term, the name "chert" is applied to microcrystalline, granoblastic rocks composed of quartz. In this area, these rocks have been referred to by most previous geologists as either phtanite or quartzite. Phtanite has fallen into disuse in this country, and although quartzite is often used as a descriptive term, it is more properly applicable to a rock formed from quartz sand. Most of the chert is sericitic, and rock containing so much sericite so that it can be scratched with a hammer point is here referred to as quartzose slate.

"Limestone" is used loosely to include carbonate rock ranging in composition from limestone to dolomitic limestone and possibly to dolomite, and in texture from aphanitic to coarsely crystalline.

Three terms—cleavage, schistosity, and slip cleavage—are used to distinguish different kinds of parting surfaces of metamorphic origin. "Cleavage," without a modifier, designates the sort of planar structure characteristic of slate, the slaty cleavage of many authors. In this region development of cleavage is widespread. It has formed in fine-grained pyroclastic rocks and sandstones as well as slate. It commonly crosses bedding, forms a simple regional pattern, and in most places is about parallel to the axial planes of folds. "Schistosity" designates a planar structure formed by the parallel arrangement of tabular mineral grains and clastic fragments in rocks sufficiently coarse grained to be termed schist. In strongly sheared schist, slip surfaces parallel to grains and fragments accentuate the cleavage. "Slip cleavage" consists of closely spaced crinkles and micro-faults (White, 1949) cutting earlier schistosity and cleavage. Previously formed mica flakes are commonly bent to a direction parallel to the micro-faults.

SYNOPSIS OF GEOLOGY

Rocks of the western Sierra Nevada are divisible into two groups which have long been known as the bedrock complex and the superjacent series; the latter, consisting of nearly flat-lying alluvial and volcanic deposits, is not considered here. The surficial rocks have been described by Storms (1894); Piper, Gale, Thomas, and Robinson (1939); Clark (1954, p. 9–11); and Eric, Stromquist and Swinney (1955, p. 16–19).

The bedrock complex consists of metamorphosed sedimentary and volcanic rocks of Paleozoic and Mesozoic ages, and plutonic rocks of Mesozoic age. The distribution of the metamorphic rocks and the interpretation of their stratigraphy is profoundly influenced by two northwesterly-trending fault zones that divide the metamorphic rocks into three structural blocks (pl. 2). For convenience these are referred to as the eastern, central, and western blocks. The fault zones are not obscure features drawn to explain anomalous distribution of formations, but are mappable belts of cataclastically deformed and recrystallized rock ranging from a few hundred feet to a few miles wide. Most of the metamorphic rocks of Paleozoic age are in the eastern block and all the metamorphic rocks of Mesozoic age are in the western and central blocks and within the fault zones.

The oldest rocks in the region are those of the Calaveras formation, which has been defined to include all of the metamorphic rocks of Paleozoic age in the area (Turner, 1893a, p. 309; 1893b, p. 425). This usage is followed in this report, although five lithologically distinct members within the formation have been distinguished. Four of these members are in the eastern block and one is exposed in a narrow belt in the central block. All the metamorphic rocks of the eastern structural block are included in the Calaveras formation. The most complete section of the formation is exposed along the Merced River, where four members have been recognized. Two members are separable from one another near the Merced River, but not elsewhere. Strata of the Calaveras formation are apparently progressively younger eastward along the Merced River. Diagnostic fossils have been found at only one locality in the eastern block, near the top of the Merced River section of the Calaveras formation, and suggest a Permian age. For convenience, the four members of the Calaveras formation in the southern part of the area have been designated from west to east, the clastic, volcanic, argillaceous, and chert members. These terms do not adequately describe the various sequences of beds, but emphasize the distinguishing features of each.

The clastic member, exposed between Bagby and the North Fork of the Merced River, consists in its lower part of thinly interbedded slate and graywacke. In its upper part it consists largely of slate, with interbedded pyroclastic rocks, and a thin-bedded chert unit several hundred feet thick. The volcanic member consists mostly of volcanic breccia and tuff, but contain some pillow lava. The argillaceous member is composed largely of black carbonaceous slate and siltstone, but contains appreciable amounts of bedded chert. Except in deep road cuts along the Merced River, the chert is preferentially exposed and for this reason the argillaceous member is not readily distinguishable from the chert member in most places. The chert member consists dominantly of interbedded black carbonaceous quartzose slate, phyllite, schist, and chert, but limestone lenses are larger in the lower part of the chert member than elsewhere in the formation and north of Sonora limestone forms a prominent part of the section. The chert member underlies a much greater area than the other three members combined.

A fifth member of the Calaveras formation is exposed in a small part of the central fault block, where it underlies the Cosumnes formation, of probable Late Jurassic age. This member has long been referred to as the western belt of the Calaveras formation. It includes lenticular clastic limestone which at several localities has yielded fossils of Permian age, and probably includes quartzose slate and minor pyroclastic rocks. Other rocks may be part of the Calaveras formation here, but the central block is structurally complex, and it is uncertain whether some of the rocks in this vicinity belong to the Calaveras formation or to younger formations. The member in the central block is unlike any of those exposed in the eastern block.

The western and central fault blocks are characterized by northwesterly trending alternating belts of epiclastic and volcanic rocks (pl. 1). Many of these belts are several miles wide and continuous for great distances, but the stratigraphy is complex. Rocks were correlated by earlier geologists on the basis of lithologic similarity, although fossils are sparse and have not been found in some belts. To avoid unjustified correlation and possible oversimplification of the geologic history of the region, previously proposed formation names are used only in belts which contain their type localities. New names are proposed for the formations of other belts.

Mesozoic stratified rocks in the central block are conformable and consist of the Amador group, comprising the Cosumnes and Logtown Ridge formations, the Peñon Blanco volcanics, the Mariposa formation, and epiclastic and volcanic rocks of uncertain stratigraphic position. No fossils have been found in the Peñon Blanco volcanics. But fossils indicate that the age of the upper part of the Cosumnes formation is within the interval extending from middle Bajocian to late Callovian, that the Logtown Ridge is of Callovian to late Oxfordian or early Kimmeridgian age, and the Mariposa is of late Oxfordian and early Kimmeridgian age.

STAGES OF THE MIDDLE AND LATE JURASSIC

After Arkell (1956, p. 7–8) except that the Callovian is here included in the Late Jurassic.

- Late Jurassic
  - Tithonian
  - Kimmeridgian
  - Oxfordian
  - Callovian
- Middle Jurassic
  - Bathonian
  - Bajocian

The Cosumnes formation consists of dark-gray slate, abundant conglomerate, graywacke, and tuff. Much of the conglomerate contains limestone fragments derived from the Calaveras formation. The Mariposa formation is similar to the Cosumnes formation except that conglomerate is much less abundant in most places and the Mariposa contains a thick volcanic member. The Logtown Ridge formation consists largely of coarse porphyritic volcanic breccia, but contains some tuff and minor pillow lava. The Peñon Blanco volcanics consist largely of volcanic breccia and tuff, but a thick mass of lava, some showing pillow structure, forms the lower part of the section.

Stratified rocks of Mesozoic age in the western block are also conformable. They consist in most of the area of three formations, here named the Gopher Ridge volcanics, Salt Spring slate, and Copper Hill volcanics. Two other formations, the Peaslee Creek volcanics and Merced Falls slate, are distinguished in the southern part of the aréa. The Salt Spring slate is about equivalent to the Mariposa formation and of late Oxfordian or early Kimmeridgian age, and the Gopher Ridge volcanics are presumably about equivalent to the Logtown Ridge formation. The Copper Hill volcanics may be of Kimmeridgian age, or may be younger. The only area where continuity of these formations across the strike can be observed is in the north where the Salt Spring slate thins and intertongues eastward with the Gopher Ridge and Copper Hill volcanics. This suggests that the Salt Spring slate was not laterally continuous with the Mariposa formation, at least not in all places.

Graded bedding, widely and abundantly developed in the tuff and graywacke of Mesozoic age, indicates that these beds accumulated in quiet and probably deep water. Textures and structures indicative of deposition in agitated water are rare or absent.

Plutonic rocks in the region include ultramafic rocks which are mostly altered to serpentine, hornblende gabbro, diorite, and granodiorite. All the plutonic rocks are younger than the metamorphic rocks. Ultramafic rocks form narrow, elongate bodies in major fault zones, and less commonly form somewhat thicker bodies that extend beyond the limits of the fault zones. The proximity of ultramafic rocks to fault zones, including possible sill-like bodies, and the general absence of such rocks elsewhere suggests that emplacement of the ultramafic rocks was controlled largely by the fault zones. As cataclastic deformation associated with these fault zones is much more extensive, both along and across the strike, than are the ultramafic rocks, it is not likely that the serpentine controlled the locus of faulting.

Only a few individual plutons in the region have been dated, but most of the granitic rocks appear to fall into two separate series, those of the western and central blocks apparently being appreciably older than those of the eastern.

The easternmost of the two major fault zones is the Melones fault zone and the western one, the Bear Mountains fault zone. The Melones fault zone coincides throughout much of its length with the Mother Lode gold belt. Schistosity within the fault zones suggests that they dip eastward, at angles between 65° and 90°. The two fault zones form part of the Foothills fault system (Clark, 1960a), which extends from south of the area studied to the northern limit of exposures of metamorphic rock in the western Sierra Nevada, a distance of about 200 miles, and perhaps farther. Steeply plunging lineation and minor fold axes suggest that the dominant component of movement along the Melones and Bear Mountains fault zones was horizontal. Some faults of the system are cut by granitic plutons of the older series. Previously mapped reverse faults that control the quartz veins of the Mother Lode are within the Melones fault zone in most, but not all, of the area. These faults also dip eastward but less steeply than the Melones fault zone, and in the northern part of the area are exposed as much as one mile west of the Melones fault zone. They are probably younger than the Melones fault zone, and may have formed concurrently with emplacement of the Sierra Nevada batholith.

Although large folds repeat the outcrop of formations in places, older beds are generally exposed in the western part and younger beds in the eastern part of each of the three fault blocks. This arrangement suggests that the region lies on the west side of a large synclinorium, but is reversed by the Melones and Bear Mountains fault zones, so that the youngest exposed metamorphic rocks of the region are in the western block, the oldest in the eastern block, and rocks of intermediate age in the central block.

Only general features of the structure of the eastern block have been worked out because of the monotonous lithology of a great part of the Calaveras formation and because bedding has been destroyed by shearing in much of the region. Much of the Calaveras formation is schistose. Near the Merced River, where it is less recrystallized, the structure of the eastern block is apparently homoclinal with tops east. Where bedding is preserved, it nearly everywhere dips steeply. Large folds may occur near the Merced River, but none are large enough to repeat any of the four members distinguished in the Calaveras formation. In the southern part of the area, the northwest regional trend of belts of rock in the Calaveras formation is truncated at an acute angle by the Melones fault zone. Near San Andreas, a large easterly plunging complex anticline is truncated at a large angle by it.

The amount of deformation in the central and western blocks is about equal. Isoclinal folds occur in the central block near the middle of the area, but the beds are homoclinal with tops east farther north and south. In the north half of the western block are large open folds overturned to the west. In the southern part of the western block, folds also occur, but their form and position are obscure because they occur in thick sequences of sheared volcanic rocks with little bedding and no graded bedding. Intersections of bedding and cleavage, the plunges of minor fold axes, and the areal patterns of outcrop show that the major folds plunge at low angles, generally less than 25°. Cleavage occurs widely and schistosity locally in rocks of the central and western blocks. Most rocks of the eastern block are schistose.

Most of the deformation within all three fault blocks preceded the major faulting and probably took place during an orogeny that appreciably antedates intrusion of the Sierra Nevada batholith.

STRATIGRAPHY

CALAVERAS FORMATION

The term Calaveras formation was used for all the metasedimentary and metavolcanic rocks of Paleozoic age in the Sierra Nevada, except the Silurian and Upper Carboniferous rocks of the Taylorsville region (Turner, 1893a, p. 309; 1893b, p. 425). This broad usage is followed here. The formation was named for beds in the central block about 2 miles east of the crest of the Bear Mountains in Calaveras County that in this report are included in the Mariposa formation.

DISTRIBUTION AND CHARACTER

Within the report area, most of the Calaveras formation lies between the Melones fault zone on the west and the Sierra Nevada batholith on the east. A much smaller belt of Calaveras formation in the central fault block extends from south of the Mokelumne River to north of the Cosumnes River. Other small, isolated blocks derived from the Calaveras formation, surrounded by younger rocks, occur in major fault zones at widely separated localities, and in conglomerate of the overlying Cosumnes and Mariposa formations.

The Calaveras formation within the area can be divided into five members. One of these is in the central block and forms the western belt of the formation; the other four are in the eastern block. The Calaveras formation of the western belt consists largely of cherty phyllite and thin-bedded chert, with minor amounts of calcarenite. The eastern block comprises, from older to younger, (1) a member composed of slate, graywacke, chert, and tuff, here designated the clastic member; (2) an upper volcanic member; (3) an argillaceous member, recognized only on the Merced River; and (4) a member composed of thin-bedded chert, black carbonaceous slate, and limestone, here designated the chert member. The four members of the eastern block are exposed along the Merced River. Proposal of formal stratigraphic names for these units is deferred until named subdivisions of the Calaveras formation exposed north of the area covered by this report have been studied.

EASTERN BELT

The most complete section of the eastern belt of the Calaveras formation is in the southern part of the area, where it is divisible into four members. The section is apparently conformable, and contacts between members are drawn to group beds of similar lithology. Graded bedding and attitudes of beds suggest that successively younger members are exposed from west to east along the Merced River. Northwest of the Merced River the lower members of the Calaveras formation are successively truncated by the Melones fault zone; the argillaceous and chert members that form the upper part of the formation are more extensively exposed. The northeastern part of the eastern belt includes undifferentiated rocks of the Shoo Fly formation of probable Silurian age (Clark and others, 1962, p. B15–B18).

CLASTIC MEMBER

The clastic member is exposed in the Merced River between Bagby and the mouth of the North Fork of the Merced River. It is bounded on the west by serpentine and on the east by the volcanic member. It is truncated along the Melones fault zone a few miles north of the Merced River (pl. 1). It is inferred to extend south of the Merced River to a point near the boundary of the map area where it is truncated by a granitic pluton.

Fine-grained detrital rocks, chiefly black slate and siltstone, make up most of this member, but pyroclastic rocks and bedded chert constitute important parts of it. Abundant thin beds of graywacke are interbedded with the black slate in the western part of the section. Small lenses of black limestone occur at several horizons and crinoid plates are abundant in one. Poorly sorted conglomerate or breccia, consisting of pebbles and boulders of feldspathic graywacke in a matrix of sandy argillite, forms units 31 and 33 (pl. 3). These are probably mudflows, as suggested by the poor sorting, argillaceous matrix, and absence of internal bedding. The total thickness of the clastic member in the Merced River is more than 10,000 feet.

The black slate (unit 29, pl. 4) west of the bridge on State Highway 49 across the Tuolumne River is arbitrarily included with the clastic member, following Turner (1897), but may be of Mesozoic age. The slate contains two small limestone masses.

VOLCANIC MEMBER

The pyroclastic rocks exposed in the Merced River east of the mouth of the North Fork of the Merced are continuous to the northwest with a belt of metavolcanic rocks mapped previously (Turner, 1897) as amphibolite, green schist, and, locally, as gabbro. The belt extends northwestward as far as State Highway 108 (pl. 1); between State Highway 108 and San Andreas metavolcanic rocks that form separated masses are included. Although the stratigraphic position of most of those rocks has not been established, their distribution suggests that they are near the same stratigraphic level. The metavolcanic rocks may be infolded with or intertongue with the surrounding rocks. The mass east of San Andreas forms the core of an anticline and is overlain by interbedded black carbonaceous schist and chert similar to that forming the argillaceous and chert members in the Merced River (Clark, 1954, p. 8–9). It also includes thin, probably interbedded layers of chert and black schist. Small masses of volcanic rock north of San Andreas (pls. 1 and 2) are included, but may be interbedded with the argillaceous or chert member of this report. The volcanic member extends southeastward from the Merced River beyond latitude 37°30′ north. It is about 5,000 feet thick east of the mouth of the North Fork, assuming a uniform dip of 80°.

In the Merced River, the volcanic member consists almost entirely of coarse volcanic breccia, similar to some breccias of Jurassic age in color, grain size, and the presence of pyroxene phenocrysts as much as 1 cm in diameter. Two layers of black slate, each about 50 feet thick, with interbedded volcanic conglomerate and tuff lie in the breccia near its western side. Fragments of black, carbonaceous slate are common in the eastern part of the volcanic breccia.

The volcanic rocks exposed on the North Fork of the Merced River, less than a mile from the section exposed in the main stream, are more varied. Besides volcanic breccia they include green phyllite, volcanic conglomerate, and tuff. Differences in the two sections suggest very rapid interlensing of different rocks, or small folds that cannot be demonstrated by the observed bedding attitudes.

Gradually waning volcanism and conformable relations between the volcanic member and the overlying argillaceous member are suggested by the presence of interbedded epiclastic and pyroclastic rocks in the southwestern part of the section included with the argillaceous member. In secs. 25 and 26, T. 3 S., R. 17 E., on the North Fork of the Merced River, pillow lava and layers of volcanic breccia and tuff too thin to map individually are interbedded with argillaceous slate and siltstone. On the west side of the Merced River near the south end of McCabe Flat, the thick porphyritic breccia of the volcanic member is succeeded on the north by conglomerate less than 20 feet thick consisting of pebbles of volcanic rock in a black slate matrix. This is succeeded by another volcanic breccia layer less than 100 feet thick and this by black slate containing some chert. Another volcanic breccia layer is exposed at the north end of McCabe Flat. Farther east along the Merced River is fine tuff and a green phyllite that was probably a very fine tuff.

ARGILLACEOUS MEMBER

A member composed dominantly of bedded, black argillaceous rock which locally contains bedded chert occurs on the Merced River east of the volcanic member. It differs from the clastic member to the west, as it contains almost no graywacke and less variety of lithologic types, and it differs from the chert member in containing much less chert. Nevertheless, the argillaceous member cannot be distinguished from the chert member along the North Fork of the Merced River, perhaps because of increase in abundance of chert northwestward. It may, however, be due to the nature of the exposures, as the extensive fresh highway cuts along the Merced River are not comparable to the stream-polished exposures examined elsewhere. The resistant chert and quartzose slate may be preferentially exposed in some streams, giving an erroneous impression of the amount of chert.

Existence of a distinct member of argillaceous rocks is suggested also by the normally weathered rock in road cuts immediately north and south of Briceburg, and about 3 miles northeast of Coulterville, which consist largely of gray- and brown-weathering slate, at least superficially similar to weathered exposures of the Mariposa formation. Rocks of this sort do not occur in other parts of the Calaveras formation.

The total thickness of the argillaceous member is uncertain, because at several places in the Merced River bedding has been destroyed by shearing for several hundred feet across the regional strike. The widest unbroken block with apparently simple structure is between Briceburg and McCabe Flat. In this interval the beds are more than 5,000 feet thick. This represents only about one-fourth of the width of outcrop of the argillaceous member, and may represent a comparable fraction of its total thickness in the Merced River. Volcanic rock to the west and the belt of limestone to the east converge northward, suggesting that the argillaceous member thins to the north.

Rocks of the argillaceous member are chiefly slate and siltstone, the latter partly massive, partly thin-bedded. Seams of thin-bedded chert are present locally. Tuff and aphanitic green phyllite that may be derived from tuff are common on the Merced River west of Briceburg, but are lacking east of Briceburg. Along the Tuolumne River, on the other hand, pyroclastic rocks are interlayered throughout the interval between the volcanic member and the limestone that is near the southwest side of the chert member. Limestone was not observed in the argillaceous member along the Merced River, but H. W. Turner (unpublished map of the Yosemite quadrangle) mapped limestone on the hill slope about half a mile east of Briceburg. Thin beds of limestone are exposed in the comparable section on the Tuolumne River.

Conglomerate, graywacke, and sandy siltstone are interbedded with black slate and siltstone in the Merced River northeast of the mouth of Sweetwater Creek (unit 41, pl. 3). The conglomerate has a matrix of slate or siltstone and some of the graywacke beds are graded. Some of these rocks are tightly folded and the total thickness of the part of the section that contains them is unknown. Although these coarse epiclastic rocks are near the contact between two of the members they do not indicate emergence, or even shallowing of the water. The pebbles in the conglomerate are volcanic rocks, limestone, chert, quartzose slate, and carbonaceous slate which could have been derived from underlying parts of the Calaveras formation; no crystalline, metamorphic, or other rocks foreign to the Calaveras formation occur. A local source is suggested by contrasting composition of adjacent conglomerate beds; in some the pebbles are almost all volcanic rocks, and in others these are rare or absent. The argillaceous matrix of the conglomerates, the extremely poor sorting and lack of internal bedding in some layers, and the grading of associated sandstone beds suggest deposition by mudflows and turbidity currents. Very coarse slump breccia composed of sandstone blocks more than 15 feet long in a slate matrix is exposed along the South Fork of the Merced River about 1 mile east of the mouth of Devil Gulch (pl. 1).

CHERT MEMBER

The easternmost member of the Calaveras formation in this area is characterized by abundant chert interbedded with black carbonaceous slate and siltstone. A belt of lenticular limestone masses lies near the western boundary of the member, and it also includes the large mass of limestone northeast of Sonora. Some quartz-rich siltstone resembling the chert also occurs. Sandstone beds exposed near El Portal on the Merced River and along the South Fork of the Merced are here included with the chert member although their stratigraphic relations are uncertain. Lenses of volcanic rocks are widespread. The chert member is the most widely distributed subdivision of the Calaveras formation in the area, and extends from the west side of the belt of limestone lenses eastward to the batholith. It is exposed on all streams mapped and good exposures are readily accessible on all except the Calaveras and Cosumnes Rivers. It is the only subdivision of the Calaveras formation recognized on the Calaveras, Mokelumne, and Cosumnes Rivers, although perhaps some of the beds on these three streams should be included with the argillaceous member.

The chert and quartz-rich siltstone form layers 0.04 to 8 inches thick, but mostly less than 1½ inches thick, in the black carbonaceous slate, phyllite, and schist. Relative proportions of chert and quartz siltstone are unknown, but most of the textures shown in thin sections of fine-grained quartzose rocks studied do not indicate a clastic origin. The chert is aphanitic and is gray to black on fresh surfaces; the luster is chalcedonic to vitreous. Weathered chert is white and has a fine sugary appearance. Rocks of various compositions ranging from chert to phyllite are common.

Rocks composed of elliptical fragments of chert in a matrix of black carbonaceous slate or phyllite are common in the chert member. The short diameter of the fragments is mostly less than an inch. These aggregates might be intraformational conglomerates, but they are not bedded and are probably breccias, formed tectonically from interbedded chert and carbonaceous slate (Clark, 1954, p. 6–7).

Thin section study of cherts of the Calaveras formation of the eastern block indicates that they are composed chiefly of microcrystalline, equigranular quartz generally with less than 5 percent of biotite and sericite. Many cherts contain pyrite and a few contain epidote and zoisite. A carbonate mineral forms widely dispersed, small, irregular microcrystalline aggregates in most specimens. The cherts have a granoblastic texture; boundaries between quartz grains interlock but are not dentate or sutured. The micas are interstitial to the quartz, and in the coarser grained specimens penetrate boundaries of quartz grains and form inclusions in the quartz. Biotite, with X, colorless; Y, red-brown; and Z, red-brown; and absorption $X<Y<Z$, is present in all sections and is commonly both larger and more abundant than the colorless mica.

Structures probably formed by the replacement of Radiolaria are abundant in some of the finer chert layers. These structures are ovoid masses of microcrystalline quartz, generally coarser and with less mica than the surrounding chert. They resemble structures believed by Cayeux (1929, p. 356–357, 472–473, fig. 80) to be derived from Radiolaria. Taliaferro (1943b, p. 289) observed a transition from recognizable Radiolaria to similar ovoid structures in chert from the western Sierra Nevada.

The average grain size of the cherts ranges from about 0.02 mm diameter in thin-bedded chert with chalcedonic luster from sec. 19, T. 3 S., R. 19 E. on the Merced River to about 0.15 mm diameter in vitreous chert from sec. 29, T. 1 N., R. 16 E. on the North Fork of the Tuolumne River. Increase in the average size of the quartz grains in the cherts accompanies an increase in the size of the other minerals and the development of garnet in the mica-rich layers, and is apparently related to increasing metamorphic grade of the rocks.

The mica-rich layers representing originally argillaceous beds interlayed with the chert range from about 50 percent mica and 40 percent quartz to nearly all mica. Pyrite occurs in most layers. Garnet forms about 10 percent of one mica-rich layer. An opaque mineral, dull black in reflected light, forms as much as 5 percent of some mica-rich layers in the coarser chert. Some grains of this mineral have rectangular outlines in part. In the finest chert, minute black grains are too small to be resolved under the microscope.

Quartz siltstone, a very fine-grained quartzose rock thinly interbedded with black carbonaceous slate occurs about half a mile north of the mouth of Rough and Ready Creek (pl. 4). Megascopically, the rock resembles chert, but a thin section shows that the quartz grains are separated from one another by mica and are more diverse in size than those in chert. The rock is composed largely of quartz, but contains about 10 percent of biotite, 5 to 10 percent muscovite, minor pyrite and carbonate and rare albite and apatite. Some quartz siltstone beds grade into slate.

A belt of lenticular carbonate rock masses extends from south of the Merced River northward to about the latitude of Angels Camp. East of San Andreas, several blocks of limestone, probably derived from this belt, occur in a shear zone south and east of the granodiorite mass. North and east of San Andreas are several large masses of limestone of uncertain stratigraphic position, and on the Merced River scattered limestone lenses occur as far east as El Portal.

The thickness of the carbonate bodies varies widely. On the Merced River, the two limestone masses near the abandoned cement plant have a total thickness of 125 feet; at Bower Cave the limestone is about 400 feet thick, and on the Stanislaus River it is more than 5,000 feet thick.

The carbonate rocks range from limestone to dolomitic limestone, and possibly to dolomite. Most of the limestones are coarsely crystalline, but the least metamorphosed are aphanitic. Most of the dolomite or dolomitic limestone is fine grained. Metamorphic minerals formed only locally in the carbonate rocks.

The carbonate rocks in which primary structures have been observed are mostly thin bedded but include thick bedded units on the Stanislaus River. One layer, in unit 43 on the Merced River, is cross-bedded (pl. 3). Quartz sand grains are absent. The only known fossils in the carbonate rocks of this belt are the Foraminifera from near Hites Cove, south of the area studied. Absence of fossils may be due partly to the metamorphism, but not wholly, as they are also absent in the considerable volume of carbonate rock in which bedding features are well preserved.

Volcanic and metavolcanic rocks are somewhat more common in and near the limestone belt than elsewhere in the chert member. Immediately upstream from the mouth of the North Fork of the Tuolumne River, pyroclastic rocks about 500 feet thick are overlain and underlain by limestone; pyroclastic rocks are missing, however, about half a mile to the west, where the Tuolumne River crosses the projection of the same belt. Aphanitic dark-green metavolcanic rocks are interlayered with the limestone near the west quarter-corner of sec. 34, T. 3 N., R. 14 E. and in the NE¼ sec. 26, T. 3 N., R. 14 E. Quartz-mica-magnetite schist, probably derived from rhyolite, lies within a thick unit of limestone in the NE¼NW¼ sec. 34, T. 3 N., R. 14 E. on the Stanislaus River. The schist contains rudely elliptical pods (amygdules?) of coarse-grained carbonate.

Massive dark-gray quartzite is exposed on the southwest side of the Merced River about half a mile southeast of Clearing House, and thick- to thin-bedded quartz sandstone is exposed on the south side of the river in the south part of sec. 13 and the SW¼ sec. 14, T. 3 S., R. 19 E. Similar sandstones were found on the South Fork of the Merced in the northwest part of T. 4 S., R. 20 E. The stratigraphic and structural relations of the sandstone to the chert-bearing strata are not clear. In thin section, the quartzite from the first locality is seen to consist largely of well-rounded quartz grains in a matrix of fine-crystalline quartz, biotite, and muscovite. About 10 percent of the rock consists of irregularly shaped grains of cordierite or feldspar containing abundant inclusions of quartz and abundant minute grains of an opaque material. The sand-size fraction comprises about 40 percent of the sandstone in the SE¼ sec. 14. The sand grains are mostly quartz but untwinned feldspar is common; twinned plagioclase and garnet are rare. The matrix is sericite, untwinned feldspar, and quartz.

WESTERN BELT

Turner (1894a) included with the Calaveras formation of the western belt all of the sedimentary and interbedded pyroclastic rocks between the Copper Hill volcanics and the belt of volcanic rocks formed by the Logtown Ridge formation and the Brower Creek volcanic member of the Mariposa formation. Most of the major categories of epiclastic rocks are represented and the belt is cut by several faults of the Bear Mountains fault zone. From the assemblage of rocks originally assigned to this part of the Calaveras formation (and from other units) Taliaferro separated some which he included with the Consumnes formation, of Jurassic age, but his published descriptions do not provide an adequate basis for correlation of individual mappable units.

Limestone, forming scattered discontinuous bodies, is the only rock that has yielded Paleozoic fossils. All of the other rock types are known to occur in the Jurassic section, but are not known to be restricted to the Jurassic. Some of the fossiliferous limestone forms reworked blocks in the Jurassic strata or slivers in fault zones and it remains to be proven whether any of the Paleozoic rock is in place in the belt mapped by Turner as Calaveras formation. Nevertheless, the writer believes that the largest, most concentrated limestone bodies are among the rocks with which they were originally deposited. According to Turner's (1894a) map of the Jackson quadrangle, limestone lenses are most abundant and are largest in an area extending about 2 miles north from the Mokelumne River. On the banks of Pardee Reservoir (Mokelumne River, pl. 7), the rocks associated with the limestone lenses are quartzose slate and chert with minor volcanic rock and, together with the limestone, are included with the Calaveras formation in this report. Also included with the Calaveras formation here is a belt extending northward in strike with these exposures to a point north of the Cosumnes River (pl. 1).

COSUMNES RIVER EXPOSURES

Rocks exposed in and near the Cosumnes River in secs. 20, 21, and 28, T. 8 N., R. 10 E. (units 33–41, pl. 8) are tentatively included with the Calaveras formation, following Taliaferro (1943b, p. 283, fig. 2). Several shear zones, and the absence of means of determining tops of beds within the area leave open the possibility of alternative interpretations of the structure and stratigraphic relations. Taliaferro (1943b, p. 283) states that on the Cosumnes River, a thick basal conglomerate of the Cosumnes formation overlies the Calaveras formation on both sides of an anticline. Conglomerates containing limestone debris occur through several hundred feet of section in the Cosumnes formation (see pl. 10) and there is little reason to designate any particular conglomerate bed, even though it be thicker and lower in the section than the others, as the base of the formation. Similar conglomerates west of the beds here placed in the Calaveras formation are interbedded with rocks in which bedding attitudes and sedimentary features indicate homoclinal structure with tops east. These beds are probably equivalent to the Cosumnes or Mariposa formations, and if intervening beds are Calaveras formation they are repeated by faulting rather than folding, as postulated by Taliaferro.

The rocks here included with the Calaveras formation include slate and graywacke, volcanic rocks, quartz-rich sandstone and granule conglomerate, thin-bedded chert and slate, and minor calcarenite. Macroscopic descriptions of these rocks are given on plate 8. Petrographic descriptions of thin sections of quartz sandstone and granule conglomerate are given below for comparison with similar rocks included with other units.

A thin section of the granule conglomerate associated with the calcarenite on the southwest bank of the river near the center of sec. 21, T. 8 N., R. 10 E. (unit 40, pl. 8) shown well-rounded clastic grains in a matrix of coarse-grained clastic carbonate containing oolites and comminuted fossil debris. The clastic grains are composed of feldspathic quartzite, strongly sheared aggregates of quartz grains, chert with scattered carbonate rhombs, perthite, and a fine-grained granitic rock consisting of granoblastic quartz surrounding subhedral, much-altered feldspar crystals. The feldspar in some of the feldspathic quartzite clasts is mostly potassium feldspar, and in others is mostly sodic plagioclase. The feldspathic quartzites strongly resemble rocks of the Shoo Fly formation (Blue Canyon formation of Lindgren, 1900) exposed in the eastern part of the Colfax 30-minute quadrangle.

The quartz-rich sandstone exposed near the NW cor. sec. 28, T. 8 N., R. 10 E. (unit 37, pl. 8) consists largely of grains of quartz, and lesser amounts of chert, sericite slate, quartzose slate, siltstone, orthoquartzite, volcanic rocks, and quartz aggregates showing elongate quartz grains with strongly sutured contacts. The matrix is sericite, but the amount of matrix is difficult to determine because not all of it is distinguishable from the slate fragments. Most of the quartz grains are angular but some are well rounded and a few show overgrowths, as do some grains in the orthoquartzite clasts. Most of the quartz grains contain vacuoles arranged in planes and show undulatory extinction, but at least part of the undulatory extinction has been developed in the present rock, as shown by the relation of the extinction to point contacts between grains. Rare quartz grains have needle-like inclusions of rutile and one grain has inclusions of biotite. Some of the chert is microcrystalline and some cryptocrystalline. The siltstone is composed of quartz and sericite. Included under the term "quartzose slate" are grains showing a considerable range in the proportions of the two minerals. Volcanic rock fragments are dark colored and cryptocrystalline to microcrystalline and are probably devitrified glass.

MOKELUMNE RIVER AND JACKSON CREEK EXPOSURES

Rocks included with the Calaveras formation are exposed on the banks of Pardee Reservoir on the Mokelumne River and on Jackson Creek. Near Pardee Reservoir, they are separated from rocks correlated with other formations by exposed shear zones, but the contacts on Jackson Creek are not exposed. Almost all of the rock included with the Calaveras formation near Pardee Reservoir is quartzose phyllite that weathers gray to light brown. The phyllite is aphanitic and bedding is not apparent in most exposures. Other rocks included with the Calaveras formation near Pardee Reservoir are small lenses of limestone and a single exposure of amygdaloidal lava. The lava is exposed near the limestone lens in the western part of sec. 17, T. 5 N., R. 11 E. (unit 28, pl. 7). Rocks exposed near Jackson Creek that are included in the Calaveras formation differ from those near Pardee Reservoir in that quartzose phyllite is rare; black chert forming layers about 1 to 2 inches thick with interbedded black phyllite is the most common rock in Jackson Creek. The chert has a dull luster and conchoidal or splintery fracture. Fine-grained volcanic breccia (Jackson Creek section unit 7, pl. 7) is interbedded with quartzose phyllite in sec. 1, T. 5 N., R. 10 E. A thin conglomerate is interbedded with quartzose phyllite in the same section. The conglomerate contains clasts of chert, slate, and volcanic rocks, and may be of intraformational origin.

The differences between the sections exposed in Jackson Creek and on Pardee Reservoir about 3 miles away reflect the complexity of the pattern of distribution of rock types in the belt underlain by the Calaveras and Cosumnes formations.

In thin section, the quartz-rich phyllite is seen to contain 60 to 98 percent quartz, mostly in the form of a granoblastic groundmass. Angular, silt-size quartz grains are common. These grains are clear and show no undulatory extinction. Sericite and minute tremolite crystals form 40 percent to less than 15 percent of the rock. Sparse grains of a carbonate mineral, pyrite, and epidote, generally larger than the grains of the groundmass, are found in some specimens. Brown tourmaline in nearly equidimensional grains is rare. Carbonate and epidote as well as quartz form veinlets. Nearly all thin sections show round to elliptical areas as much as 0.2 mm long that may be replaced Radiolaria. They consist of granular quartz, generally coarser grained and containing much less of the associated minerals than the quartz of the groundmass.

Thin sections show the black chert to consist of about 98 percent microcrystalline granoblastic quartz with minor sericite. The round structures attributed to Radiolaria are common also in the chert, but no recognizable organic structures were found.

