Upper Cretaceous and Lower Tertiary Rocks Berkeley and San Leandro Hills California

GEOLOGICAL SURVEY BULLETIN 1251-J

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By J. E. CASE

CONTRIBUTIONS TO GENERAL GEOLOGY

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A revision of the stratigraphy of miogeosynclinal Upper Cretaceous rocks and a brief description of newly recognized Paleocene and Eocene marine beds

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UPPER CRETACEOUS AND LOWER TERTIARY ROCKS, BERKELEY AND SAN LEANDRO HILLS, CALIFORNIA

By J. E. CASE

ABSTRACT

In the Berkeley and San Leandro Hills, east of San Francisco Bay, Calif., faulted and folded Upper Cretaceous marine beds attain an aggregate thickness of about 6,000 to 8,000 feet. Five stratigraphic units, some of which contain fossils diagnostic of Late Cretaceous age, are recognized as subdivisions of a part of the sequence formerly termed "Chico formation" by A. C. Lawson. The units are, in ascending order: (1) Sandstone, shale, and conglomerate, here named Joaquin Miller Formation, which contains an ammonite (*Calycoceras*) of Cenomanian age that was found in the upper part of the unit, (2) Oakland Conglomerate, exposed on Skyline Boulevard, (3) shale and sandstone, here named Shephard Creek Formation, (4) sandstone, shale, and conglomerate, here named Redwood Canyon Formation, which contains *Baculites*, probably of post-Coniacian age, that was found near the base of the unit, and (5) variegated shale, exposed on Pinehurst Road, which contains abundant Foraminfera of Campanian age.

The Upper Cretaceous strata are overlain by siliceous shale and thin-bedded sandstone, here named Pinehurst Shale, which contains a Paleocene foraminiferal fauna. Eocene sandstone, shale, and limestone, perhaps 1,000 feet thick, contain fossils suggestive of Capay or Domengine age.

If the estimate of total thickness of Upper Cretaceous strata is correct, these beds lie west of the axis of maximum depositional thickness in the Late Cretaceous miogeosyncline in the San Joaquin and Sacramento Valleys, where up to 30,000 feet of strata has been reported.

Recognition of Paleocene and Eocene strata in the Berkeley and San Leandro Hills indicates that the lower Tertiary marine basin extended at least 10 miles farther southwest than previously suspected.

INTRODUCTION

The Berkeley and San Leandro Hills, east of San Francisco Bay, Calif. (fig. 1), provide much-studied examples of Coast Range geology where type localities of many formations were established and where the style of the Coast Range deformation was clearly portrayed by

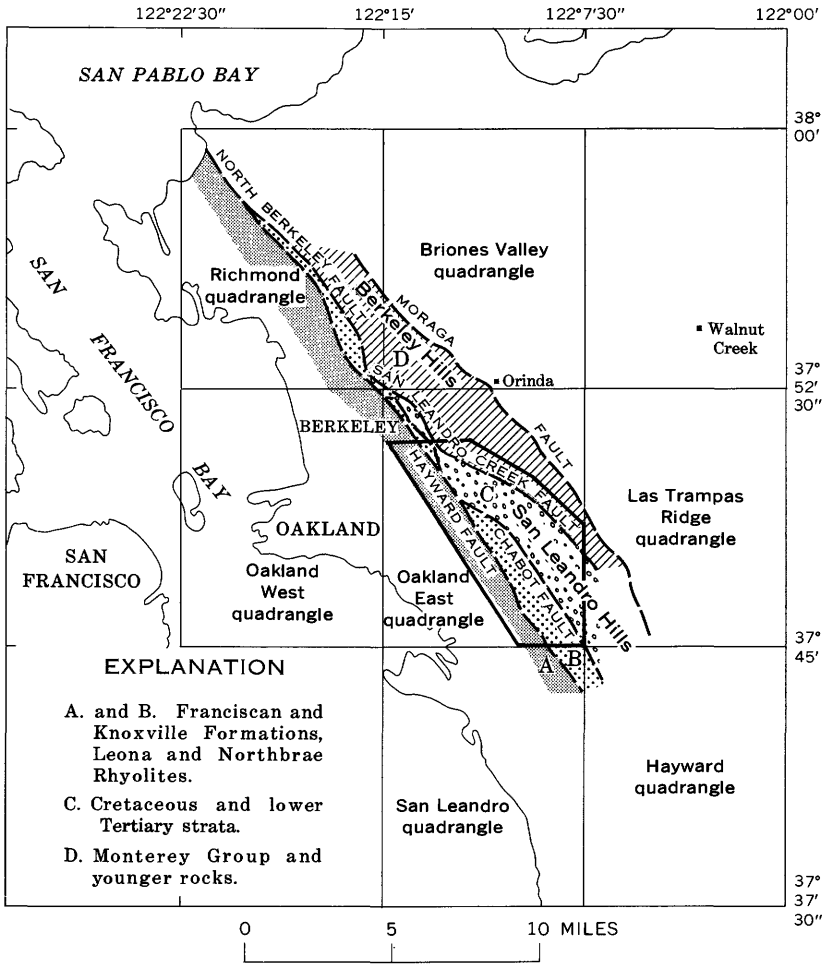

FIGURE 1.—Index map showing location of the Berkeley and San Leandro Hills. Heavy line indicates approximate outline of area shown on plate 1.

A. C. Lawson and his students (1914). Recent geologic mapping in the area (Radbruch and Case, 1967; Case, 1963; 1964a, b) has led to accumulation of new petrographic, stratigraphic, and paleontologic data on the Upper Cretaceous and lower Tertiary rocks which bear directly on the question of the petroleum and gas potential of the region. Perhaps of most significance is the identification of Eocene beds in the Berkeley Hills which indicates that much of the large synclinal area between the Berkeley Hills and the flanks of Mount Diablo (Jennings and Burnett, 1961; Taliaferro, 1951, p. 129–139) is probably underlain at depth by Eocene beds. Eocene rocks are productive of oil and gas on the north flank of Mount Diablo, and the extension of the Eocene depositional basin westward to the Berkeley Hills should enlarge the target area for future exploratory drilling. Data from diagnostic Upper Cretaceous fossils found in mappable units within the sequence of Upper Cretaceous beds lead to a considerable increase in our knowledge of regional stratigraphy. The Upper Cretaceous beds are of Great Valley lithology (Bailey and others, 1964, p. 11, 123–142), and some inferences about the provenance of sandstones and conglomerates in this thick miogeosynclinal sequence can be drawn from new petrographic evidence. In many places different formational assignments and new age designations have been made for rocks in areas previously mapped as Franciscan, Knoxville, or Chico Formation by Lawson (1914) and others. Earlier concepts of the relationships of the major rock units to major fold and fault systems also have been revised.

This report, therefore, deals primarily with the subdivisions of the Upper Cretaceous rocks of Great Valley lithology and with the newly recognized Paleocene and Eocene strata. Franciscan, Knoxville, and Miocene and younger rocks have a wide distribution in the area, but they are only briefly mentioned because relatively few new data of significance on these rocks were found in this investigation.

ACKNOWLEDGMENTS

My special thanks are extended to Mrs. D. H. Radbruch of the U.S. Geological Survey. The ideas and information supplied by her during the years since 1958 have been a major contribution to this investigation.

Many paleontologists have devoted much time and skill to the fossil collections. The stratigraphic studies in the field would have no frame of reference without their invaluable determinations. Professor J. W. Durham, Mr. J. H. Peck, Jr., and Mr. Gordon Hornaday identified pertinent fossils that are on file in the Museum of Paleontology, University of California at Berkeley. Collections of the U.S. Geological Survey were identified by Mrs. Patsy Smith and Messrs. M. C. Israelsky, D. L. Jones, and F. S. MacNeil.

REGIONAL GEOLOGIC SETTING

The Berkeley and San Leandro Hills are a northward extension or finger of the Diablo Range, a major structural uplift in the central Coast Ranges of California, whose core consists of the Franciscan Formation of Jurassic and Cretaceous age. Another northern finger of the Diablo Range is the Mount Diablo structural salient, which is separated from the Berkeley and San Leandro Hills by a synclinorium in Cretaceous and Tertiary strata that passes through the Orinda-

Walnut Creek area (fig. 1). The Berkeley Hills extend from Richmond southeastward to Redwood Canyon in the Oakland East quadrangle. The San Leandro Hills extend from Redwood Canyon southeastward into the central part of the Hayward quadrangle.

