Stratigraphy of the North Half of the Western Sierra Nevada Metamorphic Belt, California

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Prepared in cooperation with the California Division of Mines and Geology

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By LORIN D. CLARK

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STRATIGRAPHY OF THE NORTH HALF OF THE WESTERN SIERRA NEVADA METAMORPHIC BELT, CALIFORNIA

By Lorin D. Clark

ABSTRACT

A belt of metamorphic rocks, about 180 miles (290 km) long and 20–40 miles (32–64 km) wide, crops out in the western foothills of the Sierra Nevada from the latitude of Yosemite Valley northward. It lies between the Sierra Nevada batholith on the east and overlapping unmetamorphosed Tertiary strata on the west. The metamorphic rocks were derived from sparsely fossiliferous eugeosynclinal volcanic and epiclastic rocks of Paleozoic and Mesozoic age. Regional metamorphism is generally of low grade, in the greenschist facies.

Lithologic similarities between Paleozoic and Mesozoic rocks preclude correlation by lithology alone. The paleontologic record is incomplete, and some map units are undated. The Shoo Fly Formation is questionably correlated with the lithologically similar Taylorsville Formation of Silurian age exposed north of the report area. An unnamed unit of volcanic and sedimentary rocks has yielded fossils of probable Devonian age; the Calaveras Formation has yielded gastropods and corals of late Paleozoic age; an unnamed limestone contains fossils of Late Triassic(?) age; the Sailor Canyon Formation contains ammonites of Early and Middle Jurassic age; Cosumnes-type rocks have yielded ammonites of early Late Jurassic age; and the Monte de Oro Formation bears a Late Jurassic fauna.

As a result of successive deformations, the structure of the metamorphic belt is complex and incompletely understood. The structure can be generalized in terms of four blocks separated by three steeply eastward-dipping reverse faults along which younger strata have been thrust beneath older. These include, from west to east, (1) a block of predominantly Jurassic and probable Jurassic rocks, (2) a block of predominantly Jurassic rocks, (3) a disconnected block of upper Paleozoic and Mesozoic rocks, including the Calaveras Formation, and (4) a block of Paleozoic and Mesozoic rocks including the Shoo Fly Formation. Mesozoic rocks lie on both sides of the metamorphic belt, and the eastward-facing bedding tops predominating over westward-facing ones suggest the central position of the Paleozoic strata results chiefly from faulting.

Major fault zones are marked by zones of flaser rock or schist or both, which vary in width from about 100 feet (30 m) to nearly 3 miles (4.8 km) if large horses are included. Most major faults strike north or N. 30° W. Planar structures in the fault zones dip eastward more steeply than 70°. Lineations consisting of elongate rock fragments, amphibole crystals, and axes of minor folds of slip surfaces plunge steeply.

In general, Paleozoic rocks are more deformed than Mesozoic rocks in the report area, but exceptions are readily found. The present structure results from several stages of regional deformation. The greater deformation of the older rocks results partly from greater lithologic susceptibility or geographic position or both, but Silurian rocks were deformed at least twice before deposition of Triassic (?) and Jurassic strata. Jurassic rocks were folded about moderately plunging axes, and older rocks were refolded, before major faulting was completed.

INTRODUCTION

This report is based on fieldwork by Lorin D. Clark during the period 1955–61 and is an extension of his earlier work in the southern half of the western Sierra Nevada metamorphic belt. He prepared the bulk of the report in the mid-1960's, but various factors, including illness, delayed its completion. This illness also prevented the preparation of a proposed major chapter on the structure of the metamorphic belt, and so this report is limited largely to stratigraphic considerations. The basic data that led to the interpretations herein are being released separately as a series of geologic maps and cross sections at a scale of 1:62,500, with lithologic annotations, along the American, Bear, and Yuba Rivers, and Camp Creek, a tributary to the Cosumnes River (Clark and Huber, 1975).

N. King Huber, who spent the summer of 1955 in the field with Clark, assembled the final manuscrupt. Many of the internal inconsistencies inherent in most draft manuscripts and maps have been reconciled, but some remain, particularly with respect to the regional map in this report and the larger scale separate maps.

In the western Sierra Nevada, metamorphic rocks are exposed in a 20–40-mile-wide (32–64 km) belt that extends about 180 miles (290 km) from about the latitude of Yosemite Valley northwestward to the north end of the Sierra Nevada (fig. 1). On the south and east they are bounded by granitoid rocks of the Sierra Nevada batholith, and on the north and west they pass beneath unmetamorphosed volcanic and sedimentary rocks of Tertiary age. The pre-Tertiary surface can be traced westward by means of drill-hole and seismic evidence to about the center of the Great Valley of California. Sparse samples suggest that basement rocks under the valley fill are similar to those exposed in the metamorphic belt.

The southern part of the metamorphic belt was described in an earlier report (Clark, 1964), and the northern part is described herein. Throughout the belt the metamorphic rocks were derived from eugeosynclinal Paleozoic and Mesozoic volcanic and epiclastic rocks.

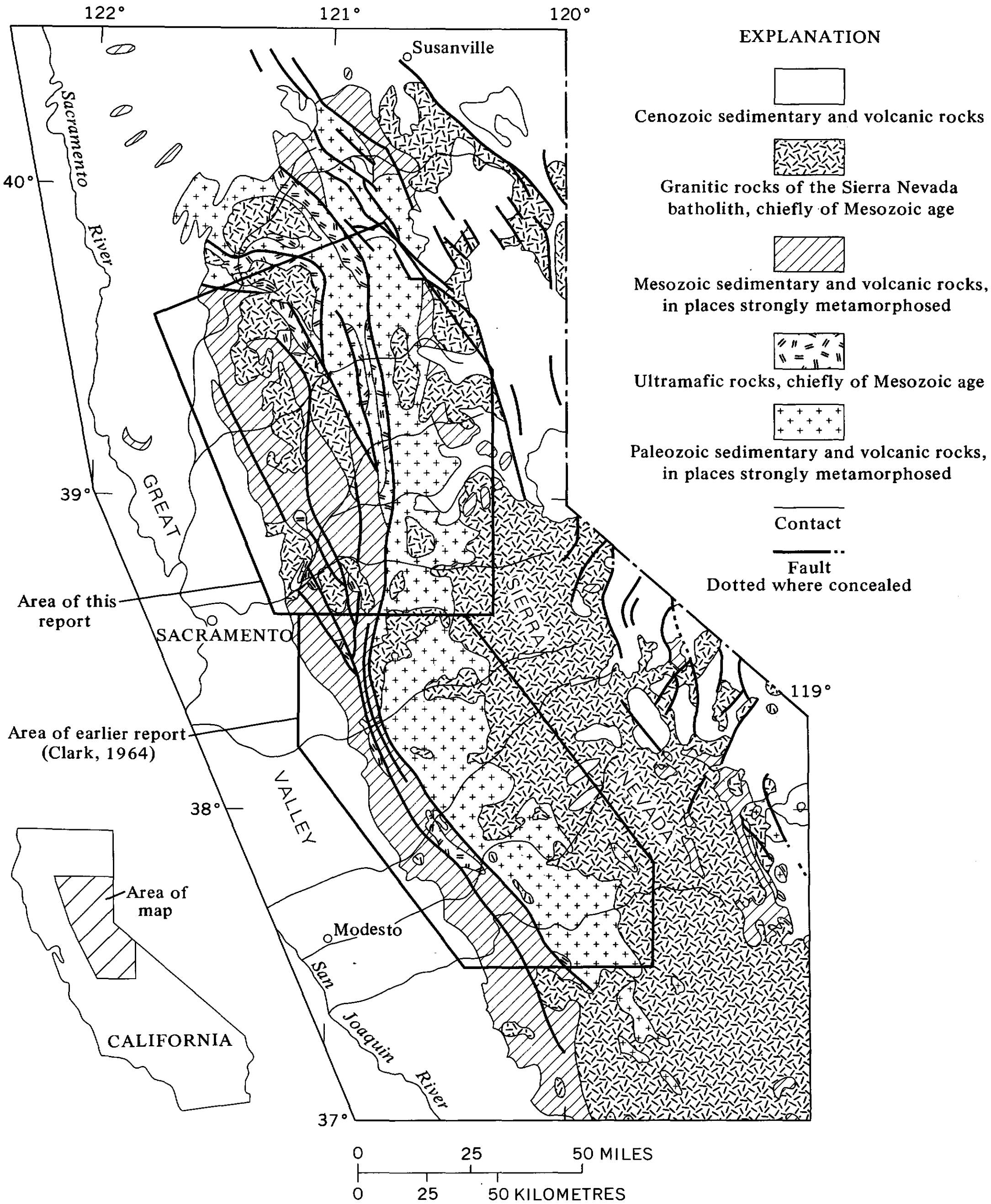

FIGURE 1.—Generalized geologic map of the western Sierra Nevada metamorphic belt. Adapted from U.S. Geological Survey and California Division of Mines and Geology (1966).

Regional metamorphism is generally of low grade, in the greenschist facies. Original textures and structures are preserved in much of the belt but were destroyed by dynamic metamorphism in some places.

The metamorphic belt discussed here underlies the gentle western slope of the Sierra Nevada, a tilted block having a steep eastern slope that is partly a fault scarp. Most of the western slope is a moderately rolling and deeply weathered upland surface formed during Late Cretaceous and early Tertiary time. As a consequence of westward tilting during the late Tertiary, this surface is dissected by youthful canyons cut by streams draining west and southwest toward the Great Valley. Canyon walls are in many places steeper than the angle of repose, and debris from rockslides is common along major streams. Depth of the canyons varies from about 5,000 feet (1,500 m) in the eastern part of the region to a few tens of feet near the margin of the Great Valley.

Most major roads in the region follow the upland surface and, in general, parallel the canyons; only one major road runs northward through most of the area. Other roads crossing river canyons are steep and tortuous.

The vegetation reflects progressively higher rainfall and altitudes eastward from the edge of the Central Valley toward the crest of the Sierra Nevada. Elevations of about 300–500 feet (90–150 m) are marked by grassland, and groves of deciduous trees are common at elevations of about 1,000 feet (300 m). Conifers become prominent at about 2,000 feet (600 m) altitude and are dominant at greater altitudes.

Much of the total California gold production was obtained from placer and lode mines in the northern Sierra Nevada, and the present towns of the region were established as centers of gold-mining activity. Copper and chromite were also mined in the past, but in 1973 little metal-mining activity in the northwestern Sierra Nevada remains. However, production of aggregate, limestone products, roofing granules, and other industrial materials has grown in response to the requirements of rapid population growth and industrialization in northern California.

PREVIOUS WORK

No attempt is made to present a complete bibliography of the numerous publications treating various aspects of the geology of the northwestern Sierra Nevada. Papers cited below provide a summary of the evolution of knowledge of the stratigraphy and structure of the region, and additional papers are cited elsewhere in this report.

Although more recent studies have made valuable contributions, the regional investigation described here was made possible by a series of geologic folios spanning the northern Sierra Nevada that were prepared between 1890 and 1900 by Lindgren and Turner (cited elsewhere in this report). These maps show rock distribution with considerable accuracy, although their structural interpretations are inadequate by modern standards and volcanic formations were treated as igneous rocks having no stratigraphic significance. Ferguson and Gannett (1932), in their study of the Alleghany mining district, refined the breakdown of lithologic units exposed near Alleghany. They were the first to recognize a major fault in that part of the Sierra Nevada and to suggest that it was an extension of a great reverse fault previously recognized by Knopf (1929, p. 46) along the Mother Lode, south of the area described here.

Although most of Taliaferro's (1942, 1943) work on the western Sierra Nevada was in the part of the metamorphic belt that lies south of the area of this report, his contributions to our knowledge of the stratigraphy and structure of the Jurassic rocks aid in understanding the northern part of the metamorphic belt. Hietanen (1951) and Compton (1955) studied chiefly the petrology of metamorphic and plutonic rocks in the northwestern part of the metamorphic belt, but their work also elucidated the structure of the metamorphic rocks as well as structural relations between the intrusive bodies and their wallrocks. Radiometric dates on isolated felsic plutons in the metamorphic belt and in the Sierra Nevada batholith, summarized by Evernden and Kistler (1970), are a valuable aid in working out the complex structural and intrusive history of the western Sierra Nevada. The regional geologic map accompanying this report was adapted from Burnett and Jennings (1962) and Strand and Koenig (1965). Among the sources cited by Burnett and Jennings for their compilation are unpublished maps by geologists of the Southern Pacific Company; their maps are not cited in the list of references herein.

FIELDWORK AND SCOPE OF THIS INVESTIGATION

Field mapping during this regional study was chiefly along major streams where exposures are nearly continuous and stream-polished surfaces facilitate observation of textures and minor structures. The purpose of the fieldwork was to obtain new structural and stratigraphic information that could be used to supplement existing information, chiefly from the folios by Turner and Lindgren, and thereby yield new structural and stratigraphic interpretations. Neither the plutonic rocks nor the Cenozoic strata that unconformably overlie the metamorphic rocks were studied.

Field observations, occupying a total of about 9 months during 1955 to 1961 inclusive, were compiled mostly on 1:24,000-scale topographic maps (fig. 2) but partly on aerial photographs.

Results of detailed mapping, together with the reports and maps of previous investigators, were used to compile a regional map (pl. 1) at a scale of 1:316,800. Strip maps and cross sections were prepared at a scale of 1:62,500 for most of the streams studied and have been published separately (Clark and Huber, 1975). These maps or the topographic quadrangle maps will be required for location of some of the place names referred to in this report. Along much of the Bear River and lower part of the Middle Fork of the American River, preparation of detailed cross sections was not warranted because gravel choking the stream channels conceals the bedrock. Rocks exposed along the Middle Feather River and Slate Creek are so sheared that detailed cross sections would show only steeply dipping schistosity and small widely separated bodies of bedded rocks.

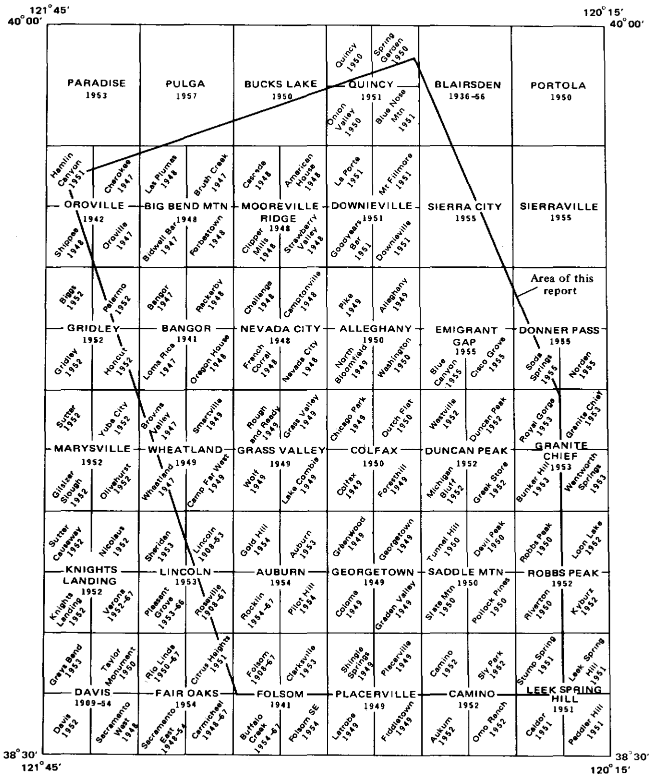

FIGURE 2.—Index of topographic quadrangle maps within and bordering the north half of the western Sierra Nevada metamorphic belt.