FOSSILS AND AGE

The Calaveras formation was thought by Turner (1893a, p. 309; 1893b) to be of Carboniferous age and is assigned to the Mississippian in Wilmarth (1938, p. 315). Taliaferro (1943b, p. 280) surmised that the Carboniferous is represented in the Calaveras formation but that part is of Permian age and part is pre-Carboniferous. During the present investigation well preserved Foraminifera were found at three localities and indicate that part of the formation is of Permian age; large parts of the formation have not yielded diagnostic fossils and may be older. Crinoid plates are abundant in limestone of the Calaveras formation at many places but the localities are not listed here because the plates are of little value in dating.

The first three fossil localities represent the western belt of the Calaveras formation, as follows:

One is in sec. 10, T. 4 N., R. 11 E., at the west boundary of the San Andreas quadrangle where Foraminifera compose most of a block of limestone about five feet in diameter exposed in the north wall of a railroad cut. Boulders of similar limestone, probably removed from the cut, are abundant south of the tracks. The limestone block is surrounded by conglomerate, tuff, and slate belonging to the Mariposa formation of Jurassic age and is interpreted as a boulder derived from the Calaveras formation of the western belt.

According to L. G. Henbest and R. G. Douglass (written communication, 1952) the Foraminifera include the following:

Tetrataxis sp.
Parafusulina or *Schwagerina* sp.
Parafusulina (apparently 2 species)
Nagatoella aff. *N. orientis* (Ozawa), 1925
Misellina sp. (or possibly a species of *Cancellina*)

They state:

Though the limestone is somewhat metamorphosed and deformed, the Foraminifera are definitely determinable as Permian * * *.

A combination of two kinds of difficulty prevents a closer age determination. One of these is uncertainty resulting from poor preservation and the other is uncertainty of the exact position of this fauna in the Permian. This fauna is distinctly circum-Pacific and Asiatic in composition and the stratigraphic records of *Cancellina*, *Misellina*, and *Nagatoella* are complicated. Leonard or possibly Word age is suggested, but on the evidence available at this time we could not prove that it is not earlier Permian than Leonard nor that it is not later Permian than Word.

The second locality in the western belt of Calaveras formation is in a limestone block exposed in Jackson Creek in the SW¼ sec. 31, T. 6 N., R. 11 E. (pl. 7). The limestone is surrounded by cherty slate and bedded chert also believed to be part of the Calaveras formation. Foraminifera were found by Turner (1894b, p. 446) on the Mokelumne River probably at about the same horizon, but his locality was not rediscovered during the present investigation.

Regarding the collection from Jackson Creek, Mr. Henbest (written communication, 1953) says:

Schubertella sp. aff. S. *kingi* Dunbar and Skinner; *Schubertella* (?); and three species of *Parafusulina* (or possibly *Pseudofusulina* in part) are barely recognizable. Permian age is definitely indicated. Fusulinids of the apparent grade of evolution represented by these specimens characterize the late Hueco and Leonard Faunas of West Texas. I doubt that they are as old as the Wolfcamp at the type locality, but may be as young as the early Guadalupian.

Fossils from a third locality in the western belt of the Calaveras formation, the Allen marble quarry in sec. 13, T. 6 N., R. 10 E., are reported by Mr. Henbest and Miss Helen Duncan (written communication) to be of Permian age.

Fossils other than crinoid debris have been found at only one place in the eastern belt of Calaveras formation in the area covered by this report. These were Foraminifera discovered by Turner (1893a, p. 309) near Hite Cove, in the El Portal quadrangle, which were identified as *Fusulina cylindrica* and regarded as of Carboniferous age. Turner's collection has apparently been lost and by modern standards "*Fusulina cylindrica*" only means Pennsylvanian or Permian age. Regarding a collection from NW¼NW¼ sec. 2, T. 4 S., R. 19 E., near Hite Cove, Mariposa County, by L. D. Clark and N. K. Huber, Mr. Henbest wrote that the fossils are altered beyond recognition.

In the Sonora quadrangle fossils were found by the writer in a block of limestone more than 30 feet wide associated with strongly sheared conglomerate that probably is part of the Mariposa formation. The locality is in Mormon Creek, 1.1 miles S. 38° W. of Jackass Hill and is within the Melones fault zone.

The conglomerate contains pebbles of limestone, chert, and black carbonaceous slate. These, as well as the fossiliferous limestone, resemble the lithologic assemblage near Hite Cove rather than that of the Calaveras formation of the western belt. Among the fossils, Mr. Henbest (written communication, 1955) identified:

?*Neofusulinella montis* Thompson, 1946
?*Parafusulina turgida* Thompson, 1946
Crinoid columnals

and says:

The fusulinids and other fossil remains are attenuated by plastic flow of the rock. Permian age is definitely indicated. Upper McCloud age is strongly suggested, but the exact age in the Permian and the generic and specific determinations listed above must be held in question because of the obscurity of the fossils.

Fragmental megafossils were found in the SE¼NE¼ sec. 22, T. 4 N., R. 11 E. about 0.6 mile southeast of the Calaveras River in a limestone mass that probably slumped into beds of the Mariposa formation during their deposition. The limestone is exposed in an area about 50 feet long and 20 feet wide. The relation of the limestone to surrounding rocks is not evident; rocks west of the limestone are not exposed, but east of the limestone are poorly exposed sandstone and conglomerate containing fragments of chert, quartz, and slate. The sandstone and conglomerate are in strike with similar rocks which form unit 26 of the Calaveras River section (pl. 6). The limestone contains abundant fragmental organic material. The following have been identified by Jack E. Smedley (written communication, 1955) of the U.S. Geological Survey:

Crinoid columnals
Spiriferina sp. undet.
Rhynchonellid brachiopod
Terebratulid brachiopod
Trigonid pelecypod
Pectenid pelecypod
Murchisonid gastropod
Spirorbis sp.

According to Smedley:

> The scraps are too incomplete and poorly preserved and the forms represented are not sufficiently diagnostic to permit accurate dating of the beds from which the fossils were collected. Moreover the forms identified belong to groups in which it is often difficult to distinguish between the Permian and Triassic genera and species even with good material. The presence of *Spiriferina*, rhynchonellids, and terebratulids in fair numbers suggests that this is a Triassic fauna. The *Spiriferina* has certain characters which relate it more to Triassic than to Permian species. The possibility that this is a Permian fauna cannot, however, be ruled out completely.

As the fossils do not permit accurate dating, and as no geologic evidence has been found to indicate that Triassic rocks occur in the region, this limestone may be of Permian age and derived from the Calaveras formation.

Although the Permian age of part of the Calaveras formation is well established, the very size of the area east of the Melones fault zone that is underlain by steeply dipping rocks included with the Calaveras formation suggests that rocks of other than Permian age might be present. In addition, available structural data suggest that the rocks included with the Calaveras formation on the Merced River constitute a generally homoclinal section with the younger beds on the east. None of the four members distinguished on plate 3 is repeated by major folds. Allowing for considerable thickening by smaller folds and faults, the section is still apparently tens of thousands of feet thick. This section can be conveniently divided by the belt of lenticular limestone masses that extend northwestward from the Merced River west of Incline which Turner (1897) has previously considered to be a stratigraphic horizon. The rocks northeast of this belt and interbedded with the limestone are the same in all sections examined during this investigation and in the Calaveritas quadrangle (Clark, 1954), except for the distinctive quartz-rich sandstone exposed near El Portal on the Merced River. These rocks apparently represent a single episode of deposition in which no significant break is known. The rocks northeast of the limestone may all belong to the same period as the limestone near Hite Cove, or they might be in part of Triassic age.

Lithologic similarity of the two lower members of the Calaveras formation to Mesozoic formations in the region suggests the possibility that these members may be of Mesozoic age. This interpretation cannot be eliminated, but is not supported by more substantial evidence. On the contrary, abundant crinoid plates in a limestone pod (unit 29, pl. 3) in the clastic member suggest Paleozoic rather than Mesozoic age and structural data indicate that the section from Bagby eastward to Hite Cove is essentially homoclinal with tops eastward; no major fault zone was found within this interval.

ROCKS OF JURASSIC AGE

Steeply dipping strata of Jurassic age underlie most of the area of bedrock exposures west of the Melones fault zone but are known east of that zone only near the south edge of the area covered by this report. These Jurassic rocks are divided into two main blocks by the Bear Mountains fault zone, along which the minimum stratigraphic separation, at least in the northern part of the area, must be many thousands of feet. The Jurassic strata consist largely of volcanic rocks, probably mostly of andesitic and basaltic composition but including some rhyolite or dacite; and of epiclastic rocks, mostly slate and partly graywacke and conglomerate. All are apparently marine deposits.

The stratigraphic nomenclature used in this report for the rocks of Jurassic and probable Jurassic age is consistent with that of previous geologists in that it separates sequences composed dominantly or entirely of epiclastic material from those consisting dominantly or entirely of volcanic material. The formations so defined are several hundred to nearly 15,000 feet thick. Even with a gross separation of this kind the stratigraphy is complicated (pl. 9) and it is impossible to work out from the fragmentary record on the present surface a complete three-dimensional picture showing the relations in time and space of all stratigraphic units to one another. Fossils are sparse and have yet to be found in some formations. Lithologic variations within any one formation, either volcanic or epiclastic, may be greater than that between two formations of either class.

The stratigraphic succession can be deciphered in any cross section normal to the strike where adequate structural information is available, but use of individual formation names can be extended with confidence along the strike only so far as the component rocks can be traced by surface exposures. If a formation name be used to include areas of exposure that are not continuous on the surface with the type locality, significant geologic relations might be masked by an oversimplified concept of the stratigraphy. Difficulties in arriving at a complete understanding of the stratigraphy, although augmented by later folding and faulting, result primarily from the original distribution of strata constituting the Jurassic section. The volcanic rocks were derived from a number of vents distributed in an unknown pattern about the area in which material of epiclastic origin was accumulating. Activity of individual vents was sporadic and certainly not all volcanic centers were active at the same time. Nevertheless, the distribution of volcanic rocks indicates that in some places deposits from two or more centers overlapped or intertongued. Because the lower, middle, or upper part of a volcanic pile related to one center can conceivably intertongue with any part of other piles, as well as with the epiclastic rocks, the possible number of complex relationships is considerable.

In this report the use of previously accepted formation names is restricted along strike to rocks that form belts of exposure continuous with type areas. In a direction across the regional strike, formation names are extended to include outcrop areas repeated by folding. New names are proposed for other outcrop areas of sufficient size to warrant naming. Type sections are designated to fulfill the requirements of stratigraphic nomenclature, but cannot be used as rigid standards of the sequence and character of deposits within each formation over an area, say, equivalent to a 15-minute quadrangle.

A minor problem of stratigraphic nomenclature involves small elliptical outcrop areas of volcanic rocks within belts of epiclastic rocks, or the reverse. Are these lenticular members of the epiclastic formation or are they tongues of the overlying or underlying volcanic formation? In some places intertonguing relationships can be shown by mapping, but nowhere is it possible to establish rigorously that a particular map unit is a lens. This results largely from the fact that dips are steep and many sections are homoclinal so that only in a few places can stratigraphic sections be studied in a direction normal to the strike. Figure 3 illustrates relationships that may be encountered in the western Sierra Nevada; the east and west faces of the block can be regarded as faults. Unit 2 (fig. 3) is readily recognizable as a tongue of volcanic formation C because in part of the area shown it can be seen on the surface to form an unbroken sequence with the rest of the formation. Exposures of unit 1, on the other hand, suggest that it is an isolated lens of volcanic rock in an epiclastic formation. As illustrated, however, it is connected beneath the surface with volcanic formation A and is therefore a tongue of that formation. Unit 3 is well within volcanic formation C and is not connected at the surface or at depth with other epiclastic rocks. It is reasonable to believe, but impossible to prove by surface mapping, that unit 3 is a member of formation C—it may be the end of a tongue formerly connected above the erosion surface with an epiclastic formation. In making the interpretations shown on the accompanying maps and cross sections, it has been necessary to decide arbitrarily whether some map units or groups of units would be shown as tongues or lenses. These decisions affect the stratigraphic nomenclature, but do not notably influence interpretation of the geologic history—whether unit 1, for example, is a tongue or a lens, it indicates that unconsolidated volcanic material was supplied at that particular stratigraphic position. They do, however, bear on problems relating to the limits and physiography of the basin of deposition and directions of transport.

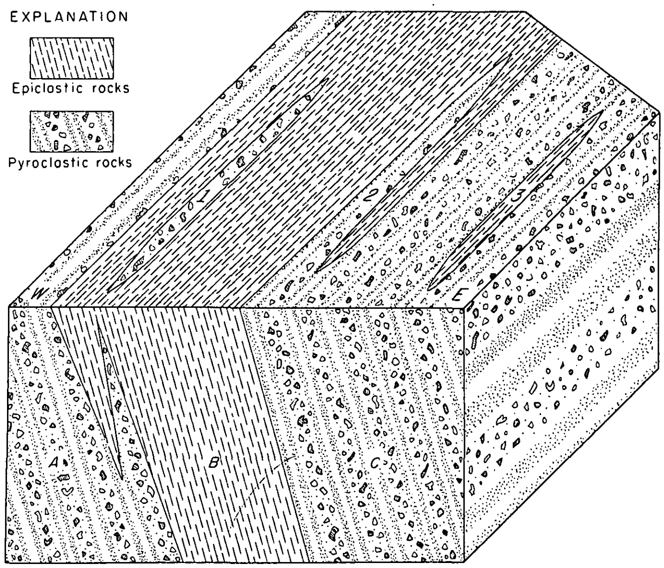

FIGURE 3.—Block diagram of homoclinal section showing intertonguing and possible lenticular relationships.

Descriptions of the stratigraphic units of Jurassic and probable Jurassic age in the following pages are brief. In many respects, the composition, texture, and original structures of the rocks are similar throughout the section and can be more conveniently discussed in terms of the area as a whole.

ROCKS EXPOSED IN THE CENTRAL BLOCK AND MELONES FAULT ZONE

ROCKS OF MIDDLE (?) JURASSIC AGE

A small isolated body of volcanic and epiclastic rocks exposed about 6 miles southwest of Sonora contains fossils determined by Imlay (in Eric, Stromquist, and Swinney, 1955, p. 12) to resemble closely species in the Mormon sandstone of Middle Jurassic age. The fossils were found in the SE¼ sec. 20, T. 1 N., R. 14 E., about 5¾ miles southwest of Sonora (pl. 1). Fossils of Middle Jurassic age have not been found elsewhere in the area between the Merced and Cosumnes Rivers. The fossils from southwest of Sonora occur in tuff, about 65 feet from the contact of the tuff with conglomerate. Eric, Stromquist, and Swinney (1955, p. 12 and pl. 2) correlated the tuff with the Logtown Ridge formation and the conglomerate with the Mariposa formation, both of Late Jurassic age, and hesitate to accept the interpretation that these rocks are of Middle Jurassic age. They do not, however, discuss the geologic evidence for their correlation and it seems entirely possible that these rocks are, in fact, of Middle Jurassic age. The fossiliferous tuff forms part of a block that is nearly surrounded by gabbro and serpentine and is separated from the main belts of the Logtown Ridge and Mariposa formations by a major fault (Eric, Stromquist, and Swinney, 1955, pl. 2). The block has been displaced and rotated, for strikes within the block are northeasterly, nearly normal to the consistent northwesterly strike of rocks outside of the Melones fault zone in this vicinity.

AMADOR GROUP

The Amador group was named by Taliaferro (1943b, p. 282–284) who designated two type sections, one on the Cosumnes River and the other on the Merced River. On the Cosumnes River, he divided the Amador group into two formations, the Cosumnes formation below, and the Logtown Ridge formation above. A generalized cross section along the Cosumnes River at a scale of about 2 miles equal 1 inch (Taliaferro, 1943b, fig. 2) indicates roughly where the contacts of the formations are to be placed. Taliaferro did not recognize the existence of the Bear Mountains fault zone at this latitude and included the rocks of both the western and central blocks with the Amador group, nor did he designate which part of the section in the Cosumnes River is meant to be the type section. Presumably, however, the type section extends westward from Huse Bridge on Highway 49, for the bridge is at the east side of the volcanic sequence that underlies Logtown Ridge. Along the Merced River, Taliaferro (1943b, p. 283) divided the Amador group into five formations, but provided only very brief descriptions of these units and did not indicate where the contacts are to be placed. The formation names proposed by Taliaferro for the Cosumnes River section are useful, but more complete descriptions of the formations are necessary. In redescribing the formations, it will be convenient simultaneously to modify Taliaferro's usage, and propose definitions that will be more readily applicable in geologic mapping.

Only one type section should be designated for the Amador group. The type section is on the Cosumnes River southwest of Huse Bridge and is shown on plate 10. The name Logtown Ridge formation is applied to the volcanic sequence, and the name Cosumnes formation is applied to the underlying epiclastic sequence. The lower contact of the Cosumnes formation is tentatively placed about 2.1 miles southwest of Huse Bridge at the west unit 42, pl. 8. The contact is not exposed on the river banks. The contact between the Logtown Ridge and Cosumnes formations, drawn at the top of the slate layer exposed on the north side of the river about 7,400 feet southwest of Huse Bridge (pl. 10), is parallel to bedding in both formations. At Huse Bridge, the Logtown Ridge formation is in depositional contact with an overlying epiclastic sequence previously included with the Mariposa formation (Lindgren and Turner, 1894; Taliaferro, 1943b, fig. 2). The upper contact of the Logtown Ridge formation is at the base of the lowermost epiclastic bed of the overlying sequence.

COSUMNES FORMATION

Exposures of the Cosumnes formation extend southward beyond Sutter Creek and probably extend northward beyond the boundary of plate 1. The most abundant rock in the Cosumnes formation is black to gray slate and siltstone. Conglomerate in which the pebbles and boulders are composed of a large variety of rock types is common in the type section. Pyroclastic rocks and graywacke are less common than the other rocks. The Cosumnes formation is about 3,600 feet thick near the Cosumnes River.

Lithology

In the type section of the Cosumnes formation, conglomerate is dominant in the lower part of the formation, interbedded graywacke and slate in the middle part, and interbedded mafic tuff and black slate in the upper part, but most of these rocks occur in varying amounts throughout the section. The proportion of conglomerate is greater in the type section of the Cosumnes formation than elsewhere in this formation or any of the others, but the conglomerates are apparently lenticular and the type section may not be representative of the whole formation. Both the conglomerates and graywackes in the Cosumnes formation resemble those in the other formations.

Conglomerates of the Cosumnes formation can be divided on the basis of sorting into two types, one resulting from current transport and the other from mudflow. The two types are interbedded with slate, graywacke, and each other. Layers of the better sorted conglomerate contain internal bedding and, at least superficially, a normal gradation of grain size from the largest fragments to the smallest—space between the larger pebbles is largely filled with smaller pebbles and sand. These are features of current-deposited conglomerate. Layers of poorly sorted conglomerate are not internally bedded and the boulders and pebbles are dispersed in a matrix of slate and siltstone (fig. 4). Exposures of poorly sorted conglomerates contain widely scattered boulders

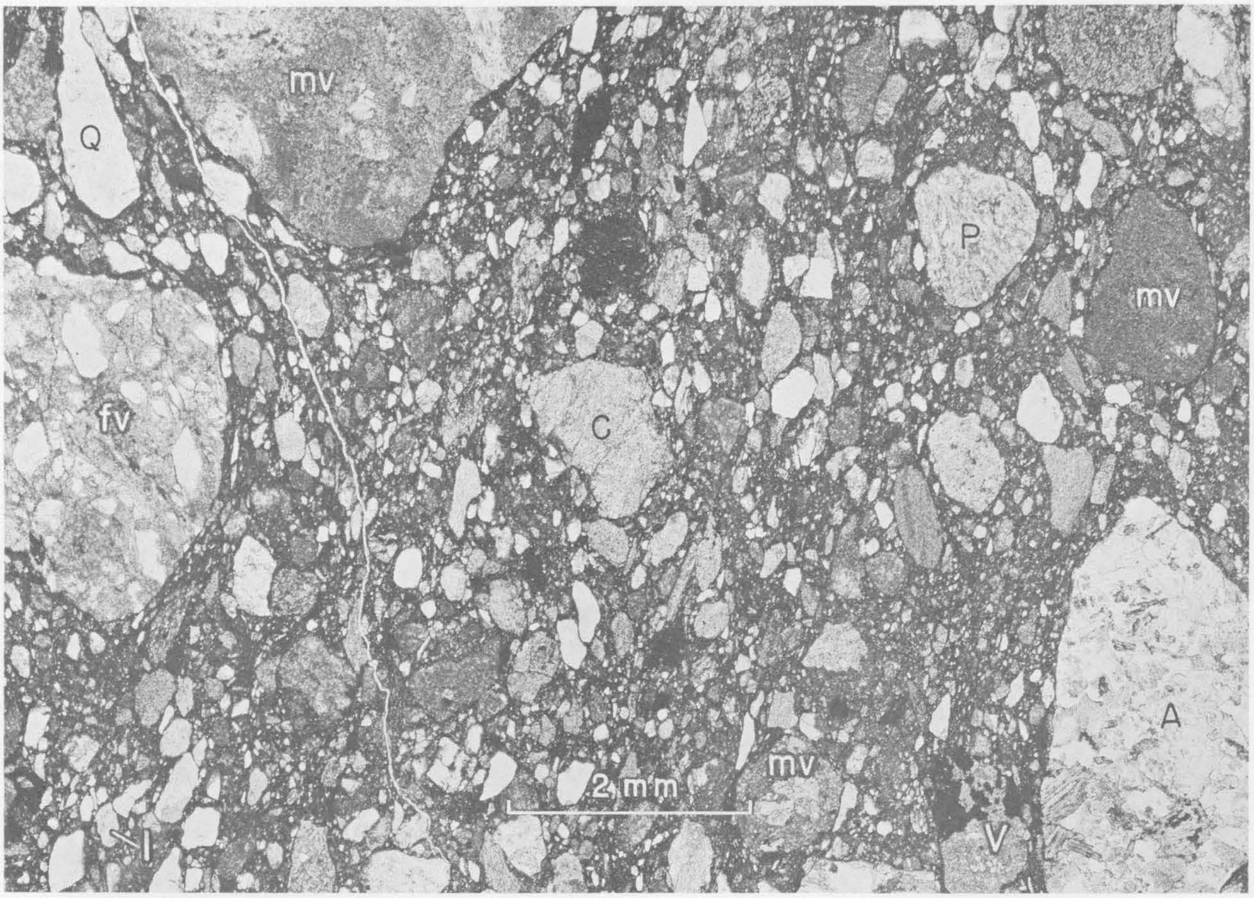

FIGURE 4.—Photomicrograph of mudflow conglomerate from Mariposa formation, NE¼NE¼ sec. 2, T. 3 N., R. 11 E. Only a small fraction of the total size range of clastic fragments is shown. Felsic volcanic rock with quartz (white) phenocrysts, fv; mafic volcanic rocks, mv, in part with plagioclase and pyroxene phenocrysts; quartz, q; granophyre composed of intergrown K-feldspar and quartz with minor biotite, a; volcanic rock partly replaced by pyrite, v; mica-quartz phyllite, p; chert-carbonate rock, c; clastic limestone, l.

which are several times as large as the other boulders in the layer. These conglomerates are probably of mudflow origin. Both kinds of conglomerate occur in the Cosumnes formation on the Cosumnes River and are well exposed in a small canyon cut into rocks of the Mariposa formation in the SW¼ sec. 1, T. 3 N., R. 11 E., about 4 miles southwest of San Andreas.

Fossils and age

Taliaferro (1943b, p. 284) ascribed to the Amador group a late Middle to early Late Jurassic age, but does not give a specific age for the Cosumnes formation. He mentions several fossil localities but does not describe the localities or faunas in detail. Later collections indicate that the age of the upper part of the Cosumnes formation is within the interval extending from middle Bajocian to late Callovian. Eric, Stromquist, and Swinney (1955, p. 10, 11) report finding an ammonite in the Cosumnes River section about 500 feet below the top as the formation is described in this report (Mesozoic locality 22175, U.S. Geol. Survey collections). This specimen was compared by Imlay (1952, p. 975) with the Callovian genus *Grossouvria*, but he now considers (written communication, January 1960) that:

> its coiling is too involute for that genus and that it agrees better in coiling and rib pattern with *Pseudocadoceras* which occurs in considerable numbers in the lower part of the overlying Logtown Ridge formation.[1] The speciman suggests, therefore, that the upper part of the Cosumnes formation is not older than Callovian. Furthermore, considering that the Logtown Ridge formation grades downward into the Cosumnes formation, the presence of *Pseudocadoceras* in the basal beds of the Logtown Ridge formation implies that the Cosumnes formation is at least in part of Callovian age * * *.

LOGTOWN RIDGE FORMATION

The name Logtown Ridge formation is applied in this report to the sequence of volcanic rocks that overlies the Cosumnes formation in the Cosumnes River

[1] While this report was being prepared for publication, a report describing late Jurassic fossils from the western Sierra Nevada in more detail was published by Imlay (1961).

southwest of Huse Bridge. It extends from north of the area studied to a point between Drytown and the Mokelumne River where it is overlapped by the Brower Creek volcanic member of the Mariposa formation. The southern boundary of the Logtown Ridge formation is drawn arbitrarily on the regional geologic map and block diagram (pls. 1 and 2), for detailed mapping that might show the position of the contact between the Logtown Ridge formation and the younger volcanic sequence is lacking. The Logtown Ridge formation has been examined only in the type section, where it is about 4,300 feet thick and consists largely of volcanic breccia and tuff. Two thin layers of pillow lava are present in the type section.

The name Logtown Ridge formation was used by Eric and others (1955, p. 11–12, pls. 1, 2) to include volcanic rocks extending as far south as Chinese Camp, and by Taliaferro and Solari (1949) to include volcanic rocks in the vicinity of Copperopolis. These sequences will be given new names because some occupy a different stratigraphic position from the Logtown Ridge formation and the position of others relative to the Logtown Ridge formation is unknown.

Lithology

In the Cosumnes River, tuff and lapilli tuff dominate the lower part of the Logtown Ridge formation and volcanic breccia dominates the upper part. Nearly all the volcanic fragments are dark green, with an aphanitic texture. Pyroxene phenocrysts in both clasts and matrix of some beds range from less than one millimeter to more than one centimeter in diameter. A few breccia beds contain scattered clasts of medium- to coarse-grained pyroxenite and coarse-grained rocks composed of plagioclase and pyroxene in various proportions. No megascopic features that indicate differences in chemical composition between the various breccia beds were observed, but the amount of porphyritic or amygdaloidal fragments differs from bed to bed. Beds may also differ in the size of the phenocrysts and in the proportion of clasts that contain phenocrysts or amygdules.

Original textures and structures of the pyroclastic rocks are well preserved along the Cosumnes River and are probably representative of features in other volcanic formations of the region that were studied in less detail. The Cosumnes River exposures show that the detritus composing various beds of pyroclastic rock was emplaced in several different ways.

Much of the volcanic breccia of the Logtown Ridge formation was apparently emplaced by subaqueous mudflows. Mudflow layers have poor sorting, lack internal bedding, and some contain boulders several feet long. Packing of fragments larger than one inch in diameter ranges widely. Clasts are angular to subrounded or well-rounded (fig. 5). The mudflow deposits range widely in composition—some contain only one or two textural varieties of lava and others contain many textural and perhaps even compositional varieties. In some layers part of the fragments are amygdaloidal but scoriaceous clasts are infrequent. Rare layers contain fragments of pyroxenite and plagioclase-pyroxene rocks. Although clasts larger than two inches in diameter are abundant in most of the probable volcanic mudflow breccias, a layer of finer volcanic breccia about 0.8 miles southwest of Huse Bridge contains widely scattered chunks as much as several feet long of somewhat contorted, thin-bedded, coarse to very fine tuff. These chunks are consistent with the notion that this layer is also a mudflow. In stream polished exposures the matrix of most of the volcanic breccias wastes away at about the same rate as the fragments (fig. 5). In one breccia layer about 100 feet thick, however, the matrix weathers much more rapidly than the fragments, leaving them in bold relief; it is exposed about 300 feet west of Huse Bridge on the Cosumnes River. Clasts are angular to subrounded and range from sand size to boulders more than 4 feet long and 2 feet thick. The large boulders are elongated parallel to the bedding in this vicinity, but no layering suggestive of bedding was observed. The clasts have little lithologic variety as nearly all contain pyroxene phenocrysts more than 2 mm in diameter—about a third of them are amygdaloidal (quartz and calcite amygdules). The matrix is composed of sand size grains of lava and pyroxene cemented by calcite. Although this layer is apparently the product of a mass movement process, "mudflow" seems hardly an appropriate term for a mass lacking in clay-size material. This layer is separated from an underlying pillow lava by about 10 feet of rubble atop the lava, and about 4 feet of bedded tuff immediately under the breccia. It is overlain by a thin amygdaloidal lava.

The mudflow deposits represent material that has moved to a permanent site after temporary accumulation in another place. A different kind of volcanic breccia, probably the result of direct deposition from explosive vents, is represented by bedded tuff and lapilli tuff layers containing scattered boulders of volcanic rock (fig. 6). Flattish blocks generally are parallel to the bedding. The shape of these fragments suggests that they are not volcanic bombs, but rather are blocks of lava. Their well-defined regular bedding indicates that the poor sorting is not the result of mass flow; and the absence of graded beds, as well as extremely wide range in the size of the clasts indicates that they were

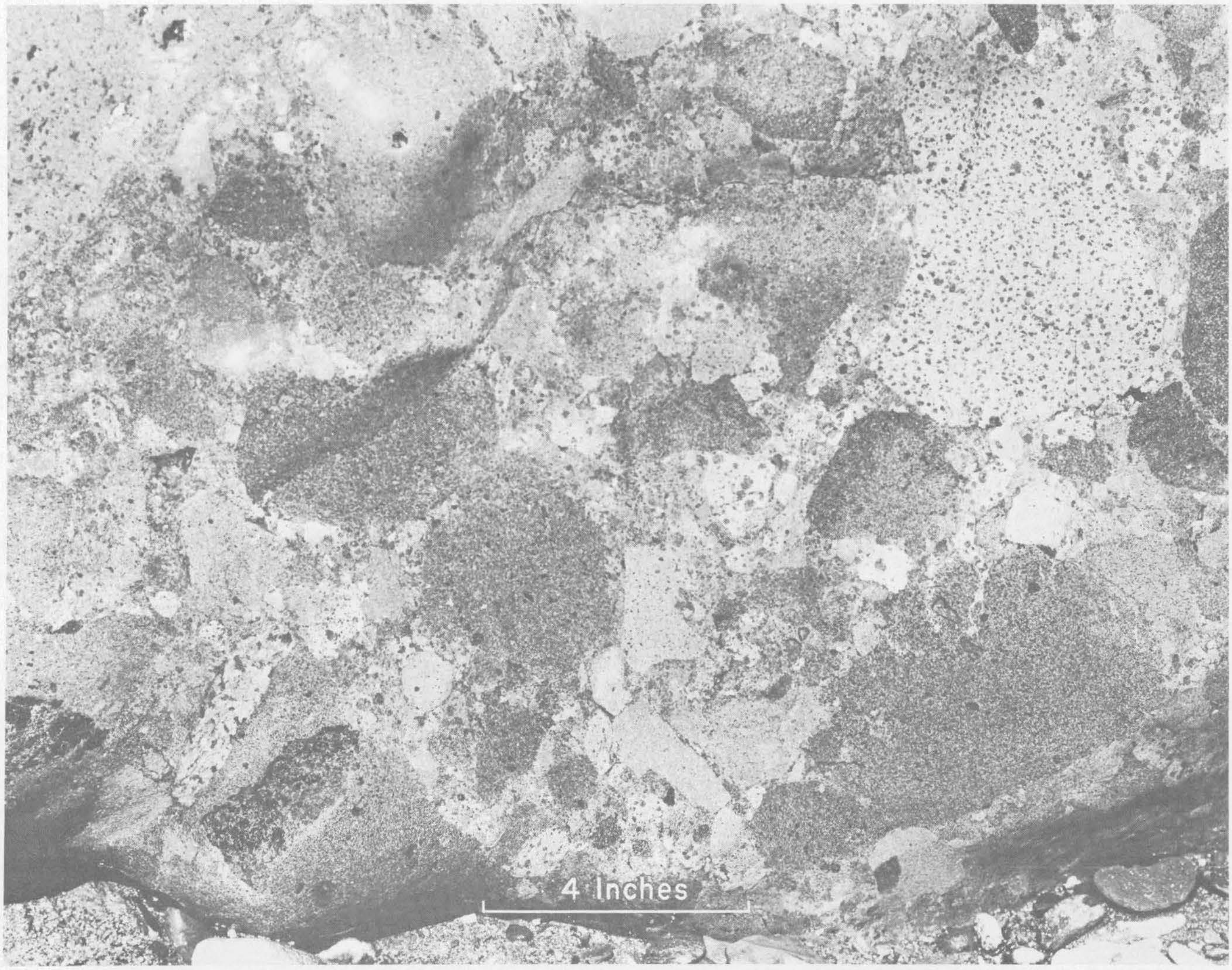

FIGURE 5.—Photograph of volcanic breccia of probable mudflow origin. Closely packed fragments. Dark spots in clasts are pyroxene phenocrysts. Fragment of plagioclase-pyroxene rock (light colored with scattered black crystals) in lower left corner between two pyroxenite (black) fragments. Part of block more than two feet long shown in upper left corner. Logtown Ridge formation, Cosumnes River, about 2,000 feet southwest of Huse Bridge.

not formed by turbidity currents. Such deposits probably record the sporadic activity of the source vent.

Load casts (Kuenen, 1957, p. 246–248, fig. 13), shown in figure 7, and more wildly contorted structures resulting from contemporaneous deformation are common in the lower part of the Logtown Ridge formation and have been noted elsewhere. Cut-and-fill structures measurable in inches are widespread in volcanic rocks of the western Sierra Nevada, but one erosion channel noted in the lower part of the Logtown Ridge formation in the Cosumnes River is about two feet deep and six feet wide at the top. The channel is cut into thin-bedded, medium- to very fine-grained tuff and filled with the same kind of material.

Many beds in the lower part of the Logtown Ridge formation contain angular fragments of very fine black tuff, like that in place in associated beds (fig. 8). In some beds the fragments are widely scattered, suggesting that they were well stirred into the enclosing coarser tuff and may have been carried a considerable distance by mudflows. In other beds the fragments are closely packed and have moved only a short distance from their source, apparently as result of restricted subaqueous slumping that involved a single layer or possibly two

FIGURE 6.—Photograph of volcanic breccia showing scattered large clasts in bedded pyroclastic groundmass. Tops of beds are toward the left. Logtown Ridge formation, Cosumnes River, about 1,000 feet west of Huse Bridge.

or three adjacent layers of the very fine tuff that constitutes the fragments.

Small clastic sills of medium-grained tuff that intruded very fine tuff (fig. 9) can be observed in the lower part of the Logtown Ridge formation along the Cosumnes River. Beds in the photograph are of subaqueous origin and graded beds are abundant stratigraphically above and below. That the medium-grained tuff forms sills, rather than lenticular beds, is shown by the associated cross-cutting dikes and by the separation and breaking of septa of very fine dark-colored tuff visible below the coin in the photograph (fig. 9). Intrusion of the sills apparently took place after deposition of the beds but before they were indurated, for although the very fine tuff was sufficiently coherent to break into angular fragments the coarser tuff was able to flow. Clastic dikes more than a few inches long are rare and both these and the sill-like bodies are the results of processes that apparently operate only locally.

Fossils and age

The Logtown Ridge formation apparently ranges in age from Callovian to upper Oxfordian or lower Kimmeridgian. Ammonites collected by Clark and R. W. Imlay (Mesozoic localities 24710 and 27397, respectively, in the U.S. Geological Survey collections) from above an abandoned ditch on the hill slope north of the Cosumnes River at the abrupt southward bend of the river about 4,550 feet southwest of Huse Bridge and about 1,000 feet above the base of the Logtown Ridge formation (figs. 4 and 28) are described as follows by R. W. Imlay (written communication, 1959):

> The ammonites belong to species of *Pseudocadoceras* that have been found in Alaska, British Columbia, and the Taylorsville area * * *. The genus *Pseudocadoceras* in Europe ranges from * * * [lower to upper Callovian].