The region east of the central part of San Francisco Bay can be conveniently divided into four main geologic units or blocks whose boundaries are major faults that strike northwest (fig. 1). Southwest of the active trace of the well-known Hayward fault, which has right-lateral, strike-slip displacement, is a heterogeneous group of rocks that includes the Franciscan Formation of Jurassic and Cretaceous age, serpentine and gabbro, Knoxville Formation of Late Jurassic age, *Buchia*-bearing beds of Early Cretaceous age, and silicic volcanic rocks of Pleistocene age. The same group of rocks also occupies the second block that lies between the Hayward fault and the major but quiescent Chabot and North Berkeley faults. Northeast of the Chabot fault lies a third block that includes marine sandstone, shale, and conglomerate of Late Cretaceous age of Great Valley lithology and marine sandstone and shale of Paleocene and Eocene age but that is devoid of silicic volcanic rocks. The northeast border of this block is marked by the San Leandro Creek fault that separates Cretaceous and lower Tertiary strata on the southwest from Miocene (Monterey Group) or younger strata on the northeast. The fourth and most easterly block is bordered by the San Leandro Creek and Moraga faults. It consists of marine and continental sedimentary rocks and volcanic rocks of Miocene to Pliocene age.

Most of the Mesozoic and Tertiary rocks have been strongly deformed (pl. 1). Complex folds, many of which are overturned, trend northwest, parallel to the tectonic grain of the Coast Ranges. The mapped folds in the Upper Cretaceous and Tertiary strata tend to be elongate and broad; the breadth between their limbs is on the order of 1–2 miles, and their length is about 5 miles or more. Most of the mapped folds are conspicuously faulted, and the prevailing sense of apparent downthrow is to the northeast. Many of the faults are inferred to have a dominant strike-slip component.

STRATIGRAPHY

No rocks older than Jurassic have been identified in the Berkeley and San Leandro Hills. The Franciscan Formation of Late Jurassic to Late Cretaceous age is a complex eugeosynclinal assemblage of sedimentary, igneous, and metamorphic rocks. Serpentine and gabbro of unknown age are commonly associated with the Franciscan. Knoxville Formation of Late Jurassic age and *Buchia*-bearing beds of Early Cretaceous age are a thick, strongly folded sequence of dark marine shales and sandstones. In this area marine sandstone, shale, and conglomerate of Great Valley lithology of Late Cretaceous age are the oldest rocks for which the structural and stratigraphic relationships are relatively clearly understood. Paleocene and Eocene marine shale and sandstone are locally present but details of their structural and stratigraphic setting are poorly known. Miocene and Pliocene sedimentary and volcanic rocks, strongly folded, are relatively well known and form a succession thousands of feet thick northeast of the San Leandro Creek and North Berkeley faults. A generalized geologic column is shown in table 1.

TABLE 1.—*Generalized geologic column*

Series	Formation or unit		Major rock types
Recent and Pleistocene	Alluvium, bay deposits		Conglomerate, mudstone, and sandstone.
Pleistocene	Leona Rhyolite		Keratophyre, rhyolite(?), and silicic volcanic glass.
Pliocene	Mulholland Formation of Ham (1952)		Siltstone, sandstone, and conglomerate. Fluviatile and lacustrine deposits.
	Bald Peak Basalt		Basalt flows and interstratified sedimentary beds.
	Siesta Formation		Lacustrine deposits of siltstone, sandstone, tuff, conglomerate, and limestone.
	Moraga Formation		Basalt and andesite flows, rhyolite tuff, and interstratified sedimentary rocks.
	Orinda Formation (In part Miocene according to Richey (1943))		Continental and marine (in lower part) sandstone, conglomerate, and siltstone.
Miocene	Monterey Group	Tice Shale	Siliceous shale, siltstone, and sandstone.
		Oursan Sandstone	Sandstone, siltstone, and shale.
		Claremont Shale	Siliceous shale, chert, and sandstone.
		Sobrante Sandstone	Siltstone, siliceous shale, and sandstone.
Eocene	Marine sedimentary rocks		Glauconitic sandstone, siltstone, shale, and limestone.

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TABLE 1.—*Generalized geologic column*—Continued

Series	Formation or unit	Major rock types
Paleocene	Pinehurst Shale	Siliceous shale, thin-bedded sandstone, and siltstone.
Upper Cretaceous	Variegated shale	Foraminiferal red and green shale, siltstone, and sandstone.
	Redwood Canyon Formation	Biotitic feldspathic sandstone, shale, and siltstone.
	Shephard Creek Formation	Shale, siltstone, and biotitic feldspathic sandstone.
	Oakland Conglomerate	Lenticular conglomerate, sandstone, and shale.
	Joaquin Miller Formation	Biotitic feldspathic sandstone, siltstone, shale, and conglomerate.
Lower Cretaceous	Marine sedimentary rocks	*Buchia*-bearing shale, siltstone, conglomerate, and limestone.
Upper Jurassic	Knoxville Formation	
Upper Cretaceous to Upper Jurassic	Franciscan Formation	Graywacke, shale, chert, basalt, greenstone, and glaucophane schist. Intruded(?) by serpentine and gabbro.

JURASSIC AND CRETACEOUS ROCKS

FRANCISCAN FORMATION

The most widespread unit of the central Coast Ranges of California is the Franciscan Formation. It consists of complexly folded graywackes, shales, radiolarian cherts, and pillow basalts, many thousands of feet thick, that were deposited in a eugeosyncline during the Late Jurassic to the Late Cretaceous. Several summaries of the paleontologic evidence on the age of the Franciscan have been published recently by Irwin (1957), Durham (1962), and Bailey, Irwin, and Jones (1964). The Franciscan is exposed along the southwest front of the hills, southwest of the Chabot and North Berkeley faults (fig. 1, pl. 1.). Metamorphic rocks in the Franciscan of the Berkeley and San Leandro Hills include glaucophane and actinolite schists. Gabbro and diorite and large bodies of serpentine apparently intruded the Franciscan.

The areal distribution of the various facies of rocks of Late Cretaceous age is of fundamental significance in making interpretations of the structural history of the region. In the Berkeley and San Leandro Hills northeast of the Chabot and Hayward faults, the Upper Cretaceous beds are of Great Valley miogeosynclinal facies. To the southwest, on San Francisco Peninsula, eugeosynclinal facies rocks of Late Cretaceous age have been found in the Franciscan Formation. If the Franciscan in the Berkeley and San Leandro Hills, southwest of the Hayward and Chabot faults, is likewise of Late Cretaceous age, then major displacement, either by strike-slip faulting or overthrusting, must have occurred along the Hayward-Chabot fault system or an older system in order to juxtapose Upper Cretaceous rocks of miogeosynclinal facies against rocks of eugeosynclinal facies. A full discussion of this problem has been presented by Bailey, Irwin, and Jones (1964, p. 158–165).

UPPER JURASSIC AND LOWER CRETACEOUS ROCKS

KNOXVILLE FORMATION AND *BUCHIA*-BEARING BEDS

The Knoxville Formation, a thick sequence of dark marine shale, sandstone, and conglomerate, is widely exposed southwest of the Chabot fault. The formation is believed to be many thousands of feet thick, but it is complexly folded and is generally found in fault contact with adjacent formations, so that its total thickness cannot be determined. Fossils are locally abundant in the sandstone and shale and occur sporadically in thin limestone beds or concretions. Most of the diagnostic fossils have been identified by J. W. Durham and D. L. Jones as *Buchia piochii* of Late Jurassic age at localities B7997, B7998, B7999, B8002, B8003, B8004 (Case, 1963, app. 6), M859, and M1015 [1] (D. L. Jones, written commun., 1964) (pl. 1). Nondiagnostic belemnites are also common. Although most of the Knoxville was deposited in a marine environment, a few seams of soft coal containing fragments of plant fossils have been found interlayered with fossiliferous marine beds in the southern part of the area, which indicates that local continental conditions existed during Knoxville time.