ACKNOWLEDGMENTS

N. King Huber and Hal G. Stephens assisted in the fieldwork as indicated on the individual geologic maps, and Huber also contributed to a petrologic study of the Shoo Fly Formation. Cordell Durrell freely discussed results of his work on the petrology of the Shoo Fly Formation and showed me in the field the stratigraphic and structural relations that he had established during his study of the northeastern Sierra Nevada. Discussions with Vernon McMath on results of his work in the Taylorsville area contributed to an understanding of Paleozoic stratigraphy in part of the report area. Ralph Imlay's diligent search for fossils in the usually barren Jurassic tuff and siltstone resulted in discoveries that contributed substantially to the stratigraphic interpretations of this report.

TERMINOLOGY

Terminology used herein is similar to that in the earlier report on the southern part of the metamorphic belt (Clark, 1964, p. 5–6) but will be repeated for ease of reference. Because the emphasis of this study is on stratigraphy, most of the lithologic terms, such as "sandstone" and "pillow lava," relate to the original character of the rock rather than to their metamorphic equivalents. Nevertheless, conspicuous metamorphic planar structures in most of the fine-grained rocks are reflected in the use of the terms "slate," "phyllite," or "schist" rather than "siltstone" or "shale." Some rocks of volcanic origin in which original structures were obliterated by metamorphism are referred to simply as "metavolcanic rocks."

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 transported and deposited in the same manner—they are both sedimentary rocks. The significant difference between them is the origin and manner of comminution of the component fragments. In recognition of this, shale, sandstone, conglomerate, and the like are designated "epiclastic" rocks to indicate that the component debris was formed by weathering of preexisting rocks.

The term "graywacke" designates poorly sorted sandstone with a matrix of silt-size and clay-size material (Pettijohn, 1957, p. 290–292.) The sand grains in the graywacke 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 used only where it is known that the rock contains both grains formed by epiclastic processes and first-cycle grains formed by pyroclastic processes.

Two kinds of conglomerate are distinguished: the gravelly conglomerate or paraconglomerate collected by ordinary water currents (Pettijohn, 1957, p. 254) and very poorly sorted conglomeratic mudstone (Pettijohn, 1957, p. 254) or pebbly mudstone (Crowell, 1957, p. 994), which in the western Sierra Nevada was emplaced as mudflows. Most conglomerate and conglomeratic mudstone in metamorphic rocks of this region are immature, for preserved in them are abundant pebbles of readily weathered rocks such as slate, tuff, and limestone. Such conglomerates are termed "petromict" (Pettijohn, 1957, p. 255).

Flaser rocks occupy most of the wide fault zones in the area. They result from shearing and are marked by phacoidal rock fragments and by pronounced line and planar structures (Tyrrell, 1929, p. 286, fig. 69). Some narrower fault zones are filled with cataclasite, "a structureless aggregate of fragmental material of various sizes" (Tyrrell, 1929, p. 284).

In the absence of a purely descriptive term, the name "chert" is applied to microcrystalline, granoblastic rocks composed of quartz. Bedding characteristics and sparse structure suggestive of replaced radiolaria imply that these rocks were indeed derived from chert. In this area, such rocks have been referred to by most previous workers as either phtanite or quartzite. Phtanite has fallen into disuse in this country, and although quartzite is often used as a descriptive term, it suggests a rock formed from quartz sand. Most of the chert is sericitic, and rock containing so much sericite that it can be scratched with a hammer point is here referred to as quartzose slate.

Three terms, "cleavage," "schistosity," and "slip cleavage," distinguish different kinds of parting surfaces of metamorphic origin. Cleavage designates the planar structure characteristic of slate, the slaty cleavage referred to by 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 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 microfaults (White, 1949) cutting earlier schistosity and cleavage. Mica flakes formed prior to the slip cleavage are commonly bent to a direction parallel to the microfaults.

SUMMARY OF GEOLOGY

Metamorphic rocks in the northwestern Sierra Nevada were derived from eugeosynclinal volcanic and epiclastic rocks of Paleozoic and Mesozoic age. Most of the rocks are of low to intermediate metamorphic grade, but higher grade contact metamorphism is evident near some plutonic contacts. Bedding and original textures are distinguishable in most of the region but have been destroyed by development of metamorphic planar and linear structures in large parts of the area. Fossils are sparse, and some large bodies of metamorphic rock have not been dated. Formational units are measurable in thousands of feet, and structural and stratigraphic continuity are interrupted by nearly vertical faults having large displacements.

There are some compositional differences between Paleozoic and Mesozoic rocks, but there are also similarities between the two groups that preclude using lithologic similarity to correlate unfossiliferous map units. Bodies of mafic intermediate volcanic rocks in the central part of the map area, for example, must be considered to be of Paleozoic or Mesozoic age until they can be dated, for late Paleozoic gastropods and Jurassic ammonites have been found in similar-appearing tuff exposed at different localities.

In general, Mesozoic (Jurassic and probable Jurassic) rocks underlie the western third of the map area (pl. 1) and form a narrower belt in the eastern part. Paleozoic rocks crop out between the two belts of Mesozoic rocks and in a small area east of Auburn. The preponderance of east-facing bedding tops suggests that the central position of the Paleozoic rocks results from faulting combined with regional tilting.

The oldest known rock in the western area is limestone containing tabulate corals and stromatoporoids of probable Devonian age, which is exposed 3 miles (4.8 km) east of Auburn (pl. 1). The limestone is apparently interbedded with volcanic rocks exposed in the immediate vicinity, but there is no assurance that all these volcanic rocks are of the same age. The volcanic rocks are of mafic to intermediate composition, but in the northern part of the unit, petromict conglomerate and bedded chert are interbedded with the volcanic rocks.

The Shoo Fly Formation, exposed in the eastern part of the map area, can be partly correlated with the Silurian Taylorsville Formation north of the area of plate 1. The Shoo Fly Formation is divided into lower and upper lithologic members. The lower member, exposed east of the north-trending fault zone in the central part of the map area, consists largely of dark-gray slate but includes some bedded chert and sparse petromict conglomerate. The upper member consists largely of quartzose and locally feldspathic sandstone here referred to as graywacke. Subordinate rock types in the upper member are slate, quartzite, carbonate rocks, and mafic and felsic volcanic rocks. In the earlier report on the southern part of the metamorphic belt (Clark, 1964), rocks of the Shoo Fly Formation were included in the Calaveras Formation.

The late Paleozoic Calaveras Formation is exposed in a wedge between two major fault zones in the north-central part and in a small area at the south edge of the map area (pl. 1). The Calaveras Formation consists largely of thinly interbedded chert and carbonaceous slate or phyllite. It includes some mafic lava and mafic or intermediate pyroclastic rocks and lenses of crinoidal limestone. Nearly everywhere in the map area, bedding in the Calaveras Formation has been destroyed by shearing.

Unnamed volcanic rocks exposed in the vicinity of Gold Lake in the northeastern part of the map area are believed by Durrell and Proctor (1948, p. 171) to be of late Paleozoic age. They found that these rocks consist from bottom to top of metarhyolite with a thin basal conglomerate derived from the Shoo Fly Formation, a sequence of interbedded chert, slate, and mafic tuff, and a thick series of mafic lava flows and tuffs.

Several other Paleozoic formations have been recognized previously in the northwestern Sierra Nevada, mostly as a result of mapping during the latter part of the 19th century. The present investigation indicates that the definition of some of these formations does not coincide with the outcrop pattern of lithologic units, and so detailed mapping is necessary to establish their validity.

Some rocks in the northern part of the map area are mapped as epiclastic rocks of Paleozoic and Mesozoic age. These rocks are lithologically similar to Jurassic formations described below, but since no fossils were found in them, the present information does not preclude the possibility that these rocks accumulated during the Paleozoic. Several long narrow belts, chiefly near the fault zone that extends through La Mar Flat and Auburn, were mapped by Lindgren (1894) as the Calaveras Formation. Along the Bear River on the same fault zone, rocks also mapped as the Calaveras Formation by Lindgren and Turner (1895) are flaser rock derived from volcanic rocks of Jurassic age.

Undated volcanic rocks in the central part of the area are mapped as metavolcanic rocks and assigned a Paleozoic or Mesozoic age. They are largely of mafic or intermediate composition but include some felsic rocks. Most rocks of this unit are schistose, but some are massive as a result of recrystallization; fine-grained bedded tuff exposed along the Middle Yuba River east of the mouth of Humbug Creek is included in this unit.

A chert breccia and limestone unit of Triassic(?) age overlies the Shoo Fly Formation with pronounced angular unconformity in the eastern part of the area near the North Fork of the American River. The lower part consists of coarse chert breccia derived from the Shoo Fly Formation. The upper part consists of limestone, which is commonly argillaceous.

The Triassic(?) rocks are overlain by the Sailor Canyon Formation from which ammonites of Early and Middle Jurassic age were collected. The Sailor Canyon Formation consists of slate derived from siltstone, graywacke, and tuff but contains sparse calcarenite. Bedding in the Sailor Canyon Formation is apparently concordant with that in the underlying carbonate rock, but relief on the intervening contact suggests an erosional unconformity.

Along the North Fork of the American River, the Sailor Canyon Formation grades upward through a zone marked by an increasing proportion of volcanic rocks into a section composed of mafic or intermediate volcanic rocks that are assigned to the Milton Formation. In its type area, near Milton Reservoir (pl. 1) in the northeastern part of the map area, the Milton Formation consists predominantly of mafic or intermediate pyroclastic rocks but contains some felsite tuff, calcarenite, and epiclastic breccia. No fossils have been reported from the Milton Formation.

The Cosumnes Formation of Taliaferro (1942, 1943), exposed in a belt extending discontinuously from the vicinity of Colfax to the south boundary of the map area, contains ammonites of early Late Jurassic age. The Cosumnes has been abandoned as a formational name, as discussed in a later section of this report, and rocks originally defined as the Cosumnes Formation are herein informally called "Cosumnes-type rocks." Cosumnes-type rocks are predominantly slate and graywacke, but tuff, petromict conglomerate, and conglomeratic mudstone are commonly interbedded with these. Blocks several feet long are common in the pebbly mudstones, and one well-exposed block, probably derived from the Calaveras Formation, is about 30 feet (9 m) long and 15 feet (4.5 m) wide.

Near the south boundary of the map area, Cosumnes-type rocks are overlain by the Late Jurassic Logtown Ridge Formation, which consists of pyroxene-bearing pyroclastic rocks and some pillow lava. Near the North Fork of the American River, the Cosumnes-type rocks are overlain by volcanic rocks possibly equivalent to the Logtown Ridge Formation.

The Monte de Oro Formation, exposed in a small area near Oroville in the northwestern part of the map area, is of Late Jurassic age, but the stage is uncertain; study of the fauna (Imlay, 1961, p. D8) suggests a late Oxfordian and early Kimmeridgian age, whereas later investigation of the flora (Fry, 1964) suggests a late Oxfordian to and including Portlandian age. If part of the Monte de Oro Formation is as young as Portlandian, it is the youngest unit yet dated in the metamorphic belt, but this remains to be confirmed. The Monte de Oro Formation, like other Late Jurassic epiclastic units, consists mostly of slate, graywacke, and polymictic conglomerate but is distinguished by the presence at its base of crossbedded sandstone and conglomerate of apparent littoral origin. The sandstone and conglomerate consist largely of debris from volcanic rocks but contain pebbles of vein quartz and fossiliferous limestone.

The Copper Hill Volcanics, named by Clark (1964), is exposed near the southwest corner of the map area. It is also one of the youngest formations in the metamorphic belt, for it intertongues with and overlies the Salt Spring Slate of Late Jurassic (Kimmeridgian) age.

Some bodies of epiclastic rocks in the central and eastern parts of the area have been mapped as epiclastic rocks of Jurassic age. Although no fossils were found in this map unit, stratigraphic and structural relations suggest that the strata are of Late Jurassic age. In the southern part of the area, this unit consists of slate, graywacke, and tuff and overlies the Logtown Ridge Formation of Late Jurassic (Callovian to late Oxfordian or early Kimmeridgian) age. Northward this unit is mostly dark-gray phyllite, but it contains some volcanic rocks and bedded chert. No top directions were found in these epiclastic rocks, but east-facing tops in volcanic rocks overlying Cosumnes-type rocks to the west suggest that the epiclastic rocks may also be east facing. The epiclastic rocks of Jurassic age, near the eastern side of the map area, consist largely of dark-gray hornfels along the North Fork of the American River but contain thin layers of conglomeratic mudstone and sparse quartzite layers. Top directions suggest that these strata overlie the Milton Formation.

Volcanic rocks that underlie much of the western third of the map area are assumed to be of Jurassic age; in most places they are moderately deformed and are exposed along the projection of a belt of similarly deformed Late Jurassic rocks that extends about 100 miles southeastward from the boundary of the map area of plate 1. The unit is mostly tuff and volcanic breccia, but lava flows, with some pillow structure, occur in some places. Field relations suggest that a body of volcanic rocks north of Greenwood, which is included with this unit, is possibly equivalent to the Logtown Ridge Formation, but there is little information to suggest the age of other bodies included in the same unit.

Plutonic rocks, not studied in detail during this investigation, are mostly, if not entirely, of Jurassic and Cretaceous age. Similar to plutonic rocks south of this report (Clark, 1964, p. 41–42), they range in composition from ultramafic through a diverse assemblage of less mafic intrusive and metamorphic rocks to granodiorite. Serpentine, most abundant of the ultramafic rocks, is associated chiefly with sheared metamorphic rocks in major fault zones west of the Shoo Fly Formation. Rocks of gabbroic aspect, identified in this report as mafic plutonic rocks of Paleozoic or Mesozoic age, include medium- to coarse-grained contact metamorphic rocks as well as rocks of intrusive origin. Most of these plutonic rocks are generally considered to be parts of the composite Sierra Nevada batholith.

