Geology of the Sierra Foothills Melange and Adjacent Areas, Amador County, California

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By WENDELL A. DUFFIELD and ROBERT V. SHARP

ABSTRACT

Detailed outcrop mapping in the western Sierra foothills of Amador County, Calif., has resulted in some major changes in the interpretation of stratigraphy and structure. The Amador Group was originally defined at its type locality on the south bank of the Cosumnes River in Amador County to include the Cosumnes Formation and the conformably overlying Logtown Ridge Formation, but the new data indicate that the lower boundary of the type Logtown Ridge should be located 600 m farther west (downsection) than originally designated and that this boundary is a fault. The strata that were originally called the Cosumnes Formation are part of a lithologically diverse assemblage of tectonically intermixed rocks that constitute a newly recognized melange and thus are not a formational rock-stratigraphic unit as the earlier workers believed. Thus, the names Cosumnes Formation and Amador Group are both inappropriate in their type area and are abandoned.

The Logtown Ridge Formation is here divided into four members, some of which cross what earlier was considered to be a formational boundary of the Logtown Ridge with overlapping pyroclastic strata. The outcrop mapping requires additional changes, although of lesser importance, in the identification and correlation of other Mesozoic rocks in Amador County.

The newly recognized melange forms a 4-km-wide belt underlying the Logtown Ridge Formation. In addition to the type section of the abandoned Cosumnes Formation and scattered fault-bounded blocks of strata of Cosumnes lithology, the melange comprises rocks heretofore mapped as "western belt of Calaveras Formation," considered to be of Paleozoic age. Single clasts of this huge tectonic breccia range from a few centimeters to a few kilometers in maximum dimension. Distinctive strata are generally disrupted, and pervasive shearing is common. In the absence of fossils, no age of original deposition can be assigned to any clast or matrix of the melange, but on the basis of indirect structural evidence, the intermixing that formed the melange probably took place during the Late Jurassic or before, and therefore the now sheared and faulted strata must originally have been at least this old.

Available data are ambiguous but suggest that rocks were intermixed to form the melange when the strata were horizontal or nearly so. Similarly, the overlying Logtown Ridge and Mariposa Formations were faulted when these rocks were essentially horizontal. The entire section was subsequently tilted to its present, nearly vertical position.

Traditional syntheses of the tectonic history of the Sierra foothills argue that the faults there have always been steeply dipping. Although this may be true for some faults, the new interpretation suggests that most faulting occurred before the section was steeply tilted. Neither suggestion can yet be proved, but we maintain that the highly deformed rocks mapped in Amador County represent primarily the effects of subduction at a continental margin, possibly augmented by gravity tectonics in a trough of sediment accumulation there. On the basis of the ages of affected strata, this period of subduction was Late Jurassic but possibly began at an earlier time. If this interpretation of the melange in Amador County is correct, a belt of similarly deformed rocks should extend far beyond the limits of the study area.

INTRODUCTION

Since the gold deposits of the well-known Mother Lode country of California were first discovered and mined over a century ago, the geology of that area has been of considerable interest. Prompted by the gold rush, initial geologic fieldwork emphasized the relation of the general geology to gold-bearing quartz veins of the Mother Lode system. More recent field investigations have concentrated on the structural and stratigraphic complexities of the pre-Tertiary metamorphic rocks to explain the origin and history of the entire Sierra Nevada province.

Relatively recent work has resulted in detailed interpretations of the geologic history of some small areas (for example, Baird, 1962; Best, 1963) and also more comprehensive treatments of a much larger part of prebatholithic rocks of the Sierra Nevada province (Clark, 1960, 1964; Kistler and others, 1971). Nonetheless, much fundamental information, such as the stratigraphic thickness of rock systems, is still unknown, and the number and nature of tectonic episodes that have affected these rocks are not generally agreed upon.

Attempts to answer these and other fundamental questions in the western Sierra foothills traditionally have been frustrated by such conditions as (1) the low ratio of outcrop area to total field area, (2) marked lithologic changes over short horizontal distances, with the result that important geological contacts commonly are more closely spaced than outcrops, and (3) a conspicuous absence of fossils to aid in dating and correlating strata. These conditions are not likely to change, but methods of fieldwork are. Large-scale mapping of all available outcrops in western Amador County (fig. 1) has enabled us to make fundamental changes in some earlier defined stratigraphic units and to demonstrate the presence of a previously unrecognized melange there.

We studied only a small part of the total foothills area; very detailed mapping elsewhere in the foothills is required for a general understanding of the geology. We recognize, however, that sufficient natural exposures of

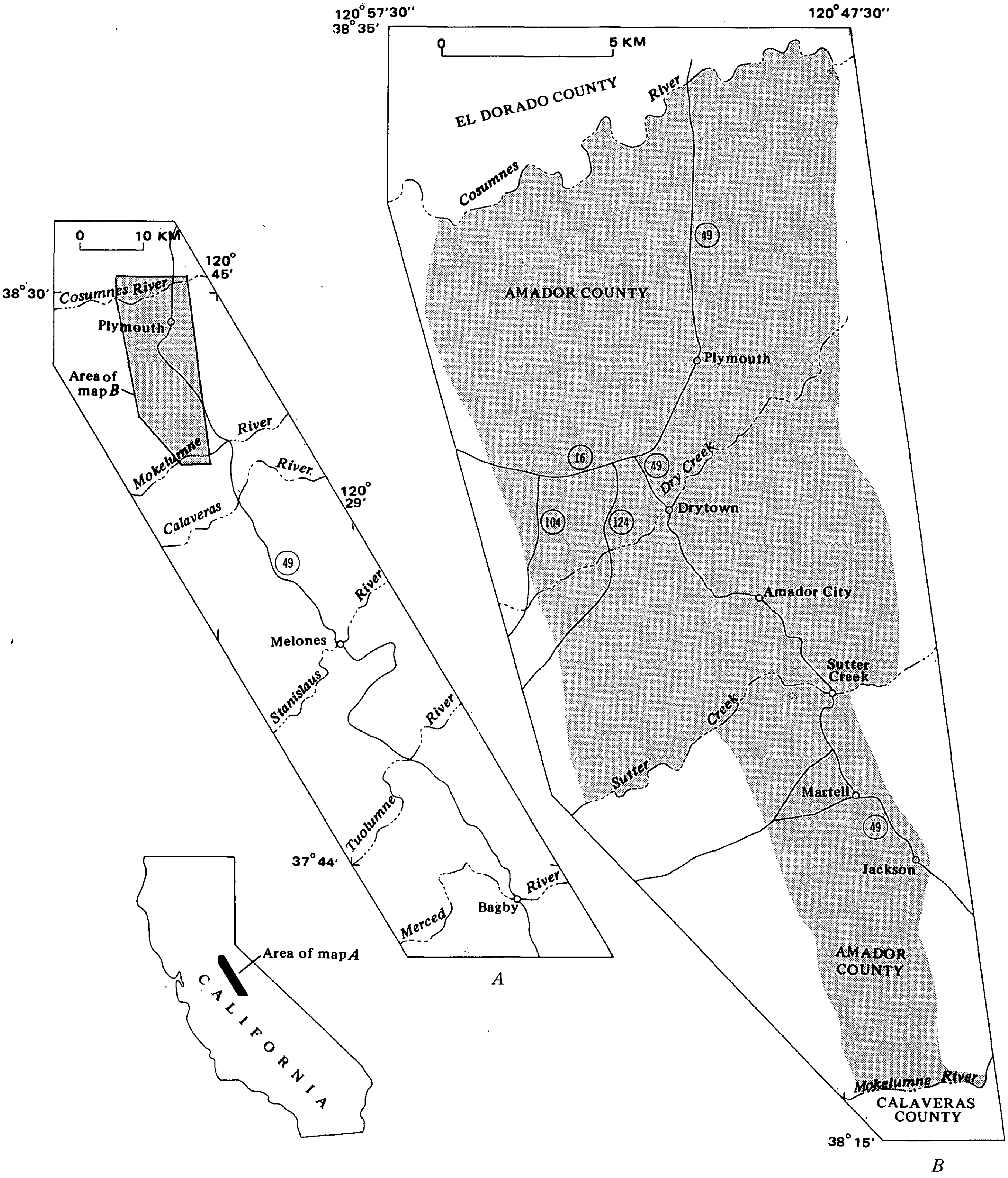

FIGURE 1.—Index maps of the west-central Sierra Foothills, showing approximate area of plate 1 (shaded area in *B*).

bedrock generally are not available, and we urge all interested workers to make detailed observations at manmade exposures as they occur.

Nearly all the evidence from which the conclusions in this paper are drawn is summarized on the geologic map, plate 1. Since contacts are rarely exposed in this area, the lines on the geologic map represent conclusions about the nature of the contacts based almost entirely on indirect evidence. Thus, a special explanation of how the map was constructed is helpful to its interpretation. The working scale was 1:12,000, and for most map units, except those in the eastern belt, individual outcrops were plotted. Contacts were drawn to interpret the distribution of lithologies at the working scale, then the entire map was reduced to a 1:24,000 scale without showing the outcrops. Figure 2 is an example of the unedited large-scale field data that provided the control for compiling plate 1.

We have shown the distribution of lithologies by the simplest possible arrangement of contacts on the map. The trend and linearity of some contacts are closely bracketed by field data. Comparison of these contacts

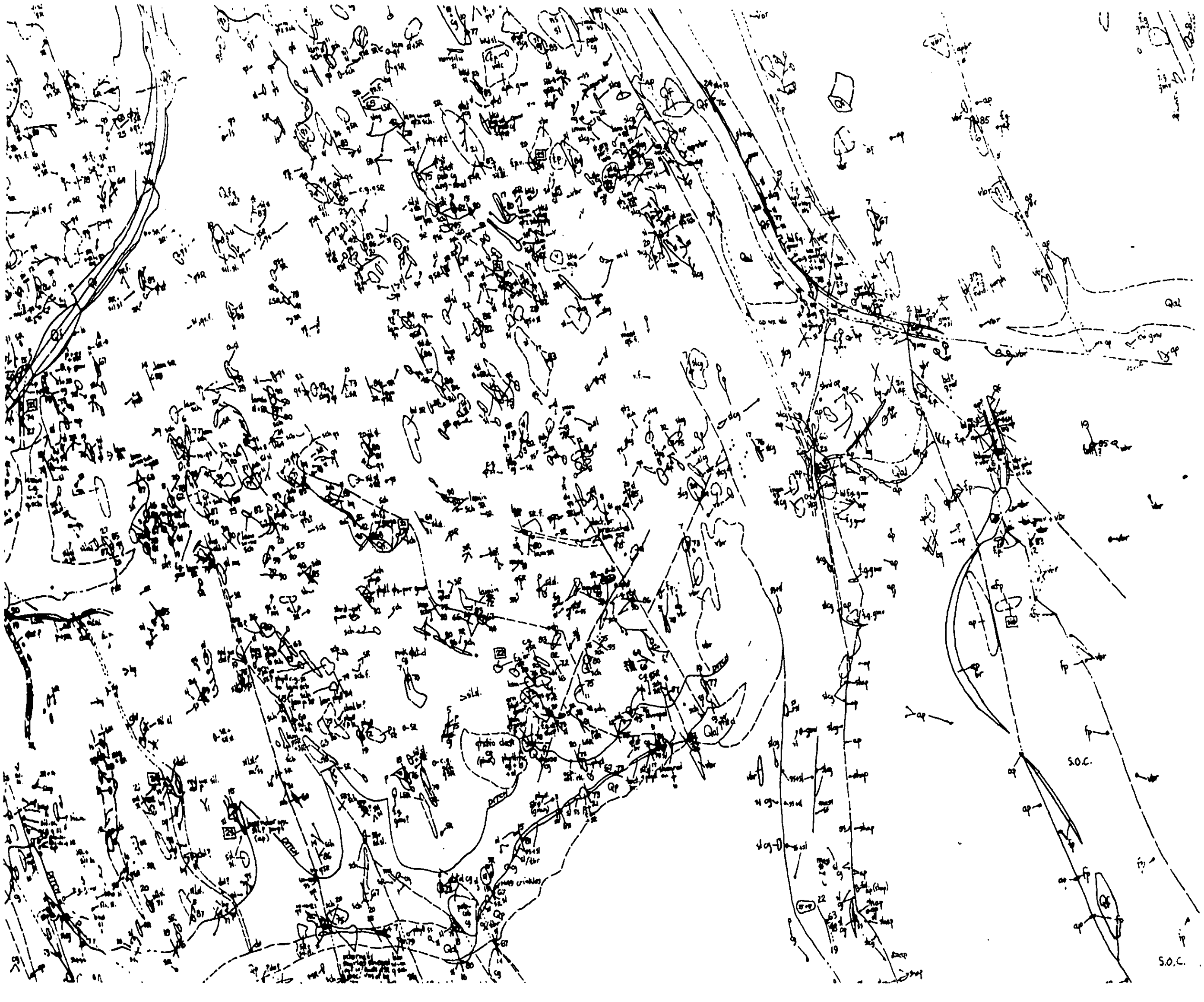

FIGURE 2.—Sample of unedited field data from which the geologic map, plate 1, was compiled. This area is about 1.2 miles square; Drytown is located at the east-central border. A few initial interpretations of the data are shown by straight dashed lines. Most outcrops are so small that they can be shown only as a dot on the map. Large outcrops are outlined with dashed lines. Letter symbols are field shorthand and do not correspond directly to the symbols of rock units used on plate 1.

with others whose form is not so well controlled suggests that the less well known ones should also be drawn as approximately linear where outcrop data permit, rather than as curved, sinuous, or even more complex boundaries. Nevertheless, it should be remembered that many of the contacts could be redrawn with different shapes and consequently would have different implications. However, the basic conclusions about structure, especially in the melange, would remain unchanged.

The subjacent series is divided into four belts of rocks (fig. 3, pl. 1); in the text, each belt is described in a separate section to permit the reader to move from the text to the geologic map with ease.

The authors shared equally in the fieldwork and manuscript preparation for this study. Donald Swanson and Othmar Tobisch reviewed the manuscript and offered many helpful suggestions.

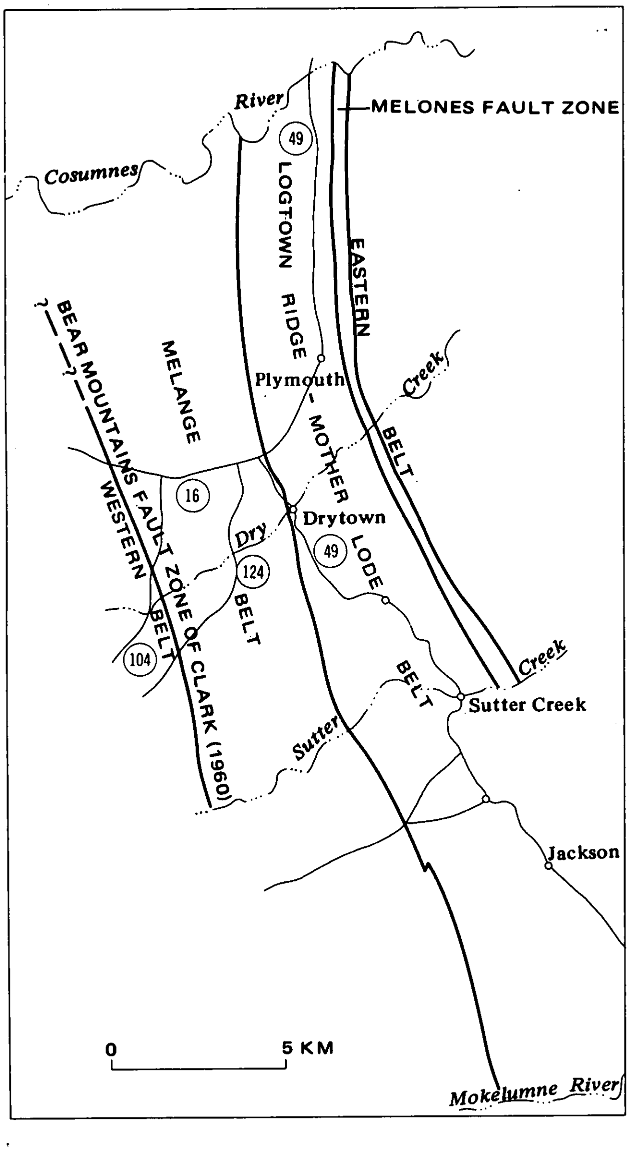

FIGURE 3.—Belts of rocks mapped on plate 1.

GENERAL GEOLOGY

Western Amador County, as all the western Sierra foothills area, is underlain by folded and faulted metasedimentary and metavolcanic rocks of Paleozoic and Mesozoic ages (the subjacent series) upon which isolated erosional remnants of a formerly extensive capping of Tertiary volcanic conglomerate and tuff (the superjacent series) lie with angular unconformity. Bedding and metamorphic planar structures in the subjacent rocks dip steeply and generally trend parallel to one another and to the crest of the adjacent Sierra Nevada. Bedding in the Tertiary rocks dips gently to the west.