The Knoxville Formation is of Late Jurassic age according to most geologists. However, a few specimens identified by J. W. Durham and D. L. Jones as *Buchia crassicollis* of Early Cretaceous age at localities B7996 (Case, 1963, app. 6) and M1016 (D. L. Jones, written commun., 1964) have been found in sandstone associated with the shales bearing *B. piochii*. Thus, either (1) beds younger than Knoxville are complexly infolded or infaulted with the Jurassic Knoxville, or (2) the Knoxville extends into Early Cretaceous time, or (3) *B. piochii* and *B. crassicollis* reflect ecological variations rather than time variations in the Berkeley and San Leandro Hills.

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[1] A letter B preceding the locality number indicates that the fossils from that locality are at the University of California Museum of Paleontology, and a letter M, at the U.S. Geological Survey, Menlo Park, Calif.

On the geologic map (pl. 1), *Buchia*-bearing beds and Knoxville Formation are shown as a single cartographic unit.

MISSING EARLY CRETACEOUS INTERVAL

No fossils indicating beds of Hauterivian to Albian age have been found in the area mapped. Strata of this age are present along the west side of the Sacramento Valley, at Mount Diablo, and elsewhere. Beds of equivalent age may have been deposited in the East Bay region, but they either are not exposed or were cut out by faulting or erosion after deposition. The Niles Canyon Formation in the Pleasanton area (Hall, 1958, p. 11) and the Berryessa Formation in the San Jose-Mount Hamilton area (Crittenden, 1951, p. 34–35) may also include sediments deposited during this time interval. Franciscan rocks of Albian age are present on San Francisco Peninsula (Schlocker and others, 1954).

UPPER CRETACEOUS ROCKS

Along the regional strike, Upper Cretaceous strata are exposed northeast of the Chabot fault from the south edge of the mapped area near San Leandro, northwest to the north edge of the campus of the University of California (pl. 1; Radbruch and Case, 1967). They extend northeast, across the regional strike, to Upper San Leandro Reservoir, where they are in contact with Tertiary beds. Mappable units of sandstone, shale, and conglomerate are found along the belt of exposure. The Upper Cretaceous beds in the southeastern part of the area have been folded into the asymmetric, faulted Grass Valley syncline that strikes northwest, except in the Montclair district, where it strikes more westerly. The southwest limb of the syncline is steep to overturned, whereas the northeast limb is normal, except near faults (fig. 2). The syncline is cut by several strike faults but apparently is not cut by large transverse faults; however, exposures are poor and discontinuous, contacts of the formations are gradational, and slumping has been extensive on steep slopes, so that many small faults have undoubtedly not been detected.

Upper Cretaceous beds described in this report were originally divided by Lawson (1914) into three units: the Knoxville Formation, which was assigned an Early Cretaceous age, and an Oakland Conglomerate Member at the base of the Chico Formation and the upper part of the Chico Formation, both of Late Cretaceous age. The beds mapped as Oakland by Lawson are subdivided into three formations in this report, as follows: (1) strata southwest of the Chabot fault are referred to the Knoxville Formation and *Buchia*-bearing beds on the basis of fossils and lithology, (2) sandstones and shales stratigraphically below prominent conglomerate layers of the Oakland

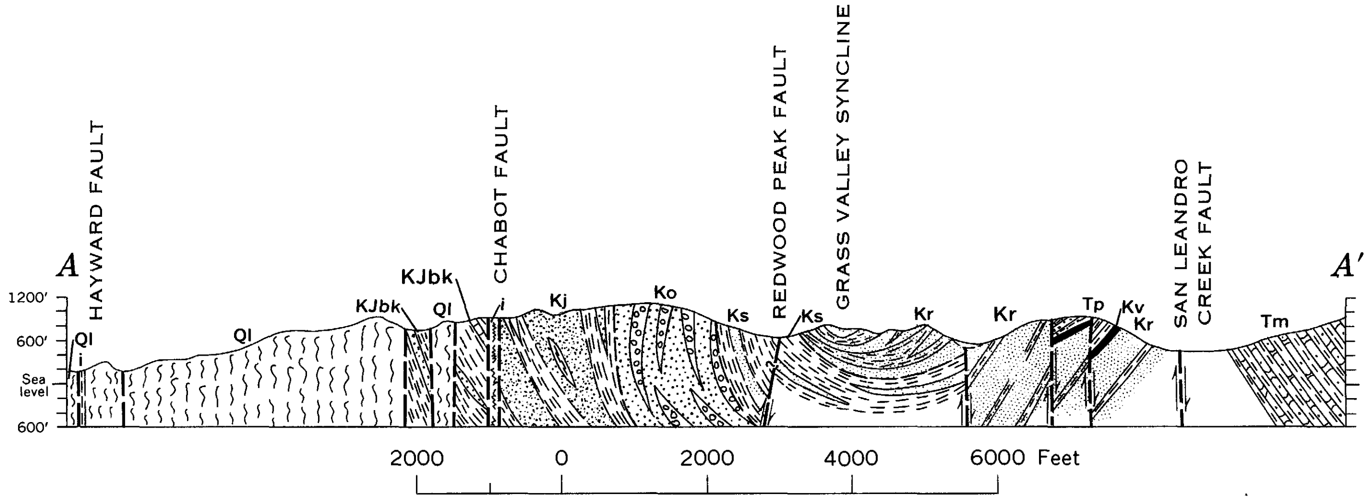

FIGURE 2.—Schematic geologic section across Grass Valley syncline. Line of section shown on plate 1. i, serpentine and gabbro of unknown age; KJbk, *Buchia*-bearing beds and Knoxville Formation; Kj, Joaquin Miller Formation; Ko, Oakland Conglomerate; Ks, Shephard Creek Formation; Kr, Redwood Canyon Formation; Kv, variegated shale; Tp, Pinehurst Shale; Tm, Monterey Group; Ql, Leona Rhyolite.

Conglomerate northeast of the Chabot fault are here named Joaquin Miller Formation, and (3) Oakland Conglomerate is used here in a sense more restricted than that used by Lawson but has been assigned formation rank. Rocks stratigraphically above the Oakland Conglomerate, termed "upper part of Chico" by Lawson, have been divided into the following new units: (1) Shephard Creek Formation, (2) Redwood Canyon Formation, (3) unnamed variegated shale, all of Late Cretaceous age, and (4) Pinehurst Shale, of Paleocene age. Some strata mapped as Chico by Lawson, near the contact with the Monterey Group, are Eocene and Miocene in age. These erroneous age assignments by Lawson probably resulted from the great lithologic similarities of weathered sandstone of Late Cretaceous, Eocene, and Miocene age.

The individual Upper Cretaceous stratigraphic units could not be traced north of the Montclair district, owing to faulting and possibly to stratigraphic lensing, and in that district rocks of typical Upper Cretaceous lithology have been mapped as Upper Cretaceous strata, undivided.

JOAQUIN MILLER FORMATION

Joaquin Miller Formation is here proposed for steeply dipping or overturned exposures of sandstone, shale, and conglomerate on the grounds of Joaquin Miller Park in Oakland, Calif., in sec. 27, T. 1 S., R. 3 W. No completely exposed sections of Joaquin Miller are available for detailed stratigraphic measurement and designation of a type section. However, the formation is relatively well exposed in Joaquin Miller Park, between the Chabot fault on the southwest and Skyline Boulevard on the northeast, and that locality is regarded here as the type area (pl. 1). The lower contact is the Chabot fault. Possibly the lower beds of the formation are exposed to the southeast in the Hayward quadrangle. The top of the formation is gradational with Oakland Conglomerate; the upper contact has been mapped at the base of the lowest conglomeratic beds of the Oakland that contain abundant clasts of pebble and cobble size. Typical exposures of the formation along the southwest limb of Grass Valley syncline may be seen in Redwood Canyon and along Skyline Boulevard, south of Redwood Peak. Somewhat poorer exposures are found along the southwest face of the continuous ridge that extends from east of Arroyo Viejo to the Montclair district.

The formation is composed dominantly of medium-grained sandstone and siltstone interbedded with shale and it locally contains conglomerate lenses. Most of the sandstone beds are massive, but some show graded bedding and sole marks. They range in thickness from a few inches to about 30 feet, but most beds are 3–10 feet thick. The cement in the sandstone consists either of an argillaceous paste or of carbonate. Carbonate and carbonate-cemented sandstone concretions are common, but only a few limestone lenses are present. The shale beds are usually much thinner than the sandstone beds, but locally attain a thickness of as much as 20 feet. Near the contact with the Chabot fault, shale beds are more abundant and could possibly be mapped as a separate formation or member. These shale beds were mapped with the Knoxville by Lawson. Sparse conglomerate lenses are 5–20 feet thick. Where well exposed, the shale, siltstone, and sandstone beds are seen in monotonous alternating sequence, similar to the Upper Cretaceous beds observed along the west side of the Sacramento and San Joaquin Valleys.