Imlay (1952, p. 975–976) reported the occurrence of an ammonite in volcanic breccia of the Logtown Ridge formation near Huse Bridge, apparently in the upper part of the formation. He then described this ammonite as being "similar to *Divisosphinctes* from the upper Oxfordian and to some of the finer ribbed species of *Pachysphinctes* from the Kimmeridgian" but later (Imlay, written communication, January 1960) stated that "This ammonite is now identified with the genus *Idoceras* of late Oxfordian to early Kimmeridgian age." Because the Logtown Ridge formation was previously assumed to be overlain by the Mariposa formation, of Kimmeridgian age, Imlay concluded (1952, p. 976) that this specimen is of upper Oxfordian age. The slates that

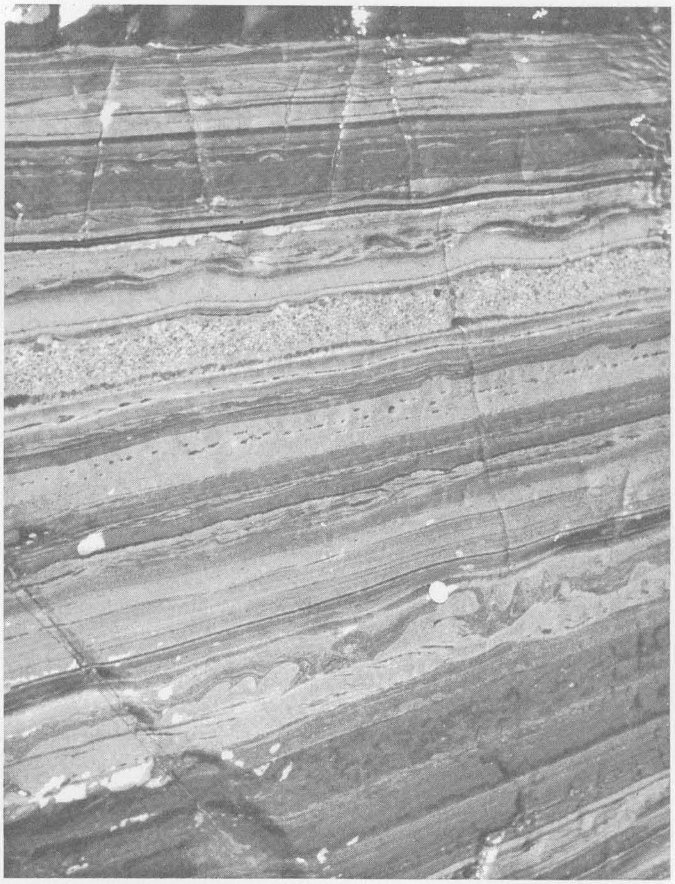

FIGURE 7.—Photograph of thin-bedded to laminated tuff showing graded bed and load casts. Dime shows scale. Elongate hard areas are concretions. Logtown Ridge formation, Cosumnes River, 1¾ miles southwest of Huse Bridge.

724-276 O-65-4

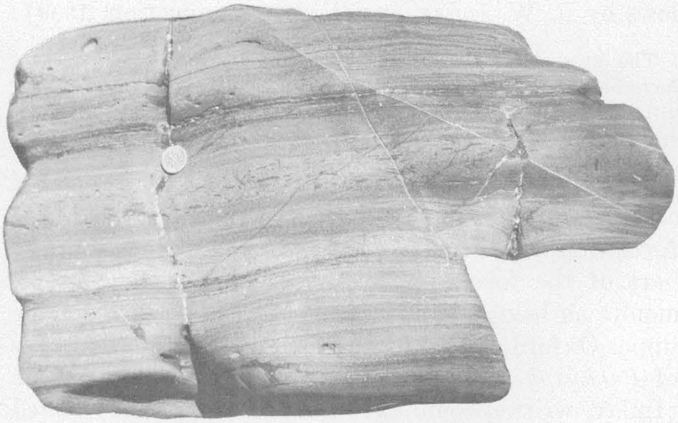

FIGURE 8.—Photograph of thin-bedded tuff showing intraformational breccia bed below dim and small-scale crossbedding under breccia.

overlie the Logtown Ridge formation, however, have not been demonstrated to be of Kimmeridgian age, so it is possible that the Logtown Ridge formation extends into the Kimmeridgian.

PEÑON BLANCO VOLCANICS

The name Peñon Blanco volcanics is here applied to the sequence of volcanic rocks that underlies the Mariposa formation from the south end of the area shown on plate 1 to a point west of the town of Melones. The formation underlies and is named for Peñon Blanco Ridge between the Merced and Tuolumne Rivers. The type section is along the Merced River. Of the three sections studied, this is the only complete one; in the Stanislaus and Tuolumne Rivers the Peñon Blanco volcanics are in fault or intrusive contact with serpentine and part of the formation is missing. The Peñon Blanco volcanics consist almost entirely of dark green mafic volcanic rocks. In the type section, where the formation is nearly 15,000 feet thick, tuff, lapilli tuff, and volcanic breccia constitute the upper part of the formation, and lava, mostly massive but some with pillow structure, constitutes the lower part. The areal pattern south of the Merced River suggests that the Peñon Blanco volcanics thin rapidly southward, beyond the edge of the map area.

The top of the Peñon Blanco volcanics is well exposed on the banks of the Merced River near the northeast corner of sec. 27, T. 3 S., R. 16 E. (fig. 23). Bedding in the Mariposa formation is parallel to that of the Peñon Blanco volcanics near the contact. The contact of the Peñon Blanco volcanics with an underlying, unnamed sequence of epiclastic rocks is in sec. 15, T. 3 S., R. 15 E., but is not exposed at the abandoned railroad grade on the south side of the Merced River where the traverse was made. A conformable contact between tuff with some interbedded chert or silicified ash and the unnamed epiclastic rocks is exposed on the margins of Lake McClure in the eastern part of sec. 7, T. 4 S., R. 16 E. The Peñon Blanco volcanics were mapped as porphyrite and amphibolite by Turner (1897) except that he differentiated a unit of thin-bedded tuff and chert which is here included in the Peñon Blanco volcanics. The Peñon Blanco volcanics of this report were placed by Taliaferro (1943b, p. 283) in the Amador group of his southern type section although he was unable at that time to establish complete correlation with the Cosumnes River section. Taliaferro (1933, p. 149–150; 1943b, p. 283) divided the Amador group in the

FIGURE 9.—Photograph of clastic sills of medium-grained tuff (light gray) in very fine tuff (dark gray). Dime shows scale. Lowest light-gray band may be a bed. Note wedge shape of various light-gray layers and brecciation of dark-gray material.

southern area into five formations but he did not define his formations and they are not used here. The Peñon Blanco volcanics of this report were included in the Logtown Ridge formation by Heyl, Stromquist, Swinney, and Wiese (pl. 2, *in* Eric, Stromquist, and Swinney, 1955). The Peñon Blanco formation is here distinguished from the Logtown Ridge formation because the two are not continuous on the surface nor are the epiclastic rocks that overlie the Logtown Ridge formation continuous with the Mariposa formation.

LITHOLOGY

Most of the Peñon Blanco volcanics are medium- to dark-green mafic pyroclastic rocks, except along the Tuolumne River where massive lavas form most of the incomplete section. Some of the pyroclastic rocks, notably those near the Stanislaus River, contain pyroxene phenocrysts. Felsic crystal tuff with interbedded chert or silicified ash, apparently in the basal part of the Peñon Blanco volcanics, is exposed in the western part of sec. 8, T. 4 S., R. 16 E. Original textures are well preserved, except on the Stanislaus River where original textures and structures have been almost obliterated by recrystallization, and in the central part of the section along the Merced River, which has been strongly epidotized. Massive aphanitic lavas, in part amygdaloidal, occur in all sections studied but form only a small part of the incomplete section along the Stanislaus River. Pillow lava forms three units near the top of the lava sequence on the Merced River; pillow structure is possible at places in lower parts of the lava sequence, but very poorly developed.

Two thin epiclastic units (units 30 and 33, pl. 5) are exposed near the Stanislaus River and are interpreted to be interbedded with the Peñon Blanco volcanics. Unit 33 is black slate; unit 30 is slate with interbedded tuff, conglomerate, and graywacke. Most of the pebbles in the conglomerate are composed of slate and volcanic rocks, but some are limestone.

With the possible exception of microcrystalline quartzose layers interbedded with the felsic crystal tuff in the western part of sec. 8, T. 4 S., R. 16 E., no chert was found in exposures along the Merced River and Lake McClure. Unit 17 (pl. 3) is on the projection of the strike of a chert unit mapped by Turner (1897) south of the Merced River and referred to by Taliaferro (1943b, p. 283) as the Hunter Valley cherts, but near the river unit 17 consists of tuff with interbedded silicified ash.

AGE

No fossils have been found in the Peñon Blanco volcanics. The upper part of the formation is not younger than Kimmeridgian for the overlying Mariposa formation is of late Oxfordian or early Kimmeridgian age. The age of the lower part of the Peñon Blanco volcanics is unknown. Part of the formation is probably of the same age as the Logtown Ridge formation.

MARIPOSA FORMATION

The Mariposa formation was named for exposures on the former Mariposa estate, southeast of Bagby (Becker, 1885, p. 18–19). As used by Turner (1894a, 1897), the Mariposa slate included all the dominantly epiclastic rocks in the various sequences west of the Melones fault zone, except those which he assigned to the western belt of the Calaveras formation. Taliaferro (for example, in Taliaferro and Solari, 1949) gave the formation a similar scope, except that he assigned some of the epiclastic rocks to the Cosumnes formation. Eric, Stromquist, and Swinney (1955, p. 12) substituted the term Mariposa formation for Mariposa slate because other rock types form important parts of the unit. Here, the name Mariposa formation is restricted to rocks in the central fault block and the Melones fault zone that are continuous on the surface with the type area, or are repeated across the strike by adequately documented structures. All previously described strata attributed to the Mariposa formation that have yielded diagnostic fossils and are within the area of figure 21 are retained in the Mariposa formation, but some rocks in the central block that were previously correlated with the Mariposa formation are excluded and will be discussed later. New names are proposed for rocks in the western block that were previously correlated with the Mariposa formation.

Exclusive of the Brower Creek volcanic member, the Mariposa formation is chiefly black slate and silty slate, but tuff and graywacke form important parts of some sections. Conglomerate is mostly scarce but is locally abundant in the lower part southwest of San Andreas.

The name Brower Creek volcanic member is here applied to a sequence of volcanic rocks, chiefly volcanic breccia, that forms part of the Mariposa formation north of the Stanislaus River. This member extends northwestward beyond the Mokelumne River, but probably not as far northwestward as the Cosumnes River. It is named for Brower Creek, whose headwaters are in the vicinity of Fowler Lookout. The Brower Creek member is thickest near Fowler Lookout, where it apparently represents an accumulation in the vicinity of a vent. Northwest of the lookout, the member divides into two tongues that are interlayered with the epiclastic rocks of the Mariposa formation. The Brower Creek member was mapped as diabase and porphyrite by Turner (1894a) and was included with the Logtown Ridge formation by Eric, Stromquist, and Swinney (1955, pl. 1). The Brower Creek volcanic member is surrounded on three sides by epiclastic rocks continuous on the surface with the type area of the Mariposa formation. Exposures of the member near Fowler Lookout and to the northwest along the strike are on the western flank of a syncline, and the beds dip steeply. Accordingly, the surface pattern portrays the true stratigraphic relations of the Brower Creek member to other parts of the Mariposa formation.

The top of the Mariposa formation is not preserved, as it is everywhere truncated by faults or erosion. North of the Stanislaus River, the Mariposa formation lies in a syncline whose eastern and western limbs are truncated by the Melones and Bear Mountains fault zones. South of about the latitude of Chinese Camp, the eastern limb of the syncline is absent and the Mariposa formation forms part of an eastward-dipping homocline. The partial section of the Mariposa formation exposed near the Merced River is about 2,700 feet thick. Near the Stanislaus River the formation seems to be much thicker, but the structure is not well enough known in the eastern part of its outcrop to justify more than a crude estimate here. Near the Mokelumne River, the Mariposa formation is about 4,000 feet thick, of which nearly all is the Brower Creek volcanic member.

The Mariposa formation is identified on all streams studied except the Cosumnes River, but the most readily accessible good exposures are on the Merced River, northwest of Bagby and in roadcuts along State Highway 49 south of Bagby. The lower part of the formation is well exposed in the Tuolumne River west of Jacksonville, and higher parts of the formation are exposed in State Highway 49 cuts northwest of Jacksonville. The railroad grade on the north side of the Calaveras River about 2½ miles west of San Andreas provides large exposures of both the epiclastic rocks and the Brower Creek volcanic member.

A departure from the usual practice of this investigation has been made in tentatively correlating with the Mariposa formation a belt of epiclastic and volcanic rocks extending from west of Altaville to south of the Stanislaus River. These rocks lie east of the main belt underlain by the Mariposa formation and are separated from it by a fault of the Melones fault zone; nevertheless, correlation of rocks in this area seems more certain than that of rocks in other outlying areas.

LITHOLOGY

The Mariposa formation, exclusive of the Brower Creek member, consists largely of slate, tuff, graywacke and conglomerate in the same manner as the Cosumnes formation. In most places, thin beds of tuff and graywacke are interbedded with the slate throughout the formation, but proportions of these rocks to slate varies considerably from place to place. In most of the sections studied, a unit of tuff about 300 feet thick is interbedded in the lower part and a unit of graywacke about 500 feet thick farther up. Eric, Stromquist, and Swinney (1955) have differentiated the slate, tuff, and graywacke of the Mariposa formation on their maps of the Angels Camp and Sonora quadrangles.

The conglomerates of the Mariposa formation mostly resemble those of the Cosumnes formation, but one type is peculiar to the Mariposa formation. This type is exposed at the south end of the area underlain by the Brower Creek volcanic member, and west of the north end of the north-trending arm of Melones Reservoir. Pebbles and cobbles of the conglomerate, as much as 5 inches in diameter in some beds, are well rounded and consist largely of resistant rocks, such as white and dark-gray vein quartz, black chert, orthoquartzite, and quartz conglomerate. Less resistant and less abundant pebbles consist of gray chert and slate, medium-grained granitic rocks, and fine-grained gneissic granitic rocks. Pebbles of volcanic rocks are rare or absent. The conglomerate and associated sandstones contain little silt- or clay-size material.

The Mariposa formation includes poorly exposed sandstone and fine conglomerate rich in quartz and chert and with little detrital matrix near the Calaveras River (unit 26, pl. 6). The quartz grains are angular to well rounded and the chert grains are angular to subangular; the sandstone also contains fragments of slate and probable quartzite made up of quartz grains with sutured contacts. The associated conglomerate has a larger proportion of slate fragments than the sandstone.

The quartz and chert sandstone surrounds an exposure of limestone in the NW¼NE¼ sec. 22, T. 4 N., R. 11 E., about 700 feet southeast of an abandoned farmhouse. The limestone is black, thin-bedded calcarenite, some beds of which contain finely comminuted organic detritus and scattered quartz grains. The shape and attitude of the limestone and its contained quartz grains suggest that the limestone may be interbedded with the sandstone.

These rocks differ from others of the Mariposa formation in being better sorted and containing a more restricted range of pebble types. However, they do not contain fragments of rocks foreign to the graywacke and other conglomerates of the Mariposa formation. Thin beds of megascopically similar sandstone are interbedded with limestone pebble-bearing conglomerate in rocks of uncertain stratigraphic position near the Cosumnes River (unit 31, pl. 8). Although the sandstone is not known to be interbedded with limestone pebble-bearing conglomerate near the Calaveras

River, such conglomerates are exposed in strike with the sandstone about 3 miles to the southeast (A. A. Stromquist, written communication 1952).

No chert has been observed in the Mariposa except in the lower part west and southwest of San Andreas, where it forms parts of units 23, 25, and 28 of the Calaveras River section. Here, it is thin bedded and light to dark gray and is interbedded with slate and quartzose slate of the same colors. Some is sericitic, with varied composition, and probably there is a complete gradation between chert and sericite slate. In thin section, much of the sericitic chert can be seen to contain small elliptical bodies composed of quartz more coarsely crystalline than the surrounding material; perhaps they formed from Radiolaria, as they differ from detrital quartz grains in their shape and polycrystalline character.

The Brower Creek volcanic member of the Mariposa formation consists largely of coarse dark-green volcanic breccia, in places containing blocks 2 or more feet in diameter. Rarely, clasts of pyroxenite and limestone occur in the breccia of the upper tongue. Pyroxene phenocrysts as large as 1 centimeter in diameter are common in fragments and matrix of many breccia layers. The upper tongue of the Brower Creek member contains some tuff and lapilli tuff and one small exposure of pillow lava. The only epiclastic detritus in the Brower Creek member, other than the rare limestone fragments, occurs on the margins of Pardee Reservoir on the Mokelumne River. Here, thin beds of slate are interlayered with the volcanic breccia of unit 31 (pl. 7) on the west limb of a syncline, and small conglomerate lenses with a few pebbles of epiclastic origin form part of unit 35 on the east limb of the syncline. J. H. Eric (written communication, 1950) reports similar conglomerates north of the reservoir about on the strike of unit 35.

FOSSILS AND AGE

According to R. W. Imlay (written communication, 1959):

The Mariposa formation is definitely of late Oxfordian to early Kimmeridgian age throughout most of its extent. The most common fossil is *Buchia concentrica* (Sowerby) which in northern Eurasia and in Alaska ranges from upper Oxfordian into middle Kimmeridgian (Imlay, 1959, * * * p. 157, 158) * * *. The Oxfordian age assignment is based on the occurrence of the ammonites *Dichotomosphinctes* and *Discosphinctes*. Of these *Dichotomosphinctes* ranges through the Oxfordian, but is particularly characteristic of the upper Oxfordian. *Discosphinctes* occurs in the upper Oxfordian and questionably in the lower Kimmeridgian * * *. The early Kimmeridgian age assignment of part of the Mariposa formation is based on the ammonite *Amoebites*, a subgenus of *Amoeboceras* [see locality 719 below]. * * *

As a result of subsequent investigations, Imlay (written communication, January 1960) believes that faunas at localities 902–903 below are probably also early Kimmeridgian.

Faunal localities in the Mariposa formation from a compilation by Imlay, are listed below. Numbers designate Mesozoic locality numbers in collections of the U.S. Geological Survey. References to current (1959) maps have been added in parentheses to old locality descriptions.

243 Near Pine Tree Mines, Mariposa Estate, Mariposa County. (See topographic map of the Coulterville 15-minute quadrangle.)
- *Buchia concentrica* (Sowerby)
- *Perisphinctes*? sp.

253 Left bank of Merced River ¼ mile below Bentons Mills, Mariposa County. (Bentons Mills known as Bagby in 1959; see pl. 1.)
- *Buchia concentrica* (Fischer)

719 Texas Ranch, Calaveras County. (Near Texas Charlie Gulch, pl. 5.)
- *Amoeboceras* (*Amoebites*) *dubium* (Hyatt)
- *Buchia concentrica* (Sowerby)

901 Trail on south side of Stanislaus River, opposite Bosticks Bar, near Reynolds Ferry, NW¼ sec. 3, T. 2 N., R. 13 E., Tuolumne County, flooded by Melones Reservoir (see pl. 5 or topographic map of Copperopolis 15-minute quadrangle, edition of 1916).
- *Perisphinctes* (*Discosphinctes*) *virgulatiformis* Hyatt
- *P.* (*Dichotomosphinctes*) cf. *P.* (*D.*) *mühlbachi* Hyatt
- *Taramelliceras*? *denticulatum* (Hyatt)
- "*Belemnites*" *pacificus* Gabb
- *Turbo*? sp.
- *Cerithium*? sp.
- *Avicula*? sp. (Hyatt, 1894, p. 429)

902 South bank of Tuolumne River at Moffit Bridge site, Tuolumne County (near Jacksonville, pl. 4) and east of contact between Peñon Blanco volcanics and Mariposa formation.
- *Buchia concentrica* (Sowerby)
- *Subdichotomoceras*? aff. *S. filiplex* (Quenstedt)

903 Stanislaus River near canyon opposite mouth of Bear Creek, near center of sec. 11, T. 1 N., R. 13 E., Calaveras County (pl. 5).
- *Buchia concentrica* (Sowerby)
- "*Belemnites*" *pacificus* Gabb
- *Subdichotomoceras*? aff. *S. filiplex* (Quenstedt)

904 Six miles from Copperopolis on road to Sonora and on grade to Angels Creek, Calaveras County. (Probably in sec. 33, T. 2 N., R. 13 E., pl. 5.)
- *Subdichotomoceras* aff. *S. filiplex* (Quenstedt)
- *Buchia concentrica* (Sowerby)
- "*Belemnites*" *pacificus* Gabb
- *Amusium aurarium* Meek

1982 Hell Hollow, north of Bear Valley, Mariposa County (pl. 3).
- *Perisphinctes*? sp.
- "*Belemnites*" *pacificus* Gabb

1983 5 miles southeast of Princeton, Mariposa County. (Princeton is shown as Mount Bullion on the topographic map of the Coulterville 15-minute quadrangle.)
Buchia sp.
Amusium aurarium Meek

20554 Woods Creek Canyon 3 miles northwest of Jacksonville, Tuolumne County. (Pl. 1 and topographic map of Sonora 15-minute quadrangle.)
Buchia concentrica (Sowerby)

22176 Left bank of Mokelumne River, 400 feet west of the east edge of sec. 17, T. 5 N., R. 11 E., Sutter Creek 15-minute quadrangle, Calaveras County (pl. 7).
Ammonite fragment

24317 Loose boulder in bed of Cherokee Creek, sec. 22, T. 3 N., R. 12 E., San Andreas 15-minute quadrangle, Calaveras County. Matrix is identifiable with beds in the Mariposa formation west of Cherokee Creek.
Perisphinctes (*Dichotomosphinctes*?) sp.

27311 Moffit bridge site. Railroad cut on south side of Tuolumne River 200 to 225 feet east of contact between Penon Blanco volcanics and Mariposa formation. Near Jacksonville, Tuolumne County, plate 4.
Buchia concentrica (Sowerby)

27312 North bank of Merced River, NW corner, sec. 26, T. 3 S., R. 16 E., Mariposa County, plate 3
Buchia concentrica (Sowerby)

27398 Crest of Woods Creek Ridge 1 mile northwest of Jacksonville, Tuolumne County. Coll. by George R. Heyl, 1946. (See topographic map of Sonora 15-minute quadrangle.)
Buchia concentrica (Sowerby)
Lima? sp.

27459 Woods Creek, Tuolumne County. Received from Becker. (See topographic map of Sonora 15-minute quadrangle.)
Buchia sp.
Lima? sp.

27460 From Mount Bullion, Mariposa County, collection by W. D. McLearn, Coulterville, California. Received May 3, 1922.
Perisphinctes (*Dichotomosphinctes*) cf. *P.* (*D.*) *mühlbachi* Hyatt

STRATA OF UNCERTAIN STRATIGRAPHIC POSITION

VOLCANIC STRATA

The Jurassic of the central part of the region includes various bodies of volcanic rock that have not been correlated with the standard formations because they are separated from them by faults, or have been insufficiently appraised during this investigation. A body that underlies Mount Bullion constitutes the only known occurrence of Jurassic rocks east of the Melones fault zone within the area covered by this report. Its true extent is unknown, but volcanic rocks extending from near the Merced River to the south edge of plate 1 have been included arbitrarily. Poor exposures on Mount Bullion suggest that the unit consists largely of coarse mafic volcanic breccia, in part containing pyroxene phenocrysts, but it also includes some mafic tuff and pillow lava. The internal structure of the unit and the kind of contact with the Calaveras formation are also unknown, owing to a lack of detailed mapping in this part of the region. The age of the unit is established by an ammonite recovered from a ground-sluice mine on top of a narrow ridge 600 feet southeast of the northwest corner of sec. 25, T. 4 S., R. 17 E., Bear Valley 7½-minute quadrangle, California. The mine was cut into bedrock and the dumps contained no material foreign to the immediate area. The ammonite, identified as *Perisphinctes* (*Dichotomosphinctes*) cf. *P.* (*D.*) *mühlbachi* Hyatt, is of late Oxfordian age (Imlay, written communication, 1959).

Another large body extends from north of the Cosumnes River to southwest of Mokelume Hill immediately west of the Melones fault zone. Near the Cosumnes River, this body is in fault contact with the epiclastic rocks to the west and with sheared granodiorite on the east. In this section the western part of the volcanic body is composed of dark-green mafic volcanic breccia with pyroxene phenocrysts. A thin unit of interbedded tuff and black slate occurs in the eastern part. Volcanic rocks of this narrow belt might belong to the Logtown Ridge formation, the Brower Creek volcanic member of the Mariposa formation, or to neither.

An elongate area in the eastern part of the Bear Mountains fault zone near Jackson Creek is shown on plate 1 as volcanic rocks of uncertain stratigraphic position but includes some bands of epiclastic rocks to small to differentiate. Near Jackson Creek, the rocks of the area are tuff, with some interbedded slate and porphyritic volcanic breccia. These rocks are faulted against serpentine on the west and to the east lie with undetermined relations against the quartzose phyllite assigned to the Calaveras formation.

The elongate fault-bounded block west of Fowler Lookout, consists mostly of mafic pyroclastic rocks but includes an amygdaloidal mafic lava flow, a thin-bedded chert unit, a thin unit of slate with some interbedded conglomerate, and small lenticular bodies of very fine-grained massive limestone. The geographic position of this block suggests that it is part of the Copper Hill volcanics or the Peñon Blanco volcanics.

EPICLASTIC STRATA

The epiclastic unit exposed along the Cosumnes River east of Huse Bridge consists largely of black slate and siltstone but contains some tuff, graywacke, and fine conglomerate. The epiclastic belt conformably overlies the Logtown Ridge formation for several miles north and south of the Cosumnes River. Absence of a break in deposition at the top of the Logtown Ridge formation is shown by top determinations along the Cosumnes River, and parallelism of beds in both units.

The unit was previously mapped as Mariposa formation (Lindgren and Turner, 1894; Taliaferro, 1943b, fig. 2), but detailed mapping in the area between the Mokelumne and Cosumnes Rivers will be necessary to determine whether this correlation is valid; for the present, therefore, the unit is not designated by a formation name. Existing maps (Lindgren and Turner, 1894; Lindgren, 1900) show the epiclastic rocks east of Huse Bridge to be part of a belt that extends continuously more than 40 miles north of the Cosumnes River. There may, however, be structural complications in part of the belt, and Imlay (1952, p. 975) believes that strata near its north end are of Callovian age, or more nearly equivalent in age to the Amador group than to the Mariposa formation. *Buchia concentrica*, *Entolium*? sp., and *Nucula*? sp., were identified by Imlay (written communication, 1959) in a collection from a narrow projection of this belt exposed in a small gully ¾ mile north-northwest of Plymouth.

In the northern part of the region another belt of epiclastic rocks lies along the western side of the central fault block from the north end of the area shown on plate 1 to south of the Mokelumne River. These rocks are black slate, graywacke, conglomerate, and mafic volcanic rocks. Pebbles in the conglomerates are composed chiefly of volcanic rocks, slate, chert, and vein quartz; some beds contain limestone pebbles. Sandstone consisting largely of well-rounded quartz grains is interbedded with the conglomerate of unit 31 (pl. 8) along the Cosumnes River.

These rocks were mapped as Calaveras formation by Turner (1894a, and Lindgren and Turner, 1894), and Taliaferro (1943b, fig. 2) included them in the Amador group. They resemble both the Cosumnes and Mariposa formations and it cannot be determined whether they belong to one or the other.

A narrow belt of conglomerate (unit 11, Jackson Creek section, pl. 7) exposed along Jackson Creek probably belongs to the Mariposa formation but may be part of the Cosumnes formation. It was included by Turner (1894a) in the Calaveras formation. The conglomerate, like those of the Cosumnes and Mariposa formations, contains varied pebbles, including limestone. It apparently lies conformably below the Brower Creek volcanic member of the Mariposa formation. The thin-bedded black chert and slate of unit 10 on Jackson Creek, exposed immediately west of the conglomerate, is here included with the Calaveras formation, but may be part of the same sequence as the conglomerate.

The epiclastic sequence exposed along the northeast side of Lake McClure (unit 13, pl. 3) consisting of interbedded black slate and tuff, underlies the Peñon Blanco volcanics. It was included by Turner (1897) with the Mariposa formation, but its stratigraphic position is incompatible with this assignment. No new name is proposed for this sequence because it extends south of the area shown on plate 1 and the exposures studied constitute but a small part of the formation.

ROCKS EXPOSED IN THE WESTERN BLOCK AND BEAR MOUNTAINS FAULT ZONE

The western block includes the area lying between the Bear Mountains fault zone and the western limit of bedrock exposures. In the northern part of this area, the rocks consist of a lower volcanic formation, a middle epiclastic formation, and an upper volcanic formation. These formations extend to the southern part of the area studied, where additional igneous and epiclastic rock formations may occur. Relations between the three most extensively exposed formations of the western block are best displayed in the Cosumnes River (pl. 8).

Volcanic rocks of the western block resemble those of the central block in that they are dominantly of pyroclastic origin and are mostly of probable andesitic or basaltic composition. Rhyolite or dacite, however, is much more common in the westernmost belt of volcanic rocks than in others. The epiclastic rocks of the western block apparently contain less graywacke and conglomerate than the Cosumnes and Mariposa formations of the central block, but are otherwise similar.

The stratigraphic sequence of the western block has not previously been distinguished from that in the central block. Structural data collected during the current investigation, however, indicate that some of the rocks of the western blocks may be younger than any exposed in the central block and that correlation of other units is complicated by the difficulty of establishing lateral continuity between the two blocks. New names are proposed for subdivisions of the western block.

GOPHER RIDGE VOLCANICS

The name Gopher Ridge volcanics is here used for the westernmost exposed volcanic formation in the part of the area shown on plate 1 that lies north of the Stanislaus River. The formation extends northwestward, and probably southeastward beyond the area studied, but the stratigraphic relations in the southern part of the area studied are less clear. The formation underlies and is named for Gopher Ridge, a prominent topographic feature near the west side of the exposed belt of metamorphic rocks between the Stanislaus and Calaveras Rivers. The base of the Gopher Ridge volcanics is probably not exposed. The formation is overlain by, and intertongues with, the Salt Spring slate. The section along the Calaveras River, at the northern end of Gopher Ridge, is designated as the type section.

The Gopher Ridge volcanics were mapped as diabase, porphyrite, and amphibolite schist by Turner (1894–1897). They were included with the Amador group by Taliaferro (1943b, fig. 2), Heyl (1948c, p. 114) and Heyl, Cox, and Eric (1948, p. 67), and with the Logtown Ridge formation of the Amador group by Taliaferro and Solari (1949, pl. 1).

The Gopher Ridge volcanics consist largely of pyroclastic rocks but they contain lavas with and without pillows. Rocks of basaltic, andesitic, and rhyolitic composition have been identified by Heyl, Eric, and Cox (*in* Jenkins and others, 1948) in detailed studies of several mine areas in the belt of Gopher Ridge volcanics. Rocks of rhyolitic or dacitic composition are locally prominent, particularly between the Stanislaus and Calaveras Rivers, but the rocks of mafic or intermediate composition are much more abundant. Some of the felsic rocks have pyroclastic textures and are interbedded with the more mafic pyroclastics, but some are massive and are probably flows, or shallow intrusives penecontemporaneous with the bedded deposits. In mapping, it has not been possible to distinguish in most places between the flows and intrusives.

Only partial thicknesses of the Gopher Ridge volcanics are known because their base is not exposed. The exposed part of the Gopher Ridge volcanics below the lowest bed of Salt Spring slate is about 4,000 feet in the Mokelumne River, 7,000 feet in the Calaveras River, and 12,000 feet in the Stanislaus River. Tongues of the Gopher Ridge in the Salt Spring slate give additional thicknesses of 8,000 feet in the Mokelumne River, 1,500 feet in the Calaveras River, and 3,000 feet in the Stanislaus River. The greatest total exposed thickness, 15,000 feet, is in the Stanislaus River. Probably the formation is at least as thick in the southern part of the area as it is in the northern but the structure of the southern part is too poorly known to permit making a meaningful estimate.

LITHOLOGY

Both pyroclastic rocks, ranging from very fine tuff to coarse volcanic breccia, and lavas constitute the formation throughout the length of the area studied. Pyroclastic rocks are far more abundant than lavas in most of the area, but lavas form thick units near the Calaveras River. Massive rocks that may be lavas form much of the section exposed on the sides of La Grange Reservoir on the Tuolumne River. Near the Merced River, volcanic breccia is more abundant than tuff.

Most of the tuff is either lithic or vitric, but recrystallization resulting from metamorphism of the rocks makes it difficult to determine in thin section whether the fragments were originally glass or microcrystalline lava. Shards have not been identified in thin section, but polished surfaces of some very fine tuff beds exposed about 500 feet west of the gaging station on the Tuolumne River (fig. 16) show thin arcuate structures that may be shards.

Most of the very fine tuff is yellow green and siliceous and, where fresh, has a porcellaneous luster; where weathered, this material is easily mistaken for drab slate. Another very fine grained black rock interbedded with coarse to very fine tuff resembles the slate of the epiclastic sequences. It commonly forms beds one inch or less thick, with a gradational lower contact with the tuff and a sharp upper contact. The rock is very well indurated, probably siliceous, and breaks with a conchoidal fracture. It is probably also very fine tuff or an argillaceous material formed by submarine weathering of volcanic detritus.

Most of the rocks in the formation referred to as lavas are not amygdaloidal, but amygdaloidal lavas occur in unit 12 on the Tuolumne River (pl. 4), and small masses of amygdaloidal rocks are dispersed in nonamygdaloidal material in unit 7 on the Calaveras River (pl. 6). Near the Calaveras River, on the west limb of the large anticline, gross layered structure suggests superimposed flows. Near the Tuolumne River are several masses of silicified massive volcanics that are possibly flows. Some of these so-called lavas may be hypabyssal intrusives, but their metamorphism appears identical to that of the pyroclastic rocks, so that they are not significantly younger. Pillow lavas are nowhere prominent, but form part of unit 1 on the Mokelumne River (pl. 7) and unit 6 on the Calaveras River (pl. 6).

Felsites containing quartz phenocrysts, probably rhyolite or dacite or both, occur on the Cosumnes and Merced Rivers, but are more common on the Stanislaus and Mokelumne Rivers. They include both massive and pyroclastic varieties. The pyroclastic rocks are tuff, siliceous ash, and volcanic breccia and are interbedded with the more mafic volcanics (for example, unit 11, pl. 7). Part of the massive felsite is intrusive, but a part may be extrusive, for strip mapping along the streams did not provide data to determine whether most individual masses were one or the other.

Intrusive felsite is probably about contemporaneous with the Gopher Ridge volcanism for it is not known to intrude the Salt Spring slate, which overlies the Gopher Ridge volcanics, and close spacial association of massive, possibly intrusive, felsite with bedded pyroclastic felsite in unit 21 on the Cosumnes River (pl. 8) and units 12 and 13 on the Calaveras River (pl. 7) suggests that the two types are essentially contemporaneous. On the other hand, the boundary of fresh-appearing amygdaloidal felsite cuts across schistosity of the greenstone on the south side of the Stanislaus River near the west quarter-corner of sec. 21, T. 1 S., R. 12 E. (pl. 5). Downstream from section 21, the relations between massive felsite and mafic or intermediate volcanics are too complex to show at the scale of this mapping.

Metamorphism has produced abundant epidote, albite, and tremolite and some chlorite in most of the rocks of the Gopher Ridge volcanics, as it has in the rocks of the central block. Nevertheless, where the rocks are not schistose, primary sedimentary textures are readily visible in outcrops, although less so in thin section. Secondary planar structure (schistosity) has in places obscured or destroyed the primary textures. In most schistose volcanics the texture of originally coarse pyroclastics is recognizable, although the fragments are elongated and flattened, but the texture of fine-grained pyroclastics is lost. Schistosity is prominent in the Bear Mountains fault zone and in the Merced River section. On the Calaveras River, some of the massive rocks, presumably lavas, have been brecciated tectonically and the cracks strongly epidotized.