Paleozoic and Mesozoic rock units form north-northwest-trending bands that have suggested a homoclinal structure to some geologists (for example, Clark, 1964, pl. 1), but our work shows that this interpretation is valid only locally where the internal stratigraphy and structure of a few formations are reasonably well documented. A more nearly correct interpretation of the structural geology includes abundant faulting and shearing, both within and between lithologic units. Accordingly, although the earlier recognized arrangement of mappable rock units into north-northwest-trending bands is preserved, the ages and the nature of juxtaposition of certain map units must now be reevaluated.

To date, the most thorough treatment of the structure of the area has been that of Clark (1960, 1964), who mapped a homoclinal sequence, with tops facing east, interrupted by two steeply dipping north-northwest-trending pre-Cenozoic fault zones, the Bear Mountains and Melones. The Melones fault zone juxtaposes Paleozoic rocks upon Mesozoic, whereas the Bear Mountains fault zone is characterized by discontinuous masses of serpentinite. In the terminology of this paper, the Melones fault zone separates the Logtown Ridge-Mother Lode belt from the eastern belt, and the Bear Mountains fault zone separates the western belt from the melange belt. (See fig. 3.) On the basis of fossil occurrences, Clark believed that the Bear Mountains fault zone also marked a reversal of stratigraphic succession, but new data indicate that this need not be so. Both fault zones undoubtedly mark zones of major tectonic dislocation and are discussed in more detail in later sections.

All the subjacent rocks have been metamorphosed to some degree, generally to the greenschist facies. The most abundant minerals of the various lithologies include white mica, epidote, chlorite, actinolite, quartz, and sodic plagioclase. Small areas of higher grade rocks occur locally. In the bedded rocks and in many lava flows, primary structures and textures, and even some original minerals, are excellently preserved in spite of the metamorphism. Because these primary structures often are the most useful identifying features of the rocks, we often use such terms as graywacke and volcanic rocks, even though metagraywacke and metavolcanic rocks would be more precise.

NOMENCLATURE

Before the work of Clark (1964), almost all the subjacent rocks of the Sierra foothills were assigned to one of three formally named rock-stratigraphic units: the Calaveras Formation, the Mariposa Formation, and the Amador Group. The Calaveras Formation was originally defined to include all the metasedimentary and metavolcanic rocks of Paleozoic age (Turner, 1893a, p. 309; 1893b, p. 425). The Upper Jurassic Mariposa Formation was named by Becker (1885, p. 18–19; 1900, p. 3) for fossiliferous and highly metamorphosed auriferous slates in Hell Hollow just southeast of Bagby (fig. 1), about 12 miles northwest of the town of Mariposa. The Upper Jurassic Amador Group was named by Taliaferro (1942, p. 89–90; 1943; p. 282–284) to include several formations; those of interest to this report are the Cosumnes Formation and the overlying Logtown Ridge Formation, whose type locality is along the Cosumnes River (fig. 1) immediately west of Highway 49.

Most workers in the foothills have correlated their map units with one of these three formally named rock-stratigraphic units wholly on the basis of lithologic similarity. Such correlations were made despite the patchy, discontinuous nature of outcrops, the structural complications, and the general absence of a fossil record; they are often unsatisfactory because none of the formations has a unique lithologic makeup. Clark (1964) recognized this problem and generally restricted his use of formation names to rocks at their type localities and adjacent areas where stratigraphic continuity can be documented.

In general, we follow Clark's nomenclature (1964). However, our mapping indicates that the name Amador Group must be abandoned (Sharp and Duffield, 1973). Briefly, although the Amador Group was originally defined as two conformable formations, the Cosumnes and Logtown Ridge, new mapping indicates that (1) these two lithologic units are in fault contact, (2) the single fossil locality originally used to date the Cosumnes Formation is within the Logtown Ridge Formation, and (3) most rocks of the Cosumnes Formation form scattered, fault-bounded blocks in a melange. Accordingly, we herein abandon the name Cosumnes Formation; only the Logtown Ridge Formation remains a demonstrable rock-stratigraphic unit in Amador County, and the use of the term Amador Group there is inappropriate.

Our use of the name Calaveras Formation follows Turner's (1893, a, b) original definition—all rocks of Paleozoic age of the Sierra Nevada—and rocks that are assigned to the Calaveras Formation in this report are so named for one or more of the following features: (1) A characteristic assemblage of lithologies, (2) a relatively complex set of structures, and (3) a degree of metamorphism higher than Jurassic rocks of the western Sierra foothills. We found no fossils during our work, and no previously described fossil localities are in the study area. Thus, our assignment of rocks to the Calaveras Formation is not beyond question. In general, we simply follow the designations used by Clark (1964), although the formational assignment of rocks in the western belt of Calaveras of all earlier workers is now questioned in view of the newly recognized melange there.

The melange forms a 4-km-wide belt of chaotically intermixed rocks that previously have been mapped as a homoclinal sequence of the Calaveras Formation (Lindgren and Turner, 1894), Calaveras plus complexly infolded Cosumnes Formation (Taliaferro, 1943, and unpub. map), and a homoclinal sequence of Calaveras Formation conformably overlain by Cosumnes Formation (Clark, 1964, pl. 8). One clast in the melange, a fragment of limestone a short distance south of the map area (pl. 1), contains Permian fossils, suggesting Calaveras Formation. But because no other fossils have been found and because the melange is a tectonostratigraphic unit of the type described by Hsü (1968), essentially all the rocks that compose the melange are of unknown age. In the absence of new age data, however, we retain the original Calaveras and Cosumnes designations for some rocks of the melange. The reader should realize that these designations are mainly for convenience in describing generally distinctive lithologies, and the implied correlation to the type Calaveras and Cosumnes Formations may, in fact, be incorrect. We further emphasize this ambiguity and also stress the fundamental chaotic character of the melange by referring to the rocks there as showing "Calaveras affinities" or "Cosumnes affinities," rather than calling them formations. We recognize that, in general, the law of superposition and the concept of rock- and time-stratigraphic units should not be applied to the chaotic mass of rocks that forms the melange, and we use the terms Calaveras and Cosumnes there only for convenience of discussion.

MELANGE BELT

The melange crops out in a north-northwest-trending belt about 4 km wide, and we have mapped it for about 15 km across Amador County. The melange includes chaotically intermixed clasts of both Calaveras and Cosumnes affinities. Common lithologies of Calaveras affinities include quartzose slate-phyllite, chert, quartzose sandstone, limestone, quartz-muscovite-albite phyllonite, and massive to blocky mudstone. Those of Cosumnes affinities are black clay slate, graywacke, and slate-clast conglomerate. Intergradation between rock types precludes unambiguous assignment of all rocks of the melange to one of these two groups, but where possible, a distinction seems valuable and may in fact reflect two or more sources of fundamentally different character.

Virtually none of the map units in the melange consists of a single lithology. Each unit contains assemblages of lithologies that generally are not unique, but the assemblages can be distinguished by the proportions of different lithologies and, locally, by the exclusion of one or more lithologies. The most widespread assemblage is quartzose slate-phyllite and intercalated thin-bedded chert, with or without more massive siliceous rocks (thick-bedded chert?), quartzose sandstone, and limestone. The most common association in a single outcrop is quartzose slate with interbedded chert and lesser amounts of quartzite. The slate generally is tan and gives a characteristic ring when hammered; cleavage surfaces commonly exhibit a phyllitic sheen. Intercalated gray chert beds range in thickness from about 2 to 20 cm, but most do not exceed 6 cm. Cleavage surfaces in chert are less closely spaced than in the associated slate, and they are refracted at the boundary between the two lithologies. Thin beds of poorly sorted impure quartzose sandstone are locally intercalated with the slate to the exclusion of chert. Also, local rhythmically bedded chert with thin slaty partings crops out to the exclusion of both slate and sandstone. A metamorphic rock cleavage is apparent at nearly every outcrop in the melange, but bedding often is not evident. Rocks at many outcrops are pervasively sheared; the original beds of chert and quartzite are so thoroughly disrupted that they form isolated pods in a matrix of sheared pelitic material.

Quartzite and poorly sorted impure quartzose sandstone form many outcrops both within and adjacent to the slate-chert terranes. These quartzites are bedded, invariably with slaty partings, and are at least partly the lateral equivalent of associated slate. Typically, the brown to tan quartzose sandstones are characterized by sparse plates of mica and by scattered well-rounded medium-grained clasts of quartz in a brown matrix. Locally, this matrix is displaced completely to form beds of quartzite.

Scattered highly siliceous outcrops are common locally. Some of this material is nearly pure massive microcrystalline quartz of light- to dark-gray color. However, much of it (for example, in sec. 21, T. 7 N., R. 10 E) displays a distinct color lamination that trends generally parallel to elongate outcrops or a group of closely spaced outcrops, suggesting that the color bands reflect original stratification.

Limestone occurs as scattered outcrops within terrain underlain by quartzose slate, chert, quartzose sandstone, quartzite, and clay slate. Exposures range from 1 to about 40 m in maximum dimension and often are clustered in relatively small north-northwest-trending elongated areas. Typically, the limestone is light gray and nearly pure carbonate; grain size is relatively uniform for outcrops at one locality, but it varies from very fine (lithographic limestone) to coarse throughout the area. At one outcrop (SW¼ sec. 9, T. 6 N., R. 10 E.), thin beds of chert are intercalated with limestone, and a distinctive calcarenite in sec. 22, T. 7 N., R. 10 E., contains about 10 percent sand-size quartz, plagioclase, and lithic fragments.

Some limestone outcrops are massive, whereas others show a color banding, which, like that in the laminated highly siliceous rocks, is believed to parallel original stratification. By projecting color bands, some outcrops of limestone (for example, in secs. 4, 5, 8, 9, T. 7 N., R. 10 E., and sec. 16, T. 7 N., R. 10 E.) can be fitted into complex folds; scattered outcrops of laminated chert can be correlated in the same manner, and at one area (SE¼ sec. 21, T. 7 N., R. 10 E.) similar folds are so outlined in both chert and limestone. These folds, together with the other structural characteristics of the melange belt, suggest that linear bands of limestone outcrops represent limbs of sheared, disrupted folds.

Irregularly shaped masses of gneissose to schistose phyllonite crop out about 0.8 km southwest of Drytown and locally elsewhere. These rocks are composed primarily of quartz, muscovite, and albite, commonly in that order of abundance, although muscovite is locally predominant. The plane of schistosity is locally folded and commonly diverges from the north-northwest trend of the regional metamorphic rock cleavage that pervades nearly the entire map area. Also, the plane of schistosity is locally crosscut by a fracture cleavage with a north-northwest trend that may have formed at the same time as the regional foliation. Schistosity apparently developed before regional cleavage and occurs only in a few clasts of the melange.

Medium-grained phyllonite, which closely resembles the schistose variety and probably differs from it only in degree of recrystallization, is associated with both the schistose phyllonite and phyllitic slate. At outcrops it is characterized by about 10 percent subrounded quartz grains 1 mm in diameter, which are embedded in a tan to gray matrix. Parallel surfaces of rock cleavage are evenly spaced at about 3-mm intervals and are lined with plates of muscovite that impart a phyllitic sheen to the rock. These surfaces appear to have resulted from concentrated shearing on evenly spaced planes. Locally, they are folded, and some fracture cleavage is developed parallel to the axial planes of such folds.

In thin section, these rocks are obviously sheared and crushed. About 80 volume percent of the rock is composed of quartz and feldspar, both as porphyroclasts and finely crushed matrix. The rest of the matrix is primarily muscovite, chlorite, and accessory sphene, apatite, and an opaque mineral.

Tan to dark-olive mudstone crops out along the west margin of the melange belt and generally underlies relatively small, northwest-trending elongate areas within the belt of serpentinite exposures. Chert, limestone, immature conglomerate, and graywacke crop out within areas that are underlain principally by the mudstone, but they are scattered and volumetrically very small.

The mudstone is unique among the epiclastic rocks of clay- and silt-size material, for it lacks the penetrative cleavage that is so widespread elsewhere. A weakly developed rock cleavage occurs locally, but rocks in most outcrops are either massive or fractured into blocks. Bedding generally is not evident, but where graywacke and immature conglomerate are interstratified, bedding strikes north-northwest and dips steeply eastward.

Moderately well sorted mature quartzose conglomerate and sandstone crop out along the east and northeast margins and locally elsewhere in the melange belt. These rocks appear to grade both laterally and vertically from one to another. Conglomerate is most abundant south of Highway 16 near the latitude of Drytown (pl. 1). The clasts are well-rounded cobbles and pebbles of quartz and chert, which are cemented by silica to form very resistant outcrops. Rocks in most exposures are light colored, commonly a pale-pinkish tint. Where outcrops can be reasonably related to one another, they form north-northwest-trending bands.

The quartz sandstone occurs primarily north of Highway 16 and extends in discontinuous north-northwest-trending fingers for about 8 km toward the north boundary of the map (pl. 1). The clasts are well-sorted medium-grained rounded to subrounded particles of quartz, minor chert, and rare feldspar (albite?) and slate, all of which show some granulation at their edges and, commonly, undulatory extinction in thin section. Outcrops are light gray and, where weathered, exhibit a few volume percent of evenly distributed pore spaces of the same general diameter as the clasts. Generally massive beds range from a few centimeters to a few meters thick.

Tan-weathering slate is associated and interbedded with both the quartzose conglomerate and sandstone. It forms outcrops in roadcuts at the intersection of Highways 49 and 16 about 2 km north of Drytown; the ridge to the south is underlain by the more resistant rocks. About 6 km to the north-northwest, the slate and interbedded quartz sandstone are well exposed in cuts along a dirt road (not shown on pl. 1) that follows the west flank of the conspicuous north-trending ridge in the west half of sections 28 and 33, T. 8 N., R. 10 E. Typically, bedding and cleavage are nearly parallel and trend north-northwest, but they are greatly divergent in the narrow axial regions of rare minor isoclinal folds.

Poorly sorted unbedded conglomerate, the largest clasts of which are subangular to subrounded pebbles and cobbles, is abundant within the melange belt, especially along the west margin. This conglomerate and associated clay slate and graywacke closely resemble slate and graywacke in the type Cosumnes Formation on the Cosumnes River. The conglomerate in some outcrops contains numerous clasts of black slate and an argillaceous matrix; in others, it is characterized by abundant volcanic clasts with no fragments of slate. These types form two end members of which most of the conglomerates are mixtures. The argillaceous conglomerate is relatively concentrated in the eastern half of the melange belt, and the volcanic conglomerate in the western half, although there are many exceptions. In decreasing abundance, the lithologies represented by the clasts of a "typical" conglomerate are (1) fine-grained and porphyritic intermediate to basic volcanic rocks, (2) black clay slate, chert, quartzite, limestone, and milky quartz, and (3) granitic rocks, mica schist, and serpentine. The only known serpentine clast occurs in the conglomerate that underlies the conspicuous hill 0.6 km southwest of Drytown.

In the volcanic conglomerate, nearly all the clasts are fine-grained or porphyritic volcanic rocks of intermediate to basic composition. These clasts are firmly cemented by tuffaceous material to form very resistant massive dark-colored outcrops. Locally, outcrops of structureless augite-feldspar porphyry several meters in maximum dimension are included with these volcanic conglomerates. Such bodies probably represent exceptionally large clasts in a fragmental rock, although they may be parts of intrusive bodies or flows.

Some of the conglomerate appears structureless; however, deep weathering commonly etches the resistant varieties in a preferred north-northwest-trending direction, and those rocks with abundant clasts of slate and an argillaceous matrix often show a well-developed planar structure unaided by weathering. This structure is reflected both in the fine-grained matrix (as slaty cleavage) and in the general parallelism of the larger clasts, many of which are discoidal. Locally, deformed clasts also define a lineation that plunges steeply in the plane of foliation. The total strain that affected the original rock, as seen in this flattening and elongation, is difficult to assess because the slaty matrix likely has undergone considerably more deformation than the coarser material. Bedding is generally absent, but the original surface of deposition is probably parallel to the metamorphic foliation because the regional trends of the conglomerate, the metamorphic foliation, and the bedding in associated graywacke are all parallel, or nearly so.

Available outcrops indicate that the entire spectrum of epiclastic rocks from cobble conglomerate to clay slate is represented in the conglomerate map units of plate 1. Slate and intercalated graywacke possibly underlie a major part of the areas mapped as conglomerate, but since the conglomerates are relatively resistant, they are preferentially exposed. Slate and graywacke form many outcrops in the easternmost zone of conglomerate perhaps because there they are shielded by the resistant volcanic rocks of the adjacent Logtown Ridge Formation. The slate is black and contains interbeds of graywacke ranging in thickness from about 3 to 20 cm. The clasts of the graywacke are subangular to subrounded grains of plagioclase and quartz, together with fragments of aphanitic and porphyritic intermediate to basic volcanic rocks, slate, and chert. Bedding and slaty cleavage are apparent at most outcrops, and with few exceptions, they diverge by 15° or less in either strike or dip. Graywacke beds commonly are graded with nearly all stratigraphic tops facing eastward. Known west-facing beds are everywhere associated with small tight to isoclinal folds.