The present distribution of metamorphic rocks in the region results chiefly from folding and reverse faulting during Late Jurassic and, possibly, Early Cretaceous time, but at least one deformation, and probably two, preceded deposition of the Late Triassic(?) carbonate rocks. The facings of bedding tops across the area underlain by Jurassic volcanic rocks are unknown, but facings across Cosumnes-type rocks, the Shoo Fly Formation, and the eastern belt of Mesozoic rocks are generally eastward. The order of succession of strata that would be inferred from bedding facings is reversed as a result of movement along the fault zone at the west boundary of the Shoo Fly Formation, the west boundary of the Calaveras Formation, and the west boundary of the Paleozoic and Mesozoic mafic intrusive and metamorphic rocks. Along all of these faults, younger strata underlie older, and the faults thus divide the area into four structural blocks (fig. 3). These major fault zones were originally thought to have predominantly strike-slip displacement (Clark, 1960, 1964), but more recent data derived from many ongoing studies in the Sierra Nevada suggest that they are steeply east-dipping reverse fault zones (Bateman and Clark, 1974).

The fault zone along the west side of the Calaveras Formation extends the full length of the metamorphic belt, a distance of about 180 miles (290 km), and throughout nearly the whole distance, the fault forms the boundary between Jurassic rocks on the west and Paleozoic rocks on the east. This fault is the northward extension of the Melones fault zone described previously (Clark, 1964). The fault zone at the west side of the Shoo Fly Formation can be traced from the north end of the

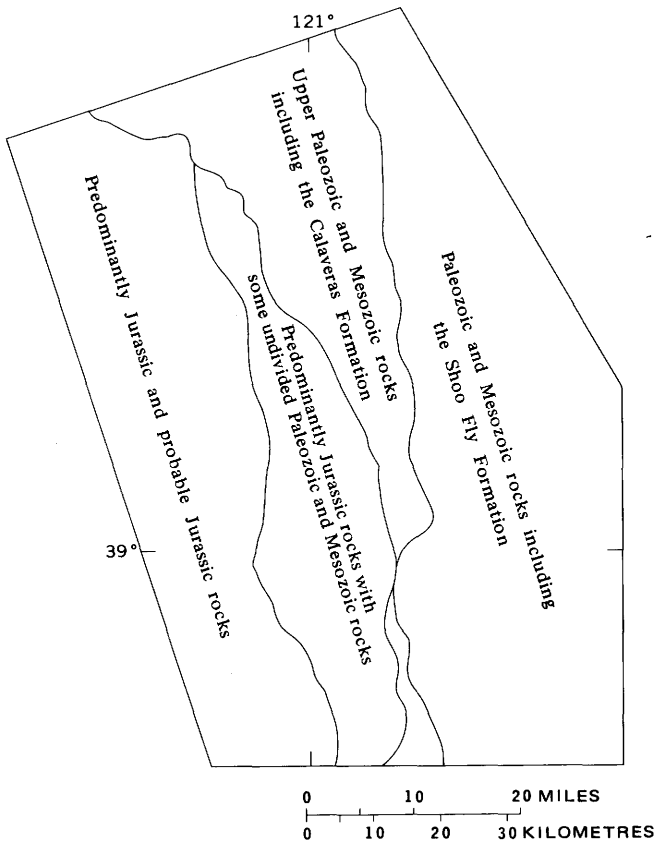

FIGURE 3.—Fault-bounded structural blocks of the north half of the western Sierra Nevada metamorphic belt.

metamorphic belt many miles southward and is inferred to continue to the south margin of the map area. It is likely that a fault zone of this magnitude continues even farther south, but this has not been established. The third fault zone, that on the west side of the undivided Mesozoic and Paleozoic rocks, appears to trend southward into the Bear Mountains fault zone (Clark, 1964). Other fault zones shown on plate 1 exhibit smaller stratigraphic separation and presumably had less total movement than the three fault zones mentioned above.

Lineations and minor fold axes within the fault zones and in many places outside of the fault zones plunge steeply. The lineations consist of amphibole crystals, mineral pods, and elongate rock fragments in a matrix of schist or crush rock. Minor folds having steeply plunging axes are marked by deformed slip and schistosity surfaces.

Recumbent folds in the southern part of the area underlain by the Shoo Fly Formation probably mark the earliest folding recorded in the region. Recumbent folds were not observed north of the Middle Fork of the American River, but bedding-plane schistosity, which is associated with the recumbent folds in the southern part of the area, was recognized as far northward as the North Yuba River. Complicated structure and steeply plunging fold axes in the eastern part of the Shoo Fly Formation along the North Fork of the American River suggest that the Shoo Fly Formation was folded more than once before the overlying Late Triassic(?) rocks were deposited.

Regional strikes and large folds in the Jurassic rocks result from folding about gently plunging northwest-trending axes. This stage of folding also accounts for the generally homoclinal structure of the eastern belt of Jurassic rocks, homoclinal structure of Jurassic strata exposed near State Highway 49 in the southern part of the area, and folds south of Lake Folsom and in the vicinity of Colfax (pl. 1). Folds in the area underlain by Jurassic volcanic rocks are of diverse orientation, but bedding attitudes near Oroville, northeast of Smartville, and near Colgate Power Station are concordant with the regional trend attributed to this stage of deformation. Where age relations of folds and faults in Late Jurassic rocks were determined, the faults are younger.

Near the north boundary of the map area, strikes of regional structures swing westward and project toward the Klamath Mountains (fig. 1; pl. 1). The part of the gross structure that is exposed in the northwestern Sierra Nevada is an anticline whose axis plunges steeply to the northeast. Felsic plutons in the northwestern part of the area are clustered in the axial region of this anticline. According to Compton (1955), plutons of this group that he studied were intruded by stopping and pushing aside wallrocks. Although Compton's evidence for both of these processes is convincing, it is possible that development of the anticline aided the magma in pushing aside the wallrocks.

PALEOZOIC ROCKS

All metasedimentary and metavolcanic rocks in the area described here were included in the Calaveras Formation as defined by Turner (1893a, p. 309; 1893b, p. 425). In part of the area (Colfax 30-minute quadrangle), Lindgren (1900) later divided the Calaveras Formation into the Blue Canyon Formation, Relief Quartzite, Cape Horn Slate, Delhi Formation, and Clipper Gap Formation at the expense of Turner's name Calaveras. In the vicinity of Alleghany, Ferguson and Gannett (1932, p. 6–7) recognized two older formations, the Tightner and Kanaka Formations, which Lindgren had previously mapped simply as "amphibolite."

Of the formation names listed above, only the name Calaveras Formation is used on maps accompanying this report, and it is considerably restricted from Turner's original definition. The name Blue Canyon Formation was abandoned by Clark, Imlay, McMath, and Silberling (1962, p. B17) when its rocks were found to be part of the Shoo Fly Formation named previously by Diller (1892). Although the boundaries of other units as previously mapped do not consistently correspond to lithologic boundaries found during this investigation, their names, even though not used on the maps accompanying this report, should not be abandoned until more detailed mapping is available. Problems related to use of these formation names are discussed later.

SHOO FLY FORMATION

The name Shoo Fly Formation was applied originally by Diller (1892, p. 375; 1908, p. 23) to a distinctive and uncommon sequence of stratified rocks exposed north of the 40th parallel and 5–10 miles (8-16 km) southwest of Taylorsville. Subsequently, other parts of a continuous belt containing the same lithologic assemblage were assigned to the Calaveras Formation or Group (Diller, 1895; Lindgren and Turner, 1894; Lindgren, 1896, p. 80–81; Turner, 1897, 1898) and to the Blue Canyon Formation (Lindgren, 1900). The name Shoo Fly Formation, having priority, was later extended to designate the entire belt of rocks characteristic of its type locality (Clark and others, 1962, p. B17). According to this usage, the Shoo Fly Formation underlies a belt as much as 20 miles (32 km) wide, extending the length of the map area (pl. 1). Its southern limit of exposure has not been determined; it was not differentiated from the Calaveras Formation in the earlier report (Clark, 1964). The formation is at least 5,000 feet (1,500 m) and probably more than 10,000 feet (3,000 m) thick. It is here divided into two intertonguing lithologic members, a lower member consisting largely of dark-gray slate and phyllite and an upper member consisting largely of quartz-rich graywacke, slate, and quartzite. Intertonguing relations are most readily observed near the mouth of Scotchman Creek 1 mile (1.6 km) east of Washington on the South Yuba River.

LITHOLOGY

The lower member of the Shoo Fly Formation is exposed in a narrow belt east of a major fault zone in the central part of the map area and forms the core of a steeply plunging fold along the Middle Fork of the American River. Thin-bedded chert, sparse coarse epiclastic rocks, and sparse metavolcanic rocks in addition to slate are found in the lower member of the Shoo Fly Formation. A layer of calcarenite about 20 feet (6 m) thick is interbedded with slate about 800 feet (240 m) southeast of the tunnel near Horseshoe Bar on the Middle Fork of the American River. Conglomerate consisting largely of slate, chert, and volcanic rock fragments crops out along the North Yuba River in the eastern part of Downieville. A similar conglomerate crops out about 50 feet (15 m) west of the bridge in Washington.

Conglomerate exposed along the Middle Fork of the American River at the northwest end of American Bar differs from those mentioned above in that it contains fragments of quartz-rich graywacke as well as slate and chert pebbles. The graywacke pebbles are very similar to graywacke in the upper member of the Shoo Fly Formation, suggesting either that rocks near American Bar are younger than the Shoo Fly Formation or that a tongue of quartz graywacke occurred at a lower stratigraphic position in the Shoo Fly Formation.

The upper member of the Shoo Fly Formation is a eugeosynclinal assemblage of rocks derived chiefly from a terrane composed of metamorphic and granitic rocks but partly from contemporaneous volcanic rocks. The formation consists largely of sandstone and slate or phyllite but includes subordinate thin-bedded chert, carbonate rocks, conglomerate, pebbly mudstones, intraformational breccia, and felsic and mafic volcanic rocks. Sandstone is predominant in most of the area, but slate and phyllite are predominant along the Middle Fork of the Feather River and near the east edge of the metamorphic belt along the North and Middle Forks of the American River.

Sandstones in the Shoo Fly Formation are medium to dark gray, bluish gray, or greenish gray on fresh surfaces. Graywacke is the most abundant sandstone, but composition and texture are variable and even include well-sorted orthoquartzite. The coarsest fraction in most of the graywacke is medium to very coarse sand, but some graywackes, particularly in the southern part of the area, contain granules. The matrix of the sandstones consists of white mica, quartz, and feldspar. Quartz is the dominant detrital mineral, and in some graywackes, as well as in the orthoquartzites, it constitutes more than 90 percent of the sand fraction. Potassium feldspar and plagioclase are found in much of the graywacke and in some places constitute about 10 percent of the sand and granule fractions. Sparse sand grains composed of granoblastic microcrystalline quartz are probably derived from chert. Most beds are between about 4 and 20 inches (10 and 50 cm) thick, but some beds are as much as 6 feet (1.8 m) thick. Graded beds are abundant throughout most of the area underlain by the upper member of the Shoo Fly Formation but are sparse along Silver Creek (pl. 1) where quartzite is the most abundant sandstone.

Under the hand lens, glassy quartz is commonly the only recognizable detrital component of the sandstones, but in some graywacke, grains of quartzite distinguished by a sugary texture and feldspar can be seen. Most quartz and quartzite grains are nearly circular or elliptical in outline, but in some feldspathic sandstones they are angular. Among the glassy quartz grains, colorless, gray, and opaline varieties can be distinguished.

In thin section both monocrystalline and polycrystalline quartz grains can be distinguished. Nearly all show undulatory extinction, but because the Shoo Fly Formation is itself deformed, it is difficult to distinguish provenance on this basis alone. Many monocrystalline quartz grains have fluid inclusions, and others contain needlelike inclusions, probably of rutile. Internal boundaries of some polycrystalline grains are characterized by many straight segments, suggesting that these grains were derived from vein quartz or possibly from granitic rocks. Sparse grains, possibly derived from quartzite, have exceptionally pronounced undulatory extinction, marked internal planar structure, and deeply sutured internal boundaries.

The upper member of the Shoo Fly Formation contains coarse-grained clastic rocks of both extraformational and intraformational origin; conglomerate consisting of well-rounded fragments of quartz in a matrix of coarse sand is most abundant. In most conglomerates the fragments are 1 inch (2.5 cm) or less in diameter. Most pebbles are colorless vein quartz, but some conglomerates contain pebbles of gray vein quartz and, particularly in the southern part of the area, of quartzite. A conglomerate exposed along Camp Creek that consists mostly of well-rounded quartz pebbles also contains angular slabs of black slate of probable intraformational origin.

Conglomeratic mudstone more than 20 feet (6 m) thick is exposed at the base of the Commodore mine trail on the Middle Yuba River. The mudstone consists of fragments of very fine grained felsite or slate and dolomite in a matrix of dark-gray phyllite. The dolomite blocks are as much as 4 feet (1.2 m) long. Another very poorly sorted breccia of probable mudflow origin, exposed along the North Fork of the American River in the western part of sec. 4, T. 15 N., R. 11 E., consists of fragments of slate, chert, quartz-rich graywacke, limestone, and volcanic rocks in a slate matrix. Intraformational granule conglomerate beds less than 2 feet (0.6 m) thick are exposed on the divide between the mouth of Big Granite Creek and the North Fork of the American River. The granules are rounded and consist of chert similar to that in the enclosing beds.

Chert in the upper member of the Shoo Fly Formation is interbedded with gray and gray-green slate and phyllite. Most of the chert is light to medium gray, grayish green, or grayish blue and forms beds that are mostly less than 4 inches (10 cm) thick. In thin section, the chert is seen to be chiefly granoblastic quartz, but much of the chert contains white mica. Some chert contains round or elliptical bodies of more coarsely crystalline quartz that are possibly replaced radiolarians.

Carbonate rocks constitute less than 1 percent of the upper member of the Shoo Fly Formation but are widely distributed. Most of the carbonate rocks are in parts of the section where orthoquartzitic sandstone and slate predominate over graywacke. Limestone, the most abundant carbonate rock, is mostly light- to dark-gray calcarenite containing detrital quartz and feldspar. Original textures of most of the carbonate rock are lost as a result of recrystallization, but in some thin sections, fragments of crinoid plates and echinoids can be distinguished. The noncarbonate fraction varies from less than 10 percent to about 50 percent and is comparable to the better sorted sandstones with respect to quartz-feldspar ratios.

The largest carbonate body found in the upper member of the Shoo Fly Formation is best exposed on the north wall of the Middle Fork of the Feather River Canyon about 3 miles (4.8 km) west of the mouth of Nelson Creek. The body contains dolomite, limestone, and dolomitic limestone and some interbedded poorly sorted orthoquartzite and quartz-pebble conglomerate. Limestone in this body is similar to that previously described, but the dolomite and dolomitic limestone contain closely packed pisolites as much as one-fourth inch (6 mm) in diameter. In some specimens the pisolites are completely replaced by chert, and in others only the matrix or a thin shell on the periphery of pisolites is replaced by chert.