AGE

No fossils have been found in the Gopher Ridge volcanics. They are probably of Late Jurassic age, although the lower part of the formation may be somewhat older. The upper part of the formation is not younger than Kimmeridgian in the northern part of the area, as fossils of late Oxfordian or early Kimmeridgian age have been found in the Salt Spring slate near the Cosumnes River, and this overlies and intertongues with the Gopher Ridge volcanics. At least part of the Gopher Ridge volcanics is probably of the same age as the Logtown Ridge formation (Callovian to late Oxfordian).

SALT SPRING SLATE

The name Salt Spring slate is here used for the dominantly epiclastic rocks that overlie and intertongue with the Gopher Ridge volcanics. The formation is named for Salt Spring Valley, which lies immediately east of Gopher Ridge (pl. 1). Exposures of the formation are poor in Salt Spring Valley and the section exposed in the Cosumnes River near the Michigan Bar Bridge (pl. 8) is designated as the type section. Black sericite slate dominates in the formation, but graywacke and tuff are widespread and thin conglomerate layers occur in some places. The Salt Spring slate is of about the same age as the Mariposa formation, but the two formations may have been deposited in separate basins, as suggested by Turner (1894b, p. 457).

The Salt Spring slate is exposed in a continuous belt, throughout the length of the area mapped, according to existing maps. North of the Stanislaus River the slate forms a single formation that overlies the Gopher Ridge volcanics. Near the Tuolumne River, however, the available data suggest that the relations between part of this slate belt and the belt of volcanics to the west may be different than they are north of the river, so that correlation of the slate exposed in Don Pedro Reservoir and to the south is tentative.

The Salt Spring slate was mapped by previous geologists as Mariposa formation (Turner, 1894a, 1897; Taliaferro, 1943b, fig. 2; Taliaferro and Solari, 1949; Heyl, Cox, and Eric, 1948, p. 66).

LITHOLOGY

The Salt Spring slate is lithologically much like the epiclastic parts of the Mariposa and Cosumnes formations except that it contains little conglomerate. Slates and graywackes in all three formations are megascopically indistinguishable. Most of the conglomerate in the Salt Spring slate is associated with graywacke and both are exposed on all streams studied. The conglomerates are mostly fine grained, have well rounded pebbles, and form bedded layers. None was found to contain limestone fragments.

Dark-gray limestone in lenses one to two feet thick and a few feet long, and black quartzose slate are interbedded with the black sericite slate at the west side of Lake McClure, near a plesiosaur locality at the high-water line at the south boundary of sec. 12, T. 4 S., R. 15 E. The limestone is a medium-grained calcarenite and in thin section is seen to consist of rounded to angular calcite grains. The black color results from abundant very finely disseminated carbonaceous material which forms inclusions in most of the grains. The quartzose slate is thin bedded and has a subvitreous luster on fresh surfaces.

FOSSILS AND AGE

The Salt Spring slate is of Late Jurassic age. Fossils are rare in the Salt Spring slate and the few found previously are not diagnostic. During the present investigation, fossils were found at four localities, but fossils from only one of these have been dated. In collections by Clark and R. W. Imlay (Mesozoic localities 25638 and 27318, respectively in U.S. Geological Survey collections) from the south side of the Cosumnes River, 0.1 mile east of the Michigan Bar Bridge, in the SE¼ sec. 36, T. 8 N., R. 8 E., Imlay (written communication, 1959) identified *?Buchia concentrica* (Sowerby), "*Belemnites*" sp., and *Phylloceras* sp. He considered them diagnostic of late Oxfordian to early Kimmeridgian age.

Belemnite molds were found in the Salt Spring slate near Don Pedro reservoir on the Tuolumne River, and part of a plesiosaur skeleton was found on Lake McClure, on the Merced River. The belemnite molds were found in slate in the south part of sec 35, T. 2 S., R. 14 E., below the high-water line on Don Pedro Reservoir. The plesiosaur skeleton was found at the high-water mark of Lake McClure on the south line of sec. 1, T. 4 S., R. 15 E., enclosed in coarse-grained black clastic limestone that forms a lens about 1 foot thick in the black slate. The skeleton has not yet been studied.

MERCED FALLS SLATE

The name Merced Falls slate is here used for the epiclastic rocks shown by Turner (1897) in the belt extending southeastward from La Grange to beyond the southern boundary of the area (pl. 1). The type section is along the Merced River east of the town of Merced Falls (see pl. 11). The formation is well exposed along the Tuolumne River and weathered exposures are plentiful on the north side of the Merced River. The top of the formation is not preserved but about 5,000 feet of strata form the type section. The Merced Falls slate overlies and intertongues with the Gopher Ridge volcanics. It apparently underlies and intertongues with the Peaslee Creek volcanics.

LITHOLOGY

Near the Tuolumne River the formation is almost entirely thin-bedded dark gray slate and siltstone, and only one thin bed of graywacke was observed. Along the Merced River, however, it includes considerable graywacke and some felsic tuff. Graywacke is interbedded throughout the Merced River section, but is coarser grained and forms thicker beds in the eastern upper part of the formation, where tuff is also common, than in the western lower part. Rare thin beds of conglomerate occur south of the Merced River.

AGE

L. E. Mannion of Stauffer Chemical Co. (oral communication, 1954) found *Buchia* in the Merced Falls slate about 1.5 miles southeast of La Grange in the south part of sec. 21, T. 3 S., R. 14 E. The present writer found none, but this genus indicates that the beds containing it are not older than late Oxfordian, as *Buchia* is unknown in older beds (Ralph W. Imlay, written communication, 1957).

Belemnite molds, not adequate for dating, were found in black slate about 20 feet west of the contact between the slate and the Gopher Ridge volcanics, near the top of the penstocks of the La Grange power plant (fig. 10).

COPPER HILL VOLCANICS

The name Copper Hill volcanics is here used for the sequence of volcanic rocks that overlies and intertongues with the Salt Spring slate. It is named for the inactive Copper Hill mine, in the NE¼ sec. 34, T. 8 N., R. 9 E., in Amador County. The type section of the formation is on the Cosumnes River (pl. 8), in Amador and El Dorado Counties. The Copper Hill volcanics are mainly pyroclastic rocks, probably mostly andesitic. The formation extends from north of the Cosumnes River to south of the Stanislaus River within and west of the Bear Mountains fault zone; volcanic rocks southward as far as the Merced River are included, but this correlation is less adequately supported. The Copper Hill volcanics are truncated on the east by faults and the top of the formation is probably not preserved in the area. The formation is exposed along the Stanislaus River and all rivers to the north. The best exposed and most complete section is along the Cosumnes River, but exposures are also excellent along the Mokelumne River.

The Copper Hill volcanics were mapped as diabase and amphibolite by Turner (1894a) and by Lindgren and Turner (1894). They were placed in the Logtown Ridge formation by Taliaferro (1943b, fig. 2), and by Taliaferro and Solari (1949). The part near Copperopolis was tentatively assigned to the Amador group by Heyl (1948b, p. 99). Parts of the Copper Hill volcanics near the Newton mine, about 6 miles west of Jackson, were named the Mountain Spring volcanics and Newton Mine volcanics by Heyl and Eric (1948, p. 52–53), and were tentatively correlated with the Amador group (1948, p. 51).

Partial sections show that the volcanic rocks of this unit are more than 7,000 feet thick on the Cosumnes River, and perhaps equally thick on the Stanislaus River, although here the rocks are more strongly foliated so that the thickness is less certain. The formation is more than 3,000 feet thick on the Mokelumne River. In the Calaveras River, the formation is strongly schistose and the thickness cannot be measured.

LITHOLOGY

The Copper Hill volcanics are moderately deformed in the northern part of the area, but much of the formation is strongly sheared near the Calaveras River and to the south. In some of the strongly sheared rocks the primary textures and structures are obscure or completely destroyed. In the northern part of the area, pyroclastic rocks form most of the formation, and tuff is more abundant than the coarser pyroclastics. Preserved textures suggest that similar proportions exist farther south. Minor pillow lava is interbedded near the Cosumnes and Stanislaus Rivers.

Most of the Copper Hill volcanics are dark to medium green in color, without quartz phenocrysts, and are probably andesitic or basaltic. Porphyritic rhyolite or dacite with quartz phenocrysts occurs on the Cosumnes and Mokelumne Rivers; some of it is massive and either of hypabyssal or volcanic origin. Other parts on the Cosumnes River (unit 21, pl. 8), are bedded and show pyroclastic textures and are certainly extrusive.

A distinctive porphyritic lava containing green saussuritized plagioclase phenocrysts as much as 8 mm long in an aphanitic groundmass is interlayered with the more common volcanic rock types in the Cosumnes River (unit 25, pl. 8). Some of this forms pillow lava, with pillows as much as 5 feet in diameter. The direction of tops indicated by the pillows is consistent with that indicated by adjacent graded beds. This porphyry is extrusive, but similar rocks form sills in the Cosumnes and Logtown Ridge formations, and in the type section of the Amador group along the Cosumnes River (pl. 10). West of Amador City a sheet of similar rock, apparently a sill (Knopf, 1929, p. 17), is interlayered in greenstone of either the Logtown Ridge formation or the Brower Creek member of the Mariposa formation.

AGE

No fossils have been found in the Copper Hill volcanics. The lower part of the formation intertongues with the Salt Spring slate and may therefore be as old as late Oxfordian. Higher parts of the formation are probably of Kimmeridgian age or younger. It is apparently the youngest formation of the bedrock complex in the area studied, although the volcanic rocks south of La Grange or the slate exposed east of Merced Falls may conceivably be younger.

PEASLEE CREEK VOLCANICS

The name Peaslee Creek volcanics is given here to an isolated mass of volcanic and possible hypabyssal rocks, at the western edge of the area of exposed bedrock south of La Grange. The type area is about 2 miles south of La Grange. These volcanics were mapped as porphyrite by Turner (1897). The base of the formation, lying on the Merced Falls slate, is exposed immediately south of the Tuolumne River (fig. 10) but its top is not preserved. The thickness of the formation as exposed is uncertain, but is probably more than 3,000 feet. Its structure is shown diagrammatically on plate 4.

LITHOLOGY

The Peaslee Creek volcanics are not exposed in the Tuolumne River and relatively poor exposures about 1 mile south of La Grange were examined to complete the Tuolumne River section. Here, bedded pyroclastic rocks form the northeastern and lower part of the unit, and consist of tuff and volcanic breccia of probable mafic or intermediate composition, similar to those of the other volcanic sequences. The southwestern higher part of the unit consists of massive rocks without amygdules but with small feldspar phenocrysts and hardly with quartz phenocrysts. Most of the massive rocks are fresh-appearing and may be of hypabyssal origin, perhaps appreciably younger than the bedded pyroclastic rocks in the northeastern part of this belt.

AGE

No fossils have been found in the Peaslee Creek volcanics, but its stratigraphic relations to the Merced Falls slate indicate that it is of Late Jurassic age, and probably Oxfordian or younger.

STRATIGRAPHIC RELATIONS BETWEEN THE FORMATIONS OF THE WESTERN BLOCK

STRATIGRAPHIC RELATIONS BETWEEN THE SALT SPRING SLATE AND GOPHER RIDGE VOLCANICS

Stratigraphic relations between the Salt Spring slate and the Gopher Ridge volcanics are shown best near the Cosumnes River. Moreover, this section is the only one where facies changes normal to the strike can be examined. Less complete data in the rivers as far south as the Stanislaus supplement those in the Cosumnes River, and show that the Gopher Ridge volcanics underlie and intertongue with the Salt Spring slate. Near the Tuolumne River, however, some of the epiclastic rocks previously interpreted as continuous with those in Salt Spring Valley apparently underlie the Gopher Ridge volcanics. In the Merced River, the contact between the main belts of these formations is faulted. The more significant sections are described below.

Cosumnes River exposures.—The Gopher Ridge volcanics and Salt Spring slate are exposed near the western end of the Cosumnes River section and are repeated by folding east of the Michigan Bar Bridge (pl. 8). Bedrock is concealed near the contact between the two formations east and west of the Michigan Bar Bridge. Enough observations can be made of tops of beds, bedding attitudes, and kinds of rock to show that the epiclastic rocks are conformable with the volcanic rocks and that there is little if any interbedding. No slate body of comparable thickness occurs on the east limb of the anticline east of Michigan Bar Bridge, and the approximate stratigraphic equivalent of the slate at Michigan Bar Bridge is interbedded slate and pyroclastic rocks. Gross aspects of the interbedding are shown on plate 8, but the two rocks are also much more thinly interbedded, and exposed contacts are common. Here bedding dips consistently eastward and graded beds are abundant. Although precise correlations cannot be made between the two limbs of the anticline, the stratigraphic interval corresponding to the epiclastic sequence at Michigan Bar Bridge almost certainly lies within the more than 12,000 feet of strata on the east limb of the anticline.

The contrast between the lithology in the syncline at Michigan Bar Bridge and that on the east limb of the anticline indicates that the Salt Spring slate intertongues eastward with volcanic rocks. In the Cosumnes River area, the volcanics interbedded with slate on the east limb of the anticline have been divided arbitrarily between the Gopher Ridge volcanics and the Copper Hill volcanics. The outcrops suggest that the Salt Spring slate may be absent and the two volcanic formations in contact with one another at depth at the latitude of the Cosumnes River.

Mokelumne River exposures.—Near the Mokelumne River, the Salt Spring slate forms three belts in a part of the section that is interpreted to be homoclinal with younger beds on the east. Each belt of slate must therefore be a tongue in the volcanic rocks. The volcanic rocks at Pardee Dam have been included arbitrarily with the Gopher Ridge volcanics. The volcanics at the dam are not continuous either northward or southward according to Turner (1894a), and might be a volcanic member within the Salt Spring slate, or a tongue of the Copper Hill volcanics. Thin layers of tuff interbedded in dominant slate units and thin layers of slate interbedded in dominant pyroclastic units are well exposed in the spillway and river canyon immediately west of Pardee Dam. Again, only gross relations could be mapped. The eastern belt of Salt Spring slate is poorly exposed around the margins of Pardee Reservoir and yields little stratigraphic information.

Calaveras River exposures.—Exposures of the Salt Spring slate in the Calaveras River are generally poor but top determinations within both the slate and the Gopher Ridge volcanics near the western contact of the slate indicate tops towards the east so that the slate overlies the Gopher Ridge volcanics. Near Hogan Dam the structure has arbitrarily been interpreted as homoclinal with the volcanic rocks forming a tongue of the Gopher Ridge volcanics, but definitive structural data are lacking.

Stanislaus River exposures.—The belt underlain by the Gopher Ridge volcanics is wide, and the belt underlain by the Salt Spring slate is narrow, south of the Stanislaus River. Near the river the map pattern (pl. 5; Taliaferro and Solari, 1949) indicates that the two formations intertongue or are infolded. Graded beds are scarce and exposures do not certainly show the relations between the two formations. Taliaferro and Solari (1949) interpreted the pattern as being the result of tight folding, but details within single exposures indicate that pyroclastic rocks are interbedded, rather than infolded, with epiclastic rocks. Small folds, such as are common where rocks of differing competency are tightly folded are rare or absent. The tuff and epiclastic rocks alternate with each other in layers ranging down to less than one inch in thickness so that the units shown on plate 5 are generalized.

Tuolumne River exposures.—Exposures near the Tuolumne and Merced Rivers contribute little to an understanding of the relations between the Gopher Ridge volcanics and the Salt Spring slate to the east. Near the margins of Don Pedro Reservoir on the Tuolumne River (pl. 4), epiclastic rocks on the trend of the Salt Spring slate are cut out by a plutonic body. Those between the pluton and Don Pedro Dam, tentatively included in the Salt Spring slate, project southwestward into the belt of the Gopher Ridge volcanics and apparently underlie at least part of them. An apparently depositional contact between the two is exposed in the NE¼ sec. 2, T. 3 S., R. 14 E., where the rocks are folded on a small scale but are not much sheared. The part of the volcanic section that appears to be structurally conformable with the epiclastic rocks immediately northeast of the dam extends southwestward from the dam for nearly a mile and is at least 700 feet thick. Volcanic rocks farther west are separated from this part of the section by shear zones and possible faults and their relations to the rocks nearer Don Pedro Dam are less certain.

As suggested on plate 4, the epiclastic rocks northeast of Don Pedro Dam may form the core of an anticline and be a tongue of the Salt Spring slate overlain by a tongue of the Gopher Ridge volcanics that includes units 13, 16, 17, and 19. The tongue of epiclastic rocks would correspond approximately to the lower part of the slate in Salt Spring Valley, and the tongue of pyroclastic rocks to the upper part of the Gopher Ridge volcanics southeast of the Stanislaus River. However, if the fault extending toward the northwest corner of T. 3 S., R. 15 E. (pl. 1) continues into the approximate axis of the inferred anticline, epiclastic rocks southwest of the fault might be appreciably older than the Salt Spring slate.

Merced River exposures.—Near the Merced River epiclastic rocks tentatively placed in the Salt Spring slate are exposed on the shores of the northwest-trending arm of Lake McClure and west of Exchequer Dam. Of these, only those west of the dam are known to be in depositional contact with the Gopher Ridge volcanics.

The epiclastic rocks on the shores of Lake McClure and in railroad cuts on the east side of the lake are on the extension of the belt of epiclastic rocks that underlies Salt Spring Valley. No long uninterrupted sections across the strike are available in this vicinity and scattered bedding attitudes and top determinations indicate that the rocks in this area are folded. At least part of the contact between these epiclastic rocks and the Gopher Ridge volcanics to the west is faulted as well.

The epiclastic rocks west of Exchequer Dam (units 6–8, pl. 3) form a syncline in the Gopher Ridge volcanics and are probably separated by a fault from the epiclastic rocks that underlie the western part of Lake McClure. The western contact of the epiclastic rocks is not exposed, but about one foot of the eastern contact is exposed immediately below the road. Here, undisturbed slate is in contact with a layer of massive, amygdaloidal, nonporphyritic lava about 25 feet thick. Graded beds in the tuff immediately east of (below) the lava indicate that tops are to the west and that the slate overlies the lava. Graded graywacke beds in the western part of the slate belt indicate that the graywacke and associated slate overlie the volcanics to the west.

STRATIGRAPHIC RELATIONS BETWEEN THE SALT SPRING SLATE AND COPPER HILL VOLCANICS

Stratigraphic relations between the Salt Spring slate and Copper Hill volcanics are shown best on the Cosumnes River. The contact between the two formations on the Mokelumne and Calaveras Rivers is poorly exposed and top determinations have not been made nearby. The Salt Spring slate and Gopher Ridge volcanics are exposed near, but not at, the contact on the Stanislaus River and top determinations have not been made near the contact. On the Tuolumne River, the formations are separated by intrusive rocks and near the Merced River they are separated by a fault.

On the Cosumnes River, the volcanics interbedded with epiclastic rocks on the east limb of the anticline east of Michigan Bar Bridge have been divided arbitrarily between the Gopher Ridge volcanics and the Copper Hill volcanics. The stratigraphically lowest unit included with the Copper Hill volcanics is unit 18, plate 8. Within this unit and the epiclastic units on the two sides graded beds are common and exposures are excellent, showing an interbedded, conformable relation. Graded beds were not found for several hundred feet stratigraphically above the uppermost epiclastic unit (unit 19, plate 8).

STRATIGRAPHIC RELATIONS OF THE MERCED FALLS SLATE TO THE PEASLEE CREEK VOLCANICS AND GOPHER RIDGE VOLCANICS

No graded beds were found in the Merced Falls slate along the Tuolumne River, but minor folds near La Grange suggest that the slate is on the western limb of an anticline (fig. 10). The Merced Falls slate thus probably overlies the Gopher Ridge volcanics and underlies the Peaslee Creek volcanics. The western contact of the slate is not exposed near the river, but the eastern contact is well exposed at the La Grange powerhouse (fig. 10). Neither this exposure nor a smaller one in the canal on the north side of the river indicate the stratigraphic relations although they suggest that the two formations are conformable. Below the headgates of the penstocks, the massive volcanic rocks east of the slate form a vertical face, and the slate is exposed in a gully at the base of the face. The volcanics are not bedded, but bedding in the slate parallels the surface of the volcanic rocks. Within a few feet of the contact, fragments of volcanic rock are present in the slate—they might be interpreted as either the first or the last small episode of volcanism related to the accumulation of volcanic rocks east of the slate. In the bank of the canal north of the river a similar relation is shown. Here, a layer of amygdaloidal volcanic rock about two feet thick is interlayered with pumice-bearing slate near the contact of the slate with the volcanic sequence.

Abundant graded bedding between tightly folded areas in the slate east of Merced Falls shows that tops are consistently westward in noncrumpled parts of the belt (plate 11). This is consistent with the gently plunging minor folds in the westernmost slate belt exposed in the Tuolumne River. At the eastern side of the belt underlain by the Merced Falls slate, the rocks are strongly crumpled, and the volcanic rocks with which they are in contact are schistose, suggesting that the two formations may be in fault contact. The slate belt becomes narrower, and the Gopher Ridge volcanic belt wider, northeast of Merced Falls. This probably results from intertonguing of the slate with the volcanics, for the most southerly projection of volcanic rock extends nearly to the Merced River, and tops are to the west in the epiclastic rocks on both sides of this projection. In addition, thin tuff beds are commonly interbedded with the slate and graywacke near the tongue.

ROCK AND MINERAL FRAGMENTS IN ROCKS OF JURASSIC AGE

Field examination of conglomerate pebbles was made at about 50 localities and laboratory study was made of 34 thin sections of graywacke and fine conglomerate. More information is available from the Mariposa and Cosumnes formations than from other units which contain fewer graywacke and conglomerate beds.

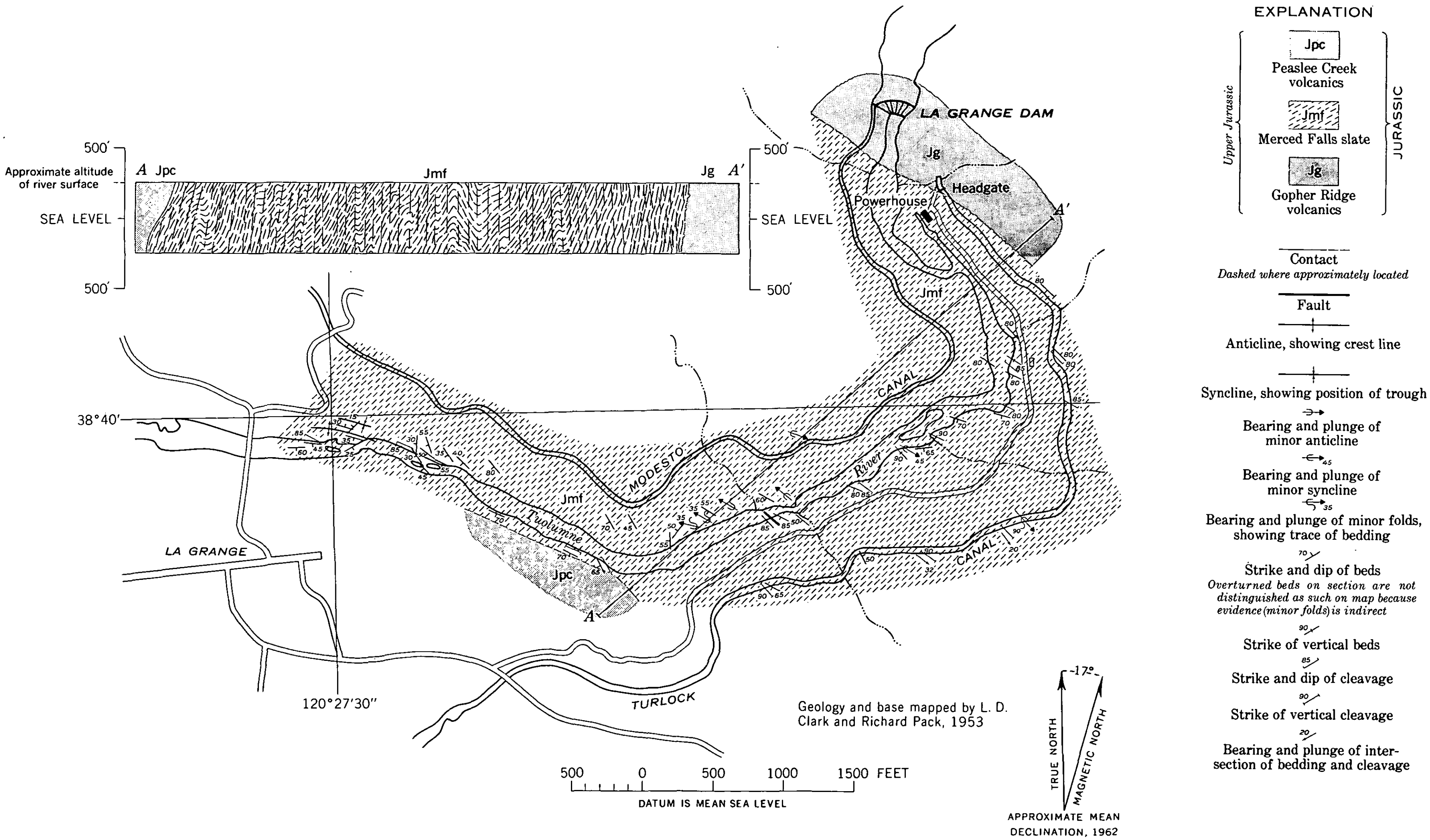

FIGURE 10.—Geologic map and cross section showing structure of slate along Tuolumne River east of La Grange, Stanislaus County, California.

COMPOSITION AND SHAPE OF FRAGMENTS

The pebbles are similar in all formations studied and consist largely of volcanic rocks, slate, and chert, but those of quartzite and high-grade metamorphic rock are ubiquitous also (figs. 11, 12). Pebbles and boulders of felsic plutonic rocks have been found in the Cosumnes and Mariposa formations, and some sand grains in the Salt Spring slate may have been derived from the same rocks. Although the various formations are alike in composition of fragments, proportions between various rock types in adjacent beds of single formations vary strikingly, even in beds of similar grain size. Moreover, slate is less abundant and chert and quartz are more abundant in graywacke than in conglomerate. Most of the Jurassic rocks are in the greenschist or higher metamorphic facies, and most fragments derived from terranes of lower metamorphic grade have now been altered to the same metamorphic grade as the enclosing rock.

Pebbles in the conglomerate are well rounded to angular. In some beds nearly all are angular, in others nearly all well rounded, but they range widely in degree of roundness. Degree of rounding is not everywhere directly related to hardness; some beds contain both well-rounded pebbles of vein quartz, and angular pebbles of chert, quartzose phyllite, and volcanic rocks.

Carbonate rock fragments occur only in the Cosumnes and Mariposa formations. They are chiefly calcarenite containing much rounded organic detritus, including abundant crinoid fragments. Two fragments of oolitic limestone were found in coarse breccia consisting mostly of volcanic rocks in the western part of unit 28 on the Calaveras River (pl. 6). A large boulder of fusulinid limestone of Permian age was mentioned previously (p. 14). The metamorphic rocks include quartz-mica schist, nonmicaceous aggregates of strongly strained quartz, and crinkled sericite slate. Granitic detritus is rare in all the conglomerates. In addition to fragments of coarse-grained rocks composed of quartz and potassium feldspar, separate grains of untwinned feldspar and one grain showing a micrographic intergrowth of quartz in feldspar were observed.

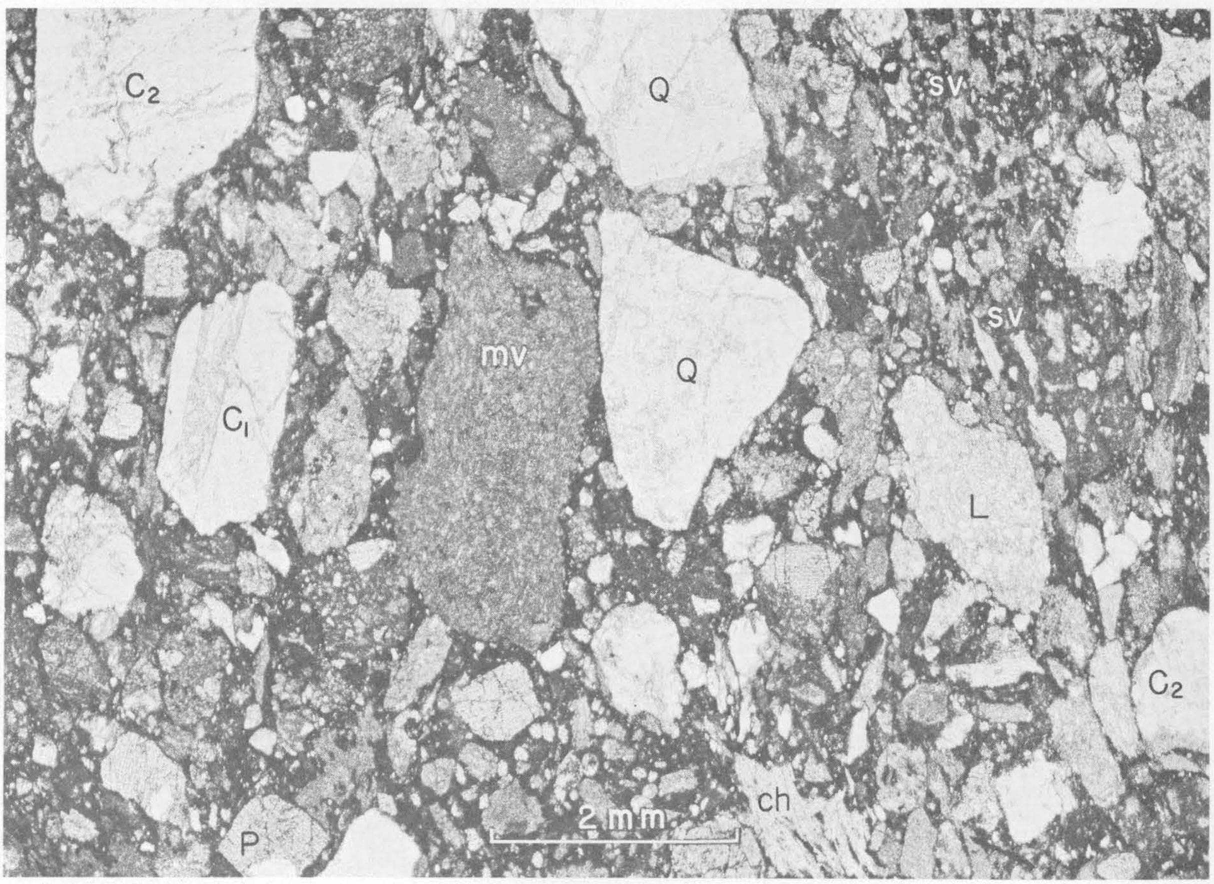

FIGURE 11.—Photomicrograph of very coarse graywacke from Cosumnes formation, Cosumnes River, NW¼ sec. 22, T. 8 N., R. 10 E., showing mixture of detritus of volcanic, metamorphic, and sedimentary rocks. Chert with carbonate spicule(?), C_1; schistose quartz sandstone partly replaced by carbonate, Q; chert with scattered carbonate, C_2; granular limestone with scattered embayed quartz grains, L; scoriaceous mafic volcanic rock, sv; pyroxene, p; chlorite, ch; mafic volcanic rock, mv. Plain light.

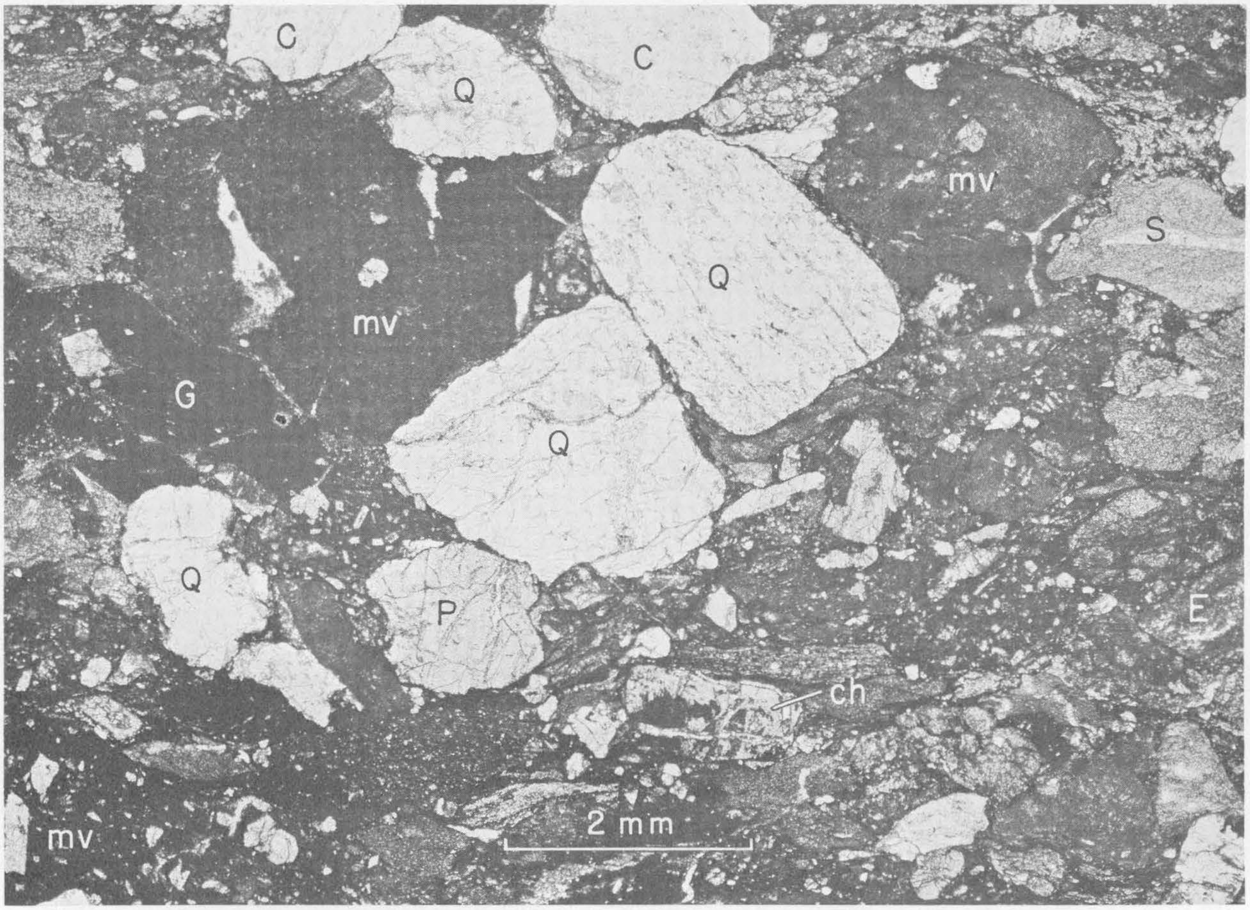

FIGURE 12.—Photomicrograph of very coarse graywacke from Mariposa formation, SE¼ sec. 16, T. 3 N., R. 12 E., showing association of detritus from diverse terranes. Chert with carbonate rhombohedrons, C; quartzite(?), Q; pyroxene, P; porphyritic mafic volcanic rock, mv; slate with quartz veinlet, S; devitrified volcanic glass(?), G; chlorite pseudomorph, ch; microcrystalline epidote rock, E. Plain light.

Pebbles and boulders of granitic rocks are rare but occur as fragments in the conglomerates of the Cosumnes and Mariposa formations; they have not been found in the Salt Spring slate or Merced Falls slate, where conglomerates are less abundant. Most of these are fine-grained aplite or slightly coarser. In the Mariposa formation pebbles of medium-grained granitic gneiss occur in conglomerate on the south flank of the ridge topped by Fowler Lookout, and Knopf (1929, p. 13) reports a pebble of coarse diorite near the contact of the Mariposa formation and the Peñon Blanco volcanics "one-half mile west of Kittridge" in the canyon of the Merced River.