A relatively thin (230–500 m in outcrop width) yet quite persistent band of black slate with thinly interbedded graywacke and minor immature slate-clast conglomerate roughly bisects the melange belt in a north-northwest direction. These rocks are indistinguishable from the slate and graywacke of much less volume, which are associated with similar conglomerate as described in the preceding paragraph.

Beds of graywacke in this narrow band range in thickness from 3 to 20 cm and provide abundant opportunities for direct measurements of bedding, cleavage, and stratigraphic top. Nearly all tops face eastward; they are most commonly indicated by noticeable grading, but a few examples of refracted cleavage were noted. Bedding planes are even and regular and seldom diverge from the attitude of associated cleavage by more than 20° in either strike or dip. Known folds in bedding are few; they are very tight to isoclinal with axial plane cleavage and measure only 1–2 m in wavelength.

The continuity of this map unit is interrupted for a short interval near its intersection with Highway 16 (pl. 1). The exact nature of this break is not well documented, although it almost certainly is structural rather than stratigraphic. Regardless of the nature of the break, this sequence of rocks provides the most nearly throughgoing marker unit of the entire melange belt and thereby represents the largest known clast in the melange.

GENERAL INTERRELATIONS OF ROCKS IN THE MELANGE BELT

The melange belt of this report was originally mapped as the "western belt of Calaveras Formation" on the U.S. Geological Survey folios. The Cosumnes Formation was later separated from these rocks by Taliaferro (1943, p. 306, fig. 2), and still later Clark (1964, p. 17) refined Taliaferro's original designation of the Cosumnes Formation. Although these earlier workers differed on the number of formations and the structural relations of one to the other, they all believed that the formations formed normal stratigraphic successions which had been tilted or folded or both.

Our work shows that such simplicity does not exist. As plate 1 indicates, individual marker beds or sequences of beds do not extend far, normally no more than a few kilometers. Lithologies of distinctive appearance, such as limestone and laminated chert, generally persist for far shorter distances and locally are greatly contorted. Many outcrops are pervasively sheared. Although the exact nature of contacts is unknown because they are not exposed, all this evidence suggests the presence of a chaotic tectonic intermixture of rocks.

Thus, a normal stratigraphic succession cannot be deciphered from rocks within the melange. In fact, the age of rocks that compose the melange, except for clasts which actually contain diagnostic fossils, must now be considered unknown. Indirect structural evidence discussed in a later section suggests that the melange formed in Late Jurassic or older time; thus the rocks of the melange presumably also are Late Jurassic or older.

PROBLEMS OF REGIONAL CORRELATION

The retention of the Calaveras designation for some rocks of the melange is supported by lithologic similarity of these rocks to generally accepted Calaveras rocks described by others elsewhere and by the discovery of Permian fossils from the Allen marble quarry (Clark, 1964, p. 14) within an area directly on strike with what is now recognized as the melange. Clark (1964, pl. 1) indicated that this band of Paleozoic rocks (the "western belt of Calaveras Formation") pinches out southward from Amador County between fault slices of Jurassic rocks. However, inspection of other maps south of Amador County and comparison of detailed rock descriptions for river profiles by Clark (1964, pls. 6, 7) suggest a southeastward continuation of the melange because of similarity in rock types, such as shown in the Jackson folio (Turner, 1894a). A brief excursion we made along highways near the Calaveras River substantiates the similarity of the rocks there to the "Calaveras" rocks exposed in the melange of Amador County. Although south of northwestern Calaveras County, Clark (1964) and Clark, Stromquist, and Tatlock (1963) uniformly assigned these rocks to the Jurassic Mariposa Formation, isolated blocks of limestone there locally have yielded Permian fusulinids (Douglass, 1967). Clark (1964, p. 14) interpreted these as blocks of Permian limestone that probably slumped into massive beds of the Mariposa Formation during Jurassic time, but in view of the new data, the possible southward extension of Paleozoic rocks within the melange in Amador County must be considered. It now seems probable that sufficiently detailed mapping will show intimate tectonic intermixture within all the rocks labeled "western belt of Calaveras Formation" by Turner (1894a) and considerable extension of the melange belt southward from Amador County.

A comparable problem exists for recognition of the melange northward from Amador County. Lindgren and Turner (1894) showed northward continuity of the Calaveras Formation into El Dorado County to the latitude of Placerville in their Placerville folio, but subsequent regional compilation by Clark (1964, pl. 1) replaced much of this map unit in El Dorado County with the designation "epiclastic rocks of uncertain stratigraphic position." Unfortunately, newer and more detailed maps than the original folio sheet have not been made in the critical area to solve this problem of continuity, and structural intermixing of the type found in the melange belt in Amador County cannot yet be demonstrated there.

Possible lateral extension of the melange beyond the western boundary as shown on plate 1 is suggested by aeromagnetic surveys. Within the map area, magnetic anomalies form north-northwest-trending patterns with especially strong positive anomalies directly over serpentinite bodies (Henderson and others, 1966; U.S. Geological Survey, 1969). The most pronounced bands of magnetic highs are concentrated along the Melones fault zone and the west boundary of the melange belt, where serpentinite is most abundant. Similar bands of magnetic anomalies are located along the east edge of the Great Valley of California, over the relatively flat lying Cenozoic sedimentary rocks that floor the valley. These data suggest that north-northwest-trending belts of serpentinite lie beneath the Cenozoic rocks of the valley and imply the existence of major zones of faulting there. Thus the zone of chaotically intermixed rocks in the foothills region may have a far greater width than we suggest.

EASTERN BELT

Most of the metamorphic rocks in the eastern belt are phyllite, phyllonite, and chert, which occur separately or in various proportions in single outcrops. Lithologic similarity precludes delineation of separate map units among these rocks by the methods of this study, although known bedding attitudes generally trend north-northwest and dip steeply to the east, in accord with the regional structural grain of the foothills. Assignment of these rocks to the Calaveras Formation follows the usage of earlier workers.

The phyllitic and phyllonitic rocks appear very similar in the field. Both exhibit a dark-gray to silver-gray color, a sheen from oriented plates of muscovite, a rock cleavage parallel to this mica, and a steeply plunging color streaking in the plane of the cleavage. In thin section, however, the rocks show clear evidence of different histories. Phyllite is composed principally of granoblastic quartz, muscovite, albite, chlorite, and actinolite and probably represents recrystallized sedimentary rocks of appropriate composition. Phyllonite shows grain granulation textures. One phyllonite sample consists of quartz, microcline, perthite, and minor muscovite as strained and fractured grains that are in turn surrounded or partly bounded by more finely crushed material.

Phyllite is more common than phyllonite or chert, and locally it exhibits two foliations. The older foliation trends north-northwest, dips steeply to the east, and is paralleled by plates of mica and the dominant direction of rock cleavage. The younger trends about north-south, dips steeply to the west, and appears either as crenulations on the older foliation or as distinct planar fractures. Steeply plunging color-streaking lies in the plane of the older foliation and generally parallels the axes of associated minor folds.

The chert is indistinguishable from that in the melange belt. It is locally massive but more commonly occurs in beds from 3 to 20 cm thick, separated by thin phyllitic partings. Minor isoclinal folds as much as 1 or 2 m in wavelength occur in the chert; their axes plunge from 20° to 80° to the southeast, averaging about 60°.

Two relatively large masses of coarsely porphyroblastic white-mica hornfels lie within and adjacent to a granodioritic pluton near the Cosumnes River. The textural and mineralogical character of the hornfels indicate a higher grade of metamorphism than that found in any rocks around the eastern periphery of the pluton. In addition to white mica, the hornfels contains medium-grained granoblastic biotite, quartz, and calcic oligoclase, with weak development of planar fabric defined by biotite grains. White mica forms relatively large (6 mm) poikiloblastic grains without preferred orientation, through which the earlier biotite foliation extends without interruption. Tourmaline and opaque minerals form small accessory grains.

Although no similar rock is known elsewhere in the Calaveras terrane of the eastern belt, the hornfels is included with the Calaveras Formation because one mass is continuous with typical Calaveras rocks in El Dorado County to the north, according to relations shown on the Placerville folio (Lindgren and Turner, 1894). Probably because of their geometry, the bodies of hornfels are more extensively recrystallized than other weakly hornfelsed rocks found along the eastern contact of the pluton. One mass is surrounded by granodiorite, and the other forms a deeply penetrating appendage of wallrock.

Minor bodies of serpentinite, gabbro, diorite, and limestone (for example, in sec. 6, T. 7 N., R. 11 E.) also crop out in the eastern belt, but most are too small to be shown on plate 1.

LOGTOWN RIDGE–MOTHER LODE BELT

Most of the Logtown Ridge–Mother Lode belt is underlain by marine stratified rocks of Jurassic age. These rocks are divided into two formations, the Logtown Ridge and overlying Mariposa, which trend north-northwest and dip steeply to the east. Detailed lithologic descriptions of outcrops along the Cosumnes River have been reported by Clark (1964); the present discussion emphasizes significant new stratigraphic subdivisions, refinements, and changes relating to Clark's work.

LOGTOWN RIDGE FORMATION

The Logtown Ridge Formation, a sequence of Late Jurassic mafic volcanic sedimentary rocks and interlayered flows and sills, has been substantially revised by our detailed mapping in Amador County. The formation has been removed from the Amador Group, a term no longer retained, and its base at the type locality has been redefined (Sharp and Duffield, 1973); the formation is herein divided into four distinctive members, most of which are traceable on a regional scale. The distribution of the various members sheds much light on original depositional features within the formation, as well as the character of subsequent deformation.

Strata of the Logtown Ridge Formation form a nearly vertical homocline with its top toward the east (pl. 1). The thickness of the formation varies greatly within Amador County, ranging from a maximum of about 3,000 m near Sutter Hill to a minimum of about 600 m at Drytown. At the type locality, along the Cosumnes River, the thickness is about 2,000 m. As will be discussed later, much of the variation in thickness may have resulted from complex tectonic truncation along the base of the formation, rather than original stratigraphic irregularity.

The basal unit of the Logtown Ridge Formation in Amador County is here designated the Rabbit Flat Member for good exposures on the north bank of the Mokelumne River, sec. 17, T. 5 N., R. 11 E., about 3 km south of Rabbit Flat. It consists of coarsely porphyritic augite basalt breccia and massive flows or sills, as well as minor bedded pyroclastic rocks. The base of the member is in fault contact with the melange (pl. 1). The Rabbit Flat Member reaches a maximum thickness of about 2,000 m west-southwest of Martell and thins less abruptly to the south than to the north. As shown on plate 1, the thickness at the Mokelumne River is about 640 m. At that location, the Rabbit Flat Member was called unit 29 of the Brower Creek Member of the Mariposa Formation by Clark (1964, pl. 7).

Clasts in the breccia range from subangular to subrounded pebbles and boulders of coarsely porphyritic augite basalt. The clasts and matrix are generally similar in lithology, having phenocrysts as much as 1 cm in diameter, but are distinguished chiefly by abrupt though slight contrasts in abundance or size of the phenocrysts. The breccia appears unstratified in single outcrops but probably is coarsely bedded at a scale larger than most outcrops. A few well-bedded fine-grained pyroclastic rocks similar to those of the overlying member crop out near the base of the member at Sutter Creek.

The Rabbit Flat Member is basaltic in composition, as shown by chemical analyses of two representative samples of massive augite porphyry (table 1). The composition of these samples is nearly the same as those for all of the overlying members of the formation; it is especially similar to that of the Pokerville Member, which consists chiefly of the same rock types.

The age of the Rabbit Flat Member is unknown, insofar as reported discoveries of fossils have not been definitely located within it. The only possible fossil occurrence from this unit is a specimen of the Callovian ammonite *Pseudocadoceras* cited by Imlay (1961, tables 2, 3, loc. 15). However, the exact site of the fossil collection is unknown. Nonetheless, since the Rabbit Flat Member is conformably overlain by the Goat Hill Member of documented Callovian age, both are considered to be of Late Jurassic age.

The Goat Hill Member is here named for exposures on the north bank of the Mokelumne River, secs. 16 and 17, T. 5 N., R. 11 E., about 1 km south of Goat Hill. This member is composed chiefly of well-bedded marine pyroclastic rocks, locally forming as much as half the thickness of the Logtown Ridge Formation. In Amador County the member is exposed along a continuous belt ranging in width from 335 to 1,465 m. Because the underlying Rabbit Flat Member is structurally truncated at Drytown, the Goat Hill Member from that point northward to beyond the Cosumnes River is the basal unit of the formation. Southward stratigraphic thin-

TABLE 1.—*Chemical analyses of greenstone from the Logtown Ridge–Mother Lode belt*

[Analyses by rapid-rock method. Analysts: Lowell Artis, G. W. Chloe, P. L. D. Elmore, J. L. Glenn, James Kelsey, Hezekiah Smith. Analyses recalculated with H_2O^- omitted]

	Logtown Ridge Formation								Unknown stratigraphic position
	Rabbit Flat Member		Goat Hill Member			Pokerville Member			
Specimen	1	2	3	4	5	6	7	8	9
SiO_2	49.2	48.7	51.2	51.1	50.0	49.1	49.6	49.2	55.5
Al_2O_3	15.2	15.5	16.6	17.0	17.9	14.6	10.6	14.8	16.3
Fe_2O_3	.9	1.7	.5	1.9	3.2	1.0	1.7	1.5	3.0
FeO	7.9	6.4	9.9	7.9	5.2	8.0	6.8	8.0	6.1
MgO	7.1	6.3	4.8	2.9	3.3	8.5	11.8	6.9	3.4
CaO	11.0	11.4	5.7	7.7	8.2	8.9	11.6	10.7	9.5
Na_2O	2.1	3.2	2.8	3.3	3.8	3.6	2.4	2.8	1.7
K_2O	1.1	1.1	1.3	2.8	2.7	.9	1.2	.9	1.1
H_2O^+	3.2	2.7	4.5	3.4	2.6	3.8	2.3	3.0	2.1
TiO_2	1.0	.6	1.7	1.2	1.3	1.1	.7	1.0	.8
P_2O_5	.2	.2	.5	.2	.5	.3	.4	.2	.3
MnO	.1	.2	.2	.2	.2	.2	.2	.2	.2
CO_2	1.0	1.9	.4	.3	1.0	.2	.8	.9	.1
Total	100.0	99.9	100.1	99.9	99.9	100.2	100.2	100.1	100.1

1. 900 ft east of west boundary and 300 ft south of north boundary of sec. 2, T. 6 N., R. 10 E. Massive augite porphyry.
2. 1,600 ft east of west boundary and 1,000 ft south of north boundary of sec. 2, T. 6 N., R. 10 E. Massive augite porphyry.
3. South bank Cosumnes River, 50 ft west of east boundary of sec. 21, T. 8 N., R. 10 E. Very fine grained tuff.
4. Roadcut, Old Sacramento Road, 750 ft east of west boundary of sec. 10, T. 7 N., R. 10 E. Nonporphyritic volcanic breccia.
5. North side of Tonzi Road, 90 ft west of east boundary of sec. 2, T. 6 N., R. 10 E. Coarse plagioclase porphyry pillow lava.
6. Roadcut, west side of State Highway 49, 100–150 ft south of south end of Huse Bridge across Cosumnes River. Sample location and analysis from Clark (1970, table 2). Coarse augite porphyry.
7. Roadcut, west side State Highway 49, 1,390 ft north of south boundary sec. 15, T. 7 N., R. 10 E. Coarse augite porphyry.
8. Augite porphyry dike(?) west of Jackson (precise location unknown). Sample location and analysis from Turner (1894b, p. 473). Coarse augite porphyry.
9. East side Plymouth Ditch, 340 ft north of south boundry of sec. 26, T. 8 N., R. 10 E. Phyllonitic greenstone.

ning of the overlying Pokerville Member leaves the Goat Hill Member as the uppermost unit of the formation for the 3-km interval immediately north of the Mokelumne River (pl. 1) and perhaps for a considerable distance farther south in Calaveras County.

Some of the rocks of the Goat Hill Member are here incorporated into the Logtown Ridge Formation for the first time. At the Mokelumne River, the member corresponds to Clark's (1964, pl. 7) units 30, 31, and 32, all designated by him as the Brower Creek Volcanic Member of the Mariposa Formation. Furthermore, the Goat Hill Member at the Cosumnes River is equivalent to most of Clark's (1964, pl. 8) unit 47 of the type Cosumnes Formation, combined with units 48 and 49 assigned by him to the Logtown Ridge Formation. The structural and lithologic evidence supporting the latter reassignment has been discussed in detail by Sharp and Duffield (1973).

Three principal rock types constitute the Goat Hill Member: (1) thin- to thick-bedded very fine to medium-grained tuff, (2) coarse pumice lapilli tuff in commonly thick locally graded beds that are interlayered with the finer tuff, and (3) thick-bedded fine to coarse volcanic breccia that grades upward into medium- and fine-grained tuff. Additional but relatively minor types of rock found within the Goat Hill Member and mapped separately on plate 1 include massive and pillow-structured very coarse plagioclase porphyry and augite-plagioclase porphyry (Duffield, 1969). These rocks occur in thin sheetlike flows and sills north of Sutter Creek but have not been found farther south in Amador County (pl. 1). Known outcrops are either within or at the base of the Goat Hill Member. Similar rocks that form sill-like and other irregular masses intrude the melange.