One fairly continuous partial section of the formation is exposed along an unpaved road that descends from Skyline Boulevard into the valley below Leona Heights, in the SW¼ sec. 1, T. 2 S., R. 3 W.

Some of the beds of sandstone contain large amounts of potassium feldspar, up to 16.9 percent, as determined by staining and microscopic examination (table 2). Such large quantities of potassium feldspar are characteristic of Upper Cretaceous sandstone of Great Valley lithology (Bailey and Irwin, 1959; Bailey and others, 1964, p. 139–141). Quartz is abundant; plagioclase and lithic fragments— chiefly quartz aggregates, chert, granitic and metamorphic fragments— are less abundant. Most quartz grains are very angular. Composition of the silt-sized and larger sized fraction of three representative beds of sandstone is listed in table 2. Composition of the matrix of the sandstone varies considerably; most of the sandstone is loosely cemented with argillaceous material or a combination of argillaceous and carbonate material. Where the sandstone is carbonate cemented, it forms bouldery outcrops that are very resistant to erosion. The carbonate cement is sporadic through the formation, and cuts across bedding planes in places; it may be a replacement cement or it may have been precipitated after an original argillaceous cement had been flushed by ground water.

These sandstones are generally similar to Upper Cretaceous sandstones described by Briggs (1953) from the east side of the Diablo Range, except that the quantity of quartz is somewhat greater and that of volcanic lithic fragments is somewhat less in the Berkeley and San Leandro Hills. The sandstones are arkosic and feldspathic wackes in Gilbert's (1954) classification.

Thickness.—The maximum thickness of exposed parts of the formation, measured from cross section, is about 2,500 feet. This amount is only a crude approximation of the thickness because little is known about the extent of repetition or omission of strata by small folds and faults.

TABLE 2.—*Mineral and lithic composition, in percent, of silt-sized and larger sized fraction of representative Upper Cretaceous sandstone*

[Tr, trace; Nr, not recorded]

	Joaquin Miller Formation			Oakland Conglomerate			Shephard Creek Formation		Redwood Canyon Formation			
Sample	1	2	3	4	5	6	7	8	9	10	11	12
Field No. (501–)	31	36	63	12	32	68	69	71	5	11	61	70
Quartz	48.9	49.9	48.6	40.3	40.0	55.5	58.9	43.2	47.6	47.5	57.1	60.5
Plagioclase	7.2	9.7	10.4	13.9	10.3	10.4	6.2	10.8	10.6	6.7	7.0	8.2
Potassium feldspar	8.5	15.2	16.9	18.4	19.3	16.9	16.8	17.6	19.0	20.6	15.4	17.6
Chert, quartz aggregates, and granitic lithic fragments	18.8	9.6	9.8	9.6	9.0	3.2	1.6	3.3	10.0	10.0	6.0	3.9
Volcanic lithic fragments	2.0	Tr	1.0	1.0	.7	.8		.3	1.3	1.3		1.3
Biotite	Nr	Nr	Nr	7.3	3.0	4.0	9.8	6.9	5.1	3.9	7.5	2.3
Other lithic fragments (shale and metamorphic rocks)	11.2	8.1	Nr	6.0	10.0		Nr	Nr	4.5	4.2		
Other minerals (includes opaque minerals, biotite, white mica, chlorite)	3.4	7.5	13.3	3.5	7.7	9.2	6.7	17.9	1.9	5.8	7.0	6.2
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Sample	*Locality*	*Cement material*	*Number of points counted*
1	Las Trampas Ridge quadrangle, extreme southwest part.	Clay-iron oxide	305
2	Oakland East quadrangle, fossil loc. B7090, Skyline Blvd. in Joaquin Miller Park.	Clay	308
3	Oakland East quadrangle, sec. 1, T. 2 S., R. 3 W., near Skyline Blvd.	Clay-iron oxide	307
4	Oakland East quadrangle, sec. 27, T. 1 S., R. 3 W., Joaquin Miller Park.	Clay	302
5	Skyline Blvd.	do	300
6	Oakland East quadrangle, north of fire station on Skyline Blvd.	Clay-iron oxide	249
7	Oakland East quadrangle, 15-ft-thick sandstone bed on Escher Dr.	Clay-iron oxide	301
8	Oakland East quadrangle, 18-in.-thick siltstone bed north of Park Blvd. in Shephard Canyon.	do	306
9	Redwood Road near Upper San Leandro Reservoir.	Clay	311
10	Joaquin Miller Park, fossil loc. B7091	do	310
11	Oakland East quadrangle, Redwood Canyon, sec. 36, T. 1 S., R. 3 W.	do	315
12	Oakland East quadrangle, Shephard Canyon, north of Park Blvd.	do	306

Age and correlation.—A coiled ammonite was found near Redwood Peak, at locality B7090 on Skyline Boulevard in overturned beds of the Joaquin Miller Formation just below Oakland Conglomerate. The ammonite was identified as *Calycoceras* sp. of Cenomanian age by D. L. Jones of the U.S. Geological Survey and J. W. Durham of the University of California (Case, 1963, app. 11). Fragments of *Phylloceras* and *Inoceramus* were associated with the ammonite. This fossil locality is near the contact between Oakland Conglomerate and Knoxville Formation, as mapped by Lawson.

The strata below the ammonite locality may range downward in age to Early Cretaceous; but the lithology of the Joaquin Miller is very similar to that of younger Cretaceous strata, and it is believed that most of the formation is no older than Cenomanian. Abundance of potassium feldspar in the sandstone suggests Upper Cretaceous rocks (Bailey and Irwin, 1959; Bailey and others, 1964, p. 139–141).

The Cenomanian age of the *Calycoceras* sp. indicates that the Joaquin Miller Formation is in part equivalent to the lower part of the Del Valle Formation of the Pleasanton area (Hall, 1958, p. 10–11), to part, at least, of the Panoche Formation in the Tesla quadrangle (Huey, 1948, p. 24–31), and possibly to the upper part of the Berryessa Formation of Crittenden (1951, p. 33–35) in the San Jose-Mount Hamilton area; however, Crittenden reported beds containing *Buchia piochii* in the Berryessa Formation, so that part of the Berryessa would appear to be much older than Cenomanian. The lower part of the Joaquin Miller Formation may be equivalent to the Niles Canyon Formation of Hall (1958, p. 8–11) and to parts of the Berryessa Formation of Crittenden (1951, p. 33–35). The Joaquin Miller Formation is equivalent to part of the unnamed "Jurassic-Cretaceous" formation of Colburn (1962, p. 409) in the Mount Diablo region. Franciscan limestone on the San Francisco Peninsula contains Foraminifera of Cenomanian age. An ammonite, *Mantelliceras* of Cenomanian age, was found, not in place, associated with Franciscan graywacke in southern Marin County. (See summary by Bailey and others, 1964, p. 115–123.)

OAKLAND CONGLOMERATE

The age of the Oakland Conglomerate has been the subject of much debate. Lawson considered the Oakland Conglomerate to be a member of the Chico Formation of Late Cretaceous age, but he mapped at least two distinctly different conglomerate units as a single unit across the trace of the Chabot fault near the boundary between the Concord and Hayward 15-minute quadrangles. The erroneous correlation of the two contrasting units was made through mapping of terrace gravels. Robinson (1956) discovered that Lawson had mapped terrace gravels as Oakland Conglomerate in the northwestern part of the Hayward 7½-minute quadrangle. After Lawson's early map was published, workers in the Hayward and San Jose area found specimens of *Buchia* and belemnites of Early Cretaceous and Late Jurassic age to be associated with conglomerate mapped as Oakland by Lawson. The age of the Oakland thus became accepted as Early Cretaceous. (See Popenoe and others, 1960.) Conglomerate associated with beds containing a *Buchia piochii* fauna are here referred to Knoxville Formation. Beds of conglomerate in the city of Oakland, along Skyline Boulevard near Redwood Peak, are of Late Cretaceous age.