Untwinned feldspar, in part perthitic, is common in graywackes of the three epiclastic formations of Mesozoic age, and granophyre clasts are widespread. They are probably derived from felsic volcanic or hypabyssal rocks as they are most abundant in exposures of the Merced Falls slate east of Merced Falls. Here, felsic tuff of the Peaslee Creek volcanics intertongues with the Merced Falls slate. Graywackes of the Salt Spring slate also contain more undeformed quartz than those of other formations. The Salt Spring slate overlies and intertongues with the Gopher Ridge volcanics, which contain more felsic volcanic and hypabyssal rock than the other volcanic formations.

Pebbles of coarse quartz-mica schist occur in the Cosumnes and Mariposa formations, and books of muscovite, probably derived from areas of high-grade metamorphic rocks, are widespread in all the epiclastic formations. Fragments of fine-grained quartz schist containing very little mica is sparsely present in the Mariposa formation and Salt Spring slate.

Fragments of chert and quartzose slate are abundant in the graywackes and conglomerates. The cherts range in color from nearly white to nearly black as well as several shades of green, and very rarely red. The chert varies in purity and texture. The silica in nearly all the chert is microcrystalline quartz, but chert consisting of opal or chalcedony occurs in graywacke of the Mariposa formation west of Angels Camp and near the Tuolumne River. Chert, mostly phyllitic, with abundant finely disseminated carbonaceous material was found in all formations, but in a larger proportion of thin sections of the Salt Spring slate. Chert with scattered carbonate rhombs was observed in several thin sections of the Mariposa formation and Salt Spring slate. Chert, in part phyllitic, with ovoid structures (Radiolaria?) occurs in all formations.

Nearly all of the clast-forming slate and siltstone resembles at least superficially the rocks with which the graywackes and conglomerates are interbedded. Some slate and siltstone clasts, however, contain abundant finely disseminated black material, probably carbonaceous, which is absent from most of the Jurassic rocks of the region.

Fragments of volcanic rocks and minerals are abundant in most of the graywackes and conglomerates (fig. 11) and in some form more than 90 percent of those megascopically visible. Most of these fragments are microcrystalline or porphyritic with a microcrystalline groundmass. Their present texture, except for the phenocrysts, results largely from the regional metamorphism which has affected the Jurassic rocks, and they may have been derived either from volcanic glass, lava, or both. The phenocrysts are pyroxene and sericitized plagioclase, and these minerals also form discrete grains in some of the graywackes.

Quartz is abundant in most of the graywackes and conglomerates, but adds little data about source terranes. Both white and gray vein quartz have been distinguished in the conglomerates of the Cosumnes and Mariposa formations, but vein quartz has not been distinguished from quartz of other origin in thin sections of graywacke. Many of the quartz grains seen in thin section are strongly deformed aggregates that may have been derived from quartzite, veins, or granitic rocks. Nearly all the quartz shows strain shadows and vacuoles that are commonly arranged in planes.

Sandstone fragments (figs. 11 and 12) occur in all three formations but especially in the Cosumnes formation. They are of three sorts: orthoquartzite, or quartz sandstone with quartz cement (Pettijohn, 1957, p. 295–296), graywacke, and sandstone having a carbonate matrix. The orthoquartzite ranges from fine sandstone to fine conglomerate, and consists of well-rounded quartz grains, many of which show overgrowths, but are not markedly sutured. Most of the component quartz grains show undulatory extinction and lines of vacuoles. The graywacke consists of angular grains of quartz or quartz and feldspar in a sericite matrix which commonly contains a minor amount of carbonate. The proportion of quartz to feldspar ranges widely, half of the grains in some clasts being feldspar. Potassium feldspar is more abundant than plagioclase. Sandstones with a carbonate martix show similar variations between individual grains in proportion of quartz to feldspar. The carbonate of the matrix is coarse grained and generally twinned. Recrystallization has destroyed many of its original features.

ORIGIN OF LIMESTONE BLOCKS

Isolated small masses of limestone, surrounded by other rocks, are widely distributed in the region studied. Some are lenses formed in place in the enclosing rocks and others are probably horses in faults. However, other blocks were probably emplaced into younger beds by sliding or slumping. Many of these lie in conglomerates of the Mariposa formation; some lie in slate of the Mariposa formation. Contacts of the blocks are rarely exposed but their shape and character is such as to indicate that they neither developed simultaneously with surrounding rocks nor were emplaced by plastic flow; available evidence suggests that they were emplaced by slumping during deposition of the surrounding beds. Modern subaerial mudflows containing boulders 40 to 50 feet long have been described by Blackwelder (1928, p. 471) and much larger blocks emplaced by slumping in other sediments have been described by King (1937, p. 66–68, 89–92), by Renz, Lakeman, and Van Der Meulen (1955), and others.

Limestone masses are commonly grouped. Two groups of limestone blocks have been mapped by A. A. Stromquist (written communication, 1952) on the San Andreas northwest quadrangle, in the western belt of the Mariposa formation near the Calaveras River. One group (in strike with unit 23, plate 6) is about ¼ mile northwest of the river in sec. 15, T. 4 N., R. 11 E. and as much as ½ mile southeast of the river in sec. 22, T. 4 N., R. 11 E. Another group (in strike with unit 28, figure 26) occurs in the SW¼ sec. 14, T. 4 N., R. 11 E. within ¼ mile both northwest and southeast of the river.

In unit 28, plate 6, contact relations of smaller limestone blocks, about 5 feet and less in diameter, are exposed in two places. One block is in the previously mentioned 14 railroad cut in sec. 10, T. 4 N., R. 11 E., where fusulinid limestone of Permian age is surrounded by slate and conglomerate of the Mariposa formation. A narrow zone of gouge surrounds the limestone and can be traced from the bottom to the top of the cut. The rocks on the two sides of the zone are similar, however, and the displacement along the fault marked by the gouge is probably minor. On the north bank of the Calaveras River (plate 6), near the west side of unit 28, is a very coarse sheared breccia consisting largely of porphyritic andesite like that of the Brower Creek volcanic member to the east but containing scattered blocks 6 feet and less in length of limestone and bedded chert.

Another group of limestone blocks, within the Melones fault zone in the NW¼ sec. 22, T. 3 N., R. 12 E., about 7 miles slightly east of south of San Andreas, has been mapped by D. B. Tatlock (written communication, 1952). These are surrounded by strongly sheared conglomerate in which the less resistant rock fragments are much elongated. The fragmental rock is probably not a tectonic breccia, as the fragments include a considerable variety of rocks including widely scattered granitic rocks.

A group of limestone blocks exposed near the Stanislaus River in sec. 26, T. 2 N., R. 13 E. (pl. 5) was mapped by Eric and Stromquist (*in* Eric, Stromquist, and Swinney, 1955, pl. 1). A block composed of limestone on the west and carbonaceous quartz-mica schist on the east is distinguished as unit 46 on plate 5. The contact of the schist with conglomerate on the east is poorly exposed. On the west, the limestone is in fault contact with pyroclastic rocks of the Brower Creek volcanic member. The limestone and schist may be a tiny remnant of the basement on which the Mariposa formation was deposited, fortuitously exposed on the present land surface. Relations of other limestone masses in the area are not clear.

The limestone blocks at the localities mentioned are associated with conglomerate. Of the group west of San Andreas a limestone block has been found to be in contact with conglomerate only at the railroad cut exposure, but lenticular conglomerates are in strike with the beds surrounding the limestone blocks in the two groups west of San Andreas. Conglomerate surrounds the limestone southwest of San Andreas and overlies the exposure in the Stanislaus River.

The shape and size of the limestone blocks, together with their internal texture and structure and their relations to surrounding rocks, are not consistent with the hypotheses that they were formed in place or were emplaced by faulting. The limestone blocks range in shape from very elongate to nearly equidimensional. They apparently range in size from the smallest pebbles of the conglomerate to blocks more than 100 feet long. Bedding is not apparent in most of the blocks. Breccia structure is common, but whether it is of epiclastic or cataclastic origin was not determined. No conglomerate or other rock is interbedded with the limestone of the individual blocks, nor are there tongues of limestone extending into surrounding rocks. Although some limestone blocks that are apparently horses in faults are coarsely crystalline and have planar structures suggestive of great deformation and plastic flow, these features have not been found in the blocks at the localities described above. Several of the blocks contain fossils but the visible original textures indicate that the limestones are bioclastic deposits rather than reefs.

SOURCE OF FRAGMENTS

Some of the fragments in the Cosumnes and Mariposa formations and the Salt Spring slate were apparently derived from older formations exposed in the Sierra Nevada, and others from nearly contemporaneous beds in or near the Upper Jurassic basin of deposition of the western Sierra Nevada. Derivation from sources west and northwest of the Sierra Nevada has been neither established nor disproved. No evidence has been found by the writer to support Taliaferro's (1942, p. 89) contention that sediments of Jurassic age become coarser westward. Furthermore, when considering deposits transported by turbidity currents and mudflows, the site of deposition of coarse material provides no reliable evidence of its source, as coarse detritus carried down submarine canyons may bypass finer deposits laid down on the continental shelf on either side of the canyon.

Other than the region of the Sierra Nevada, conceivable sources include the sites of the present Klamath Mountains, California Coast Ranges, and Central Valley. The eastern part of the Klamath Mountains, about 200 miles northwest of the Cosumnes River, may have been exposed during Late Jurassic time. It is about on the projection of the strike of the Upper Jurassic rocks under discussion. The strike of the Upper Jurassic rocks may be parallel to the axis of the basin in which they were deposited but some debris-laden currents probably move parallel to the axis of a basin of deposition as well as across it. Common rocks exposed in the eastern Klamath Mountains include mafic, intermediate and felsic volcanic rocks, chert, shale, graywacke, and intrusive rocks ranging in composition from ultramafic to granitic. Chert and quartz-mica schist are not abundant.

Taliaferro (1942, p. 103) believes that the site of the California Coast Ranges was a land mass during deposition of the Amador group and the Mariposa formation. In that region, sedimentary rocks shown to be older than the Mariposa formation are rarely exposed except in the Santa Lucia Range, about 100 miles southwest of the Merced River. These rocks, the Sur series, consist of "quartzose schists and gneisses, quartz-biotite schists, marbles, and plagioclase amphibolites" (Reiche, 1937, p. 118) and quartzite (Trask, 1926, p. 127). They may have been more widely exposed in the Coast Ranges during Late Jurassic time. On the other hand, Hill and Dibblee (1953, p. 449), suggest that displacement of pre-Cretaceous rocks by the San Andreas fault may total 350 miles since Jurassic time, so that these rocks may not then have been in their present position. Well-borings in the Central Valley provide some information on the basement rocks but are too widely spaced in most places to provide complete information. The well borings have penetrated slate, amphibolite, schist, granitic rocks, serpentine, and quartzite, suggesting that the basement rocks are similar to those exposed in the western Sierra Nevada (Taliaferro, 1943b, p. 129).

Evaluation of the possible sources is hindered by factors other than the extensive cover of post-Mariposa strata. There is insufficient knowledge of the petrography and composition of both the transported fragments and possible source rocks in place and the possibility that some rocks exposed during Late Jurassic time may have since been either removed by erosion or emplacement of plutonic rocks, or metamorphosed beyond recognition. Large parts of the Klamath Mountains and Sierra Nevada have not been mapped in detail and possibly not all the distinctive lithologic varieties in these areas are known.

Some geologists, for example (Taliaferro, 1943b, p. 187) have suggested that areas now buried beneath the sea, or younger deposits are more attractive sources of epiclastic rocks in northern California than exposed areas of older rocks, when these areas apparently do not include the lithologic types found in the clasts. Nevertheless, erosion has removed much material from the exposed areas and all the kinds of rocks exposed there during Late Jurassic time are not necessarily still represented. Moreover, the Paleozoic rocks now exposed in the Sierra Nevada, are almost certainly of higher metamorphic grade than the Paleozoic rocks exposed during Late Jurassic time, as the batholith was since then emplaced and eroded to considerable depth. The metamorphism would probably affect the texture of much of the chert. The volcanic rocks are characteristically lenticular, and distinctive varieties originally present in modest volume might have since disappeared, owing to erosion and emplacement of plutonic rocks, or their appearance may have changed owing to extensive recrystallization. Other rocks less notably lenticular might also have been removed or altered beyond easy recognition.

Fragments of sandstones, and carbonaceous slate, siltstone, and chert were probably derived from formations exposed in the Sierra Nevada, and limestone clasts in the Cosumnes and Mariposa formations were derived from the part of the Calaveras formation that is represented by the western belt of exposures. Nearly all of the limestone in both the clasts and the masses believed to be in place in the western belt is coarse calcarenite with abundant organic debris. In addition, Permian fossils have been identified in one limestone boulder in the Mariposa formation (p. 14). Clasts of black carbonaceous slate, phyllite, and chert strongly resemble rock types that are abundant in the chert unit of the eastern belt of the Calaveras formation and may well have been derived from this unit.

The granules and pebbles of orthoquartzite, graywacke, and quartz-feldspar-carbonate sandstones may have been derived from the Blue Canyon formation, exposed in the Sierra Nevada in a wide belt extending beyond the north and south limits of the Colfax 30-minute quadrangle (Lindgren, 1900). All these rocks are in the Blue Canyon formation, including the unusual sandstone consisting of angular quartz grains in a sericite matrix. Of the rocks already discussed, exposures of all but the calcarenite of the Calaveras formation are east of the exposures of the Upper Jurassic formations. However, these rocks may also have been exposed west of this belt during Late Jurassic time. The abundance of calcarenite boulders and blocks, however, indicates that the source of the calcarenite was close to the site of deposition.

Fragments of slate, noncarbonaceous chert and volcanic rocks may have been derived from penecontemporaneous or older Mesozoic beds in the western Sierra Nevada. These rocks might also have been derived in part from the Calaveras and other formations of Paleozoic age in the western Sierra Nevada, the Central Valley area, or the Klamath Mountains. Many of the fragments of volcanic rocks might be the result of contemporaneous volcanism.

The source of the granitic rocks, schist, and gneiss is unclear. Little can be added to Knopf's (1929, p. 19) thesis that the granitic pebbles were derived from masses exposed within the area of this investigation. Other possible sources for these materials are the previously mentioned regions northwest and west of the Merced-Cosumnes River area.

BEDDING FEATURES AND CONDITIONS OF DEPOSITION

The Cosumnes and Mariposa formations and the Salt Spring slate have similar bedding features which indicate that all three were deposited in like environments. The three volcanic formations are likewise similar to one another in their primary structural and textural features. Besides, structures of some of the pyroclastic rocks are almost identical with those of the epiclastic graywackes and conglomerates and indicate that both kinds of rock were carried to the site of deposition in a similar manner. Fossils in the Logtown Ridge and Mariposa formations and Salt Spring slate indicate that the deposits are marine; the Cosumnes formation, Copper Hill volcanics, and Gopher Ridge volcanics differ from them in no way that would suggest a different origin. Structures in the sands and finer sediments indicate deposition in quiet water, but structures in coarser sediments are not diagnostic. Wide distribution of graded beds in both epiclastic and pyroclastic rocks is indicated by the maps of individual traverses. Current-ripple bedding (small-scale cross-beds), in places associated with minor cut-and-fill structures, is widespread but not common. Load casts and crumples generally associated with contemporaneous deformation are also widespread but are only locally common. They are strikingly exposed in the lower part of the Logtown Ridge formation and the upper part of the Cosumnes formation in the Cosumnes River (pl. 8). Flutes and grooves have not been observed.

Most of the graywacke forms beds less than 3 feet thick but tuff is generally thicker bedded and some tuff and lapilli tuff layers several tens of feet thick show no internal discontinuities in grain size. At least some volcanic breccias have no textural discontinuities through stratigraphic intervals of several hundred feet. Some beds of slate and very fine tuff are only a few inches or millimeters thick.

Graded beds have been described elsewhere (Pettijohn, 1943, p. 949; Kuenen and Migliorini, 1950; and Shrock, 1948, p. 78–84) and have been noted previously in the western Sierra Nevada by Heyl, Cox, and Eric (1948, p. 68), but they are fundamental to the structural and stratigraphic interpretations of the region and are therefore described here in some detail.

Graded units are marked by progressive changes in color as well as grain size. In graywacke-slate sequences, the coarser material is of lighter color than the fine, but among the pyroclastic rocks either the coarser or the finer material can be lighter, depending on the mineral content. Some beds appear megascopically to grade uniformly from the coarsest to the finest material, but in others the grading is apparent in only part of a bed and is obscure or absent in other parts. In these, size-grading may be in the lower, middle, or upper part of the bed. There are no single isolated graded beds; instead, they form sequences commonly many tens of feet thick in which more than half of the beds are graded.

Graded graywacke [2] layers are common both in dominant graywacke and dominant slate. In both, bottoms of the coarse layers precisely mark one boundary of a bed. The upper boundary of some coarse layers is well marked by the base of the overlying coarse layer or by an abrupt change to finer grain size. In other beds the upper boundary of the coarse layer is ill-defined because changes in grain size from sand to clay take place over appreciable parts of the beds. The sediments constituting graded beds range from fine conglomerate to shale, but the complete range between these size grades seldom occurs in a single layer or unit. Pebble conglomerate forms the lower parts of rare graded layers. Most of the well-graded beds are ¼ inch to 6 inches thick, but some well-graded beds are as thin as 2 mm or as thick as 30 inches. The bottoms of most graded beds are smooth, but some are irregular from minor channeling of the underlying finer material, formation of load casts, and from post-depositional crumpling.

Compositional sorting is lacking in graded graywacke layers but is pronounced in some graded tuff layers. Thin sections indicate that such beds range from crystal tuff to lithic or vitric tuff. Rock fragments are microcrystalline, in part at least, because of metamorphism, and it is difficult at best to distinguish originally glassy from originally lithic material. Crystal fragments are much more abundant in the coarser lower parts of these beds and lithic fragments are equally or more abundant in the finer upper parts. The original composition of the very fine tuff is uncertain, as it consists of microcrystalline mixtures of quartz, zoisite(?), white mica, and chlorite, with scattered plagioclase and pyroxene crystal fragments.

In thin sections studied, proportion between rock and crystal fragments does not always vary directly with the grain size. In some, contiguous layers of similar grain size have different proportions of rock and crystal fragments, and in others an upward increase in proportion of fairly coarse rock fragments reverses the size grading in small thicknesses of the bed.

Current-ripple bedding is generally associated with small cut-and-fill structures and is common in sequences having many graded beds. Nearly all cross-laminated units are less than 2 inches thick and the thickness of cross laminae is measurable in millimeters. Grain sizes in most cross-laminated layers range from very fine sand to clay.

Features suggestive of deposition in agitated water are rare or ambiguous. Distorted ripple marks are exposed on many surfaces of thin-bedded tuff near the gaging station about 1 mile west of Don Pedro Dam on the Tuolumne River (fig. 16) but have not been found elsewhere. Graded beds are absent or rare near the ripple marks. No diagnostic bedding features were noted in the quartz-rich sandstone included with the Mariposa formation near the Calaveras River (unit 26,

[2] The terminology used in this paragraph to describe phenomena related to size sorting is that of the epiclastic rocks. Although these features are equally common in the pyroclastic rocks the nomenclature for comparable size grades is different and verbiage can be reduced by describing a single genetic type.

pl. 6), but the scarcity of clay and silt in this rock suggests deposition in agitated waters. In contrast with other sandstones in the Jurassic formations, there is little fine detrital material in the matrix of this rock, and labile constituents are scarce. If these isolated beds do result from a shallow water environment, they were probably formed in places where the depositional basins temporarily filled to wave base.

Structures and textures of the graded sandstones and tuffs and the clean, bedded conglomerates suggest that they are turbidity current deposits. The mud-matrix conglomerates were probably emplaced by submarine slides. Similar deposits of Pliocene age in the Ventura Basin have been ascribed a similar origin (Natland and Kuenen, 1951, p. 102–105). Lawson (1933, p. 10) held that unsorted conglomerate in rocks near Colfax equivalent to the Mariposa formation is tillite, and reported a glaciated surface beneath them. The alleged glaciated surface may, however, be a fault surface, as faults are common in the region.

The thickness of the prism of Jurassic deposits suggests that the basement surface upon which they were laid formed a basin, as the thickness of the stratigraphic section is as great or greater than the depth of the modern ocean except in the deeps. The aggregate thickness of the Gopher Ridge volcanics exposed in the Mokelumne River and the Copper Hill volcanics exposed in the Cosumnes River is about 19,000 feet. The total apparent thickness of the Peñon Blanco volcanics and Mariposa formation in the Merced River is nearly 20,000 feet. The bedding of some of the deposits, especially of volcanic rocks, may have been inclined, so these values may be greater than the depth of the floor below sea level. Nevertheless, the figures are minimum values because the complete stratigraphic section is nowhere exposed and some allowance must be made for the water column above the uppermost deposits, which must have been laid down at considerable depth. The deposits were probably bathyal or abyssal, but the absolute depth probably cannot be ascertained in the absence of diagnostic fossils (Kuenen, 1950, p. 203). The wide distribution of graded beds, and the general absence of sorted clastics of other than clay size indicate not only transportation by turbidity currents and mudflow, but also that the bottom water was not sufficiently agitated by currents or wave action to destroy the characteristic structures.

The depth of the basement beneath the mass of deposits is only indirectly related to the depth of water over the accumulating deposits, for the two depend on the rate and time of downwarp and the rate and time of accumulation of the deposits. At one extreme, downwarping might have preceded significant accumulation of detrital material, and at the other subsidence might have coincided exactly with filling. If the first, each succeeding bed would be laid down in shallower water whereas in the second all would be laid down at equal depth. The history of most filled basins is probably between these two extremes. Moreover, lava and coarse pyroclastic rocks characteristically are built up as mounds or ridges on the sea floor so that volcanic material in a given basin might be deposited at shallower depths than contemporaneous epiclastic sediments.

GREEN SCHIST

Green schist, derived from volcanic rocks, has been mapped within the Melones fault zone near San Andreas and in the Bear Mountains fault zone at the north end of the area studied. Because of their occurrence in fault slices these rocks are of unknown age. The mass near San Andreas probably includes rocks of both Paleozoic and Jurassic ages because in this vicinity volcanic rocks of both ages lie adjacent to the Melones fault zone.

Most of the rock included with this unit near San Andreas is markedly schistose. In most places, the primary textures and structures are obliterated, but volcanic breccia texture is preserved locally. The mass at the north end of the map area as exposed in the Cosumnes River is locally schistose, but consists largely of massive fine- to medium-grained amphibolite.

PLUTONIC ROCKS

Plutonic bodies exposed in the region consist of ultramafic rocks and rocks ranging in composition from gabbro to granite. The ultramafic rocks form linear belts and are most abundant west of the central part of the area. The less mafic plutonic rocks form the Sierra Nevada batholith in the eastern part of the area and small isolated plutons elsewhere. Most of the plutonic rocks east of the Melones fault zone are granodioritic to granitic whereas most of those west of the fault zone, except for the ultramafic rocks, are gabbroic to quartz dioritic, although all types occur in varying amounts on both sides of the fault zone. The composition, origin, and mode of emplacement of the plutonic rocks were not studied in detail for this project. General descriptions of the plutonic rocks are given by Turner (1894a, 1897, 1899) Turner and Ransome (1897) and Knopf (1929, p. 18–21). Calkins (1930) discusses the petrology and sequence of emplacement of some plutons of the western part of the Sierra Nevada batholith near the Merced River. Several of the ultramafic bodies have been mapped and described by Cater (1948a, 1948b).

ULTRAMAFIC ROCKS

Ultramafic rocks include serpentine, talc-antigorite-ankerite schist, and less commonly, peridotite, dunite, and saxonite. Serpentine is much more abundant than the other rocks in most places, but talc-antigorite-ankerite schist is more abundant east of the Melones fault zone near the latitude of San Andreas. Peridotite, dunite, and saxonite occur in some of the serpentine masses. The ultramafic rocks in the region form elongate masses from less than a foot wide and several feet long to nearly four miles wide and more than 15 miles long. Most of the serpentine is blocky, with each surface strongly slickensided, but part is strongly foliated.

AGE

The ultramafic rocks of the area are probably of Late Jurassic age. The faults which apparently controlled the emplacement of the serpentine cut nearly all the Jurassic and Paleozoic stratified rocks of the region. The youngest of these, the Copper Hill volcanics, overlie beds of Kimmeridgian age. Serpentine is cut in turn by felsic plutonic rocks north of the area of this report. A felsic pluton northeast of Folsom (see Lindgren, 1894) which cuts serpentine has been dated by Curtis, Evernden, and Lipson (1958, p. 6) by the potassium-argon method as 131 million years and quartz diorite from the same pluton as 142.9 million years old. Serpentine is also cut by another, undated, pluton near Placerville (see Lindgren and Turner, 1894).

STRUCTURAL RELATIONS

In plan, ultramafic bodies are elongate parallel to the regional strike of bedding and fault zones. Where adjacent to schistose rocks, the contact of the ultramafic rocks is parallel to the schistosity. Surface exposures suggest that the bodies dip steeply, but whether more or less steeply than adjacent bedded rocks is unknown. The extent and magnitude of the fault zones has not been recognized previously and the orientation of the ultramafic bodies has been cited as evidence that they were intruded as sills (Taliaferro, 1943b, fig. 2). Ferguson and Gannett (1932, p. 21–22), on the other hand, recognized as a major fault a large part of the structure here referred to as the Melones fault zone and suggested that it determined the position of serpentine emplacement. Distribution of the ultramafic rocks supports this, as many of the smaller masses are confined to belts of cataclastically deformed rocks and even the larger masses in the area that intrude layered rocks are adjacent to fault zones. The strongly sheared condition of the serpentine, however, indicates that it was emplaced before fault movement ceased.

Ultramafic bodies that extend beyond the margins of known fault zones are the two large masses east of Latrobe, the mass exposed in the eastern part of Pardee Reservoir, the mass about 3 miles west of Fowler Lookout, the large mass crossed by the Stanislaus and Tuolumne Rivers, and the mass near Bagby. These have irregular contacts which locally cross the structure of layered rocks. Although these masses are largely serpentine like the rest, they differ from most of the smaller masses in containing some preserved peridotite, dunite, and saxonite, (Cater, Rynearson, and Dow, 1951, p. 120–125; and Cater, 1948a, 1948b).

In contrast to these large masses the smaller ones are characterized by straight contacts and are confined to zones of sheared rocks. On the regional map (pl. 1) several of these are indicated west of the Bear Mountains, but many more are shown on individual river sections. Small sheets of serpentine, some less than a foot thick, are widely distributed in the shear zones. The serpentine bodies with straight contacts are probably horses or masses that were injected plastically into their present positions.

The close areal relation of ultramafic rocks and the shear zones shown on the regional maps (pls. 1 and 2) suggests that the serpentine and fault zones are somehow related. By far the greater part of the ultramafic rocks of the region are within the area encompassed by the Melones and Bear Mountains fault zones and many of even the sill-like bodies are bounded on at least one side by faults. Ultramafic rocks are scarce east of the Melones fault zone and are absent west of the Bear Mountains fault zone. It is more likely that the major faults controlled the position of the ultramafic rocks than that the ultramafic rocks controlled the position of the faulting (Clark, 1960a, p. 488).

It is true that the ultramafic rocks are strongly sheared, probably owing to later movements on the fault zones, but they have not localized the shearing, as the belts of sheared rocks marking major fault zones are more persistent than the ultramafic rocks. The large mass of serpentine exposed on the Calavaras River is thus flanked on the west by a wide belt of schistose rocks, and the serpentine southeast of Bagby is flanked on the west by a belt of sheared slate about 200 feet wide exposed in cuts of State Highway 49 about 1½ miles southeast of Bagby. The Melones fault zone is believed to extend the length of the metamorphic belt, but in much of the segment covered here it contains little serpentine.

GABBROIC TO GRANITIC ROCKS

Hornblende gabbro and diorite are abundant in the isolated plutons of the western Sierra Nevada. They form nearly all the mass exposed in the northeast part of Don Pedro Reservoir, the part of the mass southeast of Jackson that is cut by the Mokelumne River, the mass 5 miles southwest of Sonora that is associated with serpentine, and many smaller masses. These rocks also form the marginal parts of some less mafic plutons such as the one east of San Andreas (Clark, 1954, p. 11), and the whole of many smaller bodies (for example, Eric, Stromquist, and Swinney, 1955, pl 1). The hornblende gabbro and diorite range in texture from medium to fine grained. Masses of gabbro and diorite are generally adjacent to or are surrounded by metavolcanic rocks, and in places grade into them texturally, suggesting that they may have been formed in part by metamorphism of the volcanics. Eric, Stromquist, and Swinney (1955, p. 21) suggest that they are at least partly differentiates from the same magma as that of the serpentines, because of gradational contacts. Durrell (1940, p. 74) found evidence of similar origin of the gabbro in the western Sierra Nevada about 100 miles south of Sonora. Compton (1955, p. 18–20) on the other hand found that some of the gabbroic rocks in the western Sierra Nevada, north of the area covered, are products of replacement or recrystallization in place and that others are intrusive.

Granitic rocks form most of the larger isolated plutons of the area, the Sierra Nevada batholith, and the cores of some smaller masses that are mostly mafic. The granitic plutons, except near their borders, are much more uniform in texture and composition than the mafic bodies. Contacts of the isolated plutons with metasedimentary rocks are sharp, and in many places the metasediments at the contact are but slightly coarser grained than elsewhere. Contact metamorphism is more pronounced at the border of the batholith. Contacts of isolated plutons with metavolcanic rocks are less sharp and the grain size of the metavolcanics increases markedly toward the contact. Granitic dikes commonly cut the wall rocks near the plutons.

AGE

Although most geologists previously considered all the granitic rocks of the area covered here to be of about the same age, Knopf (1929, p. 18–19) suggested two sets of intrusions, one of late Carboniferous age and another of post-Mariposa age. Curtis, Evernden, and Lipson (1958, p. 6–9) more recently showed that two distinct sequences of emplacement of granite rocks can be distinguished by potassium-argon dating.

Two bodies of the older series near the map area have been dated. Granodiorite from Rocklin, dated as 131 million years old, and quartz diorite from Horseshoe Bar, dated as 142.9 million years old, form parts of a pluton north of the area that extends to within 4 miles of the northern map boundary (for location, see Curtis, Evernden, and Lipson, 1958, fig. 1). Quartz monzonite from the Guadaloupe intrusive about 5 miles south of the southern boundary of plate 1 and immediately east of the projection of the Bear Mountains fault zone was originally dated as 142.9 million years old but later recalculated as 136 million years (Best, 1963, p. 113). A granitic body west of Columbia has been correlated by Baird (1962, p. 18) with the older series on the basis of structural evidence. The younger series composes the Sierra Nevada batholith in the Yosemite region east of El Portal and ranges in age from about 77 to about 95 million years. Evidence of Carboniferous age of some granitic intrusions is indirect and inconclusive, but has not been disproved.

Curtis, Evernden, and Lipson (1958, p. 10–11) pointed out that according to the Holmes A time scale (*in* Zeuner, 1952) the older series is of Early Cretaceous age and according to the Holmes B time scale it is of Early Jurassic age. They cite stratigraphic evidence to show that the older series is of Late Jurassic age and that the Holmes scales need revision.

The intrusions assigned by Knopf (1929, p. 18–19) to the Carboniferous are those east of Plymouth, at Mokelumne Hill, and southeast of San Andreas. They intrude the Calaveras formation and the plutons east of Plymouth and at Mokelumne Hill are in fault contact with rocks of Late Jurassic age. Knopf's age assignment was based on (a) the occurrence of granitic pebbles in the Mariposa formation, (b) cataclastic deformation of rocks in the plutons, (c) higher metamorphic grade of the Calaveras formation as compared with the Mariposa formation, and (d) exceptionally strong pleochroic haloes in the micas of these plutons. This evidence is suggestive rather than conclusive, and the present author believes that all intrusives in the area are of Late Jurassic to middle Cretaceous age, but the occurrence of Carboniferous intrusives has not been disproved.

The plutons east of Plymouth and at Mokelumne Hill are truncated by the Melones fault zone and are therefore apparently older than the dated pluton that truncates faults of the Foothills system north of the mapped area. On the other hand, emplacement of granitic rocks certainly, and fault movements probably, occupied finite parts of geologic time, and it is unlikely that granites of a single series of intrusions would everywhere show the same relations to the faults.

HYPABYSSAL ROCKS

Massive rocks of possible hypabyssal origin, because of their uncertain relations, are grouped with the formations with which they are associated and are not discussed here. Most of the rocks known to be of hypabyssal origin form dikes. Swarms of fine-grained leucocratic dikes cut the metamorphic rocks west of the gaging station downstream from Don Pedro Dam on the Tuolumne River (fig. 16) and along the Merced River between Bagby and the mouth of the North Fork of the Merced River (pl. 3). A porphyritic leucocratic rock with fine-grained groundmass, probably forming a dike, is poorly exposed in the south bank of the Calaveras River at the western side of bedrock exposures (pl. 6). Knopf (1929, p. 21–22) has described several albitite dikes from other localities in the region.

Some mafic sills consisting of saussuritized plagioclase phenocrysts in a fine-grained groundmass intrude the lower part of the Amador group near the Cosumnes River (see pl. 10). A similar rock is intruded at the base of the upper tongue of the Brower Creek volcanic member of the Mariposa formation south of the Calaveras River. The dike rock is not exposed along the river, and is represented only by boulders.

A vertical dike of porphyritic rhyolite or dacite intrudes unit 2 of the Calaveras River section (pl. 6). The unit shows horizontal columnar jointing.

Dikes and sills intruding the metamorphic rocks cannot be precisely dated. The upper age limit is defined by the land surface which truncates the dikes. The surface apparently developed largely during the Late Cretaceous. The oldest Mesozoic rocks cut by dikes are probably not older than Middle Jurassic and the youngest are of Late Jurassic age. The sills in the lower part of the Amador group post-date the consolidation of enclosing beds, for dike walls are straight for considerable distances, bedding is not more distorted at dike contacts than elsewhere, and some dike walls show sharply angular offsets. Some dike rocks in the eastern block may be of Paleozoic age. The vertical rhyolite or dacite dike exposed near the Calaveras River is tentatively interpreted as of Tertiary age on the basis of its fresh appearance, jointing and attitude.

STRUCTURAL GEOLOGY

Metamorphic rocks of the western Sierra Nevada are on the west limb of a faulted synclinorium, the axial part of which is occupied by the Sierra Nevada batholith (Bateman and others, 1963). The strike of bedding and major fault zones, about parallel to the trend of the axis of the synclinorium, is generally northwest except in the northern part of the map area where bedding and the fault zones turn northward. Beds in most places dip eastward at angles of more than 60° or are vertical. Isoclinal folds occur in some places and more open folds elsewhere, but there are wide areas with homoclinal dip. The major folds and homoclinal sequences are truncated by the Bear Mountains and Melones fault zones, which are elements of the Foothills fault system (Clark, 1960a). In most homoclinal sequences, tops of beds are eastward, and in large parts of each of the three blocks separated by the Bear Mountains and Melones fault zones older beds are on the west and the younger beds on the east. This distribution is reversed by the major fault zones, as the youngest bedrock unit of the region, the Copper Hill volcanics, is in the western block and the oldest, the Calaveras formation, is in the eastern block. Metamorphic rocks exposed in the central block are of intermediate age.

Axes of major and minor folds related to development of the snyclinorium are essentially horizontal; they plunge northwest and southeast at angles of 35° and less. The folding was followed by a second stage of deformation that involved the major faulting and development of slip cleavage and steeply plunging minor folds and *b*-lineations, particularly east of the Melones fault zone (Clark, 1960b). Most of the minor structures in the region are identifiable with these two stages, but minor structures in some small parts of the map area have different attitudes than those so identified. Baird (1962, p. 35–44), for example, has described a prominent slip cleavage and lineation direction in limestone northwest of Columbia. He found these structures to be younger than the first regional deformation but older than the second.

The structure of the western and central blocks is similar, but the eastern block is deformed more severely and differently than the others. These differences have led some geologists to infer that the Calaveras formation was strongly folded before deposition of the Cosumnes formation, but this is not assured. The greater age of the metamorphic rocks in the eastern block relative to those farther west indicates that the eastern block has been relatively uplifted by faulting, hence that the exposed metamorphic rocks of the eastern block were deformed under greater pressure at lower levels of the earth's crust than metamorphic rocks exposed farther west.