The interbedding of the various lithologies of the Goat Hill Member, as well as other sedimentary features including cut-and-fill structures and soft-sediment deformation, is dramatically exposed along the banks of the Cosumnes River. Most of these features have been described and depicted in detail by Clark (1964, p. 19–22). The common occurrences of undeformed highly vesicular fragments of pumice, graded beds, abundant examples of soft-sediment deformation, and known associated marine fossils indicate that the bedded sequence of this member is of subaqueous pyroclastic origin of the type described by Fiske (1963) and Fiske and Matsuda (1964).

Chemical analysis of typical specimens of bedded Goat Hill rocks suggests that the predominant composition of the member is basaltic (table 1). Samples of very fine grained tuff and volcanic breccia with granule- to pebble-size clasts in very fine grained matrix that is similar in lithology to the clasts strongly resemble one another in composition. However, these rocks, as well as the coarse plagioclase porphyry separately mapped within the member, contain slightly more SiO_2 and Al_2O_3 and less MgO and CaO than samples from other members of the formation.

The age of the Goat Hill Member is well established by fossils along the Cosumnes River. Specimens of the ammonite *Pseudocadoceras,* of Callovian age, have been collected from strata about 395 m above the base and within 275 m of the top of the member (compare Eric and others, 1955, p. 10; Imlay, 1961, p. 3, 6; Clark, 1964, p. 18, 21; pl. 1, this report). Although a slightly older age than Callovian is possible for the basal part of the member, the uppermost part probably is also Callovian in age, on the basis of fossil occurrences in the overlying Pokerville Member.

The Pokerville Member is here named for exposures on the south bank of the Cosumnes River in secs. 14 and 15, T. 8 N., R. 10 E. Pokerville is an early name of the nearby town of Plymouth (Gudde, 1969, p. 252). Nearly all the Pokerville Member is coarsely porphyritic augite basalt; it forms massive flows, pillow lavas, and coarse-bedded pyroclastic deposits, but volcanic breccia with virtually monolithologic clasts and matrix is dominant. Even the few clasts of different lithology observed in the breccia were mostly mafic volcanic rocks. The clasts and matrix in the breccia are essentially identical to those found in the Rabbit Flat Member.

Chemical analyses of samples of the Pokerville Member are nearly identical with those made on the lithologically similar Rabbit Flat Member. (See table 1.) Analyzed samples from widely scattered localities within the Pokerville, from the Cosumnes River on the north to the latitude of Jackson on the south, are all basaltic and vary little in bulk chemistry.

Throughout most of Amador County, the Pokerville Member is the uppermost map unit of the Logtown Ridge Formation, but east and southeast of Drytown it is overlain by the New Chicago Member. West of Plymouth, the Pokerville forms nearly three-fourths of the formation, but its proportion and thickness diminish stepwise southward through a series of three tectonic blocks. In the southernmost block, south of Drytown, the member commonly forms less than 10 percent of the formation, and it gradually thins southward and pinches out about 3 km north of the Mokelumne River. Its maximum thickness in the county is approximately 1,370 m 0.8 km north of Plymouth.

The Pokerville Member overlies the Goat Hill Member with apparent conformity south of Drytown. North of Drytown, however, the irregularity of the contact between the members suggests disconformity. At two localities northwest and southwest of Plymouth, the members seem to intertongue, suggesting that the relief on the contact may be a depositional rather than an erosional feature and that the contact is everywhere conformable. Strong evidence, to be discussed more fully elsewhere in this report, suggests that faulting occurred in the Rabbit Flat and Goat Hill Members of the Logtown Ridge Formation when sediments of the Pokerville Member were accumulating.

The age of the Pokerville Member is probably Callovian, but it may extend upward into latest Oxfordian or early Kimmeridgian, depending on the actual locations of two previously recovered and identified ammonites described by Imlay (1961, table 3). Although the locational data for one latest Oxfordian or early Kimmeridgian ammonite, *Idoceras,* led Imlay to believe that it came from the upper part of the Logtown Ridge Formation near the Cosumnes River (Imlay, 1961, table 3, loc. 10), the description of the enclosing rock as "metamorphosed andesitic tuff" makes it difficult to assign it to any part of the Logtown Ridge except the Goat Hill Member in the lower half of the formation. It is more likely that the andesitic tuff is one of the lenticular tuffaceous greenstone bodies that we assign to the Mariposa Formation, immediately overlying the Pokerville Member at that location. (See pl. 1.) This interpretation resolves an additional dilemma regarding the other ammonite, *Peltoceras,* recovered from the nearby Mariposa Formation, according to original records (Imlay, 1961, p. 6; compare to his table 3, loc. 13). Despite the original notes referring this specimen of *Peltoceras* to a location near Big Indian Creek, which parallels Highway 49 north of Plymouth, Imlay argued that it probably came from a position near the middle of the Logtown Ridge Formation, in order to avoid placing the Callovian specimen above the Oxfordian or early Kimmeridgian one. No inversion of the time sequence results if this specimen of *Peltoceras* is assigned to the Mariposa Formation but at a stratigraphically lower position than the *Idoceras*-bearing tuff unit within the Mariposa. Such a reconstruction is consistent with all the published data and suggests that the entire type Logtown Ridge Formation on the Cosumnes River is Callovian in age.

The uppermost unit recognized in the Logtown Ridge Formation is here named the New Chicago Member, for exposures in and near the roadcut of Highway 49, sec. 36, T. 7 N., R. 10 E. This member is named after the settlement of New Chicago, about 1.6 km north of the type locality. The member is composed chiefly of fine volcanic breccia with vesicular fine-grained to aphanitic clasts in a similar matrix. Vesicular fine-grained massive greenstone, sparsely and finely porphyritic augite porphyry, and coarse volcanic breccia containing clasts of both fine-grained to aphanitic greenstone and minor amounts of vesicular coarse augite porphyry are also intermixed in this member.

Volcanic breccia of the Pokerville Member that immediately underlies the New Chicago Member also possesses a distinctive vesicular character. Although scattered clasts of such vesicular augite porphyry can be found through much of the Pokerville breccia, such clasts are especially abundant throughout a thickness of several meters where overlain by the New Chicago. This close spatial association of unusually vesicular rocks assigned to both members suggests that a single source or vent which produced abundant vesiculated debris possibly existed locally from Pokerville into New Chicago time.

The New Chicago Member is restricted to the south half of the Logtown Ridge Formation (pl. 1). It forms thin, discontinuous, elongate bodies; the thickest is 150 m, and the longest is about 3 km.

Fossils have not been found in the New Chicago Member, but its conformable relationship with the underlying Pokerville Member indicates that it is only slightly younger. If the basal beds of the directly overlying Mariposa Formation are Callovian, as those near the Cosumnes River may be, then the New Chicago Member would be additionally restricted to a Callovian age along with the remainder of the formation; however, the actual age may be somewhat younger.

Published maps indicate the continuity of the Logtown Ridge Formation northward from Amador County; southward continuity into Calaveras County is not agreed upon. Clark (1964, pl. 1) believed that the Logtown Ridge Formation thinned southward stratigraphically and disappeared in Amador County under an overlapping tongue of lithologically similar rocks, the Brower Creek Volcanic Member of the Mariposa Formation. Our mapping, however, shows that the Logtown Ridge Formation extends southward across this boundary to the Mokelumne River and probably beyond. Examination of relatively detailed maps of Calaveras County by Eric, Stromquist, and Swinney (1955), Clark, Stromquist, and Tatlock (1963), and Clark (1964), as well as the early folio maps of the U.S. Geological Survey, strongly suggests that the Logtown Ridge rocks in Amador County are equivalent to at least some of the metavolcanic strata to the south. Indeed, all existing data suggest that the Logtown Ridge designation by Eric, Stromquist, and Swinney (1955, pl. 1) for rocks exposed northwest from Brower Creek along Hogback Mountain in Calaveras County and depicted on many maps (for example, Clark and others, 1963; Clark, 1964, pl. 1) along a belt connecting with what is now definitely Logtown Ridge Formation at the Mokelumne River is valid by reason of stratal continuity. Proof of this correlation, as well as the possible inclusion of other rocks deemed Logtown Ridge by Eric, Stromquist, and Swinney (1955) in Calaveras County, must necessarily await more detailed subdivision and mapping. However, regional stratigraphic correlation of these rocks is now open to multiple interpretation, and future detailed work may invalidate some of the currently favored stratigraphic nomenclature of the Upper Jurassic metavolcanic rocks south of Amador County.

MARIPOSA FORMATION

Rocks immediately overlying the Logtown Ridge Formation west of the Melones fault zone are here designated the Mariposa Formation. These rocks include black clay slate interbedded with graywacke, conglomerate, and fine-grained mafic tuffaceous rocks and are intruded by porphyritic volcanic rocks or hypabyssal sills. Although these rocks were originally termed the Mariposa Slate by Turner (1894a) on the Jackson folio, Clark (1964, p. 27) later assigned them an unknown but post-Logtown Ridge stratigraphic position because they could not be clearly connected with the well-documented Mariposa Formation in Calaveras County to the south. However, lateral continuity with rocks termed Mariposa Formation at the Mokelumne River by Clark (1964, pls. 1, 7) is now established by detailed mapping. (See pl. 1.)

Following the usage established by Clark (1964, p. 23), volcanic rocks within the Mariposa Formation are here designated the Brower Creek Volcanic Member. These volcanic rocks apparently dominate the Mariposa section in the southern half of Amador County, although the eastern extent of the Mariposa Formation has not been defined in plate 1. Northward from Amador City, bodies of Brower Creek rocks diminish in abundance and are virtually absent midway between Drytown and Plymouth, but north of Plymouth small bodies of Brower Creek crop out as numerous thin bands in the Mariposa Formation.

Although the greatest width of the belt of Mariposa Formation where both of its edges have been mapped is about 2,100 m measured east-northeastward from near Drytown, it is not possible to establish the true stratigraphic thickness there owing to isoclinal folding and possible repetition of section by faulting. Northward from that location, the formation thins by tectonic truncation to about 800 m at the Cosumnes River. Uniformly eastward stratigraphic top determinations on nearly vertical bedding near the Cosumnes River, combined with a distinctive stratigraphic succession, suggest that the 800-m width of the Mariposa belt there approximates a true stratigraphic thickness. The Mariposa Formation along the Mokelumne River possibly forms a nearly 915-m-wide belt (Clark, 1964, pl. 8), but abundant small-scale folds there suggest that the section may be considerably repeated. (See pl. 1.)

Field evidence indicates that there was little, if any, hiatus in deposition across the Logtown Ridge-Mariposa boundary. This is supported, first, by apparent stratigraphic conformity at the only clear exposure of the contact in the roadcut of Highway 49 immediately south of the Cosumnes River (see also Clark, 1964, p. 26), second, by the general conformity of mapped marker beds within the Mariposa Formation to the contact, and third, by the continuity of a very thin strip of Mariposa slate between the Logtown Ridge and Brower Creek rocks from Martell southward to the Mokelumne River (pl. 1). Such a conformable relationship is consistent with the ages of fossils discussed in the section "Logtown Ridge Formation."

The dominant nonvolcanic rock type in the Mariposa Formation is black clay slate, generally with sparse thin interbeds of fine- to medium-grained graywacke. At most locations along the contact, these rocks rest directly on the Logtown Ridge Formation. Between Plymouth and Drytown, these interbedded rocks constitute nearly the entire thickness of the Mariposa Formation, but to the north and south other lithologies, principally greenstones, dominate the section.

Detailed descriptions of the lithologic character and sedimentary features found in Mariposa slate and its interbedded graywacke were given by Clark (1964, p. 24, 39–41). This slate and graywacke are virtually indistinguishable in hand specimen and outcrop from some rocks of Cosumnes affinity in the melange belt. However, Mariposa slate contrasts strongly with both the siliceous and nonsiliceous slates of Calaveras affinity found in the melange. The chief differences are the total absence of chert beds and silicified lentils or other irregular masses that are nearly ubiquitous in Calaveras siliceous slate and the presence of graywacke interbeds that have not been observed in the Calaveras nonsiliceous slate. Although we think that these contrasts are noteworthy and consistent with other major differences between the Mariposa and Calaveras Formations, Clark, Stromquist, and Tatlock (1963) and Clark (1964) have not made such distinctions south of Amador County; there, much of the slate shown on their maps as Mariposa Formation is lithologically equivalent to slate of Calaveras affinity in the melange.

Two types of conglomerate have been mapped in the Mariposa Formation in Amador County. Conglomerate with abundant well-rounded clasts of quartzite and similarly resistant rock types form locally very thick beds near the base of the Mariposa Formation between Amador City and Enterprise (near the Cosumnes River). Thick beds of immature conglomerate, made chiefly of granule-sized clasts of shale chips and subordinate amounts of cherty and quartzose clasts, are interbedded with coarse graywacke and slate for 3.2 km south and an unknown distance north from the Cosumnes River.

The quartzite-cobble conglomerate intertongues and locally grades laterally into finer conglomerate, coarse graywacke, and slate. An unusually thick bed of such conglomerate with intercalated coarse graywacke partings forms a section about 275 m thick along Dry Creek northeast of Drytown, but this unit abruptly thins to the north and south and intertongues with slate and graywacke. The lateral extent of individual thin beds of quartzite conglomerate is remarkable, more than 3 km for some beds. Well-rounded quartzitic clasts everywhere predominate, but there is an appreciable fraction of more angular clasts of volcanic rocks as well. The matrix is poorly sorted coarse graywacke containing substantial amounts of relatively well rounded quartz grains. The quartzite clasts are fine to very coarse grained and contain some relatively coarse white mica that defines foliation surfaces randomly oriented from clast to clast. These clasts were derived from a metamorphic terrane possible of relatively high grade, judging by the coarseness of the white mica and apparently annealed textures. The matrix and interbedded slaty rocks show only slight evidence of metamorphism, and so the foliation in the clasts is definitely pre-Mariposa in age.

The distribution of the quartzitic conglomerate suggests that the main deposits are fillings of channels that followed depresssions on the upper surface of the Logtown Ridge Formation. The principal channel was east and north of Drytown, where the conglomerate is thickest. The fact that this channel lies directly above a zone of structural dislocations within the Logtown Ridge Formation (pl. 1) suggests that faulting affected the area at or just before the time of Mariposa deposition. This conclusion is critical to our interpretation of structure in Amador County, and its implications are more fully discussed under the section "Structure."

The second kind of conglomerate in the Mariposa Formation, the immature shale-clast granule to pebble conglomerate, is mostly restricted to a small area within 3 km of the Cosumnes River in Amador County. Elsewhere, similar rocks have been recognized only in a small lens near Sutter Creek. These rocks are interlayered with thick-bedded fine- to coarse-grained graywacke and black clay slate, both of which resemble similar rocks from the main slate zone in the Mariposa belt but lack the common thinly interbedded relationship. Although most of the clasts in the conglomerate appear to be angular very fine grained argillaceous fragments which are similar to the matrix of the rock, except for slight variations in color, an appreciable fraction of the clasts consists of chert, quartzite, and fine-grained volcanic rocks. Metamorphic rock cleavage generally is almost as well developed within the clasts as in the matrix, rendering them markedly fissile. The shale-clast conglomerate is virtually identical lithologically to some rocks of Cosumnes affinity in the melange.

Volcanic greenstones of chiefly pyroclastic origin interbedded with epiclastic rocks constitute the Brower Creek Volcanic Member, which forms a major part of the Mariposa Formation in Amador County, particularly south of Sutter Creek. The member also includes bodies of intrusive and extrusive greenstone. Although much of the Brower Creek appears to be small lenticular masses entirely enclosed in sedimentary contact within Mariposa slate, the largest bodies as depicted on plate 1 probably are separated from the remainder of the formation by faults, and thus their assignment to the Brower Creek Volcanic Member is tentative. Locally, however, epiclastic rocks similar to those of the Mariposa Formation are widely intercalated within the larger bodies mapped as the Brower Creek. The justification for including many of these rocks in the formation therefore is chiefly based on these interbedding relations and cannot yet be substantiated by age dates from fossil occurrences.

The most prevalent rock in the Brower Creek Volcanic Member in Amador County is fine- to medium-grained thin- to thick-bedded tuffaceous greenstone that is intercalated with black clay slate and graywacke similar to that found in other parts of the Mariposa Formation. The largest body of this rock extends from about midway between Plymouth and Drytown southward to the Mokelumne River, where it corresponds to Clark's (1964, pl. 7) units 34 through 37. Many smaller lenses of tuffaceous greenstone are scattered throughout the Mariposa section north of Plymouth. The tuffaceous rocks form beds from less than 1 cm to more than 1 m thick. Grading within these beds has only rarely been detected. No chemical analyses are available, but on the basis of lithologic resemblance to the Copper Hill Volcanics of the western belt, these rocks probably are andesitic to basaltic in composition. The proportion of graywacke and slate interbedded with the tuffaceous greenstone varies greatly, and no attempt has been made to separate these rocks on plate 1 because of the complexity and scale of interbedding.