Although felsic volcanic rocks probably contributed detritus to sandstones in the Shoo Fly Formation, mafic volcanic rocks have been identified in only a few places. Pillow lava is associated with felsic volcanic rocks along the Middle Yuba River in the SE¼ sec. 9, T. 19 N., R. 12 E. Felsic tuff occurs along the North Fork of the American River about a quarter of a mile (0.4 km) east of the mouth of Big Granite Creek but is more abundant near the granitic pluton that intrudes the upper member of the Shoo Fly Formation along Canyon Creek and the Middle Yuba River. Felsic volcanic rocks are interlayered with epiclastic rocks of the Shoo Fly Formation west of the pillow lava and along the North Yuba River; felsite tuff, partly quartz bearing, occurs between Sierra City and the small pluton to the west.

Abundant felsite dikes, many containing quartz and feldspar phenocrysts, cut the Shoo Fly Formation along the Middle Yuba River east of the large pluton, suggesting a possible genetic relation between the pluton, dikes, and felsic pyroclastic rocks.

STRATIGRAPHIC RELATIONS

The lower member of the Shoo Fly Formation is in fault contact with rocks exposed to the west. On the east, the upper member is unconformably overlain by volcanic rocks of late Paleozoic age in the northeastern part of the area and by Late Triassic(?) and Early Jurassic rocks near the North Fork of the American River.

Durrell and Proctor (1948, p. 175) found that in the northeastern part of the area rocks here included with the Shoo Fly Formation were folded before the overlying late Paleozoic rocks were deposited but that the angular discordance at the contact is small. They suggested that the pre-late Paleozoic folding was not severe and that intricate folds in the Shoo Fly Formation probably are mostly the result of a later deformation during which the Shoo Fly Formation and the more competent overlying rocks were folded together. In contrast, the Shoo Fly Formation near the North Fork of the American River is overlain with pronounced angular unconformity by rocks of Triassic(?) age (Lindgren, 1900, p. 2–3; Clark and others, 1962). The contact is well exposed on the north side of the canyon of the North Fork of the American River and near New York Canyon (Clark and others, 1962, fig. 6.1). The Shoo Fly Formation is immediately overlain by chert breccia. Both bedding and cleavage in the Shoo Fly Formation are truncated at the contact. Although the contact is a nearly straight line at map scale, it shows in detail a relief of several feet. In some places the contact alternately follows bedding of the Shoo Fly Formation and fracture surfaces that cut across that bedding. Owing to complex folding near the contact, the angle of unconformity between the Shoo Fly Formation and the overlying strata varies from near 0° to near 90°.

AGE

The Shoo Fly Formation has yielded few fossils, but according to Clark, Imlay, McMath, and Silberling (1962, p. B17–B18) and McMath (1966, P. 176, 179), who correlated its upper part with the more fossiliferous Montgomery Limestone of Silurian age (Diller, 1908, p. 16) exposed near Taylorsville, the Shoo Fly Formation is of Silurian age. Four fossil localities have been attributed previously to the Shoo Fly Formation. Of two localities described by Lindgren (1900, p. 2), one is in a limestone exposed near the confluence of Big Granite Creek and the North Fork of the American River that was subsequently shown to be of Triassic(?) age, and the other yielded fossils that suggested only Paleozoic age. Diller (1908, p. 23) found "Carboniferous fossils, such as *Fusulina*" near Spanish Ranch, north of the area of this report, in rocks that he considered correlative with the Shoo Fly Formation, but McMath (1966, p. 178) considered that rocks at this locality are almost certainly separated from the Shoo Fly by a fault. Poorly preserved stromatoporoids suggesting a Devonian or Mississippian age were found by Clark (1930) in a chert lens near the contact between the Shoo Fly Formation and an overlying volcanic sequence southwest of Long Lake. His description of the locality does not permit unequivocal assignment of the fossiliferous rocks to either the Shoo Fly Formation or the overlying volcanic sequence.

McMath's (1966) extension of the name Shoo Fly Formation, the type locality of which is in the lower plate of a thrust near Taylorsville, to the nearby upper plate is based upon lithologic similarity of the Shoo Fly and overlying units in both plates. The type Shoo Fly Formation in the lower plate west of Taylorsville consists of the same assemblage of sandstones and slates that characterizes the formation elsewhere. An overlying unit in the Shoo Fly Formation is about 2,000 feet (600 m) thick and consists largely of black or grayish-green obscurely laminated phyllite and slate and also thin beds, commonly graded, of feldspathic, possibly tuffaceous graywacke. The same sequence occurs in the Shoo Fly Formation in the upper plate.

CALAVERAS FORMATION

The Calaveras Formation as mapped during this investigation includes rocks named the Blue Canyon Formation, Relief Quartzite, Cape Horn Slate, and Delhi Formation by Lindgren (1900) in the Colfax 30-minute quadrangle and rocks assigned to the Calaveras Formation by Turner (1897, 1898) and Lindgren and Turner (1894) in the Downieville, Bidwell Bar, and Placerville 30-minute quadrangles.

The Calaveras Formation consists largely of interbedded chert and dark-gray commonly graphitic phyllite with subordinate interbedded mafic and intermediate volcanic rocks and sparse lenses of carbonate rock.This assemblage of rocks closely resembles a unit mapped as undivided argillaceous and chert members of the Calaveras Formation in the southern part of the metamorphic belt (Clark, 1954, p. 5–8; 1964, p. 8) and is probably stratigraphically equivalent to that unit. Strong shearing of the Calaveras Formation precludes a meaningful estimate of its thickness.

The Calaveras Formation is nearly everywhere in fault contact with adjacent metamorphic rocks. Possibly some blocks derived from the lower member of the Shoo Fly Formation have been mapped with the Calaveras Formation where the two units are separated only by fault zones or by fault zones and serpentine. The two map units are lithologically similar enough to make distinction difficult in greatly sheared areas.

The phyllite and most of the chert in the Calaveras Formation are dark gray on fresh surfaces and light gray where weathered. On stream-polished surfaces chert beds are commonly much lighter colored than the surrounding slate, apparently as a result of percussion figures and other fractures. The chert in which mica is sparse has a chalcedonic luster and conchoidal fracture. In thin section the chert is seen to consist of microcrystalline quartz containing in some places roundish blebs of more coarsely crystalline quartz that possibly are replaced radiolarians. Much of the chert contains some mica, and composition grades from phyllite with little quartz to chert with almost no mica. Chert and slate are not uniformly interbedded in the Calaveras Formation; near Sherman Bar, for example, thinly interbedded phyllite and chert form units as much as 80 feet (24 m) thick in a belt several hundred feet wide that consists mostly of phyllite. Bedding is preserved only locally and is strongly crumpled in these places.

A body of dark-gray fine- to medium-grained limestone or dolomite is exposed in an abandoned quarry on the east side of Bear River due west of Colfax. The rock contains abundant crinoid fragments, and corals were distinguished in one loose block. Foraminifera were recognized in thin sections. This body was considered by Lindgren (1900) to be a detached block of Clipper Gap Formation. Exposures are poor near the carbonate body, and its stratigraphic and structural relations to surrounding rocks are unclear. An exposure of sheared volcanic rock was found on the east side of the carbonate rock, and a small exposure of sheared epiclastic rock was found on the west side of it. The carbonate rock probably is a horse in a major fault zone (pl. 1) but is possibly a block that slumped into the area of deposition of the Cosumnes Formation of Taliaferro.

Tentatively included in the Calaveras Formation is a block, exposed in sec. 18, T. 17 N., R. 10 E., along the South Yuba River, that is bounded by faults. Most of the block consists, as does the formation elsewhere, of chert, phyllite, and mafic or intermediate volcanic rocks but also includes some epiclastic breccia and conglomerate. From the belt of schistose volcanic rocks exposed in sec. 17 westward, the rocks are as follows: a belt about 700 feet (210 m) wide of bedded chert with slate partings; massive locally fossiliferous tuff about 100 feet (30 m) wide; dark-gray phyllite about 75 feet (23 m) wide that contains some conglomerates; and mafic volcanic rocks, about 700 feet (210 m) wide, with interbedded chert. Most pebbles in the conglomerate are chert, but some consist of carbonate rock that contains fossil fragments. Breccia consisting largely of chert fragments, but containing some volcanic rock fragments, is exposed near the mouth of New York Canyon on the South Yuba River. The breccia is possibly of tectonic origin but is not sheared, as is most tectonic breccia in the region. Small bodies of carbonate rock exposed about 200 feet (60 m) downstream from the mouth of New York Canyon are surrounded by volcanic rocks and are probably slivers in a narrow gently dipping fault zone. Coarse-grained epiclastic rocks are not characteristic of the Calaveras Formation but also were found along the Merced River (Clark, 1964, p. 10) south of the area described here.

FOSSILS AND AGE

Fossils found at three localities in the Calaveras Formation suggest a late Paleozoic age but do not permit closer age assignment. In view of the lack of stratigraphic control within the area mapped as Calaveras Formation, it is possible that rocks included in the formation span much of late Paleozoic time. Although crinoid fragments are abundant in many of the carbonate rocks of the Calaveras Formation, more diagnostic fossils are sparse. Permian fossils were collected from the southern part of the metamorphic belt (Clark, 1964, p. 13–14) from rocks that are not necessarily stratigraphically equivalent to the Calaveras Formation exposed in the area of this report.

A large isolated block of fossiliferous limestone is exposed along the Bear River west of Colfax. This block is believed to have slumped from an exposure of Calaveras Formation and been incorporated in the Cosumnes Formation of Taliaferro during Late Jurassic time. Lindgren (1900, p. 2), who first reported finding fossils in this limestone body, considered the limestone to be of early Carboniferous age on the basis of *Clisiophyllum gabbi* Meek, *Lithostrotion whitneyi*, and brachiopod fragments of various species. Helen Duncan (written commun., 1956) reported that a partly crushed and metamorphosed coral found at this locality during the present investigation is *Stylidophyllum?* sp. indet. She further stated that although *Stylidophyllum* is regarded as a zone fossil for the Permian by Asian workers, her own work suggests that in parts of the western United States it is associated with Late Mississippian faunas. However, she believed it certainly to be of late Paleozoic age.

Fragmentary corals found in a small body of carbonate rock on the bank of the South Yuba River in the SW¼ sec. 18, T. 17 N., R. 10 E., were studied by W. J. Sando. He found (written commun., 1958) that although generic and specific determinations were impossible, one specimen appears to be a simple zaphrentoid coral and the others are possibly lithostrotionoid corals. He found the material suggestive of a late Paleozoic age but felt that further refinement of its stratigraphic implications could not be made.

Three external molds of gastropods were found in massive tuff exposed at the mouth of a small tributary canyon on the north side of the South Yuba River south of North Bloomfield, about 500 feet (150 m) west of the east boundary of sec. 18, T. 17 N., R. 10 E. The specimens were identified by Ellis Yochelson (written commun., 1958) as *Euphemites*, a bellerophontid gastropod ranging from Mississippian to Permian. Yochelson stated that the specimens do not appear to have been previously described, but show some similarities to *Euphemites blaneyanus* McChesney, and are more likely to be of Pennsylvanian than of Mississippian or Permian age. He did not believe that the specimens warranted a systemic designation.

RELIEF QUARTZITE

Lindgren (1900, p. 2) named the Relief Quartzite for exposures near the hamlet of Relief, about 3 miles (4.8 km) west of Washington, Nevada County. He mapped it as a belt of rock about 1 mile (1.6 km) wide extending from a point northwest of Washington to near Towle (pl. 1) along the line of a major fault zone. He described the Relief as a very hard grayish siliceous rock with streaks of siliceous clay slate and noted that the stratification planes are extremely contorted. Ferguson and Gannett (1932, p. 12) later correlated several bodies of schistose micaceous quartzite exposed in the vicinity of Alleghany with the type Relief Quartzite and extended the formation beyond its northern limit as mapped by Lindgren.

The Relief Quartzite is not differentiated on maps accompanying this report, and its validity as a formation is doubtful; the Relief Quartzite as mapped by Lindgren is a shear zone containing thin layers of serpentine and abundant sheared metamorphic rocks derived from formations exposed on either side of the shear zone (Clark, 1960, p. 490–491). Exposures along the South Yuba and Bear Rivers that were originally mapped as Relief Quartzite consist of blocks of volcanic rock and of chert in a matrix of flaser rocks.

Rocks mapped as Relief Quartzite by Ferguson and Gannett, in areas too small to plot on plate 1, were examined during this study only at a point along Kanaka Creek about 1¾ miles southwest of Alleghany. There, the rock is true quartzite, unlike the shear-zone assemblage originally mapped by Lindgren as Relief Quartzite. The quartzite near Alleghany constitutes part of a stratigraphic unit that is distinct from those shown on maps accompanying this report or, more probably, is in fault blocks detached from the upper member of the Shoo Fly Formation.

CAPE HORN SLATE

Lindgren (1900, p. 2) applied the name Cape Horn Slate to a unit of clay slate and sparse bodies of limestone typically exposed at Cape Horn, a prominent point overlooking the North Fork of the American River, about 2 miles (3.2 km) northeast of Colfax. The rocks form a belt 1½–5 miles (2.4–8 km) wide that extends northward through the central part of the map area (pl. 1). During the present investigation, sparse bedded chert and volcanic rocks were found interbedded with the slate, and in the northern part of the area, chert and volcanic rocks are more abundant than slate. The lithology of the Cape Horn Slate does not appear either sufficiently distinctive or consistent to warrant retaining the name. Rocks in the southern part of the area that were mapped originally as Cape Horn Slate are here tentatively shown as epiclastic rocks of Late Jurassic age, and the more cherty rocks in the northern part of the belt are mapped as Calaveras Formation.

Lindgren (1900, p. 2) reported finding crinoid fragments in a small limestone body in the Cape Horn Slate below Cape Horn. This limestone is probably a fault block; it is in strata here included with Cosumnes-type rocks and is along the strike projection of conglomeratic mudstones exposed along the North Fork of the American River.

DELHI FORMATION

The Delhi Formation was named by Lindgren (1900, p. 2) for its typical development near the Delhi mine, about 5 miles (8 km) northwest of North Bloomfield, Nevada County. He stated that it consists mostly of dark-brown to black flinty rock that resembles hornfels and rarely shows bedding or schistosity. He noted that some rocks in the formation show a clastic character and others resemble chert. Crinoid fragments found in one of the few carbonate rock lenses in the formation suggested to Lindgren that the Delhi Formation is of Paleozoic age.