Most of the deformation of the region is older than the Sierra Nevada batholith, and is part of a zone of deformation that coincides with a belt of eugeosynclinal deposits and granitic rocks of Jurassic age that extends with some interruptions from the western Sierra Nevada through the western part of the Klamath Mountains into southwestern Oregon. The Jurassic rocks of the western Sierra Nevada were folded and the folds were truncated by major steep northwest-striking faults before emplacement of the Upper Jurassic plutons. Much of the deformation of the eastern block was also earlier, for regional structures in the block are truncated by the Melones fault zone, and slip cleavage related to the faulting locally offsets bedding and previously formed schistosity in the eastern block.

Little evidence for large-scale deformation accompanying emplacement of the Sierra Nevada batholith has been found. Faults, probably thrusts, in and near the Melones fault zone are later than the strike-slip deformation and may be related to emplacement of the batholith. Perhaps spacial adjustments of considerable magnitude were accommodated by previously formed structures without leaving a record that is readily distinguishable. Structures available for such adjustments include folds, wide shear zones in the Melones and Bear Mountains fault zones, and an infinitude of slip surfaces in schists of the Calaveras formation.

TOP DETERMINATIONS

Structural interpretations presented here, as well as those of stratigraphic sequence, depend greatly on determinations of tops of beds, based on graded bedding, crossbedding, pillow lavas, minor folds, and relations between cleavage and bedding (Shrock, 1948).

More determinations have been based upon graded bedding than on all other features. As tuff is more abundant than graywacke, most of the determinations are on tuff beds (fig. 13). No plotted determination has been based on less than three graded beds, and some represent scores of them. Exposures showing obscure, or spurious, grading and apparently conflicting top directions within stratigraphic intervals of a few feet have been ignored. Curved cleavage planes, convex stratigraphically upward, distinguish some steeply dipping graded beds showing no megascopically apparent size gradation, as well as many beds with such gradation (fig. 14). In these beds, the angle between cleavage and bedding is a function of grain size so that cleavage planes make a large acute angle with bedding in the coarsest part of the bed, and approach parallelism to the bedding as the material becomes finer. This phenomenon is more common in graywacke and slate than in tuff.

Throughout the region relation of cleavage to bedding indicates that cleavage is parallel or nearly parallel to the axial planes of the folds (fig. 15). In much of the area of Jurassic rocks, this relation should provide reliable top determinations. However, locally developed cleavage which is at least superficially similar to the pervasive cleavage is probably related to a stage, or several stages, of deformation later than that which formed the regional folds and may have a random relation to axes of these folds. Because of these uncertainties only two top determinations based on cleavage were recorded.

FIGURE 13.—Photomicrograph of graded tuff bed in Copper Hill volcanics, NE¼NE¼ sec. 28, T. 2 N., R. 12 E. Light-colored grains are pyroxene and sodic plagioclase crystal fragments. Dark grains are chlorite after lithic or glassy fragments. Dark layer in upper part of photograph—originally dust-tuff—is also chlorite. Most of the coarse layer is about of the same grain size, but this layer grades into the fine material through an interval that is appreciable relative to the thickness of the bed. Note sharp contact of succeeding coarse layer at extreme top of photograph. Gray band in uppermost layer is an epidote veinlet. Plain light.

Minor folds were used to interpret structures and stratigraphic sequence in areas on the Tuolomne River near Don Pedro Dam and La Grange. Those in the Gopher Ridge volcanics near Don Pedro Dam (fig. 16) are consistent for a mile west of the slate contact near the dam and suggest that this area is on the west limb of an anticline. The folds near La Grange (fig. 10) are much less extensive. At both places the minor folds plunge as gently as the major folds of the region and

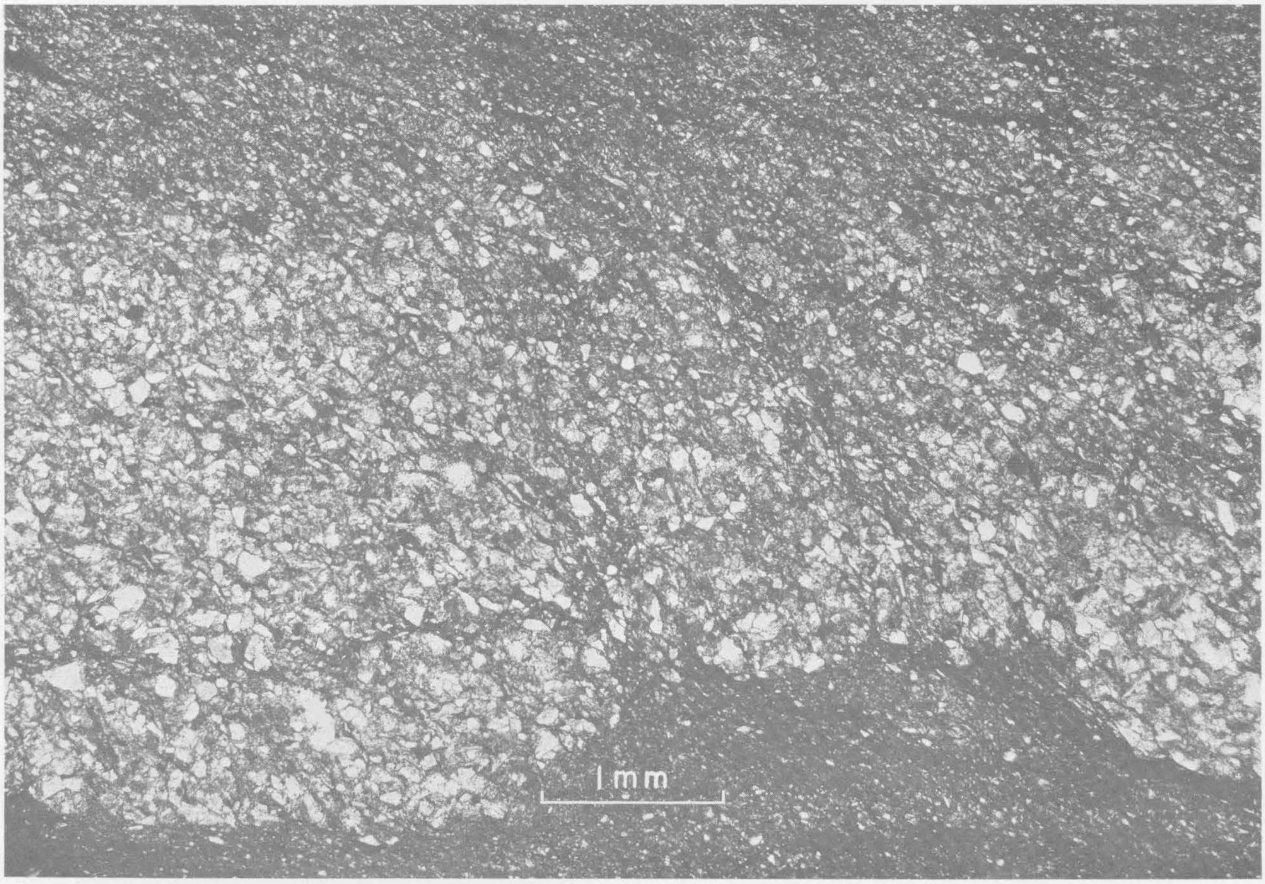

FIGURE 14.—Photomicrograph showing relation of cleavage to graded bed in fine graywacke of Salt Spring slate, NE¼NE¼ sec. 14, T. 4 S., R. 15 E. Cleavage direction, influenced by grain size, is about 60° from bedding in coarse part but changes progressively to about 25° from bedding in finer part. Such curved cleavage, convex stratigraphically upward, commonly indicates the existence of graded bedding where the gradation is not otherwise recognizable in the field. Most of the clastic grains are quartz and the matrix is sericite. Original texture is well preserved although cleavage is well developed. Plain light.

are probably related to the deformation that produced them.

FAULTS

Most major faults are components of the Melones and Bear Mountains fault zones which in turn are part of the Foothills fault system (Clark, 1960a). The Melones and Bear Mountains fault zones are the dominant structural features of the region. Faults that control the quartz veins and gold ore deposits of the Mother Lode belt are younger than the Foothills faults and are much less important as structural features. Faults with only a few feet or a few tens of feet of displacement do not notably affect rock distribution and few have been mapped.

The Foothills fault system extends more than 100 miles northwest and an unknown distance southeast of the area shown on plate 1. The width of the fault system within the latitudes considered here is unknown. Additional fault zones parallel to the exposed Melones and Bear Mountains fault zones may underlie the younger deposits of the Central Valley, and others may have once been present in the area now occupied by the Sierra Nevada batholith. The Melones and Bear Mountains fault zones have components of reverse movement, but the orientation of their net slip and that of the Foothills fault system as a whole is not established.

Both faults and shear zones shown on the accompanying maps express loci of deformation that disrupted structural or stratigraphic continuity, or produced cataclastic deformation, crumpling, or recrystallization. Most zones of dislocation of less than mappable width are indicated as faults whereas dislocation belts that are of mappable width are indicated as shear zones; some structures shown as shear zones on the detailed maps are indicated as faults on the regional map and diagram. Other faults are drawn arbitrarily at contacts of sheared ultramafic rocks where they occupy the position of major faults and at stratigraphic discontinuities where the shearing extends for many hun-

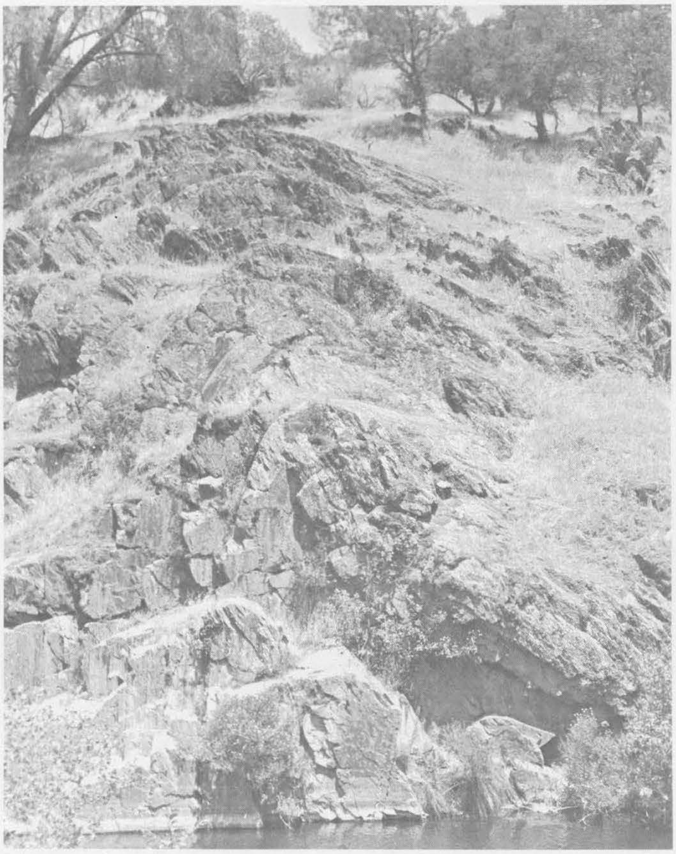

FIGURE 15.—Photograph of small assymetric anticline showing axial plane cleavage. Fold is in bedded tuff of the Gopher Ridge volcanics on the north side of the Cosumnes River in the west part of sec. 31, T. 8 N., R. 9 E. Cleavage is most pronounced in axial region and gently dipping east limb of the fold. Fold axis plunges north about 15° (away from observer).

dreds of feet in both directions, as east of Angels Camp (pl. 1; Eric, Stromquist, and Swinney, 1955, pl. 1).

Shear zones were mapped on the basis of thin platy structure; of schistose belts, some markedly more crystalline than rocks on the two sides; of zones of crumpling; and of cataclastic deformation; or of a combination of these. Rocks in the shear zones—except the metavolcanic and granitic rocks—are generally too much fractured for collecting hand specimens; some phyllitic rocks in shear zones separate into paper-thin layers. Schistosity in the shear zones results from parallel arrangement of tabular minerals and rock fragments, flat mineral pods, and closely-spaced slip surfaces. Plates have feather edges due to acute intersection of slip surfaces, and are distinct from cleavage plates of slate. Although similar schistosity is widely developed in rocks of the Calaveras formation east of the Melones fault zone, it is not there restricted to such well-defined belts. In some phyllite and fine-grained nonschistose serpentine, platy structure is caused by the slip surfaces alone. Original textures and structures are generally obscure or absent in the schists in the fault zones. The schists and phyllites are commonly lineated. Amplitudes of crumples and minor folds in the shear zones are generally measurable in millimeters or inches, and limbs of many are truncated by slip surfaces. In some places rock fragments are rotated and mineral grains broken.

MELONES FAULT ZONE

The Melones fault zone trends about N. 30° W. through most of the area studied, but near Plymouth the strike changes to northerly. From south of the area studied to about the Mokelumne River, it coincides with the area known as the Mother Lode belt. Within the area covered by the regional map (pl. 1) the Melones fault zone has been mapped in detail for a total distance of about 30 miles, through the Sonora, Angels Camp, and San Andreas NW 7½-minute quadrangles (Eric, Stromquist, and Swinney, 1955, pls. 1, 2; A. A. Stromquist, written communication, 1952). The Melones fault zone is cut about 3½ miles south of the map area by a granitic pluton that crystallized after the last movement on the fault zone (Cloos, 1932a, p. 303), but may cut metamorphic rocks exposed south of this pluton.

Existence of the Melones fault zone is indicated by both a break in stratigraphic and structural continuity, and by mechanical deformation and recrystallization. Through an 80-mile segment of the report area, the fault zone separates plutonic rocks and rocks of Paleozoic age on the east from rocks of Jurassic age on the west. Southeast of San Andreas, the regional trend of the volcanic rocks and limestone lenses in the Calaveras formation is truncated at an acute angle by the fault zone, and successively younger strata of the Calaveras formation are cut by the fault zone to the northwest. The plutonic bodies north of Mokelumne Hill are terminated on the west by the fault zone. The Mariposa formation bounds the western side of the fault zone except in the north part of the report area.

The most striking truncation of structure of the eastern block is southeast of San Andreas, where an easterly trending anticline having a core formed by volcanic rocks of the Calaveras formation is terminated abruptly on the west by the fault zone. The Melones fault zone is more nearly parallel to structures of the rocks to the west, but it cuts at a small angle a syncline formed in the Mariposa formation. The axis of this syncline is about two miles west of the fault zone near the Mokelumne River, and intersects the fault east of

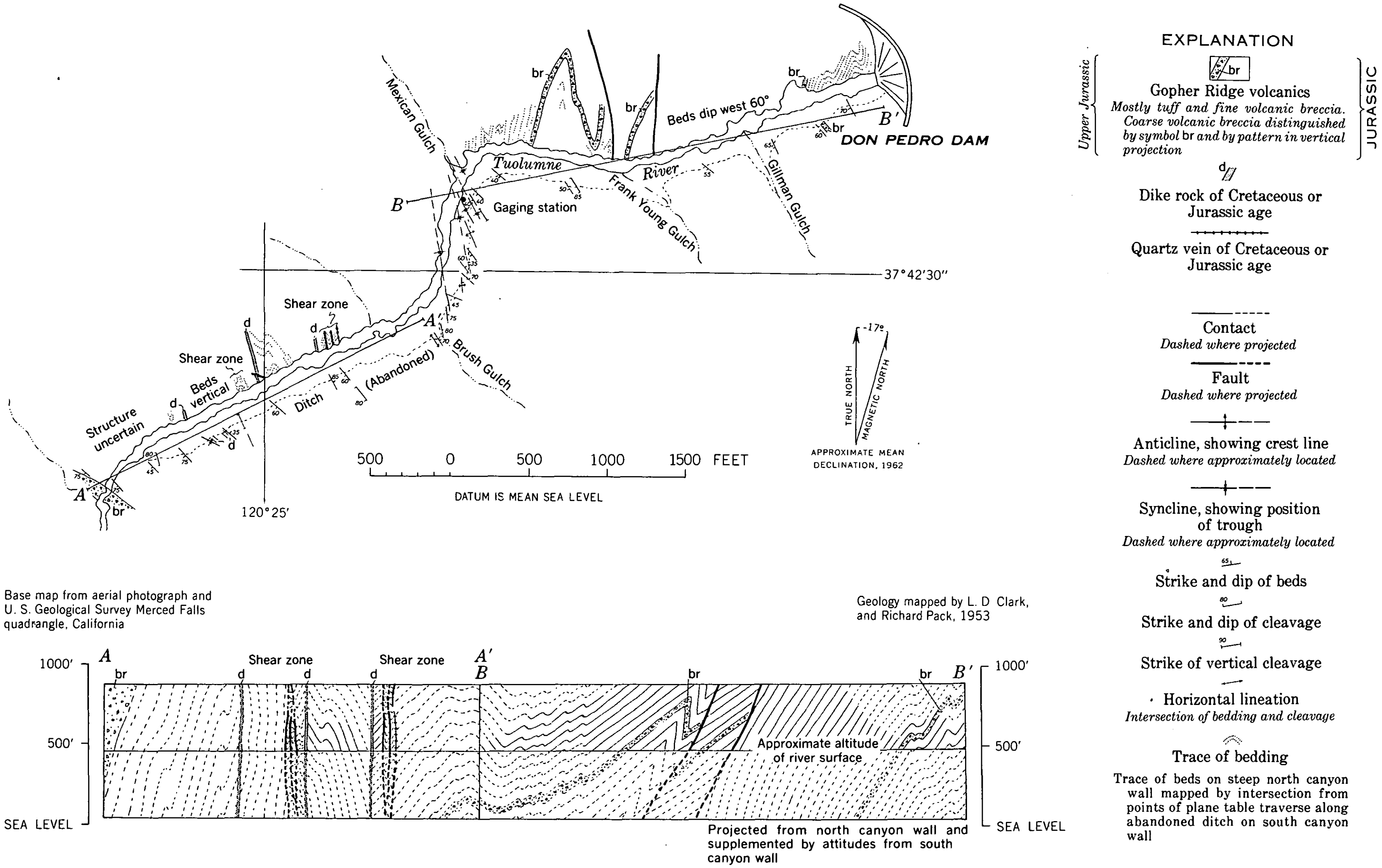

FIGURE 16.—Geologic map and vertical projection showing structure of bedded pyroclastic rocks of the Gopher Ridge volcanics of Late Jurassic age west of Don Pedro Dam, Tuolumne River, Mariposa County, California.

Chinese Camp. Farther southeast, the trough and east limb of the syncline are missing.

The west side of the Melones fault zone is marked by an abrupt transition from moderately to strongly cleaved rocks that coincides with a break in the stratigraphic sequence, whereas on the east side of the zone, slip cleavage or schistosity parallel to the fault zone commonly persists thousands of feet northeastward beyond the stratigraphic discontinuity. The greatest width of the fault zone in the map area, about 4 miles, was measured between the major breaks in stratigraphic and structural continuity northwest of Altaville, that is, between the northeast side of the Mariposa formation and the contact between the green schist of the fault zone and Calaveras formation. Across most of this interval, the rocks are greatly sheared. In addition, slip cleavage parallel to the schistosity in the fault zone can be recognized as much as 6 miles east of the fault zone in the southern part of the Calaveritas quadrangle (Clark, 1954, pl. 1). The slip cleavage is most pronounced near the fault zone, and less prominent eastward. In the northeast part of the Calaveritas quadrangle and other places where the schistosity of the Calaveras formation is parallel to that of the Melones fault zone, movements related to the faulting cannot be distinguished.

The fault zone is much narrower near the Merced River. At Bagby, near the river, exposures are inadequate to determine the width, but the shear zone is certainly less than 200 feet wide. At the Pine Tree mine, about 1½ miles south of the river, the shear zone west of the serpentine is about 100 feet wide. The serpentine, more than 600 feet wide near the Pine Tree mine, may have displaced sheared rocks and has no doubt itself absorbed some of the movement.

Dip of the Melones fault zone is indicated by internal planar structures which in most places are vertical or dip to the east at an angle of 70° or more. Lineation within the fault zone is in the planes of schistosity and marked by hornblende crystals in sheared granitic rocks, widespread elongate fragments in pyroclastic rock and conglomerate, and axes of small folds. With rare exceptions it bears eastward and is nearly normal to the strike of the schistosity; the plunge is 60° to vertical, and in most places about 80°.

The Melones fault zone is not uniformly sheared. It includes large blocks in which original structures are well preserved and the cleavage is no more strongly developed than in the Jurassic rocks west of the fault zone. In some places most of the movement was near the western side of the zone, in some places near the eastern side, but in others the locus of greatest displacement cannot be established.

DESCRIPTION OF LOCALITIES

The Melones fault zone is crossed by the Cosumnes River east of Huse Bridge (pl. 8), where there are three zones of shearing, separated by non-sheared rocks. The west sides of these zones are about 1,400 feet, 2,700 feet, and 3,600 feet east of the mouth of the North Fork of the Cosumnes River. The westernmost shear zone, about 200 feet wide, contains carbonaceous sericite schist quite unlike the rocks on either side, which retain their original textures. The central shear zone is marked by green schist that is probably formed by deformation and recrystallization of part of the volcanic breccia immediately west of the shear zone. A narrow block of slate with interbedded tuff having well-preserved original textures and structures (too small to map separately) separates the chlorite schist from metamorphosed granitic rock of the eastern shear zone. The granitic rock, exposed for about 2,500 feet on the river, is schistose throughout and contains a pronounced lineation resulting from parallel arrangement of amphibole crystals. In thin section, the feldspars are seen to be completely saussuritized and although textures suggest that some of the altered feldspar crystals have been broken, this has not been established. Quartz forms microcrystalline lenticles with granoblastic texture; undulatory extinction is weak or absent. Epidote also forms lenticles. Cataclastic deformation is shown by broken amphibole crystals. The schistose granitic rock was included by Lindgren and Turner (1894) and by Turner (1894a) with a much larger mass lying east of the Melones fault zone. Exposures examined during reconnaissance on roads east of the fault zone suggests that the granitic rocks become progressively less sheared to the east—the granitic rocks north of Fiddletown are apparently undeformed.

The granitic rock abutting the Melones fault zone on the Mokelumne River also is schistose on the western side, but the feldspars are megascopically little altered, and no lineation is apparent. Epidote is abundant and suggests metamorphism of the granitic rocks. The fault zone extends more than 3,000 feet westward from the granitic rock. Immediately west of the granitic rock is a narrow, poorly exposed belt of chlorite schist, but west of this is a belt several hundred feet wide underlain by black Jurassic quartzose slate with interbedded tuff. Another chlorite schist belt extends westward from the interbedded slate and tuff nearly to Middle Bar Bridge, but two narrow belts of black carbonaceous quartzose mica schist, very similar to parts of the Calaveras formation, occur within the chlorite schist 1,200 feet and 2,000 feet, respectively, northeast of the bridge.

On the Calaveras River, the fault zone is marked by a belt of green schist and serpentine with a total width of about 4,500 feet. Schistosity in the green schist dips eastward about 70°. Within the Calaveras formation east of the fault zone as delineated on the accompanying maps, strong schistosity parallel to the Melones fault zone extends an unknown distance eastward. This schistosity may be at least in part related to the fault.

On the Stanislaus River (pl. 5) the fault zone is divisible into two parts separated by a body of Jurassic rocks that are no more strongly deformed than those outside the fault zone. The westernmost fault of the Melones zone truncates the easternmost belt of the Brower Creek volcanic member of the Mariposa formation. The fault is marked in the river by a narrow shear zone immediately east of the Brower Creek member, and a narrow block of Calaveras formation lies against the west side of the fault. The top of the Brower Creek member west of the fault is westward, but tops in the Jurassic strata to the east are eastward, indicating that displacement along this fault is at least great enough to eliminate the crest of an anticline. Rocks of the Mariposa formation are not notably deformed and graded beds are well preserved. The main part of the Melones fault zone is between the highway bridge at Melones and the mouth of Coyote Creek because west of the bridge are characteristic Mesozoic rocks and east of the creek mouth are characteristic Calaveras rocks. Exposures in the banks of the river are poor in this interval.

Exposures of the Melones fault zone in the Tuolumne River add little to the information available elsewhere but excellent exposures of the strongly sheared rock characteristic of the fault zone are readily accessible near the State Highway 49 bridge. Only the part of the fault zone composed of serpentine is exposed on the Merced River.

BEAR MOUNTAINS FAULT ZONE

The Bear Mountains fault zone is parallel to the Melones fault zone, and like the Melones fault zone, extends beyond the limits of the area shown on plate 1. Schistose rocks along the projection of the Bear Mountains fault zone have been described by R. J. P. Lyon [3] from near Miles Creek, about 8 miles south of the southern boundary of plate 1, suggesting that the fault zone extends at least this far south. Near the Cosumnes River, the fault zone divides into two parts. The fault zone is widest between the Stanislaus and Calaveras Rivers where it is marked by a belt of greatly sheared volcanic rocks as well as by the individually mapped faults. It is narrowest in the southern part of the area. Rocks in the Bear Mountains fault zone are not as well exposed as those in the Melones fault zone, because four reservoirs extend across it. When the reservoirs are filled the original exposures on the former banks of the river are submerged and at low water they are covered with slime. The Bear Mountains fault zone includes the Bostick Mountain fault zone, the Copperopolis fault, and the Hodson fault of Taliaferro and Solari (1949), the first-named being near the east side and the last-named near the west side.

Schistosity has not been measured in the individual shear zones in the Cosumnes and Mokelumne Rivers, but farther south it dips eastward about 70° to 80°, although both steeper and more gentle dips occur. On the banks of Lake McClure the schistosity in shear zones is vertical. In general, the schistosity of the shear zones is as steep as, or steeper than, the dip of the rocks, on either side.

Near the Cosumnes and Mokelumne Rivers, the fault zone consists of two main parts—a belt of serpentine and metavolcanic rocks on the west, and a belt of narrow shear zones causing repetition of strata on the east. The metavolcanic rocks associated with the serpentine on the Cosumnes River are fine grained.

On the Cosumnes River (pl. 8) the position of the main part of the Bear Mountains fault zone is marked by two bodies of serpentine, separated by schistose and massive metavolcanic rock of unknown age. The shear zone cutting the Mesozoic rocks east of the serpentine and the shear zone separating this block of Mesozoic strata from the rocks tentatively included with the Calaveras formation are interpreted to be less important parts of the Bear Mountains fault zone.

Near the Mokelumne River (pl. 7) the locus of greatest displacement is again marked by the serpentine. Whether it is at the largest body or the smaller mass farther east depends on correlation of the volcanic rocks (unit 22, pl. 7) east of the largest serpentine here arbitrarily included with the Copper Hill volcanics. Displacement on lesser faults of the eastern part of the zone has produced horst and graben structure.

The fault zone as exposed near the Calaveras River differs from that farther north in that the volcanic rocks west of the serpentine are strongly sheared for 1½ miles west of the serpentine. The largest stratigraphic break is apparently about 1 mile east of the serpentine, at the east side of exposures of the Copper Hill volcanics. Near the Stanislaus River, the volcanic rocks west of the serpentine are also sheared, but much less so, nearly as far westward as O'Byrnes Ferry.

[3] Lyon, R. J. P., 1954, Studies in the geology of the western Sierra Nevada: (I) Tectonic analysis of the Miles Creek area, Mariposa County, California: (II) Mineralogy of the ores of the southern foothill copper belt in California: California Univ., Berkeley, Ph. D. thesis.

Taliaferro and Solari (1949) have mapped blocks of Calaveras formation within the serpentine immediately south of the Stanislaus River.

Near Don Pedro Reservoir on the Tuolumne River, sheared rocks are limited to a belt about 500 feet wide near the northeast corner of sec. 24, T. 2 S., R. 14 E., and within a volcanic sequence arbitrarily included with the Peñon Blanco volcanics. West of the shear zone is a granitic pluton which may have displaced other extensively sheared rocks. A shear zone along the strike of the one exposed in the Tuolumne River is exposed in a quarry where the road between La Grange and Coulterville crosses Piney Creek. The shear zone exposed in Piney Creek, presumably controlled the straight course of Piney Creek, and short segments of faults along this trend are found on the banks of the northwesterly trending arm of Lake McClure (pl. 3). Another shear zone, about 1,000 feet wide, is exposed in cuts alongside the La Grange-Coulterville road about 2 miles south of the quarry at the position indicated by a fault on plate 1. No corresponding shear zone was found in Don Pedro Reservoir at a period of low water.

DIRECTION AND AMOUNT OF MOVEMENT

Age relations of the rocks exposed in the three main fault blocks indicate that the vertical component of movement in the Bear Mountains and Melones fault zones was in the reverse direction, but direct determination of the orientation and amount of net slip along the fault zones is impossible, as corresponding points or combinations of planes on opposite sides have not been identified. The structure here referred to as the Melones fault zone has been described as a reverse fault by Ferguson and Gannett (1932, p. 21) and Knopf (1929, p. 45, 46). Ferguson and Gannett used the term "reverse fault" strictly in a descriptive sense, but Knopf believed the dominant component of net slip to be vertical. Taliaferro (1942, p. 90), states that "The Mother Lode represents a great Upper Jurassic thrust along which the Paleozoic was thrust westward over the Mesozoic." Cloos (1932b, p. 392–394; 1935, p. 234) discussed chiefly faults that controlled the quartz veins of the western Sierra Nevada and compares these faults to marginal thrusts related to batholiths. Cloos (1935, p. 238, 247) also, however, identified a long continuous fault (apparently the Melones fault zone of this report) as the "Mother Lode proper" and said that "It seems possible that movement along this fault began long before intrusion of the larger batholithic masses." Clark (1960a, p. 491–492) suggested the possibility that the dominant component of movement along major fault zones is horizontal (strike-slip).

Lineations within the fault zone plunge steeply, are parallel to axes of most minor folds measured within the fault zones, and parallel to the *b* tectonic axis. The steeply plunging fold axes and lineations suggest an important strike-slip component in fault movement, but many more fold axes must be measured to provide a reliable basis for interpretation. Limbs of most of the minor folds so far observed are sheared off, so these folds do not provide evidence of sense of movement. Evidence for strike-slip deformation elsewhere in the western Sierra Nevada has been reviewed previously (Clark, 1960a, p. 492).

The apparent vertical component of movement on the Melones and Bear Mountains fault zones is large. Because rocks of Jurassic age west of the Melones fault zone are juxtaposed against rocks of Paleozoic age east of the fault zone for a distance of more than 90 miles, the apparent vertical component of movement is equivalent to, or greater than, the thickness of the Jurassic section west of the fault zone. Partial sections of these rocks range from about 3,000 to almost 15,000 feet thick. Strata along both sides of the Bear Mountains fault zone are of Jurassic age, but those adjacent to the east side of the zone are at least 10,000 feet stratigraphically lower than those adjacent to the west side.

MOTHER LODE FISSURE SYSTEM

The term "Mother Lode fissure system" is used here for the system of eastward dipping faults with which the quartz veins and gold ore bodies of the Mother Lode belt are associated. The controlling faults have usually been described as reverse (Knopf, 1929, p. 45) or thrust faults, although evidence for direction of movement is scarce (Eric, Stromquist, and Swinney, 1955, p. 27). During the present investigation little study was made of the Mother Lode fault system and most of the following discussion is based largely on previous descriptions. The resulting picture may be biased, for published descriptions are, appropriately, of the large mines where veins and ore zones have been explored for distances of several thousand feet along the dip or strike, or both. Veins and ore zones within the Melones fault zone that meet this qualification post-date significant movement along the major fault zone; otherwise the veins or their controlling structures would have been broken by fault zone movements into trains of horses or boudins extremely difficult to trace successfully in mining. If small remnants of ore bodies dating from an earlier stage do exist, they would receive slight consideration in any but the most exhaustive investigation of gold ore deposits of the Mother Lode belt. Knopf (1929) gave excellent descriptions of the faults exposed in many of the mines, and the areal pattern of the quartz veins and gold mines is shown by Ransome

(1900) and Eric, Stromquist, and Swinney (1955, pls. 1 and 2).

Most of the Mother Lode fissures are in or near the Melones fault zone, but eastward-dipping faults that may be part of the same system have been recognized in the Penn mine (Heyl, Cox, and Eric, 1948, p. 75) and in the adjacent Grayhouse area (Heyl, 1948a, p. 89–90), near Campo Seco. The distribution of mapped eastward dipping faults closely parallels that of the gold and copper mines, suggesting that their recognition may depend on detailed study of well-exposed areas, and that they may be more extensive than known.

From a point about half way between the Merced and Tuolumne Rivers northward to the Mokelumne River, most of the Mother Lode fissures are within the Melones fault zone, but near the southern end of the belt and from the Mokelumne River to the north end of the Mother Lode belt, northwest of Placerville, most of the veins crop out one mile or more west of the Melones fault zone. Although the strike of some veins is moderately sinuous, the strike of most veins throughout the Mother Lode belt is about parallel to that of the Melones fault zone. Veins generally dip less steeply than cleavage and bedding west of the fault zone and schistosity within the fault zone. The veins dip eastward, mostly at angles between 50° and 70°, although one dips as gently as 20° for a considerable distance (Knopf, 1929, p. 24). Among the veins whose attitude is given by Knopf (1929) or Ransome (1900), no significant difference was noted between the dips of veins within the Melones fault zone and those west of the fault zone. Veins west of the fault zone cut and offset bedding in the country rock at acute angles. Some veins and zones of replacement ore within the Melones fault zone bear similar relations to schistosity and tabular bodies of rock drawn out parallel to the schistosity of the fault zone but others are parallel to schistosity and contacts within the fault zone. Of the veins that crop out west of the fault zone, none have been described as having been traced down dip into the fault zone.

The movement picture of the Mother Lode fissure system evidently is not simple. Knopf (1929, p. 45) believed as a result of finding older rocks on the hanging wall side of many veins that most of the veins occupied dip-slip reverse faults. He points out that flutings on post-mineral gouge indicate movement parallel to the dip in the Plymouth mine (Knopf, 1929, p. 52), but faulting that has produced the main fissure of the central Eureka mine had horizontal displacement of 120 feet (p. 62), and a strong lateral component of movement is suggested by structural relations in the Argonaut mine (p. 67). The greatest measurable displacement found by Knopf was an apparent dip-slip displacement of 375 feet in the Gover shaft of the Fremont mine (Knopf, 1929, p. 25, 54). Cloos (1932b, p. 393–394) believed the fissures to be related to emplacement of the Sierra Nevada batholith and comparable to marginal thrusts.

The mine maps and sections prepared by Knopf provide evidence that some of the Mother Lode veins and gold ore bodies post-date most of the movement along the Melones fault zone. In several of the mines within the Melones fault zone the principle ore bodies replace schist. Schistosity is much stronger in the Melones fault zone than in most of the bordering rocks and is apparently related to fault movements. Replacement of schistose rock by gold ore accordingly suggests that the ore is later than fault movement. Ore bodies of this kind are found in the Eagle Shawmut and Clio mines which are in the Melones fault zone near the Tuolumne River. In these mines Knopf interprets the sequence of events as follows: (a) reverse faulting, (b) emplacement of peridotite or similar rock, (c) serpentinization of the peridote and renewed fault movement, (d) deposition of ore. The first faulting was no doubt part of the Melones fault zone movement—the later movement noted by Knopf may be related to the same tectonic episode or to a later episode.

In contrast with ore bodies at the Eagle Shawmut and Clio mines, some of those at Carson Hill, in the Melones fault zone about one mile north of the Stanislaus River, are associated with smaller faults that cross and offset structures characteristic of the chief movement along the major fault zone. Here, gold-quartz ore bodies were found at the intersection of gently dipping veins with a steeply dipping vein. Along at least one of the gently dipping veins, contacts of the wall rocks, including serpentine and schist, have been offset in a reverse direction (Knopf, 1929, p. 76–77, fig. 23). Mapping by Eric and Stromquist (pl. 1 *in* Eric, Stromquist, and Swinney, 1955) shows that in the vicinity of Carson Hill serpentine and schist form narrow bodies elongate parallel to schistosity in the Melones fault zone as they do elsewhere in the zone.