Volcanic rocks of basaltic composition with coarse phenocrystic augite form relatively thick massive flows and flow breccia within the large body of bedded pyroclastic rocks of the Brower Creek Volcanic Member at least as far south as Sutter Creek. Other lenticular bodies of augite porphyritic basalt probably representing flows or shallow sills occur locally in the Mariposa Formation north of Plymouth. These rocks are lithologically identical to the augite porphyry greenstone of the Rabbit Flat and Pokerville Members of the Logtown Ridge Formation. An analysis of one specimen of augite porphyry from the Brower Creek Volcanic Member shows that the composition of these rocks is basaltic and nearly equivalent to the lithologically similar Logtown Ridge Formation (table 1).

Volcanic breccia containing blocks of fine-grained volcanic rocks is a minor rock type in the Brower Creek Volcanic Member. A single lenticular mass of such rock occurs along the base of a bedded tuffaceous greenstone section about halfway between Plymouth and the Cosumnes River. It is superfically indistinguishable from similar breccia in the Goat Hill Member of the Logtown Ridge Formation.

Molluscan and ammonite faunas from scattered locations throughout the Mariposa Formation indicate the late Oxfordian and early Kimmeridgian Stages of Late Jurassic age (Imlay, 1961, p. 7–8; Clark, 1964, p. 25–26). Fossils previously discovered in Amador County generally corroborate this age assignment, but as discussed earlier, the lower part of the Mariposa might possibly be as old as Callovian. Recovery of the pelecypod *Buchia concentrica* at a position probably within 152 m stratigraphically above the base of the Mariposa Formation about 1.2 km north-northwest of Plymouth (Imlay, 1961, table 2, loc. 14) demonstrates a late Oxfordian and early Kimmeridgian age there. The question remains, however, as to whether basal Mariposa strata laterally transgress time and whether beds somewhat older than late Oxfordian might also exist, or, alternatively, whether the lower range of *Buchia concentrica* is somewhat older than presently recognized.

ROCKS OF THE MELONES FAULT ZONE

A narrow band (about 250–800 m) of distinctive sheared rocks separates the Mariposa Formation on the west from the large granitic pluton and the Calaveras Formation of the eastern belt to the east. Widespread evidence of pervasive shearing in this band of rocks, as well as regional stratigraphic relations, suggests that large fault offset occurs across the zone. This zone includes the Melones fault as defined by Clark (1960, 1964). However, Clark believed that the width of the fault zone in Amador County was considerably less than we show on plate 1, and he (1964, p. 27) referred many of the rocks that compose the fault zone of plate 1 to a volcanic unit of unknown stratigraphic position. (See Clark, 1964, pl. 1.)

In general, we assign to the fault zone rocks that show noticeably greater shearing and recrystallization than adjacent rocks, on the assumption that this band of relatively highly metamorphosed rocks is coextensive with a zone of faulting. Within Amador County most of the rock types found in this band are unique to it; they include phyllitic and phyllonitic greenstone as the dominant types, hornblende-bearing rocks of metaigneous aspect ranging from leucogabbro to hornblendite, mylonitized rocks probably derived from all the previous types of rock, and medium-grained alaskitic rocks that commonly show mylonitic effects. Bodies of rock similar to material of Calaveras affinities in the melange are also incorporated within this band; they are described with the rocks of the melange, although the setting of their occurrence here is markedly different.

The phyllitic and phyllonitic greenstone generally appear nearly massive on the scale of outcrops. In hand specimen, they are distinctly more coarse grained than greenstone found in all other formations in the area except some rocks assigned to the Copper Hill Volcanics of the western belt. Typical specimens contain abundant plates of relatively coarse white mica (easily visible to the unaided eye) that give a pronounced sheen to cleavage surfaces. Some of the rocks have relict hornblende phenocrysts, but most phenocrysts have been completely or partially replaced by very fine grained aggregates of white mica, epidote-chlorite, and quartz. Bedding has not been observed in any outcrops of this rock, but in thin section, compositional layering in some specimens is evident. Most of this layering results, however from late vein formation or possibly from metamorphic segregation developed during shearing of the rock. The field distinction between phyllite and phyllonite is made on the basis of whether obvious fluxion shown by milled-down hornblende augen is evident in the rock. However, on the microscopic scale, all samples studied show generally pervasive shearing and thus possess a phyllonitic aspect.

The parent from which the phyllite and phyllonite formed probably consisted primarily of intermediate to basic porphyritic volcanic rocks. Analysis of a typical specimen (see table 1) shows an andesitic composition, but the high proportion of dark minerals in some of these rocks, generally exceeding 50 percent and reaching locally as much as 90 percent, suggests that basaltic compositions also occur. Inasmuch as hornblende porphyritic rocks are unknown as large-scale masses elsewhere in the immediate region, this belt of rocks appears to be lithologically unique.

Other rocks associated with the phyllite and phyllonite distinguish the fault zone, too. Irregularly shaped masses of fine- to coarse-grained metaplutonic rocks of generally gabbroic affinity are widely scattered in the zone. In detail, these rocks apparently grade from relatively leucocratic rocks (leucogabbro) to very dark rocks approaching hornblendite. Many of these rocks display abundant irregular greenish veins consisting almost entirely of very fine grained aggregates of epidote; the veins are generally small and follow irregular fractures in the host rock. Greenschist-facies metamorphic overprint, as well as some cataclastic shearing and post-shearing recrystallization, gives these rocks an exceptionally complex aspect both in hand specimen and in thin section. All the rocks consist of the same minerals as the associated phyllite and phyllonite: hornblende, oligoclase, epidote, white mica, chlorite, quartz, and some pyrite. A few specimens contain small remnants of pyroxene in the cores of large hornblende crystals. White mica and epidote grains, as in the phyllite and phyllonite, form felted masses generally without preferred orientation, even though a pronounced planar fabric is defined by the other minerals. This relation suggests that at least one stage of recrystallization postdated much of the shearing evident in these rocks.

Some bodies of strongly mylonitized rocks of the fault zone with abundant large hornblende augen have been mapped separately on plate 1 because of their great size and apparent internal homogeneity. These rocks resemble the phyllitic and phyllonitic rocks in mineralogy and probable bulk composition and also possess the cataclastic texture that is commonly but less strikingly developed in the other rocks. Moreover, the mylonitic rocks appear to be gradational with many of the porphyritic rocks included in the phyllite-phyllonite unit in terms of the abundance of the hornblende phenocrysts.

A few dikelike or sill-like bodies of light-colored foliated alaskite lie within the phyllite-phyllonite belt. These rocks are granitic in composition and are relatively coarse grained. Nearly all outcrops exhibit foliation to some degree, and thin sections show that it is related to cataclastic effects of widely ranging intensity. In some mylonitized phases, compositional layering is formed by thin epidote-rich and white mica-rich bands separating layers composed almost entirely of potassium feldspar and quartz. Contacts of alaskite with the surrounding materials are not exposed, and so the intrusive nature shown on plate 1 is interpretive. Although the generally concordant geometry suggests that these bodies were sills prior to the cataclastic shearing, they conceivably could represent fault slivers of much larger intrusive masses not presently exposed.

WESTERN BELT

All rocks of the western belt are assigned to the Copper Hill Volcanics, as defined by Clark (1964, p. 30–31), and consist chiefly of fine-grained pyroclastic greenstones. Although the stratigraphic base of these rocks has not been mapped in this study, Clark (1964) stated that the Copper Hill Volcanics intertongue to the west with the Salt Spring Slate, which has been dated as late Oxfordian and early Kimmeridgian age on the basis of fossils found along the Cosumnes River in Sacramento County. Stratigraphic top determinations noted by Clark along the Cosumnes River thus show the upper Copper Hill Volcanics to be younger than this slate, but the range of ages represented by these volcanic rocks is unknown at present. It should be added that tectonic intermixing of strata in a manner equivalent to that found within the melange shown on plate 1 may conceivably have occurred much farther west than has been recognized in our study; if so, then the Copper Hill

Volcanics may not rest in undisturbed stratigraphic position on the Salt Spring Slate. Detailed mapping in the Copper Hill Volcanics and farther west should answer this question.

Pyroclastic rocks of the Copper Hill Volcanics consist typically of relatively fine grained and nearly massive phyllitic greenstone. Although some of the rocks along the east margin of the formation contain relatively large quartz grains, most are nearly equigranular. Locally, on a microscopic scale, faint compositional banding is defined by white mica-chlorite-quartz-albite-epidote laminae interlayered with bands lacking white mica. Larger scale bedding, as well as other sedimentary structures, are apparently absent in the Copper Hill Volcanics. Presumably, these features, if once present, have been masked during the low-grade metamorphism that affected these rocks. Slaty argillaceous rocks interbedded with the Copper Hill Volcanics have been recognized at several locations lying west of the map area.

Parallel bands of greenschist and amphibolite, possibly part of the Copper Hill Volcanics, crop out in the northwest section of plate 1. Field evidence suggests that the transition from greenschist to amphibolite is gradational, but tectonic juxtaposition cannot be ruled out. Although these rocks form north-northwest-trending bands, schistosity diverges greatly from this direction. The plane of schistosity has been deformed into chevron folds at some outcrops, broader open folds at others, and locally (NE¼ sec. 18, T. 7 N., R. 10 E.) into isoclinal folds with superposed broad open folds. A few outcrops show interbeds of chert folded into a similar shape as the enclosing greenschist, suggesting that schistosity parallels original stratification of the parent volcanic rocks.

Contacts within and surrounding the greenschist-amphibolite terrane have not been completely delineated by our mapping, but available evidence suggests that these rocks are fault bounded rather than in normal stratigraphic sequence with underlying Copper Hill strata. The structural relations shown by Clark (1964, pl. 8) suggest that the greenschist-amphibolite rocks form a fault-bounded block of the melange that has been transported from deeper levels of the crust than adjacent rocks of the Copper Hill Volcanics.

INTRUSIVE ROCKS

Plutonic masses of both relatively deep seated and hypabyssal origin intrude rocks of all but the western belt. Part of a large coarse-grained granitic intrusion crops out in the eastern belt, but nearly all the other plutons are relatively small, irregular in outline, markedly discordant to host rocks, and fine grained or porphyritic. Compositions of the plutons range from ultramafic to granitic, although ultramafic rocks occur only in the melange. Original mineralogy has been altered in many plutons, but despite local overprinting of metamorphic texture or cataclastic structural fabric, the initial textures commonly are intact. Two masses of coarsely recrystallized hornfels lie within the large eastern pluton, but marked contact metamorphic effects usually are lacking around intrusive boundaries; where present, such effects are restricted to apparent annealing, as shown by obliteration of rock schistosity without obvious recrystallization.

MELANGE BELT

Many types of intrusive rocks, ranging in composition from pyroxenite and serpentinite to granodiorite, have been recognized in the melange. Relative ages of the various intrusive rocks are generally impossible to determine because of isolation or lack of exposure along contacts.

Outcrops of coarse-grained pyroxenite and hornblende pyroxenite are localized in a small area near the southwest corner of plate 1 (W½ sec. 15, T. 6 N., R. 10 E.); these ultramafic rocks are completely bounded by serpentinite or other intrusive rocks, including augite-hornblende gabbro and aphanitic fine-grained greenstone. Contact relations are not exposed, and the shape and distribution of these ultramafic bodies permit them to be interpreted either as tectonic blocks or inclusions in surrounding rocks, or as intrusions lying essentially in their original positions.

Other equigranular rocks suggesting relatively deep seated crystallization are widely scattered in the melange. These rocks occur chiefly as small masses commonly associated with serpentinite and include pyroxene gabbro nearly completely altered to the greenschist facies, fine- to coarse-grained augite-hornblende gabbro (in a 1.6-km-long intrusive mass near the southwest corner of sec. 9, T. 7 N., R. 10 E.), brecciated medium-grained hornblende quartz diorite (known only from a single outcrop in southern sec. 9, T. 6 N., R. 10 E.), and relatively fine grained brecciated biotite granodiorite that forms very thin sill-like bodies (western sec. 27, T. 7 N., R. 10 E.). This last rock is extensively altered locally to dolomite, magnesite, and quartz.

The bodies of ultramafic to mafic composition may be genetically related to the Pine Hill layered gabbro complex, located on strike with the melange belt about 13 km north of the area in El Dorado County. Springer (1969) and Emerson (1969) showed that the Pine Hill igneous complex is partly composed of sill-like intrusive masses that became gravitationally layered during crystallization. The conformable relation of this layering to the steeply eastward dipping country rock there indicates that intrusion and crystallization took place while the enclosing rocks were still subhorizontal, that is prior to development of the steep regional dip.

Diverse types of aphanitic to porphyritic intrusive rocks are widely distributed in the melange. Lithologically, some of these rocks are virtually indistinguishable from flows and sills in the Logtown Ridge Formation. Such rocks include coarse plagioclase porphyry greenstone and plagioclase-augite porphyry greenstone that are mineralogically and texturally equivalent to sills and pillow lavas in the Goat Hill Member of the Logtown Ridge Formation, as well as coarse augite porphyry greenstone that is identical to flows and breccia clasts in the Rabbit Flat and Pokerville Members. Plagioclase porphyry greenstone similar to that reported here was also recognized by Clark (1964, p. 31) in the Copper Hill Volcanics along the Cosumnes River a few miles west of the map area. The porphyritic rocks at that location are at least partly extrusive pillow lavas (Clark, 1964).

Other porphyritic intrusive rocks have no counterparts in the Logtown Ridge Formation. Plagioclase porphyry, hornblende-plagioclase porphyry, and biotite-hornblende-plagioclase porphyry form relatively large but extremely irregular intrusive masses that are particularly abundant in the eastern half of the melange belt. Quartz is sparse but ubiquitous in these rocks. The first two types of rock apparently grade into one another and into fine-grained aphanitic greenstone. All these rocks locally exhibit pervasive brecciation, metamorphism to greenschist facies, and rock cleavage concordant with the adjacent metasedimentary rocks.

The geometry of some plutons in the melange belt strongly suggests that their emplacement followed the main structural disturbances there. For example, the finely porphyritic and aphanitic rocks associated with the gabbroic body at the corner of secs. 8, 9, 16, and 17, T. 7 N., R. 10 E., appear to cut across boundaries of structural blocks within the melange. The brecciation of these intrusive rocks, moreover, does not appear to be related to brecciation in the wallrocks that the intrusive masses locally transect; brecciated intrusive rocks generally are magmatically healed and tightly coherent, in strong contrast to the marked fissility of the apparently earlier sheared metasedimentary rocks.

LOGTOWN RIDGE–MOTHER LODE BELT

A single small intrusion is emplaced in this belt about 1.2 km east of Sutter Creek. This rock consists of medium-grained hornblende quartz monzonite; rocks of this composition have not been found elsewhere in the map area.

Other intrusive rocks of generally mafic composition lie at the east edge of this belt along the Melones fault zone. They have been thoroughly metamorphosed and are described in the section "Melones Fault Zone."

EASTERN BELT

The large coarse-grained granitic pluton underlying most of the eastern belt is part of a much larger mass that extends nearly 32 km to the northeast. It is separated from the main body of the Sierra Nevada batholith by intervening metamorphic rocks, but its composition, texture, and structural setting suggest that it is simply an outlying part of the batholithic complex.

The rock generally is fine- to medium-grained hornblende-biotite granodiorite, but at one locality near the Cosumnes River, it has a distinctly more mafic character, with a color index over 50. This variant, probably a quartz gabbro in composition, appears to grade laterally into the more typical and much lighter colored (color index 10–20) granodiorite. A north- to northwest-trending foliation of mafic minerals is common through much of the pluton but is more strongly developed near the west margin. Prismatic crystals of hornblende form a steeply plunging lineation in the west marginal zone.

Although there is abundant evidence of cataclasis along the west contact, other contacts appear to have formed by intrusion of a liquid or liquid-crystal mixture, with no subsequent crushing effects. Strongly discordant contact relations in secs. 6, 7, and 18, T. 7 N., R. 11 E., and the weak to absent aureole of contact metamorphism in some parts of the adjacent Calaveras Formation suggest only a moderately deep level of emplacement.

AGES OF INTRUSION

Intrusive rocks in the west-central Sierra foothills generally have been assigned a Late Jurassic age by previous workers (Clark, 1964; Bateman and Wahrhaftig, 1966, p. 117; Evernden and Kistler, 1970). A Jurassic age has been determined (R. W. Kistler, written commun., 1970) by the potassium-argon method for two rock types in western Amador County. A specimen of the granodioritic pluton in the eastern belt, collected near the center of sec. 22, T. 8 N., R. 11 E., about 4.8 km east of the area included on plate 1, contains biotite dated at 157.4±4.7 million years. A small quartz diorite mass in southern sec. 9, T. 6 N., R. 10 E., within the melange, gives a hornblende age of 172±4.3 million years. The latter date suggests an Early rather than Late Jurassic age, and owing to possible disturbance of the potassium-argon radiometric clock by faulting, this should be considered a minimum.