Most of the characteristics ascribed to the Delhi Formation by Lindgren were confirmed during this investigation, but the absence of planar structures was not substantiated; rocks originally mapped as Delhi Formation show marked schistosity except in narrow zones of contact metamorphism near some intrusions. The Delhi Formation as mapped by Lindgren is indistinguishable from rocks mapped in the southern part of the metamorphic belt as undifferentiated chert and argillaceous members of the Calaveras Formation (Clark, 1964, p. 8), the formation to which its rocks are here reassigned.

CLIPPER GAP FORMATION

The Clipper Gap Formation was named by Lindgren (1900, p. 2) for exposures at the village of Clipper Gap, about 6 miles (9.6 km) northeast of Auburn in Placer County. He distinguished the Clipper Gap Formation only in the Colfax 30-minute quadrangle but stated that contiguous parts of the undivided Calaveras Formation in the adjacent Sacramento, Placerville, and Smartsville quadrangles should also be included in the Clipper Gap. As mapped by Lindgren, and subsequently by Chandra (1961, pl. 1), the Clipper Gap Formation includes a variety of rock types, some indistinguishable from rocks considered to be Jurassic by both authors. Stratigraphic problems are compounded by poor exposures, for most of the area underlain by the Clipper Gap Formation as originally mapped is a deeply weathered upland surface of moderate relief. The name Clipper Gap Formation probably should be abandoned, but more detailed mapping must precede formal action.

According to Lindgren (1900, p. 2), the Clipper Gap Formation consists of slate, argillaceous sandstone, bedded and massive chert, and limestone. Chandra (1961, p. 14) included grit and conglomerate in the formation, as well as the rock types listed by Lindgren. During the present investigation, mafic pyroclastic rocks and massive volcanic rocks were found to be common within the area mapped by Lindgren and Chandra as Clipper Gap Formation. Ellipsoidal porphyritic lava of unknown extent and age is conspicuous along Interstate Highway 80 between Clipper Gap and Applegate (pl. 1), within areas formerly mapped as Clipper Gap Formation. The ellipsoidal lava is exposed in roadcuts that were made after Chandra's work was completed.

In this report, epiclastic rocks assigned to the Clipper Gap Formation are mapped as Cosumnes-type rocks, and the volcanic rocks and chert, except for the ellipsoidal lava, are included with the undifferentiated Paleozoic and Mesozoic volcanic and sedimentary rocks. Contacts between these units in upland areas are generalized on plate 1. Graywacke, slate, petromict conglomerate, and conglomeratic mudstone exposed along Interstate Highway 80 between Bowman and

Applegate and along the North Fork of the American River, in areas previously mapped as Clipper Gap Formation, are indistinguishable from rocks characteristic of the Cosumnes-type rocks as used in this report. Chandra (1961, p. 17–18), noting the similarity of conglomeratic mudstones and conglomerates in the Clipper Gap Formation to those in the Mariposa Formation (Cosumnes-type rocks of this report), suggested that those in the younger strata had been derived from the older by submarine sliding. This interpretation is untenable because current-bedded conglomerate as well as conglomeratic mudstone occur in both units as previously mapped and because the conglomeratic mudstone and conglomerate are not interbedded with the chert-bearing part of the Clipper Gap Formation but overlie them where they were seen during this study. No difference in the proportions of such labile constituents as slate and carbonate rock pebbles has been noted between conglomerates and pebbly mudstones assigned to the Clipper Gap Formation and those of Jurassic age.

The Clipper Gap Formation was assigned an early Carboniferous age by Lindgren (1900, p. 2) on the basis of fossils found at three localities. The fossiliferous carbonate rocks at two of these localities are transported blocks. One such block, described by Lindgren as a small limestone mass and bearing fragments of crinoids and poorly preserved shells, crops out 2 miles (3.2 km) above Mammoth Bar along the Middle Fork of the American River in an area assigned by Lindgren to the Clipper Gap Formation but is here included with Cosumnes-type rocks. The locality could not be determined with certainty, but strata in this vicinity include conglomeratic mudstones with blocks of carbonate rocks that are as much as several feet long. Fossils at a second locality are in a limestone block west of Colfax along the Bear River, which Lindgren believed to have been torn loose from the main body of the Clipper Gap Formation by the intrusion of a diabase pluton. He reported finding here *Clisiophyllum gabbi* Meek, *Lithostrotion whitneyi,* and brachiopod fragments. The third locality is, from Lindgren's description, apparently a limestone body exposed in a quarry in a small valley near the east boundary of sec. 8, T. 13 N., R. 9 E., and about 800 feet (245 m) south of the south portal of a Southern Pacific Railroad tunnel (Greenwood, Calif., 7½-minute quad.), where *Phillipsastrea* and *Pleurotomaria* were found. The stratigraphic relation of this carbonate rock to volcanic rocks that form the sparse surrounding exposures has not been established.

TIGHTNER FORMATION

The Tightner Formation, named for the Tightner mine, later part of the Sixteen-to-One mine, is about one-half mile (0.9 km) south of Alleghany and consists mostly of fine-grained greenish schist probably derived from andesitic volcanic rocks (Ferguson and Gannett, 1932, p. 6–7). It contains subordinate schist that is possibly derived from siliceous igneous rocks and some limestone lenses. The Tightner Formation was believed by Ferguson and Gannett (1932, p. 6–8) to be in fault contact with the Blue Canyon Formation (Shoo Fly Formation of this report) on the east and to be overlain unconformably by the Kanaka Formation on the west, although they recognized that the western contact was poorly exposed. No fossils were found in the Tightner Formation.

The Tightner Formation is a mappable unit in the vicinity of Alleghany, but it is unlikely that it can be correlated with confidence over a larger area, owing to the great structural complexity of the belt in which the formation was originally mapped and the lack of distinctive lithologic criteria. The type area of the formation, about one-third mile (0.8 km) southeast of Alleghany, is in a block bounded by faults of large but unknown displacement (pl. 1). The Tightner Formation is similar to many bodies of schistose metavolcanic rock in the western Sierra Nevada associated with less metamorphosed volcanic rocks of both Paleozoic and Mesozoic age. In the absence of fossils, rocks outside of this fault block cannot be correlated with the type Tightner Formation except by lithology.

KANAKA FORMATION

The Kanaka Formation was named by Ferguson and Gannett (1932, p. 7–12) for exposures along Kanaka Creek, about three-quarters mile (1.2 km) south of Alleghany, Sierra County. They divided the formation into a basal conglomerate member, lower slate and greenstone member, chert member, and an upper slate and greenstone member, stating that the Kanaka Formation unconformably overlies the Tightner Formation and is conformably overlain by the Relief Quartzite. No fossils were found in the formation, but a Carboniferous age was assigned on the basis of Lindgren's earlier interpretation of the age of rocks in that area.

The two slate and greenstone members of the Kanaka Formation are megascopically similar to many other bodies composed of slate and metavolcanic rocks in the region and in this report are mapped as metavolcanic rocks of Paleozoic and Mesozoic age. The chert member is indistinguishable from rocks mapped as the Delhi Formation by Lindgren (1900) and is included with the Calaveras Formation in this report.

The conglomerate member of the Kanaka Formation was not recognized along the three forks of the Yuba River during this investigation, and its outcrop is too narrow to show on plate 1; however, it constitutes a distinctive unit from Lafayette Ridge to Oregon Creek. The mode of origin of the rock is uncertain: It is either a tectonic breccia or a greatly sheared conglomeratic mudstone. Although it resembles coarse fragmental rocks in Jurassic strata of the region, it is exposed in an area that is distant from known Jurassic rocks.

According to Ferguson and Gannett (1932, p. 8–9), the texture of the conglomerate member ranges from slate containing scattered pebbles to closely spaced pebbles in a slate matrix. The size of the rock fragments varies widely; the largest fragment observed was 14 feet (4 m) long. The most numerous pebbles are altered pyroxene andesite, and possibly dacite, but pebbles of quartz diorite are also numerous. Less common are pebbles of arkose and quartzite. During the present investigation, blocks of bedded chert were found in the conglomerate member along Kanaka Creek. Possibly the volcanic rock pebbles were derived from the Tightner Formation (Ferguson and Gannett, 1932, p. 9), which is separated from the conglomerate member by thin septa of gabbro and serpentine. The quartzite and arkose pebbles could have been derived from the Shoo Fly Formation and the chert blocks from the Calaveras Formation.

Several possible modes of origin of the conglomerate member—pyroclastic, mudflow, tillite, fanglomerate, or fossil talus slope—were discussed by Ferguson and Gannett (1932, p. 10), but no definite conclusion was reached. The mudflow hypothesis is consistent with the concept that the conglomerate member is a sheared conglomeratic mudstone and cannot be eliminated on the basis of present information. On the other hand, the matrix of the conglomerate, which "though containing small fragments of probably detrital quartz*** consists largely of very fine grained opaque black material" (Ferguson and Gannett, 1932, p. 10), is more typical of flaser rocks found in the region than of the pebbly mudstones and is unlike the matrix of pebbly mudstones found elsewhere in the region. The matrix of the conglomeratic mudstones is not opaque and consists of white mica and silt- to sand-size grains of minerals and rocks.

VOLCANIC ROCKS

Volcanic rocks of Paleozoic age exposed along the northeast border of the area were mapped by Durrell and Proctor (1948, p. 171), who found that these rocks consisted of a lower unit of metarhyolite about 4,000 feet (1,200 m) thick, an 80–300-foot-thick (24–90 m) unit of shale, chert, and mafic tuff, and an exceedingly thick unit of mafic lava and pyroclastic rocks. The lower unit rests unconformably on rocks here included with the Shoo Fly Formation and has a thin basal conglomerate (Durrell and Proctor, 1948, p. 171, 175). The thick series of mafic lava and pyroclastic rocks is probably of Permian age (Durrell and Proctor, 1948, p. 171; Wheeler, 1939, p. 107) and is overlain by the Milton Formation (Turner, 1897).

PALEOZOIC AND (OR) MESOZOIC ROCKS

VOLCANIC AND SEDIMENTARY ROCKS

Volcanic and sedimentary rocks constitute a unit mapped in the southern part of the area; in the Colfax area it forms outcrops too small to map separately. It consists largely of mafic or intermediate volcanic rocks but is distinguished from other map units because conglomerate, carbonate rocks, and chert are interbedded with the volcanic rocks and because fossils older than those found elsewhere in the area were collected from a limestone body in the unit. The unit includes some of the rocks that were mapped by Lindgren (1894, 1900) and by Lindgren and Turner (1894) as diabase, Calaveras Formation, and Clipper Gap Formation.

This unit crops out in the south-central part of the map area in the same general area as the Cosumnes-type rocks. The volcanic rocks in this unit consist mostly of breccia but include subordinate pillow lava and tuff. Bedding is obscure in the coarse volcanic breccia along the North and Middle Forks of the American River, and farther south most of the volcanic rocks are schistose. Coarse-crystalline carbonate rock, partly limestone, forms lenses in the volcanic rocks in the vicinity of Lake Clementine (North Fork Reservoir on some maps). The largest of these lenses, more than 1 mile (1.6 km) long and as much as 250 feet (710 m) wide, crosses the Middle Fork of the American River about 1.8 miles (2.4 km) upstream from the State Highway 49 bridge. Part of a carbonate rock lens, near where the south line of sec. 10, T. 13 N., R. 9 E., crosses the North Fork of the American River, is replaced by chert. Thin-bedded chert is interlayed with the volcanic rocks about 200 feet (60 m) upstream from the massive chert near the Colfax railroad station and along Interstate Highway 80. Thin-bedded chert is interbedded with slate, graywacke, and tuff within the dominantly volcanic section at several places between the dam at Lake Clementine and the juncture of the Middle and North Forks of the American River.

The west boundary of the volcanic and sedimentary rocks is a fault zone, and the east boundary is faulted in places. Moderately dipping volcanic rocks with interbedded chert, believed to be part of this unit, are unconformably overlain by conglomerate of Cosumnes type in a cutbank at the Colfax railroad station. Truncated beds below the contact show an angular unconformity of a few degrees. Along the North Fork of the American River, slate and graywacke of Cosumnes type is in fault contact with the undivided volcanic and sedimentary rocks. Along Interstate Highway 80 between Clipper Gap and Applegate, exposures of rocks typical of the Cosumnes alternate with exposures of volcanic rocks with interbedded chert. Low-dip angles that characterize these two units at this locality suggest that the contact between them is folded so as to cause an irregular pattern very difficult to trace on the deeply weathered and rolling upland surface.

Tabulate corals collected from the limestone quarry south of the Middle Fork of the American River in sec. 6, T. 12 N., R. 9 E., are of probable Devonian age, according to C. W. Merriam (oral commun., 1962). Bryozoa collected from the same locality were identified by Helen Duncan (written commun., 1967), who believes that these also suggest a Devonian age. Exposures at the quarry suggest that this limestone body is interbedded with the adjacent volcanic rocks, but owing to the meager information on the internal structure and stratigraphy of this map unit, it cannot be assumed that all rocks in the unit are of the same age. The unit is therefore considered to be of Paleozoic and Mesozoic(?) age.

EPICLASTIC ROCKS

Epiclastic rocks near the site of Las Plumas, now flooded by Lake Oroville, in the northwest corner of the area (pl. 1) consist mostly of dark-gray phyllite but contain some graywacke, volcanic rock, and conglomerate. Phyllitic conglomerate exposed in railroad cuts northwest of Las Plumas consists largely of pebbles of light- to dark-gray slate and dark-gray chert in a slate matrix with sparse granules of dark-gray quartz. A block of coral-bearing carbonate rock, 10 by 4 feet (3 by 1.2 m) in size, surrounded by sheared phyllite is exposed in the bank of Grizzly Creek at the west boundary of the Las Plumas 7½-minute quadrangle, about 3,500 feet (1,065 m) S. 80° W. of the Las Plumas powerhouse. Because the slate is sheared, it is uncertain whether the carbonate block was emplaced by faulting or by slumping, as were some of the blocks in the Cosumnes-type rocks, but it is unlikely that fossils in the block can be used confidently to date the surrounding slate. Blocks of fusulinid-bearing limestone occur on the west wall of Spring Valley Gulch at the 900-foot (270 m) elevation, the high-water mark of Lake Oroville. These blocks appear to be in fault contact with adjacent slate.

METAVOLCANIC ROCKS

Metavolcanic rocks occur in the central part of the map area and are spatially closely associated with the Calaveras Formation. They were mapped as amphibolite by Lindgren and Turner (1894, 1895), by Turner (1897), and by Lindgren (1900) and also as diabase and porphyrite by Lindgren (1900). Ferguson and Gannett (1932, p. 6–7) applied the name Tightner Formation to schistose metavolcanic rocks near Alleghany (pl. 1). Most metavolcanic rocks appear in the field to be basaltic or andesitic, but felsic volcanic rocks constitute the western part of the sheared and metamorphosed body of metavolcanic rocks along the North Fork of the American River south of Dutch Flat. The abundance of quartz in contorted banded schistose metavolcanic rocks assigned by Ferguson and Gannett (1932, p. 7) to the Tightner Formation was interpreted by them to suggest felsic composition.