MINOR FAULTS

The minor faults discussed here are those found during this investigation which are apparently not related to the fault systems discussed previously. Their displacements probably do not exceed a few hundreds of feet at the most.

The westward-dipping faults exposed in the north wall of the Tuolumne River gorge below Don Pedro Dam (see fig. 16) are apparently thrust faults related to the folding. The apparent offset of the westernmost fault is shown by the coarse volcanic breccia bed. If the volcanic breccia exposed near Don Pedro Dam is the same layer, the displacement of the easternmost fault is much greater. The faults were observed only from the south side of the river, and the true dip and direction of movement were not measured.

In the cut immediately north of Huse Bridge steeply dipping slickensided surfaces separating several blocks of volcanic breccia suggest a minor fault. Most of the slickensides plunge less than 30°, both north and south, but on one surface the plunge is steep. No comparable slickensides were found immediately south of the bridge but here about an inch of gouge separates the Logtown Ridge formation from the overlying epiclastic rocks. No evidence was found to suggest that this fault has more than a few feet of movement.

The steeply dipping fault exposed in the Cosumnes River near the SW corner of sec. 31, T. 8 N., R. 9 E., on the west flank of the large anticline, is near where Taliaferro (1943b, fig. 2) showed a major reverse fault. The fault is prominent in stream-bed exposures as it separates moderately folded but generally gently dipping beds on the east from nearly vertical beds on the west. The fault is marked by a fracture less than an inch wide, and the beds on either side are apparently not crumpled. This fault is in such striking contrast to those known to be major faults in the region that it is here interpreted as a minor structure.

AGE OF FAULTING

Movement on faults of the Foothills system began during Late Jurassic time and may have continued into Early Cretaceous time. The youngest rocks cut by the Melones fault zone include early Kimmeridgian strata of the Mariposa formation, and the youngest rocks cut by the Bear Mountains fault zone conformably overlie strata of late Oxfordian or early Kimmeridgian age but are probably pre-Tithonian. Branches of the Bear Mountains fault zone are truncated north of the report area by the Rocklin granodiorite and Horseshoe Bar quartz diorite which have yielded potassium-argon dates of 131 and 142.9 million years, respectively, and are believed by Curtis, Evernden, and Lipson (1958, p. 6, 10–12) to be of Late Jurassic age. The latest significant movement along the Melones fault zone is less closely dated: the zone is truncated south of the map area by a pluton that is presumably a lobe of the Sierra Nevada batholith (Cloos, 1932a) and of middle Cretaceous age.

Faults of the Mother Lode fissure system may be of about the same age as the Sierra Nevada batholith. They are younger than the Melones fault zone, but older than the unconformably overlying auriferous gravels of the region, generally considered to be of Eocene age (see discussion by Eric, Stromquist, and Swinney, 1955, p. 16).

STRUCTURE OF THE EASTERN BLOCK

Only some of the larger aspects of the geologic structure of the eastern block can be described, as most of the metamorphic rocks of this area lack distinctive marker units and in large areas bedding has been destroyed by shearing. Bedding is preserved in some isolated small blocks within sheared areas, but in such places it is almost invariably parallel to the regional schistosity, leading to the suspicion that it is preserved only because of this orientation. Attitudes of bedding in these isolated blocks have not been recorded. The structure of the eastern block is particularly obscure in the part that lies north of the latitude of San Andreas, except near the Mokelumne River where a northerly trend is suggested by the distribution of limestone. Regional trends can be distinguished south of this latitude.

In the southeast half of the eastern block, the volcanic member of the Calaveras formation and the belt of limestone lenses both trend northwest at an acute angle to the Melones fault zone. This trend is further substantiated by the fact that the lowermost unit of the Calaveras formation in this region, exposed east of Bagby, is missing north of the Tuolumne River, where it is truncated by the Melones fault zone. West and northwest of Sonora, distribution of volcanic rocks in the Calaveras suggests that they are repeated in folds, or that they form large lenses at various stratigraphic positions instead of a single continuous sequence. The eastward-trending mass of volcanic rock southeast of San Andreas forms the core of a large anticline (Clark, 1954). The volcanic rocks and limestone lenses converge north of the Merced River suggesting that one unit or the other, or both, thickens at the expense of intervening rocks. This is further suggested by the fact that limestone is in contact with volcanic rocks north of the Stanislaus River.

More data on the structure of the eastern block were obtained near the Merced River than elsewhere. Here, top determinations, absence of areas of general low dip, and lack of repetition of lithologic members of the Calaveras formation, suggest that the structure of the block is essentially homoclinal with younger beds on the east. Nevertheless, folds with amplitudes of a few hundred or even a few thousand feet may be present in parts of the area lacking distinctive marker units. The data are most complete between Bagby and Briceburg, and the possibility of undetected large folds is greatest between Briceburg and the abandoned cement plant where the argillaceous unit yielded few top determinations or lithologically distinctive horizons. Also, exposures on canyon walls are poor in this interval, so that the trace of bedding is not readily observed. East of the abandoned cement plant, long limestone lenses and abundant chert horizons can be traced readily on the canyon walls, and these show regular, near vertical dips. An area of tight, complex minor folding well shown in riverbank exposures in the northeast corner of sec. 19, T. 3 S., R. 19 E., may indicate the axis of a larger fold, but the limestone exposed west of this area is not repeated to the east. Structure of the metamorphic rocks east of Indian Flat Guard Station is obscure due to poor exposures and extensive crumpling.

STRUCTURE OF THE CENTRAL BLOCK

In the northern and southern parts of the area the structure of the central block is homoclinal with tops east. Near the Cosumnes River, beds are vertical and near the Merced River they mostly dip eastward 50° to 75°. In the central part of the block are isoclinal folds, the largest of which is the syncline whose core is formed by the Mariposa formation. It has been traced down the Mokelumne River to the Stanislaus River. The trough of the fold is at an acute angle to the Melones fault zone, lying 2 miles west of the fault zone on the Mokelumne River, and intersecting the fault zone between the Stanislaus and Tuolumne Rivers. The areal pattern and generally very low plunge of the lineation formed by intersection of bedding and cleavage indicates that the fold axis is nearly horizontal. The fold has been verified by repetition of beds on the Mokelumne, Calaveras, and Stanislaus Rivers, and also by top determinations in the first two areas. Most of the bedding on the limbs of the folds is nearly vertical.

An isoclinal anticline is exposed east of this syncline near the Calaveras River, where it has been established by top determinations and attitudes of bedding. The anticline is shown as far north as the Mokelume River on the accompanying maps, but here the structural interpretation, is not well established. This anticline is truncated by the Melones fault zone south of San Andreas.

The structure of the Peñon Blanco volcanics west of Melones Dam is uncertain, as only one top determination was made and bedding is obscure in much of the area between the dam and the serpentine to the west.

STRUCTURE OF THE WESTERN BLOCK

The northern part of the western block is characterized by open folds overturned to the west. Large folds are also formed in the south part of the block, but the shapes of folds are unknown because the Gopher Ridge volcanics, which there constitute much of the block, show little bedding.

In the western block, structure is best documented near the Cosumnes River (pl. 8), where the syncline at Michigan Bar Bridge, the anticline to the east, and the wide homoclinal section on the east flank of the anticline are adequately controlled by top determinations and attitudes of beds. On plate 8, the structure of parts of the anticline is generalized, as the transition from gently dipping to steeply dipping beds on both sides of the crestal region is marked by small tight folds. Axes of subsidiary folds near the crest of the anticline indicate that it plunges northwest at an angle of about 25°. The nearly horizontal attitude of beds at the west end of the Cosumnes River section is inferred from exposures in the banks of the river near Bridge House. Although no bedding was found here, lava is exposed at the low-water level for a distance of about 200 feet, whereas coarse volcanic breccia is exposed higher on the banks in the same area, suggesting a horizontal contact.

On plate 7 the epiclastic and volcanic rocks west of Campo Seco are interpreted to be a homoclinal section with tops east. This implies that the volcanic rocks in the core of the anticline at the Cosumnes River plunge beneath the bedrock surface near Ione, and that the volcanic rocks near Campo Seco are on strike with the westernmost belt of volcanic rocks exposed on the Cosumnes River. However, if it be assumed that the volcanic rocks near Campo Seco (pl. 7) are a continuation of the belt that is overlapped by Tertiary deposits near Ione, the distribution of epiclastic and volcanic rock units suggests, instead, that the large folds found on the Cosumnes River extend southward beyond the Mokelumne River. Heyl, Cox and Eric (1948, p. 67) state that tops are westward at the Penn mine (pl. 7) which may support this interpretation, although they do not indicate the size of the area covered by their observation. If this indicates a major fold, the epiclastic rocks west of the mine should be in a syncline. Nevertheless, these epiclastic rocks dip consistently eastward at an angle of about 35°, and no trace of a trough is apparent. Search for graded beds on the surface in the Penn mine area during this investigation revealed only one small group consisting of about 5 dubiously graded beds. These are on the north bank of the Mokelumne River near the west side of unit 7. The west parts of the beds were consistently lighter colored and apparently finer grained than the east parts but the light-colored parts apparently are fine-grained aggregates resulting from alteration of feldspar crystals that originally constituted the coarser parts of the beds. If so, tops of the beds would be toward the east.

Structural data are meager along the Calaveras River within the interval between A and B on the section (pl. 6) and near Hogan Dam. Between unit 8 and the western part of unit 15 the structure is indicated by top determinations and attitudes. In the SW¼ sec. 14, T. 3 N., R. 10 E., beds dip westward at angles between 65° and 90° or are vertical, and the relation of cleavage to bedding suggests tops west. In the eastern parts of secs. 22 and 27, gross layered structure, suggesting superimposed lava flows, strikes northeast, parallel to the river, and dips northwestward about 50°. The structure near Hogan Dam is arbitrarily interpreted to be homoclinal.

Near the Tuolumne and Merced Rivers, tops are westerly near the western side of the area of bedrock exposures and beds are folded near the eastern side of the block. Structure of much of the intervening area is obscure because the Gopher Ridge volcanics consist largely of massive volcanic and pyroclastic rocks in which bedding can be distinguished only locally. In the slate east of La Grange, on the Tuolumne River, no graded beds occur, but minor folds in the western part of the slate belt (fig. 10) suggest that these beds are on the west limb of an anticline. The epiclastic rocks east of Merced Falls, on the Merced River, are tightly folded in places, but many graded beds show tops west wherever the structure straightens out (pl. 11).

Drag folds exposed for nearly a mile west of Don Pedro Dam on the Tuolumne River (fig. 16) indicate that the eastern part of the Gopher Ridge volcanics lie on the west limb of an anticline. The axis of the anticline is apparently along the northwest-trending part of Don Pedro Reservoir, for tops are toward the east immediately east of this arm. However, the crest of the anticline may be cut out by a continuation of a fault extending from Lake McClure toward the northwest-trending arm of Lake McClure.

Because tops are westward on the west side of the main belt of Gopher Ridge volcanics on the Merced River, and eastward on the east side, the Gopher Ridge volcanics probably form an anticline, but part of the anticline may be faulted out as suggested by strong schistosity in sec. 2, T. 5 S., R. 15 E. A syncline with a core of slate is suggested by graded bedding west of Exchequer Dam on the Merced River (pl. 3), and folds of moderate size near the western shores of Lake McClure are indicated by the differing directions of tops of beds at various localities.

SMALL-SCALE STRUCTURES

CLEAVAGE AND SCHISTOSITY

Cleavage is widely developed in rocks of the western and central blocks, and schistosity is well developed in metamorphic rocks of the shear zones and the eastern block. Slip cleavage (White, 1949) pervades large parts of the eastern block, and occurs locally in rocks of the western and central blocks. Nearly all the slate, and much of the graywacke, conglomerate, and tuff of the western block are cleaved. Much of the lava and coarse volcanic breccia seems massive in fresh exposures but cleavage becomes apparent in weathered exposures. Regionally, and in single exposures (fig. 15), cleavage is about parallel to the axial plane of folds. In the eastern block, argillaceous rocks east of Bagby on the Merced River show only cleavage, but most of the rocks east of the volcanic member of the Calaveras formation are phyllitic or schistose.

In all rocks here described as schistose, a large proportion of the tabular minerals are parallel to the parting surfaces. In some, however, the parting is attributable solely to parallel mineral grains and in others it results in part from parallel rock fragments of epiclastic or cataclastic origin. In most places, the schistosity results from slip parallel to the parting planes as well as recrystallization. Within major fault zones slip is indicated in conglomerate and sandstone by microfaults and mortar structure with trains of fragments and in phyllite by small drag folds with sheared-off limbs. In much of the eastern block slip parallel to the schistosity is indicated by fragmentation of beds, the development of spindle-shaped fragments, and minor folds with sheared-off limbs. In large areas bedding in the chert and argillaceous sequences of the Calaveras formation has been completely destroyed in the development of strongly lineated fragmental schist. In other parts of the eastern block, especially in some places where schistosity is parallel to bedding, the significance of slip in the development of schistosity is not apparent.

Slip cleavage that is younger than schistosity can be distinguished in some places east of the Melones fault zone. It is most apparent southeast of San Andreas where it is parallel to the schistosity in the Melones fault zone, but cuts eastward trending schistosity and related structures in the Calaveras formation (Clark, 1954, p. 12). There schistosity is commonly parallel to bedding and both are deformed along the slip cleavage planes. The slip cleavage consists of microfaults and crinkles. In thin section mica is seen to be sharply bent into the slip cleavage direction. The slip cleavage becomes less prominent eastward, where the trend of the earlier schistosity is more nearly parallel to the Melones fault zone. Where slip cleavage surfaces are closely spaced, they can be distinguished only with difficulty from schistosity. Slip cleavage is shown by the same symbol as the schistosity on the map of the Angels Camp quadrangle (Eric, Stromquist, and Swinney, 1955, pl. 1, p. 29) although it is described separately in the text as shear cleavage. In some places the only remaining foliation in the rocks of the eastern block may be related to the slip cleavage.

MINOR FOLDS

Minor folds have amplitudes of a few inches to a few tens of feet. Minor folds resulting from both stages of regional deformation are found throughout the metamorphic rocks of the map area, but most of the minor folds west of the Melones fault zone plunge gently and are related to the first stage, whereas most of those east of the Melones fault zone plunge steeply and are related to the second stage. Axes of most minor folds here interpreted to be related to the first stage of deformation plunge at angles of less than 20°, but axes of some plunge as much as 35°. Gently plunging minor folds can be readily observed on the western limb of the anticline east of Michigan Bar Bridge on the Cosumnes River, and near both Don Pedro Dam and La Grange on the Tuolumne River. Gently plunging minor folds are rare east of the Melones fault zone, but are associated with gently plunging lineations on the north side of the Mokelumne River in sec. 32, T. 6 N., R. 12 E., and along the Tuolumne River in sec. 1, T. 1 S., R. 15 E.

Axes of minor folds interpreted to be related to the second stage of deformation plunge more steeply than 60°. The steeply plunging minor folds occur in all three fault blocks and the fault zones but are scarce in the central and western blocks. Too few steeply plunging folds were mapped to provide independently a regional movement picture, but the folds served to indicate the tectonic orientation of lineations which are much more abundant. Axial planes of steeply plunging minor folds are parallel to slip cleavage and schistosity.

Further work will be necessary to establish the significance of minor folds having different orientations than folds characteristic of the two stages of regional deformation. An example of such folds is in the Merced Falls slate along the Merced River. Here, minor fold axes are of diverse orientation except near the east side of the slate belt where the plunge is consistently steep and to the southeast (pl. 11). The diversity of orientation possibly results from a local modification of regional deformation patterns by a buttress of volcanic rocks that ends north of the river (pl. 1), or from superimposed folding.

LINEATIONS

Lineations discussed in the following paragraphs are in the more strongly deformed and sheared rocks that are chiefly in the eastern block and the two fault zones. Most lineation in the less deformed Mesozoic rocks that constitute the central and western blocks results from intersections of bedding and cleavage; a pencil structure occurs where bedding and cleavage are nearly at right angles near the crests or troughs of moderately to steeply plunging minor folds in epiclastic rocks of Mesozoic age. Pencil structure in the slate east of Merced Falls provided a useful guide in locating axes of minor folds.

Lineations in the greatly sheared rocks are of several kinds: in schists some lineations are marked by flat triaxial ellipsoids derived from fragments that are of pyroclastic, cataclastic, and epiclastic origin, others by elongate flat pods of chlorite or mica or by parallel amphibole crystals. Lineations marked by minerals are commonly associated with those marked by rock fragments, but are not restricted to fragmental schists. Each kind has been found to be parallel to minor fold axes and hence parallel to *b*.

The most common lineations east of the Melones fault zone consist of elongate fragments of chert in a matrix of carbonaceous and commonly quartz-rich mica schist. Associated with them in many places are thin elongate mica pods. The lineations are very similar to some of the mullion structures in the Moine series of Scotland described by Gilbert Wilson (1953.) The chert fragments (granoblastic microcrystalline quartz) take many forms depending upon the relations of cleavage and bedding and the amount of deformation. Axial ratios range from the order of 1:1:200 or 1:5:200 in the more elongate fragments to about 1:1:5 in spindle-shaped fragments. In cross section, the fragments are circular in some places and angular in others, but more commonly show streamlined shapes. Lineations lie in the plane of schistosity where schistosity can be identified, but in rare places where the rock consists of closely packed cylinders of chert no prevailing direction of schistosity was found. Although chert fragment lineation is of the same kind throughout areas underlain by the chert-bearing rocks east of the Melones fault zone, they are not necessarily everywhere related to the same stage of deformation.

The chert fragments were formed by cataclastic processes; they are not elongated epiclastic pebbles (Clark, 1954, p. 6–7). The abundant and widespread lineation in the Calaveras formation probably results from the great extent of rocks consisting of alternating thin beds of chert and relatively incompetent carbonaceous quartz-mica schist. In exposures and specimens showing the relation of cleavage to bedding, lineation is parallel to axes of minor folds and is formed in two ways; both result in lineation parallel to the *b* tectonic axis. Where bedding crosses the schistosity, the chert beds are broken into long prisms by offset along schistosity surfaces, but where bedding is parallel to the schistosity elongate fragments are formed by boudinage. Where offset is slight, the fragments of chert beds are angular. With further movement they assume streamlined or roundish forms in cross section.

A third process depends upon the tendency, common in rocks consisting of alternate layers of competent rock and slate, for cleavage which is nearly parallel to the bedding in the slate to be refracted at a large angle to the bedding in the competent layer. Such refracted cleavage breaks the competent layer into prisms elongate parallel to b.

In much of the area deformation is so severe that bedding is completely destroyed, and the origin and tectonic orientation of the chert fragment lineation is obscure; no pattern that is consistent throughout the eastern block is apparent. Nevertheless, the attitude of lineation is reasonably consistent over large areas within which it is possible to show that the lineation is parallel to axes of small folds. Not all small folds, however, were necessarily formed during the same stage of deformation. Lineations with gentle to moderate dip are, at least in places, related to large folds apparently formed during the first stage of severe deformation of the Calaveras formation. Steeply plunging lineations, also characteristic of large areas, seem to be best explained as the result of a second stage of deformation acting on previously folded beds. Relation of moderately plunging lineations to major folds is best shown east of San Andreas where the lineations generally plunge ESE. 30° to 50°. The pattern of volcanic rocks southeast of San Andreas shows that the anticline in which they are exposed plunges eastward, but the angle of plunge is not known directly. Lineations in the Mokelumne River also plunge at moderate angles in a direction slightly more southerly than most of the lineations east of San Andreas and are probably related to the same fold system.

The few measurements on the Tuolumne River show both gentle and steeply plunging lineations and form a pattern that is not readily interpreted. Those on the Merced River and the North Fork of the Merced River fall into two groups, both lying in a vertical plane that strikes N. 70° W. and is close to the average for schistosity in this region. Lineations in the argillaceous sequence nearest the volcanic sequence plunge northwest at angles of 50° to 80° whereas those farther east plunge southeast at similar angles. The steepness of plunge of these lineations and the associated minor folds suggest that they are related to a stage of deformation that followed rotation of the beds into a near vertical position.

Intersection of slip cleavage that is parallel to schistosity of the Melones fault zone with earlier schistosity and bedding forms a prominent set of lineations consisting of axes of minor shear and flexure folds, crinkles, and crenulations on schistosity surfaces. These structures are developed southeast of San Andreas, where the eastward-trending anticline in the Calaveras formation is at a large angle to the Melones fault zone. Although the slip cleavage and associated lineations are prominent, earlier schistosity and bedding can be readily traced in most exposures. The strike of the slip cleavage ranges as much as 25° and attitudes of the bedding and schistosity range much more widely. Consequently, the plunge of lineations related to slip cleavage is apparently at random, even in areas of less than a square mile. Lineations of this sort can be expected in the Calaveras formation within a few miles of the Melones fault zone wherever slip cleavage is developed. Linear structures related to slip cleavage can be seen conveniently in the floor of the Calaveritas Hill Consolidated hydraulic pit, about 4 miles southeast of San Andreas (see Clark, 1954, pl. 1).

Lineations within the Melones fault zone lie within the planes of schistosity and shearing, and plunge eastward and southeastward at angles of 60° to 80°. The bearing of the lineation is nearly normal to the strike of the schistosity. Abundant parallel amphibole crystals form a well-marked lineation in the sheared western part of the granitic pluton north of Plymouth. The lineation is developed throughout the width of the western tongue of the pluton near the Cosumnes River, a distance of more than half of a mile, but no lineation is visible in unsheared granodiorite of the same pluton several miles east of the Melones fault zone. Between San Andreas and Angels Camp, lineation is marked by elongated fragments of volcanic breccia and elongate blebs of chlorite in the metavolcanic rocks and by elongated pebbles and boulders in the mixed-pebble conglomerate of the Mariposa formation. Within the Bear Mountains fault zone lineation is formed by elongated fragments in volcanic breccia, elongate amygdules, and thin elongated blebs of chlorite.

In summary, lineations that show a consistent pattern seem to be parallel to a b tectonic axis, but present information indicates that it will be necessary to distinguish a b_1 related to the first important folding and a b_2 related to a subsequent stage of deformation. It cannot be assumed that all b_2 lineations mapped in different places result from the same tectonic episode.

REFERENCES CITED

Arkell, W. J., 1956, Jurassic geology of the world: New York, Hafner Pub. Co.

Baird, A. A., 1962, Superposed deformation in the Central Sierra Nevada foothills east of the Mother Lode: California Univ. Dept. Geol. Sci. Bull., v. 42, p. 1–70.

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

Becker, G. F., 1885, Notes on the stratigraphy of California: U.S. Geol. Survey Bull, 19, 28 p.

Best, M. G., 1963 Petrology and structural analysis of metamorphic rocks in the southwestern Sierra Nevada foothills, California: California Univ. Dept. Geol. Sci. Bull., v. 42, no. 3, p. 111–158.

Blackwelder, Eliot, 1928, Mudflow as a geologic agent in semiarid mountains: Geol. Soc. America Bull., v. 39, p. 465–483.

Calkins, F. C., 1930, The granitic rocks of the Yosemite region: U.S. Geol. Survey Prof. Paper 160, p. 120–129.

Cater, F. W., Jr., 1948a, Chromite deposits of Tuolumne and Mariposa Counties, California: California Div. Mines Bull. 134, pt. 3, chap. 1, p. 1–32.

——— 1948b, Chromite deposits of Calaveras and Amador Counties, California: California Div. Mines Bull. 134, pt. 3, chap. 2, p. 33–60.

Cater, F. W., Jr., Rynearson, G. A., and Dow, D. H., 1951, Chromite deposits of El Dorado County, California: California Div. Mines Bull. 134, pt. 3, chap. 4, p. 107–167.

Cayeux, Lucien, 1929, Les Roches sedimentaires de France: Roches Siliceuses: Paris, Imprimerie Nationale.

Clark, L. D., 1954, Geology and mineral deposits of Calaveritas quadrangle, Calaveras County, California: California Div. Mines Spec. Rept. 40, 23 p.

——— 1960a, The Foothills fault system, western Sierra Nevada, California: Geol. Soc. America Bull., v. 71, p. 483–496.

——— 1960b, Evidence for two stages of deformation in the western Sierra Nevada metamorphic belt, California: U.S. Geol. Survey Prof. Paper 400–B, Art. 148, p. B 316–B 318.

Clark, L. D., Imlay, R. W., McMath, V. E., and Silberling, N. J., 1962, Angular unconformity between Mesozoic and Paleozoic rocks in the northern Sierra Nevada, California: U.S. Geol. Survey Prof. Paper 450–B, Art. 6, p. B15–B19.

Cloos, Ernst, 1932a, Structural survey of the granodiorite south of Mariposa, California: Am. Jour. Sci., 5th ser., v. 23, p. 289–304.

——— 1932b, "Feather joints" as indicators of the direction of movements on faults, thrusts, joints, and magmatic contacts: Natl. Acad. Sci. Proc., v. 18, no. 5, p. 387–395.

Cloos, Ernst, 1935, Mother Lode and Sierra Nevada batholiths: Jour. Geology, v. 43, p. 225–249.

Compton, R. R., 1955, Trondhjemite batholith near Bidwell Bar, California: Geol. Soc. America Bull., v. 66, no. 1, p. 9–44.

Curtis, G. H., Evernden, J. F., and Lipson, Joseph, 1958, Age determination of some granitic rocks in California by the potassium-argon method: California Div. Mines Spec. Rept. 54, 16 p.

Durrell, Cordell, 1940, Metamorphism in the southern Sierra Nevada northeast of Visalia, California: California Univ. Dept. Geol. Sci. Bull., v. 25, p. 1–117.

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

Ferguson, H. G., and Gannett, R. W., 1932, Gold quartz veins of the Alleghany district, California: U.S. Geol. Survey Prof. Paper 172.

Heyl, G. R., 1948a, The Grayhouse area, Amador County, California: California Div. Mines Bull. 144, p. 85–91.

——— 1948b, Ore deposits of Copperopolis, Calaveras County, California: California Div. Mines Bull. 144, p. 93–110.

——— 1948c, The zinc-copper mines of the Quail Hill area, Calaveras County, California: California Div. Mines Bull. 144, p. 111–126.

Heyl, G. R., Cox, M. W., and Eric, J. H., 1948, Penn zinc-copper mine, Calaveras County, California: California Div. Mines Bull. 144, p. 61–84.

Heyl, G. R., and Eric, J. H., 1948, Newton copper mine, Amador County, California: California Div. Mines Bull. 144, p. 49–60.

Hill, M. L., and Dibblee, T. W., Jr., 1953, San Andreas, Garlock, and Big Pine faults, California—a study of the character, history and tectonic significance of their displacements: Geol. Soc. America Bull., v. 64, p. 443–458.

Hyatt, Alpheus, 1894, Trias and Jura in the Western States: Geol. Soc. America Bull., v. 5, p. 395–434.

Imlay, R. W., 1952, Correlation of the Jurassic formations of North America, exclusive of Canada: Geol. Soc. America Bull., v. 63, p. 953–992.

——— 1959, Succession and speciation of the pelecypod *Aucella:* U.S. Geol. Survey Prof. Paper 314–G, p. 155–169.

——— 1961, Late Jurassic ammonites from the western Sierra Nevada, California: U.S. Geol. Survey Prof. Paper 374–D, p. D1–D30.

Jenkins, O. P., ed., and others, 1948, Copper in California: California Div. Mines Bull. 144, 429 p.

King, P. B., 1937, Geology of the Marathon region, Texas: U.S. Geol. Survey Prof. Paper 187, 148 p.

Knopf, Adolph, 1929, The Mother Lode system of California: U.S. Geol. Survey Prof. Paper 157, 88 p.

Kuenen, P. H., 1950, Marine geology: New York, John Wiley and Sons, 568 p.

——— 1957, Sole markings of graded graywacke beds: Jour. Geology, v. 65, p. 231–258.

Kuenen, P. H., and Migliorini, C. I., 1950, Turbidity currents as a cause of graded bedding: Jour. Geology. v. 58, p. 91–127.

Lawson, A. C., 1933, The geology of middle California: Internat. Geol. Cong., 16th, Washington 1933, Guidebook 16, p. 1–12.

Lindgren, Waldemar, 1894, Sacramento, Calif.: U.S. Geol. Survey Geol. Atlas, Folio 5, 3 p.

——— 1900, Colfax, Calif.: U.S. Geol. Survey Geol. Atlas, Folio 66, 10 p.

Lindgren, Waldemar, and Turner, H. W., 1894, Placerville, Calif.: U.S. Geol. Survey Geol. Atlas, Folio 3, 3 p.

Natland, M. L., and Kuenen, P. H., 1951, Sedimentary history of the Ventura Basin, California, and the action of turbidity currents, *in* Soc. Econ. Paleontologists and Mineralogists, Turbidity Currents and the transportation of coarse sediments to deep water—a symposium: Soc. Econ. Paleontologists and Mineralogists, Spec. Pub. no. 2, p. 76–107.

Pettijohn, F. J., 1943, Archean sedimentation: Geol. Soc. America Bull., v. 54, p. 925–972.

——— 1954, Classification of sandstones: Jour. Geology, v. 62, p. 360–365.

——— 1957, Sedimentary rocks: New York, Harper and Brothers, 718 p.

Piper, A. M., Gale, H. S., Thomas, H. E., and Robinson, T. W., 1939, Geology and ground-water hydrology of the Mokelumne Hill area, California: U.S. Geol. Survey Water-Supply Paper 780,

Ransome, F. L., 1900, Mother Lode district: U.S. Geol. Survey Geol. Atlas, Folio 63, 11 p.

Reiche, Parry, 1937, Geology of the Lucia quadrangle, California: California Univ. Dept. Geol. Sci. Bull., v. 24, no. 7, p. 115–168.

Renz, O., Lakeman, R., and Van Der Meulen, E., 1955, Submarine sliding in western Venezuela: Am. Assoc. Petroleum Geologists Bull., v. 39, no. 10, p. 2053–2067.

Shrock, R. R., 1948, Sequence in layered rocks: New York, McGraw-Hill, 507 p.

Smith, J. P., 1894, Age of the auriferous slates of the Sierra Nevada: Geol. Soc. America Bull., v. 5, p. 243–258.

Storms, W. H., 1894, Ancient channel system of Calaveras County: California State Mining Bureau, Rept. 12, p. 482–492.

Taliaferro, N. L., 1933, Bedrock complex of the Sierra Nevada, west of the southern end of the Mother Lode [abs.]: Geol. Soc. America Bull., v. 44, no. 1, p. 149–150.

——— 1942, Geologic history and correlation of the Jurassic of southwestern Oregon and California: Geol, Soc. American Bull., v. 53, no. 1, p. 71–112.

——— 1943a, Franciscan-Knoxville problem: Am. Assoc. Petroleum Geologists Bull., v. 27, no. 2, p. 109–219.

——— 1943b, Manganese deposits of the Sierra Nevada, their genesis and metamorphism: California Div. Mines Bull. 125, p. 277–332.

Taliaferro, N. L., and Solari, A. J., 1949, Geology of the Copperopolis quadrangle, California: California Div. Mines Bull. 145 (map only).

Trask, P. D., 1926, Geology of the Point Sur quadrangle, California: California Univ. Dept. Geol. Sci. Bull., v. 16, p. 119–186.

Turner, H. W., 1893a, Some recent contributions to the geology of California: Am. Geologist, v. 11, p. 307–324.

——— 1893b, Mesozoic granite in Plumas County, California, and the Calaveras formation: Am. Geologist, v. 11, p. 425–426.

——— 1894a, Jackson, Calif.: U.S. Geol. Survey Geol. Atlas, Folio 11, 6 p.

——— 1894b, The rocks of the Sierra Nevada: U.S. Geol. Survey, 14th Ann. Rept., pt. 2, p. 435–495.

——— 1894c, Geological notes on the Sierra Nevada: Am. Geologist, v. 13, p. 228–249, 297–316.

———1895, The age and succession of the igneous rocks of Sierra Nevada: Jour. Geology, v. 3, p. 385–414, map.

Turner, H. W., and Ransome, F. L., 1897, Sonora, Calif.: U.S. Geol. Survey Geol. Atlas, Folio 41.

——— 1897, Description of the Big Trees quadrangle: U.S. Geol. Survey Geol. Atlas, Folio 51.

——— 1899, The granitic rocks of the Sierra Nevada: Jour. Geology, v. 7, p. 141–162.

White, W. S., 1949, Cleavage in east-central Vermont: Am. Geophys. Union Trans., v. 30, p. 587–594.

Wilmarth, M. G., 1938, Lexicon of geologic names of the United States: U.S. Geol. Survey Bull. 896, pt. 1.

Wilson, Gilbert, 1953, Mullion and rodding structures in the Moine series of Scotland: Geologists' Assoc., London, Pr. v. 64, pt. 2, p. 118–151.

Zeuner, F. E., 1952, Dating the past; an introduction to geochronology: London, Methuen and Co., Ltd., 495 p.

DESCRIPTION OF MAP UNITS

TABLE 1.—*Description of map units, Merced River* (pl. 3)

Map unit	*Approximate thickness (feet)*	*Lithology*
1	2000	Top not exposed. Black slate, locally pyrite bearing, with interbedded graywacke and siltstone. Graywacke beds commonly less than one-half in. thick below Merced Falls dam, several inches thick elsewhere, locally thick bedded. Interbedded rhyolite(?) tuff eastern part. Graywacke beds commonly graded throughout the section.
2	---------	Coarse rhyolite tuff.
3	1000+	Like unit 1.
4	1000+	Schistose volcanic rocks with some rhyolite(?) tuff on west side; mafic and intermediate flows, volcanic breccia and minor tuff elsewhere. No graded tuff beds found.
5	3000+	Mafic or intermediate thick-bedded pyroclastic rocks.
6	500	Laminated black slate with interbedded thin graywacke beds. Includes thick-bedded graywacke about 100 ft thick on west side. Rare graded beds in thick-bedded graywacke. Interpreted to be equivalent to unit 8.
7	200	Bedded fine conglomerate with interbedded slate. Pebbles angular to well rounded, as much as 1 in. long in some beds, but smaller in most beds. Slate matrix. Rock fragments include slate, dark- and light-gray chert, white and gray vein quartz.
8	500	Laminated black slate with minor interbedded graywacke on west side.
9	400	Thin- to thick-bedded rhyolite tuff, lapilli tuff and silicified ash. Lapilli tuff contains fragments of chert or silicified volcanic glass or ash. Large proportion of beds are graded.
10	1500+	Locally faulted on east side. Silicified ash and volcanic breccia with quartz phenocrysts; in part, at least, rhyolitic(?); dark-gray massive rhyolite(?) porphyry; and minor black chert.
11	500+	Structure uncertain; faulted on east side. Laminated black slate with interbedded thin beds of graywacke or tuff in some places. Contains interbedded conglomerate near south quarter-corner of sec. 12, T. 4 S., R. 15 E. Slate is locally quartzose, with subvitreous luster. Near south quarter corner of sec. 1, T. 4 S., R. 15 E., contains pods about 1 ft thick of dark-gray calcarenite. One such pod contains Plesiosaur bones.

TABLE 1.—*Description of map units, Merced River* (pl. 3)—Con.