It is appropriate to review Lawson's description (1914, p. 8) of the Oakland in the light of more recent faunal data and more recent geologic mapping:

> *Oakland conglomerate member.*—In the Berkeley Hills the basal portion of the Chico formation consists of a conglomerate to which the name Oakland conglomerate member is applied, from its typical exposure at the city of Oakland. This conglomerate outcrops along a belt paralleling that of the Knoxville formation, upon which it lies conformably. Like the Knoxville it increases in volume from the northwest toward the southeast, but the increase is not uniform. At the mouth of Strawberry Canyon the conglomerate has not been discovered. In the valley southeast of Claremont creek it is exposed in rather small outcrops, which are not mapped, and at Temescal Lake it is exposed to a thickness of perhaps 100 feet. From this point it may be traced southeastward almost continuously to Redwood Peak, where it bulges out to a thickness of about 1000 feet. Beyond Redwood Peak it diminishes in volume for about a mile to 200 or 300 feet and then expands again, reaching a width of about 1000 feet northeast of Laundry Farm. From this point southeastward its thickness ranges from 500 to 700 feet, and still farther southeast, in the Haywards quadrangle, it again expands. The average thickness of the conglomerate in the Concord quadrangle may be about 500 feet. In the Haywards quadrangle its average thickness may be nearer 1000 feet.

From the foregoing description by Lawson, it seems evident that the reference locality of the Oakland Conglomerate in the city of Oakland is southeast of Lake Temescal, near Redwood Peak, where the formation attains a thickness of about 1,000 feet, and it is therefore proposed that conglomeratic beds exposed along Skyline Boulevard west and northwest of Redwood Peak, be considered the reference locality (pl. 1) of the restricted Oakland Conglomerate. Both top and bottom of the Oakland Conglomerate thus defined are gradational with the adjacent formations. The Oakland grades upward into the Shephard Creek Formation; the contact is mapped at the top of the uppermost massive sandstone or conglomerate layer of the Oakland or at the base of the thick shale sequence forming Shephard Creek.

Beds of conglomerate of the Oakland are lenticular and range in thickness from a few inches to about 25 feet. Most of the lenses are 3–10 feet thick. Sandstone beds and the few shale beds are interlayered with the conglomerate lenses. In most lenses of conglomerate, pebbles and cobbles are cemented by feldspathic sandstone similar to the other sandstone of the formation, and only a few conglomerate lenses have a shale matrix. The beds of conglomerate along Skyline Boulevard, near Redwood Peak, contain clasts of granitic rocks, quartz porphyry (rhyolite or quartz dacite), bull quartz, and minor andesitic rocks. Clasts range in size from ¼ inch to 18 inches. Most are from 1 to 3 inches in diameter and are well rounded and highly polished. A coating of iron oxide on the clasts is common. The mineral compositions of the sandstone interbedded with conglomerate are shown in table 2, samples 4–6.

Representative partial sections of the Oakland Conglomerate can be observed in secs. 7 and 18, T. 2 S., R. 2 W., east of Skyline Boulevard, as well as at the reference locality.

Thickness.—The apparent thickness of the Oakland, taken from map section, ranges from about 200 feet near Shephard Creek to about 2,000 feet in sec. 1, T. 2 S., R. 3 W. Its average thickness is estimated to be about 900 feet.

OTHER EXPOSURES OF CONGLOMERATE IN THE REGION

Knoxville conglomerates.—Conglomerates just southeast of Lake Temescal in the Hayward fault zone are associated with dark, thin-bedded shales that are similar in lithology to Knoxville shale and thus may be in the Knoxville Formation, although no diagnostic fossils were found. These conglomerates probably are those mentioned by Lawson in the first part of his description of Oakland Conglomerate. They have a dark shale matrix, as does most of the conglomerate of the Knoxville where dated by fossils.

To the south, in the Hayward quadrangle southwest of the Chabot fault, conglomerate mapped as Oakland by Lawson and Robinson is somewhat more mafic in character and includes a higher proportion of clasts of sedimentary rocks than does typical Oakland Conglomerate near Skyline Boulevard. It has a shale or dark sandstone matrix (low in potassium feldspar) in contrast to the coarse light-colored sandstone matrix (rich in potassium feldspar) of the conglomerate along Skyline Boulevard (table 2).

Robinson (1956) described Oakland Conglomerate in the Hayward quadrangle as follows:

> The main outcrops are of dark-colored poorly sorted subrounded well-cemented cobble-boulder conglomerate in a clayey sand matrix. By count, more than 50 percent of the pebbles are chert, quartzite, and greenstone of Franciscan and

possibly pre-Franciscan derivation; 10 percent are graywacke and shale from the Franciscan or Knoxville formations; 10 percent are gabbro and serpentine; and 30 percent are biotitic arkosic sandstone and pebble conglomerate, probably derived from earlier parts of the Oakland conglomerate itself.

This result is generally comparable to a count from a locality southwest of the Chabot fault in the northern part of the Hayward quadrangle, although I found a smaller proportion of arkosic sandstone and pebble conglomerate (Case, 1963, table 4, p. 39).

Upper Cretaceous conglomerates.—In the southern part of the Las Trampas Ridge quadrangle and in the northeastern and central parts of the Hayward quadrangle are conglomerate beds that are similar in composition to those of the Oakland Conglomerate in the Oakland East quadrangle near Redwood Peak (Case, 1963, table 4, p. 39).

Robinson (1956) described equivalent conglomerates in the Chico Formation in the Hayward quadrangle as follows:

The conglomerate is much like that in the Oakland and Knoxville formations, but it includes dioritic, gabbroic, and gneissic rocks and manganese dioxides.

Granitic clasts are abundant in a conglomerate from the Chico exposed on Jensen Road in Hayward quadrangle (Case, 1963, table 4, p. 39).

Hall (1968, p. 12) traced a conglomerate member of the Del Valle Formation from the Pleasanton quadrangle into the Hayward quadrangle, just below a Late Cretaceous (Turonian) fossil locality described by Robinson. According to Hall:

The pebbles, and more frequently cobbles, are porphyritic rocks and chert. Almost all the clasts are polished. A few sandstone cobbles occur within the unit some of which contain fragments of *Inoceramus* sp.

Age and correlation.—From the foregoing summary of the lithology and regional distribution of Upper Cretaceous conglomerate, the Oakland Conglomerate at its reference locality in the Oakland East quadrangle is tentatively correlated with Hall's conglomerate member of the Del Valle and with the unnamed Upper Cretaceous conglomerate recognized in the Chico by Robinson. Near Redwood Peak, the Oakland Conglomerate overlies strata which contain a Cenomanian ammonite; in the Hayward quadrangle, similar conglomerates are found associated with Turonian strata, according to Hall (1958, p. 12–13). Therefore, Oakland Conglomerate is thought to be post-Cenomanian, perhaps Turonian, in age. One fossil locality, MF760, has been found in the Oakland, but the Foraminifera comprising the fauna indicate only Cretaceous age, according to unpublished data of M. C. Israelsky (1963).

This Turonian(?) age assignment represents a return to Lawson's original designation of Late Cretaceous as the age of the Oakland

Conglomerate. From this study, it seems likely that many of the conglomerates termed "Oakland Conglomerate" by other workers in the Hayward, Pleasanton, and San Jose-Mount Hamilton areas are not equivalent to Oakland Conglomerate at the reference locality and that they should be renamed. Moreover, if the correlations given here are correct, some reinterpretations of regional structure are necessary, particularly with respect to location of and displacement along the Chabot fault in the Hayward 15-minute quadrangle. Finally, within the area mapped for this study, the degree of conformity of Upper Cretaceous and Knoxville strata is unknown, owing to faulting and to lack of faunal control.

SHEPHARD CREEK FORMATION

The name Shephard Creek Formation is here proposed for shale and sandstone exposures along Shephard Creek in the Montclair district, sec. 21, T. 1 S., R. 3 W., of Oakland (pl. 1), which is designated the type locality. The formation consists of gray, buff, and brown thin-bedded shale and a small amount of interbedded buff sandstone layers. The sandstone beds in the formation are similar in lithology and bedding characteristics to those of the overlying Redwood Canyon Formation (table 1). The formation gradationally overlies sandstone and conglomerate of the Oakland Conglomerate and is gradationally overlain by the Redwood Canyon Formation. The base of the formation has been mapped at the top of the uppermost massive sandstone or conglomerate of the Oakland Conglomerate, which commonly crops out or has good topographic expression. The top of the formation is drawn between a thick shale unit in the upper part of the shale-sandstone sequence of the Shephard Creek and the base of massive sandstone at the base of the Redwood Canyon Formation. The formation extends southeastward from Shephard Canyon to Skyline Boulevard where it is cut by the Redwood Peak fault. Shale along Redwood Canyon and Grass Valley, to the southeast, is equivalent to that at the type locality.