Springer (1969) and Emerson (1969) described a complex of gabbroic sills near Pine Hill, about 13 km north of the map area and on strike with the melange belt, that has compositional layering of gravitational origin. The sills originally were nearly horizontal as indicated by the layering, but they now dip steeply eastward in conformable relation with the preintrusion metasedimentary rocks. Thus, at least some plutonism in the Sierra foothill belt had begun prior to regional tilting of strata to nearly vertical positions. Moreover, serpentinite at the same locality predates the gabbroic sills, and thus its emplacement also predates regional tilting.

Structural and mineralogical features of hypabyssal intrusive rocks in the melange belt suggest that these bodies may have been emplaced earlier than most of the coarse-grained rocks in this and other belts. All the porphyritic rock types at least locally are altered to greenschist facies, suggesting that the regional metamorphic overprint has affected them as well as the stratified rocks. Rock cleavage locally present in the hypabyssal intrusive bodies further substantiates this interpretation. However, no radiometric ages have been obtained for these rocks.

Most coarse-grained intrusive rocks apparently postdate regional metamorphism, as shown by the general absence of greenschist facies metamorphism. Moreover, some slight hornfelsing has occurred along the east margin of the large granodioritic body in the eastern belt; the zone of hornfelsic rocks is subparallel to the margin of the pluton, but it is discordant to the metamorphic foliation of the wallrocks and hence is younger. Foliation is evident in some coarse-grained rocks, but it probably is a primary igneous feature unrelated to cleavage in the wallrocks, despite subparallelism of both with the regional structural grain.

SERPENTINITE AND RELATED ROCKS

Serpentinite forms a 14.5-km-long sheared and faulted sill-like body that trends north-northwest along the west margin of the melange. It ranges in outcrop width from about 1.6 km to several tens of meters. Smaller satellitic bodies of serpentinite crop out both to the east and west of the main mass and are thought to define crudely the lateral limits of a zone of significant tectonic dislocation. Two approximately equant bodies of serpentinite are associated with the large plutons in secs. 8, 9, 16, and 17, T. 7 N., R. 10 E.; these are thought to be genetically related to the plutons or their emplacement.

Most outcrops of serpentinite in the sill-like mass have many features in common. In plan, nearly all are elongate in a north-northwest direction, parallel to the regional structural grain. Some outcrops are massive, and others show a layered structure with scattered grains of bastite; however, most consist of slickensided lozenge-shaped fragments about 2 cm to 1 or 2 m in average diameter and generally flattened in one plane. The resulting foliation is steeply dipping but shows considerable variation in strike among outcrops, generally ranging between N. 30° E. and N. 60° W. and appearing to parallel the trend of the nearest wallrock contact. Locally, contacts are irregular in plan, but more commonly they are linear, or nearly so, and change trend abruptly, suggesting that they are steeply dipping, planar, and likely tectonic. However, they rarely are exposed for direct examination.

The contact of one small serpentinite mass is exposed in a roadcut along Highway 124 (not shown on pl. 1) about 520 m north of the highway crossing over Dry Creek (E½ sec. 28, T. 7 N., R. 10 E.). Exposures there suggest that the contact between serpentinite and wallrock conglomerate has an antiform shape that is discordant to wallrock bedding and foliation in the axial region of this arched surface. Contact metamorphic effects are clearly evident in a zone a few meters wide. The unmetamorphosed conglomerate has a black slate matrix that surrounds relatively unrecrystallized clasts of slate and porphyritic to fine-grained volcanic rocks of intermediate to mafic composition. The metamorphosed conglomerate has retained all original structures and textures, but it is pale green, more difficult to fracture, and almost completely replaced by chlorite and actinolitic amphibole. Similar metamorphic effects are not evident at the contacts of other bodies of serpentinite.

Rare inclusions of conglomerate and slate as much as 10 m in maximum dimension occur within some bodies of serpentinite. Original structures and textures are preserved in these inclusions, but the rocks are hardened and show a gray to gray-green color suggesting some recrystallization. Gneissic amphibolite locally occurs as both inclusions and narrow marginal bodies to serpentinite.

Two occurrences of rodingite in serpentinite form steeply dipping dikes from 1 m to several centimeters thick; they have sharp contacts and generally are conformable with foliation in the host serpentinite. At one locality, slickensided shear planes pass from serpentinite through the rodingite dike, but elsewhere undeformed dikes are exposed for as much as 60 m along strike. Well-preserved relict textures in thin section suggest that the original rock was diabasic.

Rare minor bodies of altered gabbro and related mafic rocks occur both marginally and internally to serpentinite, and large masses of brecciated red and gray carbonate with or without incrustations of chalcedonic silica show a similar association. This carbonate also has small scattered clots of chlorite.

The presence of bastite and associated gabbroic rocks suggests that at least some of the serpentinite formed from preexisting ultramafic plutons, but evidence for the general origin of many bodies of serpentinite is lacking. If ultramafic rocks were the common precursors of serpentinite, the serpentinite cannot now be in the original intrusive position of the plutons because contact metamorphic effects that would be expected in sedimentary rocks intruded by ultramafic melt are not evident.

The spatial association of nonfissile mudstone of hornfelsic aspect near some serpentinite bodies suggests the possibility that the serpentinite or its precursor rocks were emplaced as at least moderately warm bodies later than the regional metamorphism. Alternatively, baking of the wallrocks bordering some of the serpentinite bodies could have preceded regional metamorphism if the resultant mechanical properties effectively prevented the development of slaty cleavage during later folding and metamorphism. Although the evidence in our study area is inconclusive and no definite assessment of the age of the now serpentinized bodies relative to metamorphism is possible, Springer (1969) and Emerson (1969) showed that ultramafic and mafic plutons, including serpentinite, are at least in part older than regional metamorphism in western El Dorado County, on strike with and within 13 km of the melange belt in Amador County.

SUPERJACENT ROCKS

Shallow-dipping sediments and sedimentary rocks of Tertiary age rest in angular unconformity on rocks of the subjacent series. Although such deposits once formed extensive aprons that may have completely covered the older rocks at the lower elevations of the Sierra foothills, only scattered and relatively small erosional remnants of this blanket are preserved in western Amador County. Stratification in these deposits dips gently to the west, essentially parallel to the regional orientation of the surface of unconformity at their base. Detailed examination of the unconformity shows abundant evidence of marked local topographic irregularity and incision on the regional surface.

Two units of Tertiary age have been differentiated on plate 1. Both are included with rocks called the intervolcanic gravels by Lindgren (1911) and Bateman and Wahrhaftig (1966, p. 133). Other gravels called prevolcanic gravels (Bateman and Wahrhaftig, 1966, p. 133) are exposed in Amador County, but they lie entirely west and downslope of the area covered by plate 1. The lowermost intervolcanic deposit consists of two lithologies: quartzitic gravel, and conglomerate underlain by rhyolitic tuff; it is here assigned to the Valley Springs Formation of Piper, Gale, Thomas, and Robinson (1939). Unconformably overlying this formation at many locations, but resting directly on the subjacent rocks at most places, are volcanic gravels and conglomerate correlated with the type Mehrten Formation of Piper, Gale, Thomas, and Robinson (1939).

VALLEY SPRINGS FORMATION

The Valley Springs Formation was defined by Piper, Gale, Thomas, and Robinson (1939) to include welded rhyolite tuffs and associated sedimentary rocks exposed in northern Calaveras County near the Mokelumne River. Geochronologic age determination of correlative rocks higher in the Sierra Nevada by Dalrymple (1964, fig. 3) showed that the Valley Springs Formation probably ranges in age from 30 to 20 million years (late Oligocene to middle Miocene).

A unit of Tertiary quartzitic gravel and conglomerate mapped on plate 1 is considered part of the Valley Springs Formation because it overlies at several places rhyolitic tuff that is unknown in the prevolcanic series (Slemmons, 1966, p. 201). Although we cannot demonstrate that all the quartzitic gravel is younger than the tuff, the close spatial distribution and lithologic uniformity justify its inclusion with the Valley Springs.

Quartzitic conglomerate and equivalent unconsolidated gravel form most of the Valley Springs Formation. These strata are poorly bedded and contain well-rounded pebbles and cobbles of quartzite and bull quartz, with only very minor amounts of other types of clasts. Although the conglomerate is known to be as much as 12 m thick in the map area, only a thin veneer generally less than 2 m thick is preserved at most locations. Many of the unconsolidated deposits have been extensively worked for gold by placer operations.

At a few locations, Valley Springs conglomerate is underlain by massive white fine-grained tuff. Elsewhere, deeply weathered clay deposits have been found under the Valley Springs conglomerate, suggesting that tuff was once considerably more common than now and that it has weathered to clay. Tuff exposed at the top of the hill 3 km east-northeast of Plymouth is strongly indurated, suggesting that at least some of the tuff may be welded.

MEHRTEN FORMATION

The name Mehrten Formation was applied by Piper, Gale, Thomas, and Robinson (1939) and Curtis (1951; 1965) to andesite-clast mudflows and conglomerate at widely separated points on the west slope of the Sierra Nevada. Dalrymple (1964) radiometrically dated these rocks at 19–5 million years. Conglomerate and poorly consolidated gravel containing nearly monolithologic andesitic clasts within the map area are referred to this formation, although they could be equivalent to the Relief Peak Formation of Slemmons (1966, p. 203). The Relief Peak Formation includes rocks previously assigned to the lower part of the Mehrten Formation in the foothills south of Amador County (Dalrymple, 1964; Slemmons, 1966). The maximum thickness of these deposits is about 60 m, but presumably much thicker accumulations, perhaps as much as 300 m, once covered the area. (See Slemmons, 1966, fig. 4.)

Andesitic gravels and conglomerate in the map area are generally poorly bedded and sorted where exposed. Clasts range in size from pebbles to very large boulders and are subangular to subrounded. The matrix is gray-colored finer volcanic debris, presumably also of andesitic composition. The andesitic rock that forms nearly all the clasts contains phenocrysts of plagioclase, clinopyroxene, hornblende, and olivine. Although the clasts are very nearly monolithologic, scattered fragments of granitic and metamorphic rocks are present locally.

STRUCTURE

Traditional reconstruction of geologic history in the western Sierra foothills involves the following succession of principal events: (1) Deposition of strata from Paleozoic through at least Late Jurassic time (including possible periods of nondeposition or erosion, local metamorphism, and early folding episodes), (2) low-grade regional metamorphism with steep tilting associated with complex major isoclinal folding and accompanied by intrusion of plutonic and related hypabyssal rocks of the Sierra Nevada batholith, and (3) major faulting episodes along well-defined north-northwest-trending belts that have substantially altered the spatial distribution of the stratal units.

Field relations and structural data obtained in our detailed study of the Sierra foothills in Amador County suggest an appreciably different scheme of events that may be applicable to a much larger area, even perhaps to most of the foothills west of the Melones fault zone. These events include (1) accumulation of volcanic and epiclastic material on the sea floor, accompanied by large- and small-scale differential movement on numerous gently dipping faults, (2) regional steep tilting associated with small-scale very tight to isoclinal folding, greenschist-facies metamorphism, and intrusion by plutonic and hypabyssal rocks, and (3) large- and small-scale local faulting and minor refolding of strata.

These two solutions to the complex structural relations differ mainly in the timing and nature of the large-scale movements that caused the gross redistribution of the principal rock types into their present patterns. This paper demonstrates that many of the large displacements probably occurred while the sediments were essentially flat lying and that sediments continued to accumulate while this disruption of strata was in progress. Thus the mechanism of the major dislocations is thought to have operated in a relatively shallow marine environment essentially within the basin of accumulation (near the continental margin?), perhaps resulting strictly from gravitational and subductional stresses rather than from compressional stresses and attendant shearing associated solely with the emplacement of the Sierra Nevada batholith.

Abundant literature has been devoted to melanges in the Franciscan terrane of coastal California (for example, Hsü, 1968; Page, 1970) and the probable relations to lithospheric plates subducting at the continental margin there. In this paper, we suggest, specifically on the basis of newly obtained field data, the possibility that such events took place east of the Great Valley of California in Mesozoic time. Others (for example, Hamilton, 1969; Davis, 1969) attempted to explain the tectonics of this area using these processes, but such attempts have simply interpreted grand-scale rock distribution on the basis of the geological literature of this region. While we agree with this general type of interpretation, we believe that data published from previous field studies in the Sierra foothills are not adequate to support such interpretations.

For many geologists melange means literally a tectonic mixture of rocks, without connotations of genesis. For others, however, it carries a definite implication of how the mixture originated. We propose a specifically subduction related genesis for the melange of this report, but regardless of whether our proposal is correct or not, the existence of the melange is demonstrated by the outcrop mapping and must be accounted for in any comprehensive explanation of the tectonic history of the foothills.

In general, the Sierra foothills melange is indeed a chaotic tectonic mixture of rocks, but a limited degree of internal order is apparent from the geologic map (pl. 1) and gives some clues to the extent of mixing that the originally undisturbed rocks have undergone. To some geologists, the degree of order shown by the map may not justify using the term melange; we believe that this viewpoint is incorrect, for if we have erred in accurately portraying structure within the melange, the map suggests a lesser amount of tectonic chaos than is actually present.

Despite the apparent simplicity of some of the map units in plate 1, as well as the relatively undisturbed bedding visible in many outcrops within such map units, exposures in roadcuts and along stream courses reveal a marked degree of internal complexity in most units. In fact, these exposures suggest that many, and perhaps most, of the natural outcrops between roadcuts and streambeds are individual "clasts" in a great megabreccia. Their unfragmented state makes them relatively resistant to erosion, whereas the sheared matrix surrounding them is easily eroded. Thus, it is important to recognize that simplicity and continuity as recognized on older geologic maps may in many places mask faulting and shearing that are nearly pervasive between outcrops but cannot be proven generally because of incomplete exposure. To interpret the geology of the melange strictly on the basis of natural outcrops could lead to important misconceptions because the key evidence is largely concealed between the exposures.

MELANGE BELT

Inspection of plate 1 reveals that individual map units possess both extreme complexity and a limited degree of order and continuity on a local basis within the melange. By mapping essentially all outcrops, we have determined that most of the map units probably have abrupt, rather than gradational, contacts with one another and that in many places the possible locations of the contacts essentially rule out sedimentary intertonguing as a common relationship. It is important to reemphasize here that most contacts have not been observed directly but rather are inferred from the distribution of outcrops. Almost all those few contacts that have been observed are exposed in stream gullies and in relatively new roadcuts along Highways 16 and 124 (the latter is not shown on pl. 1).

Certain associations of rock types have been critical in establishing some of the map units within the melange. Some lithologic assemblages contain rock types that are not found in other assemblages. Still other assemblages that consist chiefly of widely distributed lithologies are themselves distinctive because of the absence of certain rock types that are relatively resistant to erosion and hence should be exposed if present. Although the definitions of several of the units in the map explanation might imply virtually complete overlap, we think that each of the divisions is real and justifiable. Such divisions demonstrate the existence and the general geometry of each assemblage in the melange. To explain the distribution of lithologies and the sheared nature of many outcrops by lateral facies changes or folding does not seem tenable to us.

The exact geographic extent of pervasive shearing in rocks of the melange is difficult to establish, although all indications suggest that it is widespread and general. Relatively few sheared outcrops are known in the western part of the melange, but they are quite common to the east, where good examples can be found on the banks of Amador Creek (sec. 34, T. 7 N., R. 10 E.), in the banks of the Cosumnes River (secs. 20, 21, 28, T. 8 N., R. 10 E.), and in roadcuts along Highways 16 and 124 (sec. 21, T. 7 N., R. 10 E.). Elsewhere, we believe, exposures of sheared rock are less common simply because such rocks are not resistant enough to form outcrops.

The pervasive shearing is characterized in pelitic material by countless steeply dipping subparallel shear surfaces along which considerable displacement appears to have occurred. The trend of shear surfaces generally is constant at an outcrop but ranges from about N. 30° E. to N. 60° W. over the entire melange. This style of deformation is best developed in quartzose slate with associated chert or quartzose sandstone. Chert and sandstone typically form subrounded fragments or pods—remnants of once continuous beds, now floating in a mass of thoroughly sheared pelitic matrix—and these fragmented lithologies apparently remained relatively competent as the pelitic material flowed plastically to fill spaces left by disruptions in bedding.