Bedded metavolcanic rocks along the North Yuba River east of Indian Valley consist largely of aphanitic dark-gray rocks that form massive beds 1–2 feet (0.3–0.6 m) thick. Interbedded with these are sparse beds of sand-size tuff. The massive aphanitic rocks superficially resemble chert but have a duller luster, and the beds are much thicker than normal for chert. Bedded metavolcanic rocks in the western part of the Middle Yuba River west of the mouth of Indian Creek consist largely of pyroclastic rocks, but one layer of lava shows suggestions of pillow structure. Chert is interbedded with the pyroclastic rocks near the pluton there. Massive metavolcanic rocks, some having the appearance of gabbro with grain size ranging from about 1–2 mm, are associated with the schistose metavolcanic rocks along the Middle Yuba River near Orleans Flat, and massive metavolcanic rocks constitute most of the eastern part of the body exposed along the North Fork of the American River.

Massive and pillow lavas occur near the east and west ends of the segment of Slate Creek that is marked by structure symbols (pl. 1) and on the Middle Fork of the Feather River near a large serpentine body. Distorted pillow structure is retained in schistose metavolcanic rocks at the State Highway 49 bridge across the North Yuba River west of Indian Valley.

Few clues are to be found regarding the age of the metavolcanic rocks, but some bodies may be temporally correlative with the late Paleozoic Calaveras Formation or, in the southern part of the area, with the Silurian Shoo Fly Formation. Preservation of original structures in some metavolcanic rocks near Slate Creek in the northern part of the map area (pl. 1), as well as the association with epiclastic rocks that are indistinguishable from Jurassic strata, suggests that at least part of these volcanic rocks may be Jurassic. If so, the volcanic rocks, as well as the associated sedimentary rocks, probably rest unconformably on the more deformed Calaveras Formation. In the absence of additional data, the metavolcanic rocks are tentatively assigned a Paleozoic or Mesozoic age.

MESOZOIC ROCKS

Epiclastic and volcanic rocks of Mesozoic and probable Mesozoic age underlie wide belts east and west of the belt of older rocks marked by the Shoo Fly Formation. They form smaller bodies that are associated with the Calaveras Formation in the central and northern parts of the map area. Probably none of these metamorphic rocks is younger than Cretaceous, for most map units are intruded by granitic rocks and no granitic rocks younger than Cretaceous have been recognized in the Sierra Nevada. Sparse Late Cretaceous sedimentary rocks in the region, not differentiated in this report, are neither folded nor metamorphosed (Lindgren, 1894; Creely, 1965, p. 34–35).

Fossils are generally sparse in the Mesozoic rocks, and they have been found in but a few map units. Epiclastic rocks here considered to be of Mesozoic age are lithologically similar to dated Jurassic rocks and resemble only the slate member of the Shoo Fly Formation among the Paleozoic strata. Some volcanic rocks in the northeastern part of the area (pl. 1), here considered to be of Mesozoic age, are possibly deformed outliers of the Paleozoic volcanic rocks that occur near the northeast boundary. Available structural and faunal evidence indicates that the Mesozoic rocks of the eastern belt are, in general, successively younger from west to east, but strata in the western belt are faulted and repeated by folds. The Triassic(?) rocks, comprising a basal chert breccia and an overlying limestone unit, are suggestive of miogeosynclinal deposition, whereas the Jurassic strata are eugeosynclinal deposits of metavolcanic rocks, silty slate, graywacke, and conglomeratic mudstone.

Mesozoic strata in the eastern part of the area are broadly divisible into eastern and western outcrop belts of epiclastic rocks separated by an intermediate belt of volcanic rocks. Turner (1894b) assigned the name Sailor Canyon Formation to the western belt of epiclastic rocks (pl. 1) and the name Milton Formation to strata composed chiefly of tuff and lapilli tuff exposed in the vicinity of what is now Milton Reservoir. However, he excluded massive volcanic breccia that is interbedded with the Milton. Lindgren (1897, 1900) included both bands of epiclastic rocks with the Sailor Canyon Formation and did not discuss the stratigraphic significance of the intervening volcanic rocks. Clark (1930, p. 8, 19–20, 28, fig. 6), who viewed the two bands of epiclastic rocks as opposite limbs of a syncline, included the volcanic rocks as well as both bands of epiclastic rocks in the Milton Formation. In this report, the name Sailor Canyon Formation is restricted to the western belt of epiclastic rocks, in accordance with the original definition. The name Milton Formation is extended to include the interbedded massive volcanic breccia that Turner mapped separately, as well as volcanic rocks east of the Sailor Canyon Formation and along the regional strike of the type locality of the Milton Formation. The eastern belt of Mesozoic epiclastic rocks is herein discussed under the informal term "epiclastic rocks."

Taliaferro (1943, fig. 2) correlated the Gopher Ridge Volcanics of this report with the Logtown Ridge Formation. Turner (1894a) and Taliaferro (1943, fig. 2) included both the Salt Spring Slate and the epiclastic rocks east of the Logtown Ridge Formation with the Mariposa Formation of Late Jurassic (upper Oxfordian and lower Kimmeridgian) age. A sparse fauna in the Salt Spring Slate (Imlay, 1961, table 2, loc. 8) suggests that its age is about the same as that of the type Mariposa Formation, but no fossils have been recovered from the unnamed epiclastic rocks that overlie the Logtown Ridge Formation. Because the fossil record is inadequate for precise correlation, the author prefers to use separate stratigraphic nomenclature for the two fault blocks.

Rocks of Jurassic and probable Jurassic age west of the Shoo Fly are more folded than those in the eastern belt, and stratigraphic continuity is interrupted by faults of large but unknown displacement. Stratigraphy and correlation problems are best illustrated near the south boundary of the area where stratigraphic sequences in two different fault blocks can be compared. South of Folsom Reservoir (pl. 1) the Gopher Ridge Volcanics of Jurassic (probable Late Jurassic) age, and the Salt Spring Slate and overlapping Copper Hill Volcanics, both of Late Jurassic age, constitute a sequence of folded concordant formations (Clark, 1964, p. 27–31, pls. 2, 8) that are more extensively exposed south of the area of this report. Farther east and separated from the above area by an intervening fault block, a similar sequence consists of Cosumnes-type rocks of Middle(?) and Late Jurassic (Callovian) age, the Logtown Ridge Formation of Late Jurassic (Callovian to upper Oxfordian or lower Kimmeridgian) age and an unnamed epiclastic formation of Late Jurassic (probably Kimmeridgian) age.

Formations in the western fault block, particularly the Copper Hill Volcanics, possibly constitute parts of unnamed map units elsewhere in the area, but they have been identified in so little of the area that further description here is unwarranted.

TRIASSIC(?) ROCKS

Rocks of Triassic(?) age were recognized only near the North Fork of the American River immediately east of the Shoo Fly Formation (pl. 1) where they include a basal chert breccia and an overlying limestone. The limestone is possibly equivalent to the Hosselkus Limestone of Late Triassic age near Taylorsville and Redding (McMath, 1966). Although the breccia and limestone were included by Lindgren (1900) with the Paleozoic rocks to the west, he was the first to recognize the existence of an unconformity in this vicinity. The lower of two units questionably assigned to the Triassic is medium to very coarse poorly sorted chert breccia having a thickness of 75 feet (23 m) or more. Chert and quartzose slate fragments similar to the rocks in the Shoo Fly Formation west of the unconformity are the most abundant rocks in the breccia; however, fragments of fine-grained dioritic or quartz-monzonitic rocks are common near Little Granite Creek, and sparse mica-schist pebbles occur on the north side of the main river canyon. Fragments of thin-bedded dark-gray slate and fine-grained graywacke or silicic tuff derived from the Shoo Fly Formation are common locally. In most places the largest fragments in the breccia are about 4 inches (10 cm) long, but near Little Granite Creek some are as much as 20 inches (50 cm) long. Near the contact on the divide between Big Granite Creek and the North Fork of the American River are outcrops of Shoo Fly Formation as much as 20 feet (6 m) long and 5 feet (1.5 m) wide that are surrounded by chert breccia; such an outcrop pattern might result either from deposition of the breccia on a very irregular erosion surface or from incorporation of detached blocks of the Shoo Fly Formation in the breccia.

The limestone that overlies the chert breccia is about 400 feet (120 m) thick on the crest of the divide between the North Fork of the American River and Big Granite Creek. It is absent in New York Canyon and is absent or concealed on the south side of the main river canyon. The lower part of the limestone unit consists of alternating layers of thin-bedded argillaceous gray limestone that weathers very light gray. Well-rounded granules or angular fragments of chert characterize some of these beds. The middle part consists of less argillaceous cliff-forming limestone, and the upper part is thinly interbedded light-gray limestone and light-greenish-gray very fine grained pyritic sandstone probably derived from silicic tuff.

The chert breccia overlies the Shoo Fly Formation with pronounced angular unconformity, and owing to pre-Triassic(?) folding of the Shoo Fly Formation, the angle between bedding in the Shoo Fly and that in the Mesozoic rocks varies from near 0° to near 90°. At the unconformity the surface of the Shoo Fly shows a relief of several feet; the contact alternately follows bedding and joints in the Shoo Fly Formation. North of the North Fork of the American River, the chert breccia is conformably overlain by limestone of Late Triassic(?) age. In New York Canyon it is overlain with possible erosional, but not angular, unconformity by the Sailor Canyon Formation. Although no fossils were found in the chert breccia, it is considered to be of Triassic(?) age.

Evidence for the age of the limestone was stated by Norman Silberling (in Clark and others, 1962, p. B18) as follows:

> A Late Triassic(?) age for the limestone is based mainly on the occurrence *** (USGS Mes. loc M1167) of numerous spherical objects with the surficial and internal structure of *Heterastridium*, a supposed hydrozoan coelenterate that is widely distributed in deposits of Norian (late Late Triassic) age. However, in view of the doubtful biologic affinities and unknown evolutionary history of this organism, the age must be considered provisional. A post-Paleozoic age for the limestone is corroborated by the presence of poorly preserved scleractinian corals, large cidarid echinoid spines, and *Pentacrinus*-like crinoid columnals with petaloid crenulations on the articulating surfaces.

Lindgren (1900) reported finding *Lithostrotion, Aviculopecten, Murchisonia,* crinoid stems, and lamellibranchs where, according to his field notes, the limestone crosses a trail on the southeast side of Big Granite Creek, but similar material was not found during the present investigation.

JURASSIC ROCKS

SAILOR CANYON FORMATION

The Sailor Canyon Formation, named by Turner (1894b, p. 232) for exposures on a tributary to the North Fork of the American River, is mostly graywacke, silty slate, and tuff. Its maximum thickness is at least 10,000 feet (3,000 m). The lowest part of the formation is greenish-gray-weathering sparsely bedded andesitic tuff about 500–700 feet (150–210 m) thick. Its texture ranges from very fine grained tuff to lapilli-tuff. The tuff is overlain by silty, locally pyritic, or calcareous slate about 1,000 feet (300 m) thick that extends eastward to the mouth of New York Canyon. Some conglomerate and graywacke are interbedded with the slate; pebbles in some conglomerate beds are restricted to carbonate rocks and chert, but others also contain pebbles of vein quartz and amygdaloidal volcanic rocks.

The most abundant rocks from the mouth of New York Canyon to the east side of Sailor Canyon are graywacke and silty slate, but tuff occurs throughout; the frequency of pyroclastic beds increases markedly near the top of the formation. Current-ripple bedding and graded bedding are common in the graywacke. In thin section, sand grains in the graywacke are seen to be mostly plagioclase and mottled untwinned feldspar, but quartz is common; some beds contain grains of microcrystalline volcanic rocks, granoblastic chert, and quartzite. Poorly sorted calcarenite or calcareous graywacke beds at the mouth of Sailor Canyon are less than 1 foot (0.3 m) thick. Detrital carbonate grains and recrystallized carbonate constitute most of these beds, but other rocks and minerals also occur.

Where the base of the Sailor Canyon Formation is well exposed in New York Canyon, its lower tuff unit rests on Triassic(?) chert breccia along an irregular surface having a local relief of about 10 feet (3 m). The tuff here contains a 4-foot (1.2 m) layer of chert breccia about 20 feet (6 m) above its base. The absence of Triassic(?) limestone and the relief of the upper surface of the breccia are interpreted as evidence of an erosional unconformity at the base of the Sailor Canyon Formation. The available evidence indicates that the Sailor Canyon Formation is structurally concordant with the Triassic(?) rocks, and the paleontologic record indicates but a very short time break at the unconformity.

The upper part of the Sailor Canyon Formation grades into, or intertongues with, the overlying Milton Formation through a stratigraphic interval about 1,600 feet (490 m) thick. The transitional zone, here included with the Sailor Canyon Formation, consists of interbedded conglomerate and volcanic rocks. The top of the Sailor Canyon Formation is drawn at the base of a thick layer of massive dark-gray volcanic breccia with abundant needlelike amphibole crystals, which is exposed on the north canyon wall.

The Sailor Canyon Formation is of Early and Middle Jurassic age. Hyatt (1894, p. 396–398) first identified *Monotis semiplicata, Monotis symmetrica, Daonella? subjecta, Daonella boechiformis, Daonella cardinoides, Gryphaea,* and ammonites including *Peronoceras? americanum* (an undescribed species). He believed that the presence of species of *Daonella* would ordinarily be regarded as evidence of a Triassic age, except for the fact that they extended into the ammonite bed which he dated as Early Jurassic (Lias) (Hyatt, 1894, p. 397). Lindgren (1900, p. 2) assigned the Sailor Canyon Formation to the Juratrias Period. Smith (1927) held that the *Monotis* species listed by Hyatt were synonyms for *Pseudomonotis* and that the Sailor Canyon Formation was therefore of Late Triassic (Noric) age. Smith's age assignment was accepted by K. B. Ketner (in McKee and others, 1959, p. 6–7) for the lowermost part of the Sailor Canyon.

C. H. Crickmay (in Clark, 1930, p. 49) studied collections made by Clark at three localities near the North Fork of the American River. Among fossils collected in Sailor Canyon above the Trinidad mine (probably the Sterrett mine of earlier reports), Crickmay determined two species of *Arniotites, "Tubellites"* sp. (=Gemmeltaroceras), and a hildoceratid. He thought that the first two indicated an early Lias date but that the third indicated middle Lias. *Arniotites* sp. and *"Tubellites"* sp. were identified also in a collection from the divide Between Big Granite Creek and the North Fork of the American River. In a collection from near the Placer Queen mine in the upper part of Wildcat Canyon, Crickmay identified sphaerocehatinid ammonites, which he believed to indicate a much younger age than fossils at the Trinidad mine locality. Similar ammonites near that mine were also mentioned by Clark (1930). In addition, Crickmay (1933, p. 52) redescribed and illustrated *Monotis semiplicata* Hyatt and *Monotis symmetrica* Hyatt, placed them in the genus *Entolium*, and dated them as "Lower Jurassic, Deroceratan." Stratigraphically, these are the lowest known fossils in the Sailor Canyon Formation. Taliaferro (1942, p. 100) stated that Upper Triassic fossils were found at or near the base of the Sailor Canyon Formation along the North Fork of the American River, Lower Jurassic fossils occur 2,500 feet (750 m) above the base, and Middle Jurassic fossils occur 9,500 feet (2,900 m) above the base.