Representative partial sections of the formation can be observed in the cuts of the abandoned railroad between Snake Road and Park Boulevard, and in Redwood Canyon and Grass Valley.

The formation does not crop out on the northeast limb of the Grass Valley syncline; hence, either it is cut out by faulting, or the syncline is more asymmetrical than indicated by the mapping, or an exceedingly abrupt facies change takes place between the two limbs of the syncline. Probably, faulting combined with thinning of the synclinal limb explains its absence.

Thickness.—The maximum apparent thickness, measured from map section, is about 1,500 feet near Shephard Canyon.

Age and correlation.—No diagnostic fossils have yet been found in the Shephard Creek Formation, but the formation overlies the Oakland Conglomerate, possibly of Turonian age, and underlies the Redwood creek Formation, which has a sparse *Baculites* fauna. As *Baculites* are probably not older than Coniacian, according to D. L. Jones (oral commun., 1961) and Matsumoto (1960, p. 177), the Shephard Creek Formation is probably in the range of Turonian-Coniacian. It may be correlative with the upper part of the Del Valle Formation of Hall (1958, p. 12–13).

REDWOOD CANYON FORMATION

Overlying the Shepard Creek Formation is a thick sequence of sandstone with minor interbedded shale that is here named the Redwood Canyon Formation from exposures in Redwood Canyon, sec. 36, T. 1 S., R. 3 W. (pl. 1), the type locality. The formation extends from the southeast edge of the map area to the Hayward fault in the Montclair district. It parallels the Shephard Creek Formation, except where it is in fault contact with Oakland Conglomerate. Its northeastern outcrop boundary is a fault at most places, where the Redwood Canyon is in contact with Paleocene, Eocene, or Miocene strata. Its total thickness is unknown but it probably exceeds 1,500 feet as indicated by exposures in Redwood Canyon and along the shore of Upper San Leandro Reservoir. It has the largest areal extent of any of the Upper Cretaceous formations.

Good exposures of the formation may be seen at many places along Redwood Canyon and along the edge of the southwest arm of Upper San Leandro Reservoir (fig. 3), where the beds maintain a uniform southwest dip. Thickness of sandstone beds ranges from a few inches to 40 feet but probably averages about 10 feet. Distinctive features of the sandstone of the Redwood Canyon Formation are "cannonball" concretionary sandstone nodules in the soil overlying the sandstone beds. The shale beds are usually 1–3 feet thick, although thinner beds are very common. Graded beds are common, though rarely pronounced. Many of the beds are crossbedded on a small scale. Contorted bedding is abundant. Sole marks seem to be relatively uncommon, but only a few suitable exposures of the bases of beds are available for examination. Most of the observed sole marks are load casts, but flute casts were seen at a few places in Redwood Canyon. Too few sole marks were observed to determine whether they show preferred orientation.

The sandstone is fine to coarse grained, but most of it is medium grained. All the beds contain much potassium feldspar and quartz and lesser amounts of plagioclase; biotite is abundant (table 2). Their compositions are very similar to those of Upper Cretaceous sandstones described by Briggs (1953, p. 423–432).

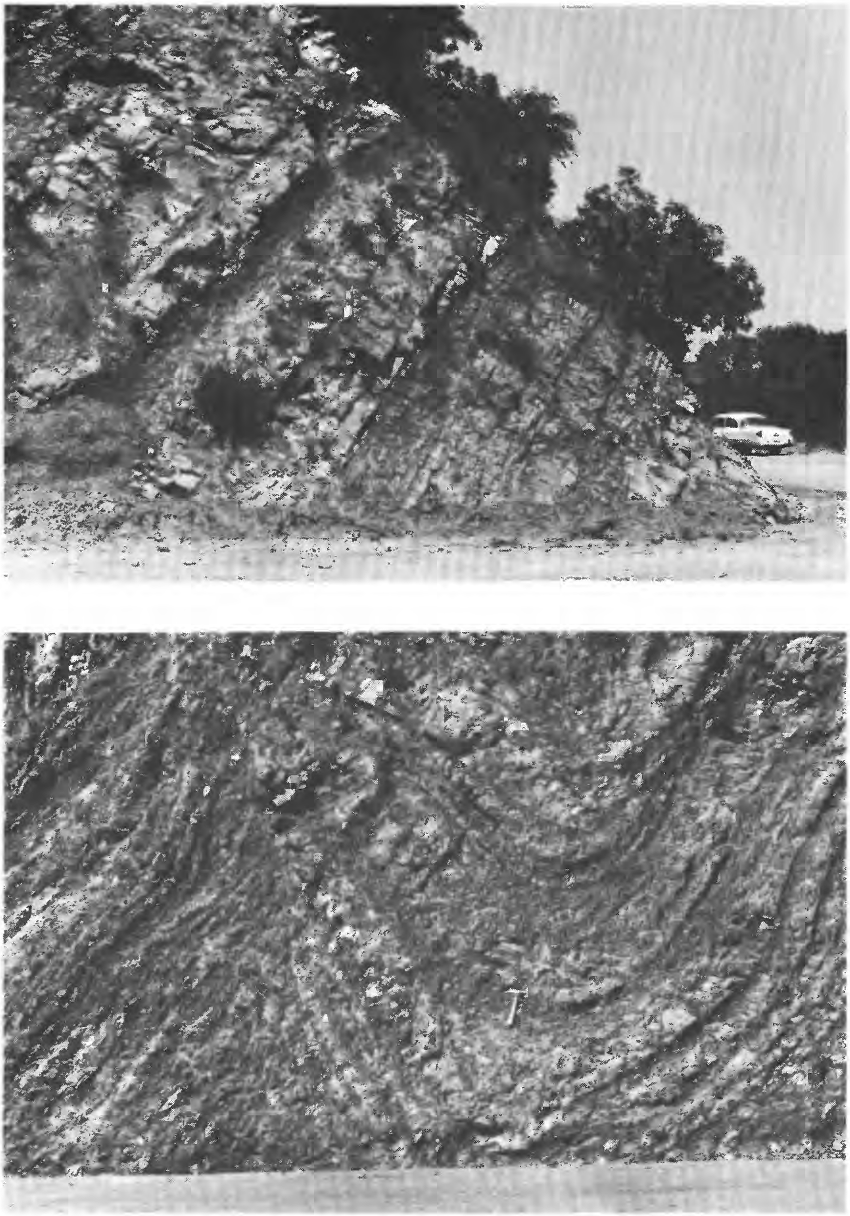

FIGURE 3.—Redwood Canyon Formation. Upper: View north at typical exposure of formation on Redwood Road near Upper San Leandro Reservoir. Lower: Small faulted folds in formation exposed on Pinehurst Road. Note that the fault cutting the anticline is approximately parallel to the axial plane.

Similar sandstone and shale occur north and east of Lake Temescal. These may be equivalent to the Redwood Canyon Formation, but they are termed "Upper Cretaceous strata, undivided," because their stratigraphic position is unknown.

Thickness.—The minimum thickness of the formation is about 1,500 feet, as determined from outcrop width and average dips.

Age and correlation.—A fragment of *Baculites* and a coiled gastropod were collected from the base of the formation at locality B7091, just above the contact with the Shephard Creek Formation. These forms are post-Turonian, probably Coniacian or younger, according to J. W. Durham and D. L. Jones (oral commun., 1961). Sutures on the baculites appear to be of moderate complexity. According to Matsumoto (1960, p. 177), moderate size and complexity of sutures of *Baculites* suggest Campanian-Maestrichtian age. Because variegated shale of Campanian age overlies the Redwood Canyon, the age of the Redwood Canyon is tentatively postulated to be Santonian to Campanian. The formation is thus probably younger than the Del Valle Formation in the Pleasanton area (Hall, 1958, p. 13).