Several broad generalizations may be made concerning the distribution of rock types and distinctive associations of rocks within the melange. South of the latitude of Drytown and along the west margin of the melange belt, irregularly sized and shaped blocks of Calaveras affinity, Cosumnes affinity, serpentinite, and intrusive rocks of various kinds are intermixed in a zone 1 km wide. (See pl. 1.) North of the latitude of Drytown, however, this zone appears to be missing; its absence is perhaps partly reflected by the shorter distance between the western serpentinite belt and the base of the Logtown Ridge Formation. East of this zone and south of the latitude of Drytown, another distinctive band consisting chiefly of conglomerate of Cosumnes affinity is intermixed with a small proportion of rocks of Calaveras affinity and a few small serpentinite bodies. The continuity of this band is broken and displaced at the latitude of Highway 16, but a similar band of rocks continues northward, in contact with the massive block of serpentinite, to the Cosumnes River. Both north and south of Drytown, this zone gives way eastward to a regionally distinctive map unit consisting of thinly and rhythmically interbedded graywacke and clay slate of Cosumnes affinity. These strata apparently rest in depositional contact on the underlying conglomerate, although the geometry of the contact is quite probably complicated by cross-faulting at low angles to the strike of the unit. Very locally, thin slices of silicic rocks of Calaveras affinity lie between the two bands, such as in sec. 3, T. 6 N., R. 10 E., and in sec. 5, T. 7 N., R. 10 E., suggesting that further tectonic complication is possible along the contact. Graded bedding in the graywacke layers is prevalent throughout the unit and almost uniformly shows the top of the section to be eastward; where the top directions are not eastward, small-scale folding is evident.

Another distinctive zone of rocks south of the latitude of Drytown lies in essentially continuous fault contact with the graywacke-slate band on the west and consists principally of rocks of Calaveras affinity that give way to rocks of Cosumnes affinity near the base of the Logtown Ridge Formation. Rocks with similar characteristics also extend northward from the latitude of Drytown, although the zone there has a considerably greater east-west dimension. This zone is further characterized, both north and south of Drytown, by many irregularly shaped small to relatively large bodies of hypabyssal igneous rocks that are lacking in the more western zones.

Contacts between and often within these zones of the melange are tectonic. None of these faults, however, transect the contact between the melange and the overlying Logtown Ridge Formation, suggesting that intermixing within the melange predates the Logtown Ridge Formation. It might be argued that intermixing occurred after eruption and deposition of the Logtown Ridge Formation but did not affect them because of their greater strength or because they were effectively separated from underlying rocks by the fault at the base of the Logtown Ridge. In view of the nature of faulting within the Logtown Ridge, however, it seems more likely to us that the melange formed either before the Logtown Ridge was deposited (before Callovian time) or at a somewhat later time but before the melange and the Logtown Ridge were juxtaposed.

If this latter explanation is correct, then the two units must have been subsequently juxtaposed from very different geologic environments. The two are indeed in fault contact, but since both show greenschist-facies metamorphism, only huge lateral tectonic dislocation would permit this explanation; if one unit had been buried much deeper than the other, grade of metamorphism should reflect the difference. Large lateral motion would fit our scheme if faulting were along subhorizontal surfaces, but we find no evidence for huge lateral displacement on steeply dipping faults, as the traditional interpretation would require. Large displacement along a subhorizontal thrust fault (subduction surface?), however, is a distinct possibility.

BEAR MOUNTAINS FAULT ZONE

The west boundary of the melange belt corresponds to part of the Bear Mountains fault zone of Clark (1960, 1964). Clark inferred the presence of this fault zone throughout the Sierra foothills from the gross stratigraphic relations and distribution patterns of Mesozoic and presumably Paleozoic rocks, the localization of serpentinite in a relatively narrow linear band, and the occurrence of sheared rocks at appropriate locations. In particular, the homoclinal sandwiching of what Clark and others before him believed to be a belt of Paleozoic rocks between Mesozoic rocks required major faulting to account for the repetition of Mesozoic strata; thus thousands of meters of reverse-slip displacement on a group of steeply dipping faults, the Bear Mountains fault zone, was inferred.

The new evidence obtained in the present study, however, allows a very different interpretation of the field relations. In fact, with recognition of the melange, no evidence now prohibits the accumulation and intermixing of all rocks of the melange ("western belt of Calaveras" of earlier workers) after the accumulation of the underlying Mesozoic Copper Hill Volcanics, and thus no compelling evidence remains for a reversal of stratigraphic succession across the Bear Mountains fault zone in Amador County.

Regardless of the presence or absence of this stratigraphic reversal, however, shearing and fault displacement occur at the west edge of the melange belt. The serpentinite bodies that are localized there provide much evidence of faulting. But there is no evidence of net fault displacement across a serpentinite mass. If the serpentinite bodies and their associated deep-seated igneous rocks were solidified before they intruded overlying rocks, the abundance of shearing within and along their margins is explained. The driving force for such a process need have been no more than gravitational instability of low-density serpentinite, but other forces, perhaps reflecting horizontal compressive stress, could have been involved as well. The boundaries of the serpentinite masses may have been controlled by preexisting faults, as Clark (1964, p. 42) argued, but these faults may have formed during melange development, shortly after sedimentary accumulation rather than later, as initially steeply dipping "rooted" faults.

In the sense that a fault should have a demonstrable net displacement across it, we conclude that the existence of the Bear Mountains fault zone cannot be ascertained at present. The dissimilarity of stratigraphic units on opposing sides of the zone makes it difficult to prove net displacement. Nevertheless, the possibility that such displacement has occurred and that serpentinite masses subsequently have invaded these preexisting shear zones, as suggested by Clark (1964), cannot be discounted. Ultimately, the distinction between "conventional" faulting as suggested by Clark and melange movements proposed by us probably must be based on whether the fault surfaces were rooted within the crust or were essentially parallel to the earth's surface at the time of their activity. We have already offered some evidence favoring the second interpretation; additional support is provided in following sections.

Even though the existence of large net displacement across the Bear Mountains fault zone is now questionable, an important reversal of stratigraphic succession apparently does exist in the foothills of Amador County between the Salt Spring Slate of Clark (1964), west of our map area, and the Mariposa Formation. Both of these rock units are late Oxfordian and early Kimmeridgian in age (Clark, 1964, p. 25, 29), and the somewhat older Logtown Ridge Formation lies between them. All the rocks dip steeply to the east in an upright position. This stratigraphic reversal and repetition of time units may have resulted from displacement on the fault at the base of the Logtown Ridge Formation, on the

Bear Mountains fault zone, or on presently unknown faults west of the map area.

EVIDENCE FOR FAULTING OF LOGTOWN RIDGE STRATA IN PRE-MARIPOSA TIME

Near Drytown, all the distinctive members in the Logtown Ridge Formation are displaced abruptly along a linear east-southeast trend (pl. 1). Because four members of the formation are involved, it is unlikely that this offset resulted from primary differences in stratigraphic thickness. A fold in the strata seems unlikely because contacts between members are nearly linear up to the discontinuity. A fault offset seems to be the only reasonable interpretation. Unfortunately, no direct evidence of faulting has been observed because of poor exposures, but the offsets of the easily mapped units are clear and, in our opinion, constitute sufficient evidence for the existence of the fault.

The top of the Logtown Ridge Formation north of this transecting fault is downdropped as much as 250 m. Distinctive quartzitic conglomerate at the base of the Mariposa Formation abuts this positive topographic irregularity on the top of the Logtown Ridge, but higher Mariposa beds are essentially flat and continuous across the irregularity. The continuity of these higher beds indicates that the fault does not extend from the Logtown Ridge into the Mariposa Formation. The top of the Logtown Ridge Formation most probably is not a fault surface, in view of its irregularity and direct evidence from a single exposure where Highway 49 crosses the Cosumnes River; thus the fault transecting the Logtown Ridge terminates at the top of the section and must be pre-Mariposa in age. A similar though less well documented pre-Mariposa fault in the Logtown Ridge is located about 3 km north of Drytown (pl. 1).

The age of faulting along the base of the Logtown Ridge Formation is difficult to determine. All field data indicate that the fault crossing westward through Drytown terminates at the base of the formation, suggesting that the basal fault is relatively younger. However, the cross-fault and the basal fault may have been simultaneously active, with the cross-fault splaying from the principal plane of dislocation as a minor finger. Some support for coeval activity of this sort is seen in field relations at and near the base of the Logtown Ridge Formation west and southwest of Jackson. (See pl. 1.) For example, about 3 km west of Jackson, the base of the Logtown Ridge Formation is displaced about 550 m by a northeast-trending cross-fault. The distribution of nearby outcrops in the melange belt suggests that the cross-fault does not extend west of the basal fault, and the undisturbed contact between the Rabbit Flat and Goat Hill Members of the Logtown Ridge Formation indicates that the fault does not extend far on trend to the northeast. Several reconstructions of the time relations involved with this faulting are possible, but considering the characteristics of faulting in the Logtown Ridge Formation as a whole, we believe that this tectonic dislocation occurred simultaneously on the basal fault and cross-fault in pre-Goat Hill time.

Other fault relations show that some movement at the base of the Logtown Ridge Formation probably postdated the Mariposa Formation. At the latitude of Plymouth, a northeast-trending fault transects the Logtown Ridge Formation and continues through the Mariposa Formation before converging with the Melones fault zone. On the southwest this structure apparently terminates at the base of the Logtown Ridge, as suggested by the distribution of rock types nearby in the melange. (See pl. 1.) This implies that at least part of the fault at the base of the Logtown Ridge was active either coevally with deposition of the Mariposa Formation or at a later time.

Episodes of faulting involving the Logtown Ridge Formation apparently began while Logtown Ridge deposition was underway and continued locally during and after accumulation of the Mariposa sediments. Because the initial slopes on which deposition occurred probably were relatively flat, the faults that are now essentially vertical must have been much less steeply dipping when they were active.

TILTING AND FOLDING

After the formation of the melange and the Logtown Ridge and Mariposa faulting, all the rocks were tilted to their present steeply dipping positions, a process that was probably contemporaneous with late Mesozoic magmatism of the Sierra Nevada province. As the rocks were tilted, some were very tightly to isoclinally folded, and a slaty cleavage developed, which is locally axial planar and pervades rocks of the entire foothills area.

Detailed statistical studies of these and associated structures elsewhere in the foothills (for example, see Best, 1963; Baird, 1962) indicate multiple episodes of folding, and a more recent analysis of regional deformation extends the multiple episodes to the entire Sierra Nevada province (Kistler and others, 1971). Structural data from our map area generally suggest only two widespread periods of deformation—subhorizontal dislocations and later tilting and folding—although the subhorizontal displacements continued for a long period of time, judging from the complex relations within the melange belt and Logtown Ridge and Mariposa Formations.

Metamorphic rock cleavage that parallels the dominant structural grain of the foothills is evident at nearly all outcrops, and its general orientation is north trending (pl. 1). Paired measurements on bedding and cleavage and on axes of folds are restricted to a few sequences of interbedded slate and graywacke in the melange belt and to Mariposa slate and graywacke; elsewhere, either most rocks are not visibly bedded, or original stratification has been thoroughly disrupted. The paired measurements summarized in figures 4, 5, and 6 show the essential parallelism of bedding and cleavage. Contoured stereographic projections of poles to bedding reflect the very tight to isoclinal nature of known folds, whereas measurements of fold axes suggest one episode of noncylindroidal folding. Clearly, the data are too few to develop strong statistical arguments against multiple episodes of folding, but the simplest explanation of available data is that axial plane cleavage and isoclinal folds formed simultaneously; the plunge of resulting fold axes varies greatly along a uniform strike. Such variation might have resulted from locally anomalous fluid pore pressure and the uneven vertical or horizontal strain of material during dewatering of what probably was predominantly a sequence of water-saturated sedimentary rocks.

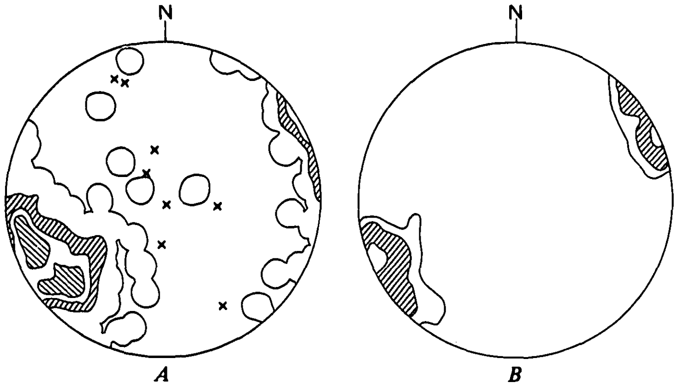

FIGURE 4.—Summary of bedding, regional cleavage, and axes of minor folds for slate and graywacke of the Mariposa Formation between Plymouth and Amador City. Projection on the lower hemisphere of an equal-area net. *A*, One hundred sixty-six poles to bedding contoured at 0.6, 3.0, 5.4, and 7.8 percent per 1 percent total area. Fold axes are marked by ×. *B*, Fifty-seven poles to cleavage contoured at 1.8, 5.3, and 19.3 percent per 1 percent total area.

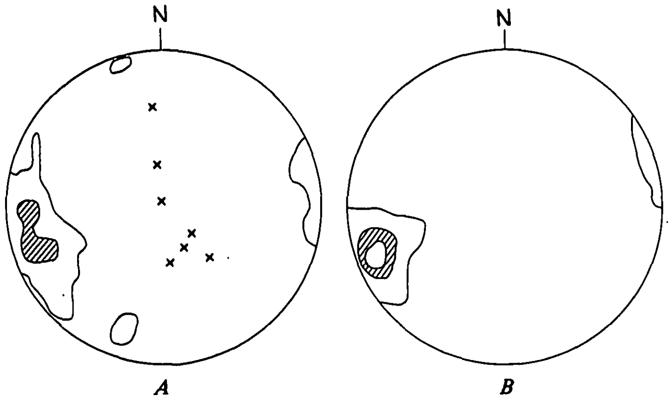

FIGURE 5.—Summary of bedding, regional cleavage, and axes of minor folds for slate and graywacke of the melange belt south of Highway 16. *A*, Fifty-five poles to bedding contoured at 1.8 and 12.7 percent per 1 percent total area. Fold axes are marked by ×. *B*, Fifty-seven poles to cleavage contoured at 1.8, 12.3, and 29.8 percent per 1 percent total area.

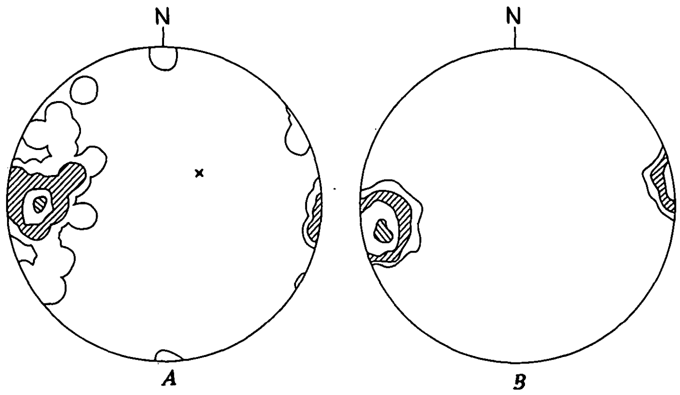

FIGURE 6.—Summary of bedding, regional cleavage, and axis of a minor fold for slate and graywacke of the melange belt north of Highway 16. *A*, Sixty-two poles to bedding contoured at 1.6, 4.8, 14.5, and 21.0 percent per 1 percent total area. Fold axis is marked by ×. *B*, Sixty-five poles to cleavage contoured at 1.5, 4.6, 13.8, and 35.4 percent per 1 percent total area.

A word of caution is offered here for structural studies of cleaved slate and graywacke sequences elsewhere in the Sierra foothills. Even though cleavage generally parallels axial planes of known folds, and, statistically, zones of cleavage-bedding intersections are parallel to zones of fold axes, the relation of bedding to cleavage at an outcrop is not a dependable indication of stratigraphic top. This is evident from our study at numerous outcrops where stratigraphic top was determined independently from multiple graded beds. A similar situation probably exists throughout the foothills.

DEFORMATION AFTER REGIONAL TILTING

The map area contains evidence for both local and more widespread deformation subsequent to the episode of tilting and folding. Fracture cleavage in phyllite was described in the section "Eastern Belt." The areal extent of this cleavage is unknown, but it appears to be restricted to rocks east of the Melones fault zone in the map area. Other posttilting structures are better documented.

MELONES FAULT ZONE

Clark (1960, p. 493–494; 1964, pl. 1) described the Melones fault zone as a major Late Jurassic zone of dislocation that juxtaposes Paleozoic rocks upon Mesozoic ones and truncates major folds in rocks of both ages. Rocks within the zone of faulting are also generally characterized by relatively great shearing.

Lacking any substantial new evidence to the contrary, we follow Clark's suggestion that the Melones fault formed in Late Jurassic time after the rocks of the foothills had been tilted to their presently steep attitudes. Future studies, however, may indicate a subhorizontal origin, similar to that proposed by us for the faulting in the melange and in the Logtown Ridge and Mariposa Formations. Davis (1969) has already proposed such an origin with broad correlations between major structures and map units in the Klamath Mountains and Sierra Nevada.

In Amador County, the Melones fault zone ranges from about 250 to 800 m in outcrop width and generally separates the Mariposa Formation on the west from a granodiorite pluton and Calaveras Formation on the east. Most rocks within the fault zone are pervasively sheared and recrystallized phyllitic greenstone of unknown age. The phyllitic fabric and the fault zone itself are parallel. Minor amounts of other lithologies are also contained within the fault zone, especially in the southeastern part of plate 1; these are described elsewhere in the text.