More recently, all U.S. Geological Survey fossil collections from the Sailor Canyon Formation were studied by Imlay (1968, p. C7, C8, C12–C17; Clark and others, 1962, p. B19), who concluded that the formation reprsents most of the Early Jurassic and at least the early Middle Jurassic. The evidence consists of the late Sinemurian ammonite *Crucilobiceras* about 1,000 feet (300 m) above the base of the formation, the late Pliensbachian ammonites *Arieticeras* and *Reynesoceras* about 2,000 feet (600 m) above the base, and the early Bajocian ammonite *Tmetoceras* from 9,000 to 10,000 feet (2,700 to 3,000 m) above the base. The unverified report of sphaeroceratid ammonites near the Placer Queen mine suggests that the upper part of the formation may be as young as middle or late Bajocian.

Several stratigraphically useful pelecypods collected in the Sailor Canyon Formation include *Entolium? semiplicatum* (Hyatt), associated with the late Sinemurian ammonite *Crucilobiceras,* and *Lupherella boechiformis,* associated with the late Pleinsbachian ammonites *Arieticeras* and *Reynesoceras*. In addition, *Bositra buchii* (Roemer) occurs with *Tmetoceras* of early Bajocian age, but its total range is late Toarcian to Kimmeridgian. Of these pelecypods *Entolium? semiplicatum* (Hyatt) occurs in Nevada, eastern Oregon, and southern Alaska in beds of the same age, and *Lupherella boechiformis* (Hyatt) occurs in eastern Oregon associated with many ammonites of late Pliensbachian age (Imlay, 1967, p. B9).

MILTON FORMATION

The Milton Formation was named by Turner (1894b, p. 232–234) for exposures near an old stage station at about the present site of the dam for the Milton Reservoir on the Middle Fork of the Yuba River. The Milton consists mostly of andesitic pyroclastic rocks;

subordinate rocks are felsite tuff, calcarenite, conglomerate, mudflow breccia, and dark-gray slate or very fine grained tuff. Graded beds are few in the Milton Formation, but current-ripple bedding, small cut-and-fill structures, and load casts mark some tuff beds. Along Haypress Creek contact metamorphism has converted slate or fine-grained tuff to hornfels and destroyed original textures and structures of most volcanic rocks east of the pillow lava. Following Turner (1896, p. 624), isolated exposures of coarse-crystalline limestone along Pass Creek are included arbitrarily with the Milton Formation, although stratigraphic relations of the limestone are uncertain. The Milton Formation exposed along the North Yuba River is at least 10,000 feet (3,000 m) thick if not folded in concealed areas. Along the North Fork of the American River, the Milton is apprently equally as thick, but this is uncertain because contact metamorphism has obscured bedding in the eastern part of the formation. Owing to more moderate and variable dips along the Middle Yuba River, the exposed part there is probably less than 5,000 feet (1,500 m) thick. Near the North Fork of the American River, the western part of the Milton is coarse mostly thick-bedded mafic or intermediate volcanic breccia. The eastern part, owing to contact metamorphism, is mostly massive fine-grained rock of dioritic appearance.

Thin- to thick-bedded tuff of probably andesitic composition constitutes most of the Milton Formation near the Middle Yuba River and much of the formation along Haypress Creek. Massive amygdaloidal lava occurs near the mouth of Haypress Creek, and at Loves Falls the North Yuba River cuts through a thick massive layer of pyroclastic or flow breccia. Massive felsite containing quartz phenocrysts occurs in roadcuts of State Highway 49 at the west boundary of sec. 27, T. 20 N., R. 12 E., and at the mouth of Haypress Creek. Very fine grained dark-gray slate with some interbedded fine- to medium-grained tuff and chert or quartzose tuff extends about 3½ miles (5.6 km) north from Wild Plum Campground.

Along the Middle Yuba River west of the mouth of the Milton-Bowman tunnel, bedded felsite lapilli-tuff having interbedded layers of dark-gray slate and chert as much as 1½ feet (0.5 m) thick is overlain by poorly sorted intraformational conglomeratic mudstone about 50 feet (15 m) thick with chert fragments in a matrix of felsite tuff. The fragments range from small massive pebbles to internally thin-bedded blocks more than 8 feet long and 2 feet thick (2.4 m and 0.6 m). Obscure layering in the conglomeratic mudstone is marked by differences in spacing of fragments and by parallel arrangement of elongate or tabular fragments. Constitutents of the breccia were apparently derived from tuff and chert beds that occur within 40 feet (12 m) stratigraphically below the breccia.

Along the road about 500 feet (150 m) west of the Milton Reservoir dam, conglomerate layers less than 10 feet (3 m) thick are interbedded with tuff. Most of the pebbles are fine-grained dioritic and gabbroic rocks; less common pebbles are chert, mafic volcanic rocks, and biotite schist.

Medium-grained dark-gray obscurely bedded calcarenite is exposed along the Middle Yuba River near the center of sec. 18, T. 19 N., R. 13 E. The calcarenite contains pebbles of mafic volcanic rocks, and under the microscope sand-size grains of plagioclase, untwinned feldspar, and mafic minerals are visible. Carbonate rocks along Pass Creek appear to be much less contaminated by noncarbonate detritus.

Along the Middle and North Yuba Rivers, stratigraphic relations between the Milton and Shoo Fly Formations to the west are obscured by shear zones marking faults of probable large displacement. On the North Yuba, this contact is tentatively drawn at a shear zone that marks the east limit of chert in this vicinity. Sheared mafic or andesitic volcanic rocks occur both east and west of the contact as drawn, but such rocks are known to occur in both the Shoo Fly and Milton Formations. On the Middle Yuba River, this contact is drawn at a narrow serpentine body at the west limit of unsheared rocks of the Milton Formation. Near the North Fork of the American River, the Milton grades into or intertongues with the underlying Sailor Canyon Formation. Turner (1894b) considered the Milton Formation to be younger than the Sailor Canyon Formation and older than the Mariposa Formation, that is, within the range of late Middle to early Late Jurassic age. This interpretation is consistent with available structural and stratigraphic information. Along all three rivers the Milton is truncated on the east by granitic intrusive rocks.

AMADOR GROUP OF TALIAFERRO (1942, 1943)

The Amador Group was named by Taliaferro (1942, p. 89–90; 1943, p. 282–284); he divided the group into the Cosumnes and overlying Logtown Ridge Formations on the basis of exposures along the Cosumnes River, the north boundary of Amador County. His original definition was slightly modified by Clark (1964, p. 17) as the result of reexamination of its type locality. Both Taliaferro and Clark described the Cosumnes Formation as consisting predominantly of sedimentary rocks and the Logtown Ridge Formation as consisting predominantly of pyroclastic rocks with associated volcanic breccia and pillow lava.

Recent detailed mapping in Amador County, including the type locality of the Amador Group (Sharp and

Duffield, 1973; Duffield and Sharp, 1975), has resulted in the following major revisions within the Amador Group:

1. The basal contact of the Logtown Ridge Formation is located 2,000 feet (600 m) farther west than originally designated.
2. This contact is a fault, and thus the Logtown Ridge Formation is not conformable with the Cosumnes Formation as previously described.
3. Most strata originally defined and mapped as the Cosumnes Formation are part of a diverse assemblage of tectonically intermixed rocks—a melange—and thus the Cosumnes is not a valid formational rock-stratigraphic unit in Amador County.
4. The names Consumnes Formation and Amador Group are both inappropriate in their type areas and thus are abandoned.

The decision of Sharp and Duffield to abandon the Cosumnes Formation and Amador Group is accepted in the present report, although a belt of rocks similar to the Cosumnes Formation as originally defined has been mapped northward from its original type locality on the Cosumnes River into the southern part of the area of this report (pl. 1). To provide continuity between the present report and the earlier report on the south half of the foothill belt (Clark, 1964) and still recognize the recent contributions of Duffield and Sharp, these rocks are here referred to informally as Cosumnes-type rocks, in much the same way that Duffield and Sharp (1975) describe some rocks of the melange discussed by them as having Cosumnes affinities.

Cosumnes-type Rocks

Cosumnes-type rocks include strata along the regional strike of the type locality of Taliaferro's (1943) Cosumnes Formation as far northward as the Bear River (pl. 1). Much of the western part of the belt so included was assigned by Lindgren and Turner (1894) to the Calaveras Formation and a small part northeast of Applegate was assigned by Lindgren (1900) to the Clipper Gap Formation. Most of the rocks north of the North Fork of the American River that are here included with Cosumnes-type rocks were assigned to the Mariposa Formation by Lindgren (1900) and Chandra (1961). They were identified as slate and tuff of the Colfax Formation by Smith (1910, chart opposite p. 217). In some places between the South and Middle Forks of the American River, the east boundary of the unit is drawn arbitrarily, and much of the west boundary is also arbitrary owing to scarcity of exposures. The unit is at least 4,000 feet (1,200 m) thick in the map area.

Cosumnes-type rocks include dark-gray silty slate, gravelly conglomerate, conglomeratic mudstone, graywacke, and a small proportion of volcanic rocks. Major components of the graywacke and conglomerate are angular fragments of light- to dark-gray chert, volcanic rocks, and quartz. Minor constituents of the graywacke identified in thin sections are detrital grains of quartz-rich graywacke having sparse plagioclase probably derived from the Shoo Fly Formation and, from other sources, quartzite distinguished by pronounced undulatory extinction and deeply sutured contacts between its component grains, quartz-mica schist, and microcrystalline graphite-bearing quartz phyllite.

Current-bedded conglomerate and conglomeratic mudstone are sparse along the South Fork of the American River but are common farther north. Conglomeratic mudstone containing blocks of carbonate rock occurs along the Middle Fork of the American River from Kennebeck Bar to Poverty Bar, in Bunch Canyon, along the river near the south boundary of sec. 36, T. 15 N., R. 9 E., and along Interstate Highway 80. A conglomeratic mudstone about 1,000 feet (300 m) north of the south boundary of sec. 36, T. 15 N., R. 9 E., contains a block of deformed thin-bedded chert about 15 feet (4.5 m) wide and 30 feet (9 m) long. Most pebbles and boulders in the conglomeratic mudstone are of thin-bedded chert. Pebbly mudstone about 50 feet (15 m) thick, exposed 0.7 mile (1.1 km) northeast of the mouth of Codfish Creek, truncates bedding in the underlying slate and graywacke. Enclosed in the mudstone are blocks of interbedded slate and graywacke similar to strata underlying the pebbly mudstone. Other pebbly mudstones in that vicinity include contorted masses of slate and graywacke.

Few contacts of Cosumnes-type rocks with other units are exposed in the map area, and of these, several contacts are with units that are not well fixed stratigraphically. Thick conglomerate in the basal part of the Cosumnes-type rocks suggests but does not prove that the basal contact is an unconformity. In cut banks east and west of the railroad station in Colfax, coarse breccia containing abundant fragments of volcanic rocks and some chert fragments, here included with Cosumnes-type rocks, unconformably overlies volcanic rocks having some interbedded chert. Truncation of the chert below the contact at the south end of the cut east of the railroad station suggests an angular unconformity of a few degrees, but the age of the rocks beneath the unconformity is uncertain.

Cosumnes-type rocks contain rocks of early Late Jurassic (Callovian) age, which were originally considered younger. Hyatt (1894, p. 424–425, 427; in

Lindgren, 1900, p. 3) identified *Perisphinctes colfaxi* Gabb collected from a railroad cut 1 mile (1.6 km) west of Colfax and *Olcostephanus lindgreni* Hyatt occurring about 1½ miles (2.4 km) south-southwest of Colfax and concluded that they indicated a Late Jurassic (Tithonian) age. Smith (1910, chart facing p. 217) mentioned the occurrence of *Perisphinctes colfaxi* Gabb in these strata, which he named the Colfax Formation, and believed them to be of Late Jurassic age and younger than the Mariposa Formation. Crickmay (1933, p. 57) identified *Olcostephanus lindgreni* Hyatt as *Galilaeiceras lindgreni* and gave its age as early Late Jurassic (Callovian). Imlay (1961, p. D6–D7) listed *Ammonites colfaxi* Gabb, *Kepplerites lorinclarki* Imlay, and *K.* (*Gowericeras*) *lindgreni* (Hyatt) from the Colfax Formation of Smith (1910) as Callovian ammonites. A fossil identified by Imlay (1961, p. D7–D8, table 3) as *Perisphinctes* (*Dichotomosphinctes*) *mulbachi* Hyatt of possible early Oxfordian but probably late Oxfordian (Late Jurassic) age is reported to have been found near Greenwood (pl. 1). A late Oxfordian age is more in accord with the age of the Mariposa Formation south of the area of this report than with Cosumnes-type rocks at Greenwood, but as the geologic structure in this area, as well as the name of the collector and precise locality of the fossil, is uncertain, the age is questionable.

Logtown Ridge Formation

In its type locality immediately west of the Huse Bridge on State Highway 49 over the Cosumnes River, the Logtown Ridge Formation consists largely of pyroclastic rocks, ranging from very fine grained tuff to very coarse volcanic breccia, but contains some pillow lava. Within the area covered by this report, it was examined only along the South Fork of the American River, where it consists of pyroclastic rocks ranging in texture from very fine grained tuff to volcanic breccia. The pyroclastic rocks consist largely of fragments of mafic or intermediate volcanic rocks, but some breccia also contains fragments of slate and felsic volcanic rocks.

As mapped by Lindgren and Turner (1894), rocks here assigned to the Logtown Ridge Formation are continuously exposed from its type locality, 6 miles (9.6 km) south of the boundary of the present study area, to a point southwest of Placerville where they are truncated by a felsic intrusion (pl. 1). Similar pyroclastic rocks bordering the east side of Cosumnes-type rocks from a point south of Georgetown northward to a point near Cape Horn (pl. 1) probably belong to the Logtown Ridge Formation; however, no paleontologic confirmation was found, and thus they have been mapped simply as volcanic rocks of Jurassic age.

The Logtown Ridge Formation is of early Late Jurassic (Callovian to late Oxfordian or early Kimmeridgian) age (Imlay, 1961, p. D6) on the basis of the presence of *Pseudocadoceras* in its lower 600 feet (180 m) and of *Idoceras* aff. *I. planula* (Heyl) in its upper part.