UNNAMED VARIEGATED SHALE

The youngest known Cretaceous rocks of the area are thin-bedded red and green variegated shales and mudstones that overlie the Redwood Canyon Formation on the downfaulted northeast limb of Grass Valley syncline, between Redwood Creek and Upper San Leandro Reservoir. These shales are overlain by apparently conformable siliceous shale and thin-bedded sandstone of the Pinehurst Shale of Paleocene age. The outcrop pattern of the variegated shale is very irregular as a result of faulting, folding, poor exposure, and slumping. The maximum exposed thickness of the shale is about 200 feet. The shale has not been recognized outside sec. 36, T. 1 S., R. 3 W.

Age and correlation.—The red shales at localities B8016, B8019, MF523, MF524, MF525, MF534, MF592, and MF769 contain an abundant foraminiferal fauna, which indicates that the age of the beds is probably Campanian, according to G. R. Hornaday (written commun., cited in Case, 1963, app. 17), and M. C. Israelsky (written commun., 1961–63). These beds are apparently slightly older than the Moreno Formation of the Tesla area, which is probably Maestrichtian in age (Popenoe and others, 1960, chart 10e).

UNDIVIDED UPPER CRETACEOUS STRATA

Structural complexity and facies changes prohibit the mapping of individual Upper Cretaceous formations throughout the area of study. The strata along the front of the Berkeley Hills between Lake

Temescal and the campus of the University of California are not well dated. They are similar in lithology to other Upper Cretaceous strata of the area and resemble the Redwood Canyon more than any other formation. B. L. Clark obtained specimens of *Turrilites* and *Inoceramus* from the SW¼ sec. 7, T. 1 S., R. 3 W., which Anderson (1958, p. 62) thought indicated that the "beds are high in the Upper Asuncion group." The upper part of the Asuncion Group, as used by Anderson (1958, table 5), includes Maestrichtian and Danian strata; these strata, therefore, may be younger than the Redwood Canyon Formation. On the other hand, Matsumoto (1960, p. 70) identified one of the fossils from Clark's locality as *Turrilites costatus;* occurrence of this fossil indicates a Cenomanian age.

Near the Lawrence Radiation Laboratory, at the head of Hearst Avenue, conglomerate is exposed that is very similar in lithology to the Oakland Conglomerate and that may be correlative with the Oakland; therefore, some of the beds are probably older than those reported by Anderson (1958, p. 62). Fossils from locality MF526, just north of the Montclair district, are apparently Campanian or Maestrichtian, according to M. C. Israelsky (written commun., 1961).

In general, beds assigned to Upper Cretaceous north of Lake Temescal are biotite-rich, buff sandstone and subordinate shale. These beds are cut by many small shear planes, which have caused the beds to slump extensively on the steep slopes of the front hills.

Some of the beds mapped as Cretaceous on the basis of lithology may, indeed, be of early Tertiary age or they may be sandstone of the Miocene Monterey Group.

INFERRED DEPOSITIONAL HISTORY OF UPPER CRETACEOUS STRATA

The record of deposition of Upper Cretaceous strata in the East Bay region is far from complete, but a few generalizations can be made from results of this investigation and from recent work elsewhere in the region. Several facts about these miogeosynclinal rocks are outstanding.

1. Upper Cretaceous sandstone is abundantly rich in quartz and potassium feldspar, as determined by staining and microscopic examination, which suggests that the source of this sandstone was a granitic terrane (fig. 4).
2. Most of the granitic rocks in the Sierra Nevada and ancestral Gabilan Highland, both postulated sources of detritus, are quartz monzonitic rather than granitic; the plagioclase is subequal in amount to potassium feldspar. Dominance of potassium feldspar

over plagioclase in Upper Cretaceous sandstone indicates either that the detritus from the parent rocks was derived by preferential weathering of plagioclase to clays and incompletely weathered potassium feldspar detritus was transported as mineral fragments, or that potassium metasomatism subsequently occurred on a regional scale (little evidence of potassium metasomatism was observed in the sandstone).

3. Abundant biotite in these rocks, in contrast to its scarcity in Knoxville sandstone, indicates that a biotite-rich source terrane became available for erosion between Lake Jurassic and middle Cretaceous.
4. Abundant granitic, quartz, dacite, or rhyolite clasts in the conglomerate indicate a silicic igneous provenance.
5. Andesitic debris indicates that the source terrane contained intermediate vlocanic rocks.
6. Angularity of the detrital grains in the sandstone and the scarcity of secondary overgrowths on quartz suggest that the sands were first-cycle sands.
7. No evidence of the marked angular unconformity has been found in the sequence of known Upper Cretaceous formations of the area which suggests that sedimentation was virtually continuous from perhaps Cenomanian through Campanian.

Evidently the source terrane was composed largely of granitic rocks and andesitic to rhyolitic volcanic rocks. Granitic terranes that have been postulated as a source of Upper Cretaceous beds in the region include a western landmass, the ancestral Gabilan Highland (Taliaferro, 1943, p. 130–134; 1951, p. 127–128; Huey, 1948, p. 28; and Briggs, 1953, p. 434–441), and an eastern landmass, the ancestral Sierra Nevada (Taliaferro, 1951, p. 127; Huey, 1948, p. 28; Curtis and others, 1958, p. 13–16; and Bailey and others, 1964, p. 146–147). Unfortunately, no data were obtained in this investigation that indicate direction of sediment transport.

Within the mapped area, the alternation of lithologic types indicates cyclical sedimentation on all scales: on a small scale, individual shale and sandstone units are rhythmically bedded; on a formational scale, sandstone, conglomerate, and shale alternate. Generally quiet, slow mud deposition characterized early Joaquin Miller time; this interval was followed by deposition of increasing amounts of coarse, clastic material, culminating in deposition of the coarse Oakland Conglomerate. Another episode of quiet mud deposi-

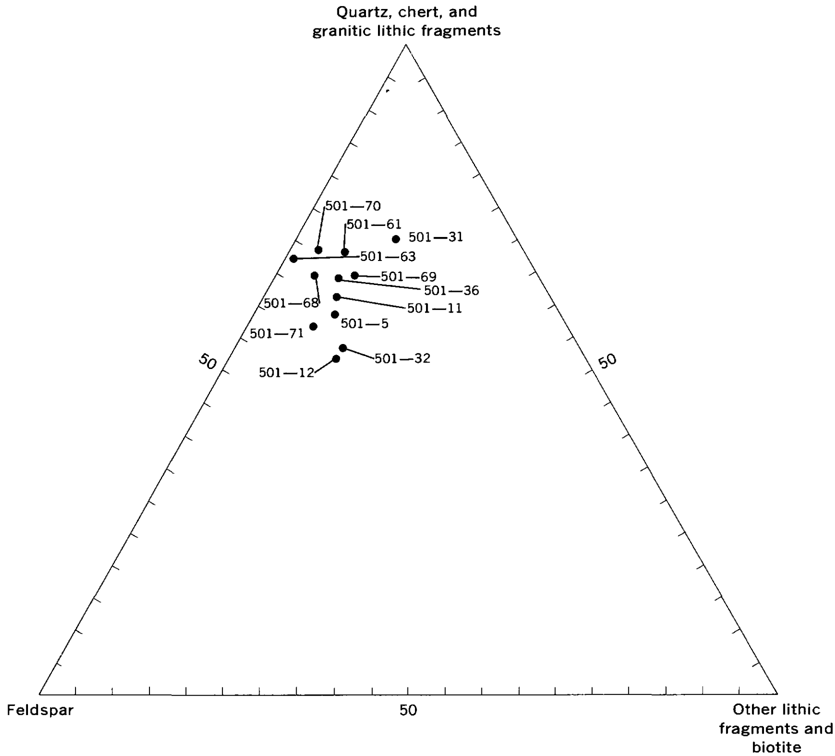

FIGURE 4.—Composition of Upper Cretaceous sandstone. Compositions of fraction, silt sized and larger, exclusive of matrix. Compositions listed in table 2, exclusive of "Other minerals" category, recalculated to 100 percent.

tion is represented by the Shephard Creek Formation; this episode was followed by increased deposition of coarse, clastic detritus during Redwood Canyon time. An abrupt change in environmental conditions then occurred with the deposition of the foraminiferal variegated red and green muds.

Deposition of most of the sands was through the agency of turbidity currents, as indicated by graded bedding, sole marks, and intrastratal crumpled bedding. Crossbedding may indicate that some of the sandstones were deposited by normal marine currents.