Contacts of the fault zone with adjacent rocks generally are gradational over a width on the order of tens of meters. However, the eastern contact, along the granodioritic pluton of the eastern belt, is difficult to determine because cataclastic texture of the pluton is structurally conformable to phyllitic greenstone of the fault zone there. Moreover, these cataclastic structures closely resemble shear structures in rocks of the fault zone, suggesting that the age of the pluton is prefaulting and that marginal cataclasis is due to Melones faulting. This interpretation is consistent with radiometric and fossil-derived ages. Near Indian Gulch east of Amador City, however, the granodiorite transects the boundary between Calaveras rocks of the eastern belt and the phyllonitic greenstone belt, indicating that the intrusion is younger than the juxtaposition of Calaveras and the phyllonitic greenstone. If that juxtaposition resulted from movement on the Melones fault zone, then the marginal cataclasis in the pluton must postdate at least some of this movement. However, it is conceivable that this Calaveras-phyllonitic greenstone contact is essentially an original irregular stratigraphic boundary and that subsequent shearing has occurred but has not substantially altered the relative positions of the two rock types. If this were true, then shearing of all the rocks, including the granodiorite, could be coeval with or younger than the emplacement of the pluton. We arbitrarily chose to exclude the margin of the pluton from the fault zone.

The direction and amount of slip on the Melones fault zone are not well known. Clark (1964, p. 51) concluded that a vertical component of 900–4,500 m is indicated by the juxtaposition of Paleozoic strata upon Mesozoic rocks; he also believed that steeply plunging lineations within the fault zone owe their origin to a major component of strike-slip displacement. Similarly, our work suggests vertical displacement on the order of hundreds and possibly thousands of meters, but no substantive support for strike-slip movement was discovered.

MOTHER LODE FAULT SYSTEM

The term Mother Lode fault system is used here for the eastward-dipping faults that are locally occupied by gold-bearing quartz veins of the Sierra foothills. This system of faults is minor in terms of offset but is of considerable importance for the great wealth that came from its ore bodies. Little new information on the nature of this system of faults was found during this study. Therefore, most of the pertinent information comes from previously published reports, primarily from the study within mine shafts by Knopf (1929).

The Mother Lode fault system traverses the Sierra foothills in a north-northwest direction for at least 190 km, from Mariposa to Georgetown (Knopf, 1929, p. 2, fig. 1). For most of its length, the Mother Lode fault system is in or very near the Melones fault zone (Clark, 1964, p. 52). However, locally the two structures diverge, and there is evidence that formation of the Mother Lode veins postdates movements on the Melones fault zone. (See Knopf, 1929, p. 24–25.) Movement on faults of the Mother Lode system apparently was neither simple nor great, but Knopf (1929, p. 5) believed that offset was primarily in a reverse sense, and he cited a maximum displacement of 115 m along dip.

In the southern half of the area of plate 1, most of the Mother Lode faults lie about 1.6 km west of the Melones fault zone, but from about 1.6 km south of Plymouth to the north boundary of the map, the two structures overlap extensively. Surface evidence of the Mother Lode faults includes scattered massive veins of milky quartz, thin bands of altered wallrocks, and folded cleavage originally formed during regional tilting. The veins trend roughly north-northwest and dip steeply to the east, and the chief evidence that deformation accompanied their formation is seen locally where nearby slaty cleavage has been folded and relatively thorough shearing is apparent in massive greenstones. Such effects rarely extend more than several meters away from known veins.

In the southern part of the area, most of the major veins are located at or very near the contact between slate and greenstone of the Mariposa Formation. However, Knopf (1929, p. 54, 55, 57, 58) showed that these veins dip less steeply to the east than the lithologic contact, and so at depth they are enclosed entirely within greenstone.

REGIONAL CRUSTAL FLEXURE

The map area includes the axial zone of a large-scale flexure of possibly fundamental significance to understanding late Jurassic or post-Jurassic crustal movements for the Western United States. This flexure is evident on geologic maps of the Sierra Nevada province as a change in trend of prebatholithic rock systems and the batholithic axis itself. South of the general latitude of Highway 16, the trend is approximately north-northwest, whereas to the north the trend is more nearly due north (pl. 1; also, compare figs. 5, 6). Since the mapped belts of rocks, bedding and regional cleavage, and the Melones fault zone are all affected, the flexure can be no older than Late Jurassic. Its origin is unknown.

STRUCTURAL CROSS SECTIONS

Throughout this paper, many references have been made to the work of previous investigators, especially the mapping published in the late 19th century as U.S. Geological Survey folios, the subsequent changes in stratigraphy and structure by N. L. Taliaferro, and finally the revisions offered by L. C. Clark. These principal investigators shaped the present understanding of pre-Cenozoic foothills geology, and fortunately, each of these workers summarized his ideas of the fundamental nature of the geology in Amador County with a cross section drawn along the Cosumnes River, the north boundary of plate 1.

For comparison, each of the earlier cross sections together with our interpretation are reproduced in figure 7. Although greatly generalized, these diagrams summarize the evolution of thought pertaining to the geology of the central foothills region. They do not indicate the importance of subhorizontal tectonic dislocations inferred from the present study; this point has been emphasized adequately in earlier parts of the text. The succession of such divergent interpretations is graphic evidence of the extreme complexity of Sierra Foothills geology.

REGIONAL IMPLICATIONS

Our explanation of the tectonic history of the western foothills of Amador County closely resembles that of Davis (1969), but our conclusions are drawn from a very detailed study of a small area, while his interpret the large-scale distribution of rocks in both the Klamath Mountains and western Sierra Nevada, before the Sierra foothills melange was known.

In developing the idea that the melange formed and subsequent Logtown Ridge–Mariposa faulting occurred during active subduction at a continental margin before the strata were tilted to their present steeply dipping attitudes, we have tried to avoid overinterpreting the new data. However, some degree of overinterpretation is necessary, for neither our reconstruction of structural history nor the more traditional synthesis can be proved from the presently available data. We believe, nevertheless, that the "subhorizontal" explanation is at least as reasonable as the traditional one, and implications of both must be entertained equally. Ultimately, the choice between this and the traditional type of synthesis can probably be made only after many more data are available. Recent advances in understanding motions of the earth's lithospheric plates and processes at plate boundaries as embodied in the rapidly expanding literature of global plate tectonics provide some indirect support for the foothills structural history we propose. The general foothills setting—belts of greatly deformed rocks that face parallel belts of time-related igneous rocks—is appropriate for the generally agreed upon features and related processes of subduction zones, and the melange is just the sort of structural chaos that might be expected to form at or near the surface of such a zone. This line of reasoning is, of course, largely circular but is at least partly satisfying in that it relates observations to known processes of tectonism and mountain building.

The first modern comprehensive synthesis of the geologic history and origin of rocks of the Sierra Nevada province was attempted by Bateman and his coworkers (Bateman and others, 1963; Bateman and Eaton, 1967). These investigators believed that Paleozoic and Mesozoic prebatholithic rocks collected in a subsiding trench, a complex synclinorium, whose root eventually melted in part to form magma; the relatively less dense magma subsequently pierced the overlying strata, forming a batholithic spine along the major axis of the trench. This is essentially a specific application of the traditional tectogene model of Griggs (1939).

The recent popularity of global plate tectonics, however, has given rise to several new and entirely different interpretations for the origin of structures and plutons in the Sierran province (for example, Davis, 1969; Hamilton, 1969; Dickinson, 1970; Kistler and others, 1971; Shaw and others, 1971). In general, these new syntheses relate known data to the presumed dynamics at plate boundaries with a tantalizing degree of success.

In our opinion, neither type of genetic model can be proved or disproved with the present state of knowledge of rocks of the province. We hope that this paper demonstrates the need for many more detailed field observations before any well-founded choice between the two models (or a compromise or a completely new model) can reasonably be made. We have now shown, for example, that fundamental stratigraphy and structure of the least deformed subjacent rocks of the foothills are not yet accurately established, which encourages the suspicion that even larger errors have been made in the presently depicted geology of the more deformed units.

If additional detailed mapping demonstrates the persistence of the melange belt throughout the foothills,

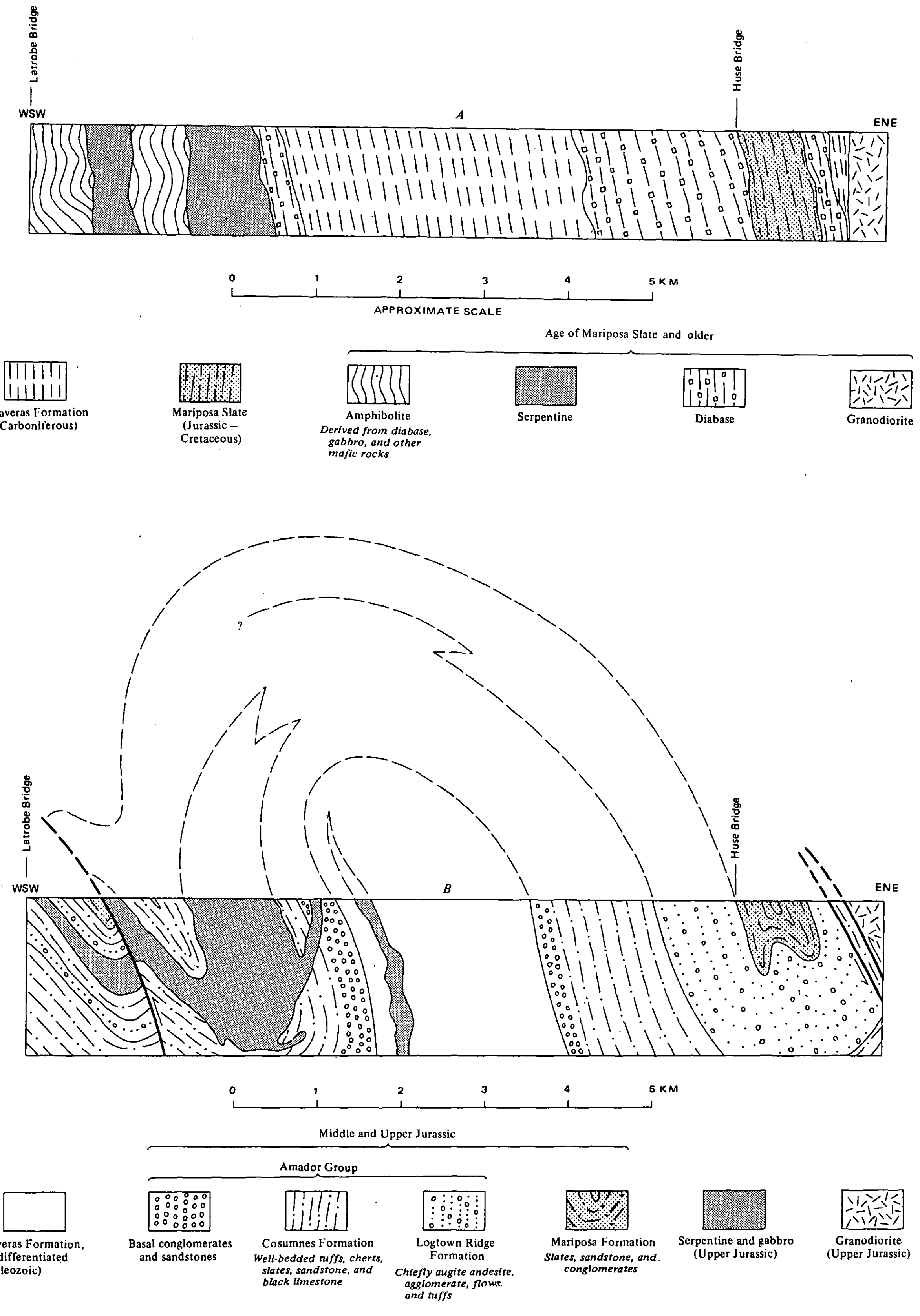

FIGURE 7.—See facing page caption for explanation.

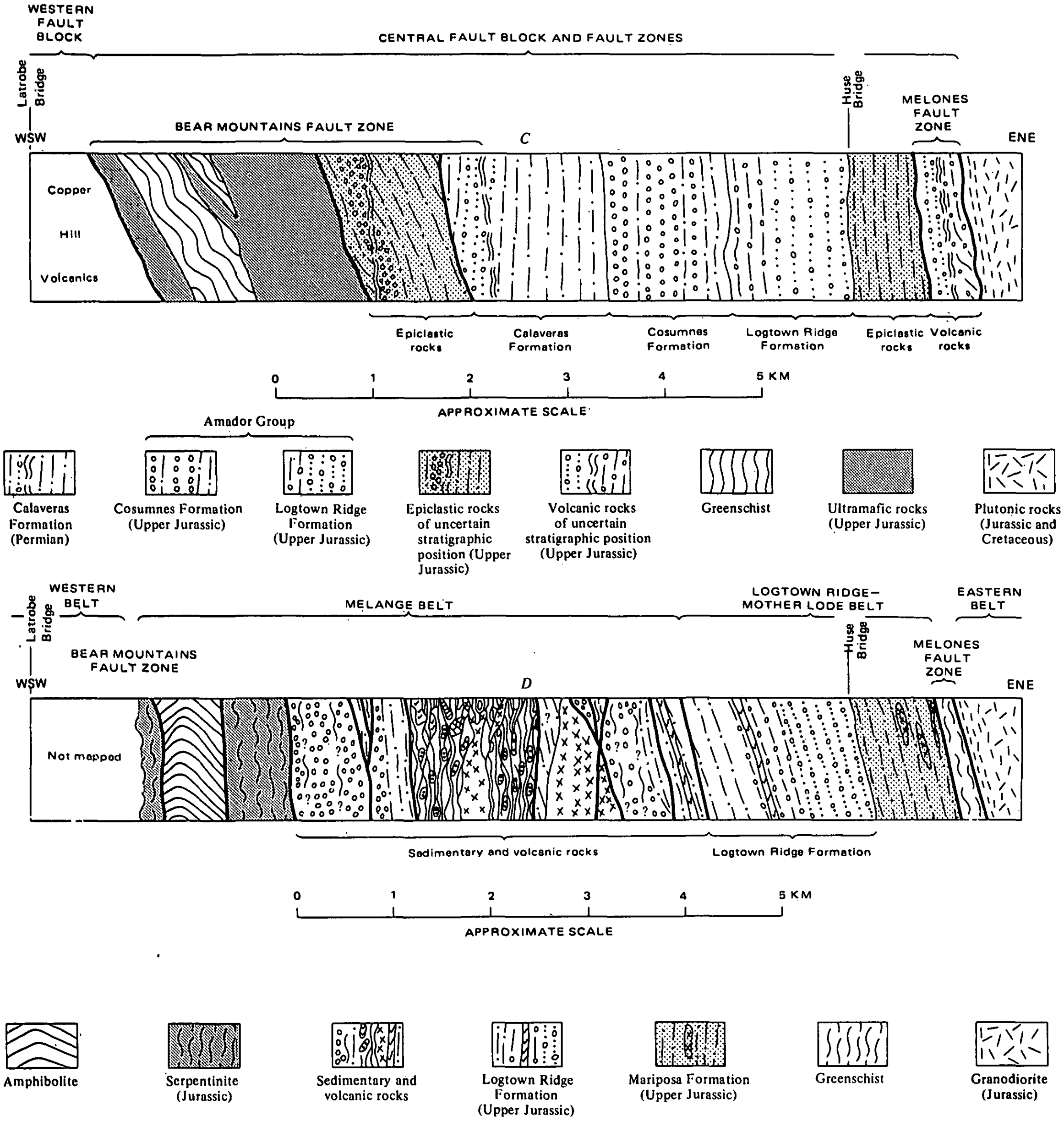

FIGURE 7.—Four cross sections illustrating the evolution of interpretations of geologic structures in pre-Cenozoic rocks along the Cosumnes River. Sources of information: A, Lindgren and Turner (1894); B, Taliaferro (1943, fig. 2); C, Clark (1964, pl. 8); D, Present study. The lithologic symbols do not correspond from one section to another, but each author generally uses them to depict the orientation of bedding. Light lines represent normal stratigraphic contacts, and heavy lines represent faults. Light broken sinuous lines in sections C and D depict shearing of certain zones, and unbroken sinuous lines in A, C, and D depict folding in amphibolite and shearing in the melange (D only). With the exception of the newly discovered melange, the section from the present study is most nearly like section A, which was the first to be published.

this will constitute important new data for selecting the most probable among various models of rock deformation, mountain building, and plutonism for the Sierra Nevada province. The melange may well mark the locus of convergence between an oceanic plate that abuts and plunges beneath a continental margin, but it only suggests this conclusion and must be weighed together with all other data to select the most probable solution. Considered alone, however, the melange does require that those who adhere to the ideas of a subsiding trough and anatexis explain the apparent absence of similarly deformed rocks on the east limb of the trough. The presence of only a western melange gives a pronounced asymmetry to the trough that is not easily explained by a simple subsiding basin in which there is sediment accumulation.

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