Monte de Oro Formation

The Monte de Oro Formation was named by Turner (1896, p. 548) for a conglomerate-bearing slate exposed in sec. 33, T. 20 N., R. 4 E., along the road immediately south of Monte de Oro, a point on the southeast end of North Table Mountain about 3 miles (4.8 km) north-northeast of Oroville where it occupies a faulted syncline (pl. 1). Silty slate, part of which contains abundant plant fossils, constitutes most of the formation, but graywacke and poorly sorted conglomerate are interbedded with the slate. On the west side of the syncline, this sequence is underlain conformably by a 200-foot-thick (60 m) section of littoral sandstone and conglomerate, partly crossbedded, that contains pebbles of vein quartz, carbonate rocks, and volcanic rocks and is much better sorted than the overlying silty beds to the east. Although the marked contrast between the littoral and deeper water facies suggests a hiatus at their contact, the littoral beds are here included in the Monte de Oro Formation following Taliaferro (1942, p. 92), who interpreted them as evidence of the west margin of a Jurassic sea. A more detailed description of the formation is given by Creeley (1965, p. 24–28).

Although no depositional contact between the epiclastic rocks of the Monte de Oro Formation and the underlying volcanic rocks was found, the synclinal structure of the formation and directions of tops of beds indicate that the Monte de Oro Formation overlies the adjacent volcanic rocks. There is no evidence to suggest that offset along faults that bound the Monte de Oro Formation is sufficient to invert the stratigraphic sequence. Deformation of the Monte de Oro is similar to that of other pre-Portlandian rocks of the western Sierra and is dissimilar to the moderately dipping and less metamorphosed strata of the latest Jurassic Knoxville Formation on the west side of the Sacramento Valley. There the Knoxville unconformably overlies metamorphic and intrusive rocks that appear to be comparable in their age and geologic history to the pre-Knoxville rocks of the western Sierra Nevada.

Both flora and fauna of the Monte de Oro Formation suggest a Late Jurassic age, although agreement between the two is not precise. Results of paleontologic studies of the Monte de Oro Formation prior to 1942 are summarized by Taliaferro (1942, p. 91). More recently, Fry (1964, p. 64A) concluded that its flora indicated an age ranging from late Oxfordian to and including Portlandian, on the basis of *Macrotaeniopteris, Baiera, Ctenis, Ctenophyllum, Pagiophyllum,* and *Taeniopteras*.

However, the plant fossils lack an epidermis, and therefore specific and generic determinations are uncertain, according to Jack Wolfe of the U.S. Geological Survey (oral commun., 1968). Imlay (1961, p. D8–D9) concluded that the fauna is of Late Jurassic (late Oxfordian to early Kimmeridgian) age, on the basis of an ammonite similar to *Perisphinctes* (*Dichotomosphinctes*) *elisabethaeformis* Burckhardt and two crushed specimens of *Buchia* that probably belong to *B. concentrica* Sowerby. Imlay (1961, p. D9) stated that the presence of *Buchia* in the Monte de Oro Formation indicates that its age does not extend to Portlandian. *Pachysphinctes,* indicative of the Kimmeridgian Stage (Imlay, written commun., 1965), was found 150 feet (45 m) below the surface in an excavation for a highway bridge in the NW¼ sec. 5, T. 19N., R. 4 E. (See topographic map of Oroville quadrangle.)

UNNAMED EPICLASTIC ROCKS

Unnamed epiclastic rocks presumably of Jurassic age occur chiefly near the east side, in the central part, and near the northwest corner of the map area (pl. 1). Epiclastic rocks near the east boundary of the area were indicated by Lindgren (1897) to be of Juratrias(?) age. Those in the south-central part of the area were included by Lindgren and Turner (1894) with the Mariposa and Calaveras Formations, and those in the central part of the area were included by Lindgren (1900) with the Cape Horn and Delhi Formations. Epiclastic rocks in the northwestern part of the area were mapped by Turner (1898) and Creeley (1965) as the Calaveras Formation. A narrow belt of sheared rocks that extends northward along a fault zone from La Mar Flat, north of Lake Combie on the Bear River, is here included arbitrarily with this map unit. Correlation of these rocks with the Calaveras Formation, as indicated by Lindgren and Turner (1895), is unlikely in view of the narrowness of the belt and its isolation from known Paleozoic rocks. Where observed near the Bear River during this investigation, the unit consists of flaser rocks derived from volcanic rocks bounding the fault zone, but in the absence of new information on the remainder of the belt, the original interpretation that these rocks are of epiclastic origin is accepted.

During this investigation the epiclastic rocks near the east boundary of the study area were examined only along the North Fork of the American River where they are more than 5,000 feet (1,500 m) thick and consist mostly of dark-gray slate now converted to hornfels. At the east boundary of the epiclastic rocks near the mouth of Serena Creek (pl. 1) is a conglomerate consisting of fragments of chert, quartz graywacke, black slate fragments, and angular to rounded quartz sand grains. Structure and top directions indicate that these epiclastic rocks overlie the Milton Formation and suggest that their age is within the range of Middle to Late Jurassic.

Near the Drum Power Station on the Bear River, distant from any similar rocks (pl. 1), a block of epiclastic rocks about 2,500 feet (680 m) wide and more than 2,000 feet (600 m) long is surrounded, or nearly so, by serpentine. The block consists of dark-gray silty slate, graywacke, tuff, and bedded conglomerate. The conglomerate and coarse graywacke contain, in addition to quartz grains, fragments of chert, fine-grained quartz-bearing intrusive rock, graywacke similar to that of the Shoo Fly Formation, quartz-mica schist, mafic or intermediate volcanic rocks, and carbonate rock.

The epiclastic rocks along Slate Creek in the north-central part of the map area (pl. 1) are represented by poor exposures of slate and graywacke. To the south, near the State Highway 49 bridge across the North Yuba River, petromict conglomerate is interbedded with dark-gray slate on the river margins and in highway cuts south of the river. Exposures near the North Yuba River west of Goodyears Bar that are included with this unit consist largely of sheared phyllite containing fragments of chert that before deformation were probably interbedded with the originally slaty fraction of the phyllite. This belt contains some interbedded tuff and, near the west boundary of sec. 12, T. 19 N., R. 9 E., contains conglomerate with pebbles of chert and volcanic rocks. The map pattern and facing of bedding tops suggest that these epiclastic rocks intertongue with the surrounding volcanic rocks. Preservation of bedding details in the epiclastic and, to a lesser extent, in the volcanic rocks permits an interpretation that they rest unconformably on the much more deformed Calaveras Formation.

The unnamed epiclastic rocks along the Middle and North Forks of the American River differ from those farther south in that chert constitutes about 5 percent of the total section and some of the slate is quartzose. Volcanic rocks, some so altered that their original texture and structure are undecipherable, constitute about 10 percent of the section along the North and Middle Forks of the American River. Recognizable tuff occurs along the North Fork north of Iowa Hill. Pillow lava occurs on the North Fork at the mouth of a tributary canyon near the east boundary of sec. 30, T. 15 N., R. 10 E., and at Fords Bar on the Middle Fork. Volcanic breccia and tuff occur near the mouth of New Orleans Gulch along the Middle Fork.

Unnamed epiclastic rocks in the south-central part of the area occur approximately along the strike projection of epiclastic rocks that conformably overlie the Logtown Ridge Formation along the Cosumnes River 6 miles (9.5

km) south of plate 1. These epiclastic rocks consist mostly of black siltstone but contain some beds of tuff, graywacke, and fine conglomerate. Along the South Fork of the American River, the composition of the epiclastic rocks is similar, dark-gray silty slate constituting most of the section east and west of State Highway 49. Conglomerate or volcanic breccia occurs in the SE¼ sec. 27, T. 11 N., R. 10 E.

Coarse fragmental rocks, some possibly of tectonic origin but most of epiclastic origin, occur along the North and Middle Forks of the American River. Conglomeratic mudstone containing fragments of carbonate rock and, in places, of volcanic rocks is interbedded with dark-gray phyllite in the bed of the North Fork of the American River about 500 feet (150 m) east of Cosumnes-type rocks. The matrix of the mudstone is phyllite similar to that with which the conglomeratic mudstone is interbedded. Conglomeratic mudstone is most readily observed along the Bunch Canyon road southeast of Colfax.

The unnamed Mesozoic epiclastic rocks in the south-central part of the area are bounded on the east by major faults; on the west the epiclastic rocks adjoin volcanic rocks that are either known or inferred to be of Late Jurassic age. Epiclastic rocks at the south boundary of the area are on strike with similar rocks that overlie the early Late Jurassic Logtown Ridge Formation 7 miles (11.2 km) south of the area of this report (Clark, 1964, p. 26–27, pl. 8). Stratigraphic relations of the unnamed epiclastic rocks suggest that the same relation holds near the South Fork of the American River. Farther north, structural and stratigraphic relations are less clear, but no flaser rocks such as those characteristic of major fault zones elsewhere in the region were found between the unnamed epiclastic rocks and the volcanic rocks to the west. In the absence of a major fault, the epiclastic rocks must be younger than the rocks to the west, for tops of beds face eastward and different lithologies on opposite sides of the contract preclude the existence of any but minor folds. Two ammonites in the unnamed epiclastic rocks suggest a Late Jurassic age: A single specimen of *Perisphinctes* (*Dichotomosphinctes?*) spp. (Imlay, 1961, pl. 5, fig. 6) was collected in Big Canyon about 2 miles north of Placerville in the SW¼ sec. 36, T. 11 N., R. 11 E., and a specimen of *P.* (*Dichotomosphinctes*) *muhlbachi* Hyatt is reported to have been found near Greenwood (Imlay, 1961, p. D7–D8, pl. 4, fig. 8).

UNNAMED VOLCANIC ROCKS

Unnamed volcanic rocks of Late and probable Late Jurassic age underlie much of the area west of the Shoo Fly Formation. They were mapped as diabase, porphyrite, and amphibolite by Lindgren (1894, 1900), by Turner (1898), and by Lindgren and Turner (1894, 1895). Lindgren and Turner considered the age of the volcanic rocks to be equivalent to or younger than that of the Mariposa Formation or, where stratigraphic information was especially scanty, simply as pre-Cretaceous. Creeley (1965, p. 11, pl. 2) considered volcanic rocks east of the Monte de Oro Formation near Oroville to be of late Paleozoic age on the basis of unspecified stratigraphic relations and degree of metamorphism. In this report these rocks are considered to be of Late and probable Late Jurassic age. In the southwestern, northwestern, and central parts of the area, the volcanic rocks are commonly schistose, but except in narrow shear zones, original textures and structures are readily identifiable. Most of these volcanic rocks appear in the field to be of basaltic or andesitic composition. Compton (1955, p. 13) found that in the vicinity of Bidwell Bar on the Feather River "by far the majority of the metavolcanic rocks were originally basalt or pyroxene andesite flows, dolerite flows and sills, and basic tuffs or tuffaceous sediments." Hietanen (1951, p. 568) found that north of Bidwell Bar near the north boundary of the map (pl. 1), the metavolcanic rocks are metabasalt, metadiorite, metadacite, metarhyolite, and metamorphosed tuff and agglomerate.

Abundant dikes suggest eruptive centers near Lake Combie on the Bear River, near the south end of Englebright Reservoir on the Yuba River where dikes as much as 30 feet (9 m) thick constitute about half of the area of canyon walls, at a locality about 1 mile (1.6 km) west of the Colgate Power Station on the North Yuba River and near Bidwell Bar. Pillow lavas are most abundant within a few miles of the dike complexes.

The unnamed Jurassic volcanic rocks are generally similar to those in the southern part of the western Sierra Nevada metamorphic belt already described by Clark (1964, p. 18–23, 26–29) and to those in the northern part of the metamorphic belt described by Compton (1955, p. 13) and Creeley (1965, p. 21–24). Accordingly, descriptions of these rocks are here limited to localities of special interest. Evidence of submarine slumping and contemporaneous deformation is well displayed along the Bear River east of the shear zone in sec. 34, T. 14 N., R. 7 E., in layers of fragmental rocks that overlie a bedded tuff unit. The bedded tuff is undisturbed except that a slumped and rotated block about 10 feet (3 m) long broke loose from the top of the upper part of the bedded tuff unit and is now separated from the in situ tuff by clastic dikes. The bedded tuff is overlain by chaotically deposited intraformational breccia about 30 feet (9 m) thick, which consists of fragments of bedded tuff that range in size from pebbles to blocks. A 4-foot-thick (1.2 m) layer of bedded intraformational breccia divides the chaotic breccia into two parts. Downstream from the breccia, thick-bedded tuff is planar, but thin-bedded tuff is contorted into complex patterns.

Selvaged lava bodies of bizarre shapes occuring at The Narrows on the Yuba River and about 900 feet (270 m) S. 30° E. of the center of sec. 34, T. 14 N., R. 7 E., on the Bear River suggest submarine emplacement of lava into unconsolidated pyroclastic material. The bodies resemble pillows in that they are bounded by selvages but differ from pillows in their angular to amoeboid form and wide range in size. Jasper forms veinlike bodies and fills some amygdules at the Bear River locality. Transition of pillow lava upward into massive lava within a single flow unit is well shown on the Yuba River in sec. 15, T. 17 N., R. 7 E. The change from pillow to massive structure is marked by attenuation of pillow selvages into discontinuous partings that disappear upward into massive lava.

Within the area of this report, fossils were found only in the volcanic strata that underlie the Monte de Oro Formation northeast of Oroville (pl. 1). These beds, as well as those adjacent to Cosumnes-type rocks in the vicinity of the anticline near Colfax are possibly equivalent to the Logtown Ridge Formation. The rocks of this map unit are considerably more folded than the eastern belt of Mesozoic rocks and those near the south boundary of the map area, and the stratigraphic section is probably duplicated. The total thickness of the exposed part of the broad western belt of volcanic rocks could be as little as 10,000 feet (3,000 m).

Owing to facies changes and fault zones that interrupt stratigraphic continuity, most of the unnamed Mesozoic volcanic rocks cannot be assigned with confidence to named formations. The Gopher Ridge Volcanics possibly occurs in the broad western belt of volcanic rocks between Folsom Reservoir and Oroville, but fossils and more detailed mapping are needed to establish correlations. Graded bedding in the Cosumnes-type rocks and in the volcanic rocks adjacent to them on the east along the North and Middle Forks of the American River indicates that tops of beds face eastward and that the volcanic rocks overlie the Cosumnes-type rocks. Some evidence of faulting was found near the contact of these units along the North Fork of the American River east of Colfax, but no evidence of a fault was found at the contact farther south along the North Fork of the American River.

A specimen of *Perisphinctes* sp. suggests that the volcanic rocks transitionally underlying the Monte de Oro Formation are of Late Jurassic (Oxfordian) age (S. W. Muller, in Creeley, 1965, p. 24).

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