Map unit	*Approximate thickness (feet)*	*Lithology*
12	1000+	Faulted on west side. Mafic or intermediate volcanic breccia and tuff; some tuff beds graded. Includes chlorite schist of the fault zone.
13	1000+	Thin-bedded black slate and tuff.
14	300+	Thin-bedded rhyolite(?), crystal tuff, and silicified ash or chert. Top not mapped.
15	1000	Coarse dark-green volcanic breccia.
16	5000	Massive aphanitic dark-green mafic lavas. Three bands of pillow lava present in upper 2000 ft; rare suggestions of pillow structure in lower part.
17	1500	Thin-bedded tuff and silicified ash; graded bedding common. Hunter Valley cherts of Taliaferro (1933).
18	3000	Recrystallized and epidotized mafic or intermediate pyroclastic rocks; top poorly exposed.
19	2000+	Coarse massive dark-green volcanic breccia with large augite phenocrysts.
20	2500	Thick-bedded coarse tuff and volcanic breccia. A few thin-bedded zones with graded bedding are present.
21	600	Black laminated slate with rare *Aucella*.
22	300	Coarse dark-green volcanic breccia.
23	500	Interbedded thin-bedded graywacke and black slate.
24	200–500	Thin-bedded tuff and silicified volcanic ash. Graded bedding common. Unit thickens to the southeast.
25	500+	Interbedded black slate and graywacke with thick-bedded graywacke horizon at base. Graywacke contains fragmental plant remains in Highway 49 roadcut on south side of Merced River at Bagby. Fault contact with serpentine on east.
26	2000	Faulted at base—in contact with serpentine. Laminated black silty slate in lower part, containing lens of black massive aphanitic limestone. One exposure of volcanic breccia with pyroxene phenocrysts as much as one-quarter inch in diameter at Bagby. Upper part is interbedded black silty slate and graded graywacke. Beds are about one-half inch thick. Parts of some graywacke beds are cross-laminated.
27	50–400	Interbedded thin-bedded green tuff, silicified volcanic ash, and black slate. Volcanic breccia occurring as float on northeast side contains pyroxene phenocrysts as much as one-quarter inch in diameter.
28	500	Dark-green quartzose slate. Bedding not visible. Cleavage fairly well developed.
29	300	Black slate, with lenticular dark-gray limestone containing abundant crinoid debris.
30	1000	Interbedded tuff and black slate. Includes thin unit of interbedded limestone (in part calcarenite), black slate, and silty sandstone exposed at sand bar in NE¼SW¼ sec. 10, T. 4 S., R. 17 E.
31	0–300	Poorly sorted schistose conglomerate containing angular to well-rounded fragments of graywacke as much as 18 in. in diameter in a mottled yellow-green and black sandy argillite matrix. Not bedded.
32	1100	Interbedded dark-gray chert and black slate. Most chert and slate beds are about 1 in. thick.
33	400	Poorly sorted conglomerate, like unit 31.
34	600	Black slate with minor interbedded tuff and volcanic breccia near center of unit.
35	400	Massive dark-green recrystallized tuff.
36	4000	Interbedded laminated black slate, massive black siltstone, and dark-green slate. Individual rock types form subunits 50 to 100 ft thick.
37	5000	Coarse dark-green volcanic breccia, volcanic conglomerate, and very fine grained metatuff with well-developed slaty cleavage Volcanic breccia contains fragments with pyroxene crystals as much as one-half inch in diameter, and locally contains abundant black slate fragments Two interbedded units about 50 ft thick near base consist chiefly of black slate with interbedded tuff and conglomerate containing volcanic rock fragments in black silty slate matrix.
38	900	Fine-grained green phyllite and phyllitic tuff with some interbedded black phyllite.
39	4000	Interbedded black slate, massive black siltstone, green slate, and fine-grained tuff.
40	5000+	Thin-bedded black slate and phyllite, graphitic in part. Contains thinly interbedded metachert locally.
41	1000	Conglomerate, argillaceous sandstone, and massive black sandy siltstone. Conglomerate contains fragments of mafic volcanic rocks, some of which are amygdaloidal, limestone, chert, and calcareous orthoquartzite. Fragments in some layers are nearly all volcanic rocks, in others, nearly all chert.
42	1500	Thinly interbedded chert and black carbonaceous slate. Contains massive black quartz-mica phyllite. Contains knots of sericite, probably after andalusite, near small plutonic body southwest of abandoned cement plant.
43	90–200	Black aphanitic thin-bedded limestone. Locally crossbedded.
44	1000	Thinly interbedded chert and black carbonaceous phyllite.
45	1500	Fine-grained hornblende-feldspar schist. Probably a metavolcanic rock.
46	--------	Like unit 44.
47	35	Dark-gray aphanitic limestone.

TABLE 1.—*Description of map units, Merced River* (pl. 3)—Con.

Map unit	*Approximate thickness (feet)*	*Lithology*
48	4000+	Thin-bedded chert interbedded with black carbonaceous phyllite and schist and massive black quartzose argillite. Chert layers range in thickness from about ¼ to 10 in. May include some quartz siltstone. In easternmost part, massive dark-gray sandstone with widely dispersed roundish quartz grains in very fine grained quartzose matrix.
49	--------	Massive microcrystalline black quartz hornfels in western part; thick-to thin-bedded quarz-mica hornfels with scattered round quartz grains, probably sandstone, in eastern part.
50	--------	Massive argillite, thinly interbedded chert, and black phyllite or schist. Some feldspathic quartzite near west side.
51	--------	Lile unit 50 but contains limestone, in part silicated or altered to tactite at eastern margin.

TABLE 2.—*Description of map units, Tuolumne River* (pl. 4)

Map unit	*Appproximate thickness (feet)*	*Lithology*
1	500+	Massive black aphanitic porphyritic rhyolite(?) with feldspar phenocrysts about 1 mm long. Possibly intrusive. West boundary not exposed.
2	4000	Volcanic and metavolcanic rocks. From west to east these are: fine-grained, massive greenstone; massive aphanitic fresh-looking rhyolite or dacite porphyry with quartz phenocrysts 0.5 mm in diameter and feldspar phenocrysts 1 to 3 mm long; medium-bedded tuff and silicified ash; interlayered light- and dark-green volcanics including some pyroclastics and massive rhyolite porphyry.
3	1000+	Thin- to medium-bedded black slate and siltstones, rare graywacke. No graded beds found. Contains belemnites east of LaGrange powerhouse.
4	500+	Medium-green massive silicified aphanitic volcanic rock. Shows vertical columnar jointing locally.
5	--------	Schistose, light-green metatuff and volcanic breccia; contains fragments of silicified ash and volcanic rocks. Fault on east side.
6	--------	Medium-bedded silicified volcanic ash and tuff, lapilli tuff, and volcanic breccia.
7	--------	Schistose, silicified epidotized volcanic rocks, with some volcanic breccia, lapilli tuff, chert or silicified ash, and massive rhyolite(?) porphyry with feldspar phenocrysts.
8	--------	Sheared agglomerate or pillow lava consisting of ellipsoidal bodies of amygdaloidal aphanitic lava as much as 6 in. thick and 3 ft long. Contains rare fragments of medium-bedded tuff.
9	100	Dark-green sheared pillow lava.

TABLE 2.—*Description of map units, Tuolumne River* (pl. 4)—Con.

Map unit	*Approximate thickness (feet)*	*Lithology*
10	--------	Phyllitic light-colored volcanic rock; includes some tuff and slate or very fine tuff.
11	500+	Massive light-colored volcanic rock. Includes some tuff and volcanic breccia. Schistose on east.
12	--------	Thick-bedded pyroclastic rocks, massive light-gray silicified volcanic rocks and minor amygdaloidal lava.
13	1500+	Thin- to thick-bedded light-green tuff and lapilli tuff with minor volcanic breccia. Thickness uncertain because of folding and faults.
14	1000+	Thin-bedded black slate with interbedded tuff near west side. Interbedded graywacke with abundant volcanic rock fragments; graded beds on east side.
15	300	Interbedded tuff and black slate.
16	500±	Massive dark-green amygdaloidal lava.
17	300±	Interbedded tuff and volcanic breccia.
18	300±	Black slate.
19	--------	Dark-green volcanic breccia, cut by granodiorite sills and porphyritic dikes with feldspar phenocrysts.
20	--------	Schistose greenstone.
21	2000+	Porphyritic rhyolite, locally sheared. Probable fault on west side.
22	--------	Massive dark-green metavolcanic rock.
23	--------	Massive dark-green metavolcanic rock containing small masses of hornblende gabbro.
24	3000+	Dark-green massive porphyritic volcanic rock with feldspar phenocrysts 1 to 2 mm long. In part silicified. Eastern part amygdaloidal.
25	700	Medium-green volcanic breccia. Amygdaloidal fragments abundant in places.
26	300	Black slate with interbedded graywacke beds 1 in. to 1 ft thick. Graywacke beds are commonly graded. Conglomerate at base of formation consists of pebbles of volcanic rocks in black slate matrix. Conglomerate lenses about 45 ft above the base of the unit contain pebbles of vein quartz. Invertebrate fossils abundant 200 to 225 ft above the base of the unit.
27	600	Thick-bedded coarse graywacke. Graded bedding not common. Only the basal contact exposed on line of traverse—upper contact projected from mapping by G. R. Heyl (written communication).
28	1000+	Black slate; very poorly exposed along line of traverse. Contains medium-bedded interlayered graywacke and slate in sec. 20, T. 1 S., R. 15 E. Many graded graywacke beds.
29	500±	Thin- to medium-bedded black slate. Contains two small limestone lenses. Faulted on east and west sides.
30	--------	Schistose metavolcanic rock.
31	--------	Black carbonaceous quartzose mica schist.
32	--------	Schistose metavolcanic rock. Fault on east side.

TABLE 2.—*Description of map units, Tuolumne River* (pl. 4)—Continued

Map unit	Approximate thickness (feet)	Lithology
33	2000±	Black thin- to medium-bedded interlayered metachert and carbonaceous mica schist.
34	200	Volcanic conglomerate and schistose metavolcanic rock.
35	1500	Black quartzose mica schist; bedding obscure in most places.
36	200	Interbedded limestone and black quartzose mica schist.
37	1500	Medium to very thin bedded interlayered chert and black carbonaceous schist with minor interbedded volcanic breccia and massive metavolcanic rock.
38	1500+	Black thin- to medium-bedded interlayered chert and carbonaceous schist. Includes some medium-bedded quartz siltstone. Locally includes pods of limestone and calcareous quartz-mica schist.
39	--------	Limestone with interbedded black, carbonaceous quartzose mica schist. Includes limestone breccia at the mouth of the North Fork of the Tuolumne River.
40	0–500	Dark-green tuff and volcanic breccia. Thins rapidly west of the mouth of the North Fork of the Tuolumne River. Includes thin zone of black quartzose carbonaceous schist at contact.
41	200	Thin-bedded limestone.
42	1100	Thin- to medium-bedded interlayered black metachert and carbonaceous schist. Contains zone of limestone breccia in middle part of unit.
43	1800	Thick-bedded limestone—probably includes some dolomite.
44	300	Massive very fine grained black metavolcanic rock.
45	200	Medium-bedded limestone.
46	300	Thin- to medium-bedded vitreous metachert and black, carbonaceous schist.
47	1000	Limestone and dolomite with interbedded metachert and black, carbonaceous schist.
48	1500	Thin- to medium-bedded black, carbonaceous quartzose mica schist.
49	3000	Coarse crystalline limestone and medium-grained dolomite with interbedded quartzose mica schist.
50	--------	Black, carbonaceous quartzose mica schist and gneiss with rare pods of coarse crystalline limestone. Cut by granitic rock and pegmatite dikes.

TABLE 3.—*Description of map units, Stanislaus River* (pl. 5)

Map unit	Approximate thickness (feet)	Lithology
1	--------	Includes volcanic rocks of mafic or intermediate composition and rhyolite (?) porphyry. Most mafic and intermediate rocks are schistose, whereas most of the rhyolite is fresh looking and massive. Contacts of rhyolite cross schistosity of more mafic rocks at least locally.
2	--------	Light-green rhyolite or dacite porphyry with aphanitic groundmass. Quartz phenocrysts rare. Locally sheared.
3	200	Dark-green massive metavolcanic rock, probably lava.
4	400	Light-green volcanic breccia with abundant fragments of white chert or silicified ash. Feldspar crystals 1 to 2 mm long are abundant in groundmass.
5	--------	Light-green thick-bedded lithic tuff and volcanic breccia.
6	--------	Coarse volcanic breccia with interbedded tuff.
7	2000	Medium to very thick bedded medium- to dark-green coarse tuff.
8	200	Dark-green volcanic breccia.
9	200	Massive amygdaloidal volcanic rock.
10	3000	Dark-green tuff and volcanic breccia. Medium to very thick bedded. Some tuff beds graded. Schistose except in eastern part.
11	300	Medium-bedded silicified ash and tuff. Some graded beds.
12	500+	Black slate.
13	--------	Volcanic breccia and coarse tuff.
14	500	Quartz-bearing rhyolite(?) tuff.
15	200	Black slate. Includes a medium-bedded tuff and silicified ash sequence about 10 ft thick.
16	300	Very fine grained tuff.
17	1000	Black slate with interbedded tuff layers 1 mm to about 1 m thick.
18	400+	Quartzose slate.
19	1000	Medium to very thick bedded volcanic breccia, tuff, and silicified ash with minor amygdaloidal lava. Contains abundant feldspar phenocrysts as much as 5 mm long.
20	400	Interbedded black slate, volcanic breccia, and tuff.
21	1400	Black slate with interbedded graywacke.
22	1000	Coarse volcanic breccia; contains fragments of white chert or silicified ash on east side. Minor tuff.
23	300	Medium-bedded tuff and silicified ash. Graded beds common.
24	1100	Black slate with interbedded tuffaceous graywacke, graywacke, and minor conglomerate. Conglomerate has angular to well-rounded fragments of vein quartz, chert, and silicified ash(?), and angular fragments of black slate.
25	--------	Coarse dark-green tuff on west; dark-green volcanic breccia in eastern part.
26	300	Medium- to thick-bedded tuff and very fine tuff.
27	5000+	Coarse yellow-green tuff with scattered thin layers of volcanic breccia. Bedding obscure. Contains zone about 25 ft thick of pillow lava in the NE¼ sec. 32, T. 1 N., R. 13 E.

TABLE 3.—*Description of map units, Stanislaus River (pl. 5)*—Continued

Map unit	Approximate thickness (feet)	Lithology
28	--------	Includes massive fine- to medium-grained metavolcanic rock; interbedded chlorite schist and black phyllite with rare limestone beds about 4 in. thick; foliated medium-bedded interlayered black chert, dark-gray phyllite, and metavolcanic rock; and dark-gray quartzose phyllite. Lithology and structure complex. Correlation uncertain; structure shown diagrammatically.
29	--------	Volcanic breccia and tuff, faulted against serpentine on west side.
30	200	Medium-bedded black slate with interbedded tuff. Minor interbedded graywacke and conglomerate. Most pebbles are black slate and volcanic rocks; contains some chert and rare limestone pebbles.
31	--------	Volcanic rocks, chiefly pyroclastics. Bedding obscure. Zone of massive amygdaloidal volcanic rock on west side.
32	--------	Pyroclastic rocks. Bedding and texture obscure.
33	100	Black medium-bedded slate. Limestone float on surface.
34	1000+	Coarse dark-green volcanic breccia. Locally contains augite phenocrysts as much as one-quarter inch in diameter.
35	--------	Coarse dark-green volcanic breccia.
36	200	Black slate.
37	200+	Coarse dark-green tuff. Eastern contact concealed.
38	1000+	Black slate with interlayered thick to very thick bedded graywacke. Some graywacke beds graded. Slate contains abundant plant remains in the SW¼ sec. 33, T. 2 N., R. 13 E., and invertebrate fossils in addition to plant remains in the NW¼ sec. 3, T. 1 N., R. 13 E.
39	400	Medium- to thick-bedded graywacke; graded bedding common.
40	500+	Black slate. Folded in NE¼ sec. 3, T. 1 N., R. 13 E.
41	500	Massive dark-green tuff.
42	300	Black slate with interbedded tuff.
43	500	Tuff.
44	--------	Interbedded tuff and black slate, poorly exposed at high-water mark. Contains tuff units as much as 300 ft thick, but in general slate and tuff zones are much thinner.
45	--------	Medium- to thick-bedded tuff with augite crystals.
46	--------	Coarse crystalline limestone and black carbonaceous quartzose schist.
47	--------	Conglomerate, containing pebbles of volcanic rocks, slate, chert, vein quartz, and limestone.
48	--------	Black slate with minor interbedded tuff and chert.
49	--------	Conglomerate, like unit 47.
50	--------	Medium- to thick-bedded tuff with interbedded black slate. Slate most abundant in eastern part. Tuff beds commonly graded.
51	--------	Volcanic conglomerate. Contains scattered pebbles of slate.
52	--------	Melones fault zone—mostly green schist containing blocks of black carbonaceous quartzose schist, and volcanic conglomerate.
53	--------	Thin- to medium-bedded chert and black carbonaceous very fine grained schist.
54	--------	Mostly derived from medium to very thick bedded mafic volcanic rocks with some volcanic breccia, but western part is interbedded black carbonaceous schist and green schist; and central part is quartzose sericite schist. In part fine-grained and schistose, and in part massive with medium-grained gabbroic texture. Eastern part is massive amphibolite, becoming coarser grained to the east. Thin zone of black carbonaceous schist in SW¼NE¼ sec. 17, T. 2 N., R. 14 E. Brecciated and cut by granitic dikes near contact with granodiorite.
55	--------	Limestone.
56	--------	Limestone.
57	--------	Thin- to medium-bedded coarse- to medium-grained limestone.
58	--------	Aphanitic dark-green metavolcanic rock.
59	--------	Massive limestone, in part coarse-crystalline, and massive dolomite or dolomitic limestone.
60	--------	Medium- to thick-bedded dolomite and limestone. Contains interbedded black carbonaceous quartzose schist on west side. Contains thin zone of quartz-mica-magnetite schist, probably metarhyolite, in the NE¼NW¼ sec. 34, T. 3 N., R. 14 E.
61	--------	Massive limestone. Includes thin zone of coarse calcareous quartz-biotite schist on east side.
62	--------	Alphanitic dark-green metavolcanic rock.
63	--------	Coarse crystalline limestone.
64	--------	Thin- to medium-bedded chert and black, carbonaceous quartz-mica schist. Chert is metamorphosed and locally vitreous. Includes some limestone. Bedding destroyed in most places. Lineation extensively developed.
65	--------	Like unit 64.

TABLE 4.—*Description of map units, Calaveras River* (pl. 6)

Map unit	Approximate thickness (feet)	Lithology
1----	--------	Massive quartz-feldspar porphyry, containing subhedral quartz phenocrysts as much as 2 mm in diameter, euhedral plagioclase phenocrysts as much as 1.5 mm in diameter, and ferromagnesian minerals in a white very fine grained groundmass.
2----	3000+--	Very fine grained dark-green massive porphyritic lava with abundant feldspar phenocrysts averaging 1 mm in diameter. Feldspar partly replaced by epidote. Includes vertical rhyolite(?) dike about 15 ft thick with horizontal columnar joints. Dike rock contains quartz phenocrysts 3 mm in diameter and plagioclase phenocrysts 2 mm long in aphanitic dark-gray groundmass.
3----	200-----	Aphanitic light-green volcanic rock.
4----	1000+--	Massive fine-grained drark-green volcanic rock.
5----	1000+--	Dark-green coarse metamorphosed volcanic breccia.
6----	800-----	Massive dark-green porphyritic metavolcanic rock, in part brecciated. Phenocrysts are of augite or amphibole after augite and are 1 to 2 mm in diameter. Includes zones of volcanic breccia and pillow lava.
7----	1000----	Massive dark-green metavolcanic rock, mostly brecciated. Some breccia contains amygdaloidal fragments widely scattered among nonamygdaloidal fragments. Breccia fragments are separated by epidote-rich seams. Some nonbrecciated parts that are not amygdaloidal contain amygdaloidal bodies 1 to 2 ft long. Contacts with unit 8 are poorly defined.
8----	1500----	Massive dark-green metavolcanic rock like unit 6, [but] contains zones of volcanic breccia and pillow lava.
9----	400-----	Volcanic breccia containing some coarse tuff zones with some graded beds.
10---	--------	Massive dark-gray rhyolite(?) porphyry containing quartz and feldspar phenocrysts about 1 mm in diameter.
11---	150-----	Dark-green coarse volcanic breccia. Includes some massive lava.
12---	300-----	Coarse porphyritic rhyolitic(?) volcanic breccia with abundant feldspar phenocrysts and widely scattered quartz phenocrysts.
13---	--------	Massive dark-gray porphyritic rhyolite(?). Contains common plagioclase phenocrysts 1 to 2 mm in diameter and widely scattered quartz phenocrysts.
14---	1800±--	Light-green volcanic breccia, tuff, lapilli tuff, and silicified ash.
15---	1500----	Black slate with some interbedded graywacke and minor interbedded tuff.
16---	800-----	Pyroclastic rocks.
17---	200-----	Black slate.
18---	500-----	Pyroclastic rocks.
19---	2000+--	Black slate with some interbedded graywacke—poorly exposed.
20---	--------	Schistose metavolcanic rocks. Includes some metatuff and feldspar porphyry on east side. Poorly exposed.
21---	--------	Metamorphosed volcanic breccia containing phenocrysts probably composed of amphibole after augite.
22---	3000-----	Tuff, with some interbedded volcanic breccia.
23---	500+---	Slate, in part quartzose. Weathers gray. Minor interbedded very coarse graywacke.
24---	--------	Tuff.
25---	--------	Not exposed in river. Probably dark-gray quartzose slate and sericitic chert as exposed south of river.
26---	500±---	Well-indurated dark-gray coarse sandstone and fine conglomerate composed chiefly of fairly well-rounded fragments of vein quartz and chert. Slate fragments common.
27---	400±---	Coarse dark-green volcanic breccia containing augite phenocrysts more than 2 mm in diameter.
28---	1000-----	Dark-gray quartzose slate and sericitic chert. Includes scattered zones of fine conglomerate containing fragments of chert, slate, and volcanic rocks. Conglomerate is possibly infolded.
29---	--------	Dark-green massive porphyritic dike rock with tabular saussuritized plagioclase phenocrysts. Not exposed on river banks.
30---	2000+---	Coarse dark-green volcanic breccia containing augite phenocrysts more than 2 mm in diameter.
31---	1000+---	Thin- to medium-bedded black slate with interbedded tuff.
32---	2000+---	Thin- to medium-bedded black slate with interbedded tuff. Includes lenticular conglomerates and possibly some chert.
33---	--------	Green schist.
34---	--------	Green schist.
35---	--------	Black medium-bedded interlayered chert and carbonaceous schist. Some interbedded limestone.

TABLE 5.—*Description of map units, Mokelumne River* (pl. 7)

Map unit	Approximate thickness (feet)	Lithology
1----	1500+---	Massive dark-green metavolcanic rocks; includes lavas and volcanic breccia. Pillow lava present in SW1/4 sec. 5, T. 4 N, R. 10 E. Some lavas and volcanic breccia in eastern part contain feldspar phenocrysts. Poorly exposed.
2----	700-----	Massive feldspar (rhyolite?) porphyry with very dark gray aphanitic groundmass. Quartz phenocrysts 2 mm and less in diameter.

TABLE 5.—*Description of map units, Mokelumne River* (pl. 7)—Continued

Map unit	Approximate thickness (feet)	Lithology
3	1500	Thin- to very thick bedded medium-green rhyolite(?) tuff, lapilli tuff, and light-green silicified ash. Tuff contains abundant feldspar phenocrysts and scattered quartz grains. Graded beds common.
4	200	Medium-green volcanic breccia. Feldspar crystals and crystal fragments common and quartz grains scattered in groundmass.
5	600	Tuff and lapilli tuff, like unit 3.
6	600+	Thin- to medium-bedded black silty slate with some interbedded graywacke. Contains a tuff horizon about 15 ft thick near the east side.
7	800	Foliated medium- to thick-bedded meta-andesite and metadacite pyroclastics.
8	500±	Foliated metamorphosed volcanic breccia. Includes minor intrusive rhyolite porphyry.
9	200	Medium- to dark-green basaltic pillow lavas.
10	500±	Dark-green foliated pyroclastic rocks.
11	1000±	Interbedded rhyolite and mafic or intermediate pyroclastic rocks. Contains many vertical quartz veins.
12	500	Porphyritic rhyolite or dacite.
13	600	Mafic or intermediate volcanics.
14	1500+	Porphyritic rhyolite, foliated in eastern part. Quartz phenocrysts are as much as 2 mm in diameter. Vein quartz, sericite schist, and much-altered strongly foliated volcanic rocks in eastern part.
15	1000+	Light-green foliated fine- to medium-grained tuff.
16	2000	Interbedded medium- to thick-bedded tuff and black slate. Predominantly slate. Tuff beds commonly graded.
17	1500	Medium- to very thick-bedded fine tuff, lapilli tuff, and volcanic breccia.
18	700+	Black slate. Poorly exposed around margins of reservoir.
19	1500+	Tuff with minor interbedded slate. Includes chlorite schist and sericite schist in the NE¼SW¼ sec. 23, T. 5 N., R. 10 E. Thickness measured in sec. 15, T. 5 N., R. 10 E.
20	200	Porphyritic foliated metarhyolite or metadacite.
21	2500+	Dark-green tuff and volcanic breccia in western part; massive metavolcanic rocks with some interbedded metachert and metatuff in eastern part.
22	500+	On northwest side of reservoir; from west to east: coarse massive dark-green metavolcanic rock, massive amygdaloidal lava. Exposed on southeast side of reservoir, light-gray thin- to medium-bedded very fine grained limestone about 30 ft thick, and bedded tuff. On southeast side of reservoir, undifferentiated volcanic rocks.
23	200+	Tuff with interbedded conglomerate.
24	--------	Quartzose phyllite, weathers light gray.
25	500+	Interbedded black slate, conglomerate, graywacke, and tuff.
26	100±	Limestone.
27	--------	Interbedded black slate and tuff on west. Coarse dark-green volcanic breccia with augite phenocrysts as much as 5 mm in diameter on east. Not exposed on northwest side of reservoir.
28	--------	Quartzose phyllite, weathers light gray to light brown. Contains light-green foliated amygdaloidal lava about 6 ft thick and limestone about 20 ft thick in the SE¼NE¼ sec. 18, T. 5 N., R. 11 E. Limestone is calcarenite and breccia with limestone and dolomite fragments. No noncalcareous detrital grains noted.
29	1500+	Coarse dark-green volcanic breccia containing augite crystals more than 5 mm in diameter.
30	500	Tuff, poorly exposed.
31	500	Medium- to thick-bedded tuff with interlayered black slate.
32	1500	Medium- to very thick-bedded tuff and lapilli tuff.
33	100+	Black slate with interbedded tuff.
34	1300	Medium- to very thick-bedded tuff and lapilli tuff.
35	500+	Tuff with interbedded conglomerate or breccia. Conglomerate consists chiefly of fragments of volcanic rock in a tuffaceous matrix, but also contains scattered fragments of black slate and vein quartz. Most volcanic rock fragments are angular.
36	--------	Black slate with interbedded tuff, very coarse graywacke, and fine conglomerate.
37	--------	Medium-bedded coarse to fine tuff.
38	--------	Black slate with interbedded tuff.
39	--------	Tuff with interbedded slate. Poorly exposed.
40	--------	Chlorite schist. Fault zones contain thin units of black carbonaceous quartzose schist, probably derived from the Calaveras formation.
41	--------	Black carbonaceous quartzose phyllite with lamellae of metatuff.
42	--------	Interbedded tuff and black phyllite. Includes chlorite schist on east side.
43	--------	Chlorite schist, coarse crystalline limestone, and black quartzose schist. Intruded by gabbro dikes.
44	--------	Medium-bedded metachert and black carbonaceous quartz-mica schist. Possibly includes quartzose siltstone. Includes chlorite schist and limestone pods on east side.
45	--------	Interbedded black carbonaceous schist, metachert, and possibly quartzose siltstone.
46	--------	South part like unit 45, north part coarse crystalline limestone.
47	--------	Like unit 45.

TABLE 5.—*Description of map units, Mokelumne River* (pl. 7)—Continued

Map unit	Approximate thickness (feet)	Lithology
48	--------	Coarse crystalline limestone with interbedded quartz-mica schist.
49	--------	Like unit 45.
50	--------	Coarse crystalline limestone.
51	--------	Like unit 45.

TABLE 6.—*Description of map units, Jackson Creek*

Unit No.	Thickness	Lithology
1		Dark-green metavolcanic rock.
2		Coarse- to fine-bedded tuff.
3		Interbedded black slate and graywacke.
4		Interbedded black slate and tuff.
5		Tuff and porphyritic volcanic breccia with pyroxene phenocrysts.
6		Light-green buff-weathering quartzose phyllite.
7		Gray-green fine-grained volcanic breccia with feldspar phenocrysts less than 2 mm long.
8		Light-green quartzose phyllite with thin interbedded conglomerate. Conglomerate contains pebbles of chert, slate, graygraywacke, and volcanic rocks.
9		Interbedded thin-bedded gray quartzose phyllite and black chert. Includes limestone lens, probably bioclastic, with Foraminifera locally abundant, in eastern part.
10		Thin-bedded black chert, with phyllite partings. Limestone lens on east side.
11		Interbedded coarse and fine conglomerate, containing pebbles of volcanic rocks, chert, vein quartz, quartz schist, limetone, and rare granitic(?) rocks.
12		Volcanic breccia.

TABLE 7.—*Description of maps units, Cosumnes River* (pl. 8)

Map unit	Approximate thickness (feet)	Lithology
1	--------	Coarse dark-green volcanic breccia containing augite phenocrysts as much as 5 mm in diameter. Probably equivalent to unit 3. Exposed in upper part of river banks; not shown on map.
2	--------	Massive dark-green very fine grained lava. Base not exposed.
3	1100	Coarse dark-green volcanic breccia. Fragments have quartz amygdules as much as .1 in. in diameter, and chalcedony amygdules as much as 1½ in. in diameter.
4	400	Massive dark-green very fine grained lava. Contains some epidotized breccia.
5	500+	Medium-green rhyolite volcanic breccia and coarse tuff. Contains abundant roundish quartz grains mostly less than 1 mm in diameter.
6	500+	Fine to coarse medium- to very thick-bedded tuff and lapilli tuff.
7	1000	Black slate with interbedded graywacke. Includes fine-grained metatuff on east side.
8	200+	Graywacke.
9	200+	Black slate with interbedded graywacke. Includes thin crystal tuff unit on east side.
10	1000	Thick- to thin-bedded graywacke, minor slate. Graded beds common. Coarse to fine tuff about 100 ft thick at western side.
11	2000	Black slate with minor interbedded graywacke. Eastern part fossiliferous.
12	1000+	Medium- to thick-bedded tuff and lapilli tuff with minor silicified ash. Graded beds common.
13	200	Black slate with interbedded tuff.
14	500	Volcanic breccia and tuff.
15	300	Black slate with interbedded tuff.
16	1000	Medium-bedded tuff.
17	700	Medium-bedded interlayered graywacke and black slate.
18	600	Tuff and volcanic breccia.
19	300	Black slate with interbedded tuff.
20	500	Mafic or intermediate pyroclastic rocks.
21	400	Porphyritic rhyolite(?), including massive lava and pyroclastic rocks.
22	1200	Mafic or intermediate pyroclastic rocks with minor pillow lava.
23	700+	Massive porphyritic rhyolite(?) with some interlayered mafic or intermediate volcanic rocks.
24	3000+	Massive fine- to medium-grained tuff with some volcanic breccia, lapilli tuff, and pillow lava. Zone of lapilli tuff and volcanic breccia 80 ft thick about 1600 ft north of the south quarter-corner of sect 27, T. 8 N., R. 9 E., contains feldspar crystals as much as 1 in. in diameter and abundant scoria fragments. Pillow lava is porphyritic, with saussuritized euhedral feldspar phenocrysts about 5 mm long. Zone of black carbonaceous slate about 10 ft thick occurs about 1500 ft west of the east quarter-corner of sec. 27, T. 8 N., R. 9 E.
25	1100	Porphyritic lava containing saussuritized euhedral feldspar phenocrysts and clusters of phenocrysts as much as 8 mm long in aphanitic matrix. Much of this lava has pillow structure.
26	1000+	Mafic or intermediate tuff and volcanic breccia. Some graded beds and cross-laminated beds.
27	1000+	Tuff in western part, green schist in eastern part.

TABLE 7.—*Description of map units, Cosumnes River* (pl. 8)—Continued

Map unit	*Approximate thickness (feet)*	*Lithology*
28	--------	Metavolcanic rocks, including massive greenstone, green schist, and medium-bedded metatuff.
29	--------	Green schist.
30	--------	Medium-bedded fine- to coarse-grained tuff.
31	700+	Thick- to very thick-bedded conglomerate with interbedded sandstone on east side. Conglomerate consists mostly of fragments of volcanic rocks but also contains vein quartz, black and gray chert, and black slate, in a tuffaceous matrix. Fragments of volcanic rocks and slate are angular to well rounded; chert and quartz fragments are well rounded. Some beds contain pebbles of fine-grained gray limestone. The sandstone is well indurated and consists mostly of well-rounded quartz grains, but contains some less resistant grains.
32	1000+	Thin- to medium-bedded interlayered fine to coarse graywacke and black slate. Graywacke beds commonly graded. Contains rare limestone beds less than 1 ft thick. Near west side, includes massive porphyritic lava or hypabyssal intrusive rock with feldspar phenocrysts. Eastern part includes volcanic rocks about 200 ft thick.
33	1000+	Interbedded graywacke, massive gray slate, and fine-grained tuff or tuffaceous sandstone.
34	600	Tuff and volcanic breccia.
35	300	Volcanic rocks.
36	--------	Black slate with interbedded pyroclastic rocks.
37	--------	Well-indurated dark-gray sandstone consisting chiefly of quartz grains. Chert and black slate grains are common. Grains are angular to well rounded. Contains some fine conglomerate.
38	--------	Black medium-bedded interlayered chert and carbonaceous phyllite. Some quartz schist.
39	--------	Quartz sandstone, like unit 37.
40	1000+	Black slate. Contains beds of black argillaceous very fine grained limestone 1 in. to 1 ft. thick on southeast side of river near the north quarter-corner of sec. 28, T. 8 N., R. 10 E. Contains poorly exposed fine conglomerate with interbedded arenaceous limestone (calcarenite) on the southwest side of the river near the center of sec. 21, T. 8 N., R. 10 E. Conglomerate contains well-rounded granules of volcanic rocks, vein quartz, chert, and quartzite.
41	400	Very fine-grained dark-green massive metavolcanic rock.

TABLE 7.—*Description of map units, Cosumnes River* (pl. 8)—Continued

Map unit	*Approximate thickness (feet)*	*Lithology*	
42	300	Interbedded black slate, volcanic conglomerate, and tuff.	Conglomerate in this interval contains angular to rounded clasts of volcanic rocks, chert, slate, clastic limestone, vein quartz and rare quartzite, and gneiss.
43	200	Fine conglomerate.	
44	500	Coarse conglomerate.	
45	600	Interbedded black slate, siltstone, with subordinate graywacke and conglomerate. Includes massive, porphyritic sill rock with plagioclase phenocrysts.	
46	300	Coarse conglomerate.	
47	800	Black slate, medium- to thick-bedded graywacke, and lenticular conglomerate.	
48	1000	Tuff, black slate, coarse conglomerate, graywacke. Includes porphyritic dike rock with plagioclase phenocrysts.	
49	1500	Thin- to thick-bedded tuff and lapilli tuff and some volcanic breccia. Pyroxene crystals abundant in lower part. Many graded beds, some slump structures. Upper part fossiliferous. Includes several porphyritic sills with plagioclase phenocrysts.	
50	900	Very coarse thick-bedded dark-green volcanic breccia with abundant augite phenocrysts.	
51	60	Pillow lava.	
52	1900	Very coarse thick-bedded to massive volcanic breccia with abundant augite phenocrysts. Minor tuff.	
53	500	Medium- to thin-bedded black slate with interlayered graywacke. Interbedded slate and tuff near Huse Bridge.	
54	300	Medium-bedded fine- to medium-grained tuff.	
55	400	Thin-bedded black slate with interlayered graywacke.	
56	300	Coarse thick-bedded graywacke with interlayered black slate.	
57	--------	Black sericitic carbonaceous(?) schist.	
58	--------	Dark-green volcanic breccia with augite phenocrysts commonly 4 mm in diameter.	
59	--------	Metavolcanic rock. Green schist with crystalloblasts of augite or amphibole replacing augite.	
60	--------	Schist, consisting chiefly of sausseritized feldspar, quartz, and hornblende. Derived from granitic rock.	
61	--------	Medium-bedded chert and black carbonaceous quartzose schist with interlayered chlorite schist.	

INDEX

[Major references are in italic]

U.S. GOVERNMENT PRINTING OFFICE : 1965 O—724-276