If we assume that a virtually complete section of 6,000–8,000 feet of Upper Cretaceous strata is preserved in the mapped area, and if we assume that displacement is small along strike-slip faults intervening between the exposures in the East Bay region and those on the east flank of the Diablo Range, then Upper Cretaceous strata thickened southeastward to 30,000 feet or more along the west side of the Sacramento and San Joaquin Valleys (Briggs, 1953, p. 419–421;

Bailey and others, 1964, p. 13). Thus, the Upper Cretaceous strata in the East Bay region were deposited west of the axial part of the miogeosynclinal basin of deposition of rocks of Great Valley facies. Generalized regional correlations are shown in figure 5.

At present, Upper Cretaceous eugeosynclinal Franciscan rocks lie to the west on San Francisco Peninsula. To explain the distribution of Upper Cretaceous rocks of miogeosynclinal facies nearly juxtaposed against eugeosynclinal rocks of the same age or slightly older age, one must invoke strike-slip faulting of many miles along the Hayward-San Andreas fault system, oblique rifting, or westward thrust faulting of miogeosynclinal facies over the eugeosyncinal facies. These hypotheses are developed in considerable detail by Bailey, Irwin, and Jones (1964, p. 158–165).

TERTIARY SEDIMENTARY ROCKS

PALEOCENE STRATA

PINEHURST SHALE

Along Pinehurst Road and along the ridge northeast of Redwood Creek, beds of siliceous shale and thin, hard, light-colored—white to tan—sandstone are exposed over a distance of about 1¼ miles. The beds of sandstone range from 1 inch to about 1 foot in thickness, and the intervening siliceous shale beds have similar thickness (fig. 6). These beds contain an abundant radiolarian fauna and a sparse foraminiferal fauna at localities B8006, B8021, and MF766, which indicate Paleocene age (M. C. Israelsky, written commun., 1963; see also, Case, 1963, app. 18). As far as can be determined from slumped exposures, these beds conformably overlie the unnamed variegated shales that contain an undoubted Late Cretaceous fauna.

This distinctive siliceous unit is here named Pinehurst Shale for exposures along Pinehurst Road in sec. 36, T. 1 S., R. 3 W., designated the type locality. The maximum exposed thickness of the unit is about 500 feet.

Age and correlation.—Foraminifera collected by D. H. Radbruch from the NE¼ sec. 36, T. 1 S., R. 3 W., at MF766, have been identified by M. C. Israelsky (written commun., 1963) as indicative of Paleocene age, probably Ynezian Stage. Thus, these beds are equivalent in age to part of the Martinez Formation in the Pacheco syncline area, 10–15 miles northeast of the exposures on Pinehurst Road (Mallory, 1959, p. 29, fig. 7) or to the Vine Hill Sandstone of Weaver (1953, p. 21–30). Lithology of the beds in the Pacheco syncline area is very dissimilar to that of the beds of the Pinehurst, and a major facies change must be present between the two areas if the Pinehurst and Martinez are correlative.

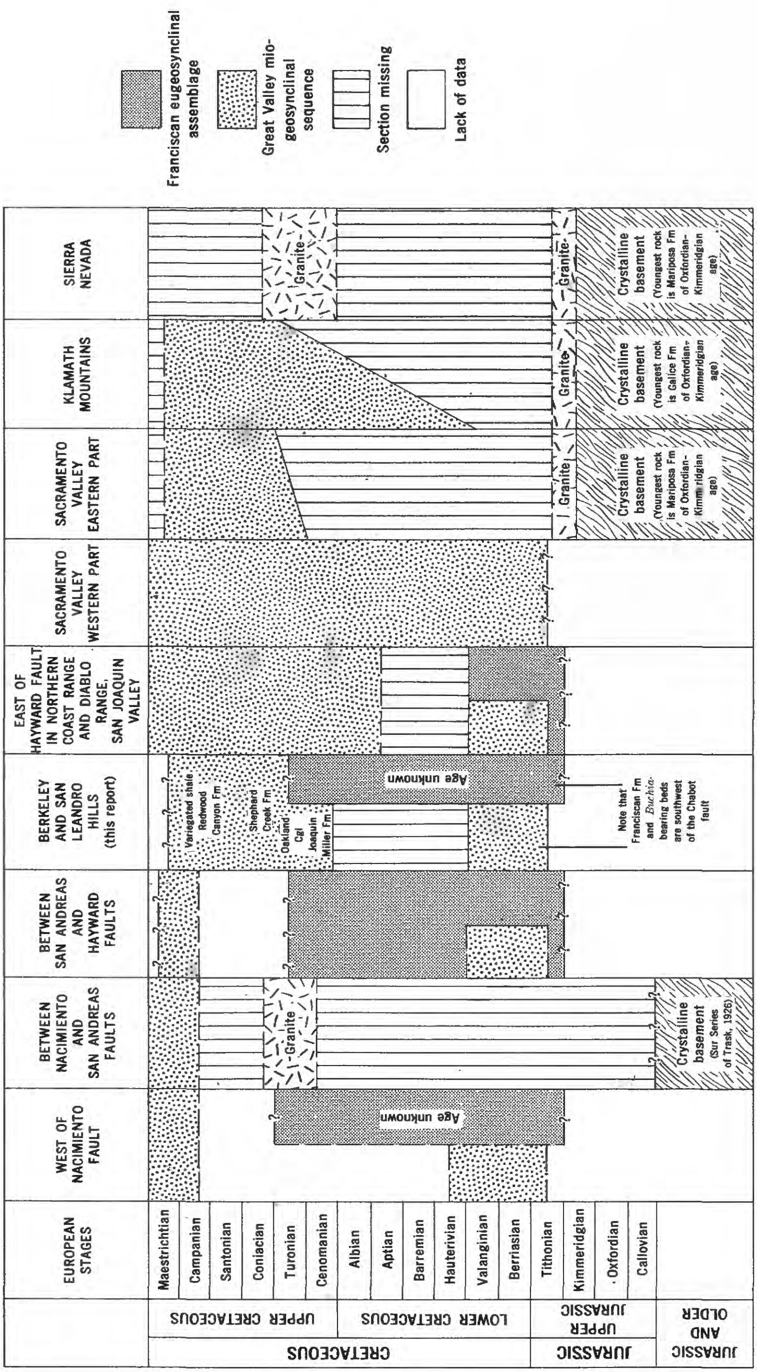

FIGURE 5.—Correlation chart of upper Mesozoic rocks of the Coast Ranges, Great Valley, Klamath Mountains, and Sierra Nevada. (Modified from Bailey and others, 1964, fig. 23, p. 123.)

FIGURE 6.—Pinehurst Shale exposed on Pinehurst Road on ridge southeast of Upper San Leandro Reservoir. Sandstone dike cuts diagonally across siliceous shale and thin resistant sandstone of the formation.

EOCENE STRATA

Eocene strata have been found within the area previously mapped by Lawson as "Chico formation." They extend in a band from the ridge northeast of Redwood Creek northwestward nearly to the Hayward fault zone near Lake Temescal. These lower Tertiary beds are similar in many respects to the Cretaceous beds, and it is thus difficult to distinguish them in the field, except on the basis of contained fossils. In general, however, Eocene sandstone is finer grained than the Upper Cretaceous sandstone; it contains a higher proportion of glauconite, and it is much more fossiliferous. Fossils indicate that these strata are equivalent to the Capay Formation, and possibly to the Domengine Formation, according to J. W. Durham (see Case, 1963, app. 19), so that a fairly restricted time range is represented. The maximum preserved thickness of these beds is unknown, but it is probably about 1,000 feet.

Sandstone beds are most abundant in the sequence, although beds of shale are common. Minor amounts of conglomerate are found, and thin beds of fossiliferous limestone crop out on the crest of the ridge northeast of Redwood Creek. The sandstone is fine grained and equigranular, and it consists of abundant quartz and lesser amounts of potassium feldspar and volcanic lithic fragments.

Elsewhere in the region, Eocene strata have been described in the Martinez area by Weaver (1949, p. 52–64; 1953, p. 21–35), in the Mount Diablo region by Colburn (1961), as well as others, in the Las Trampas Ridge area by Ham (1952, p. 7–8), and in the Briones Valley quadrangle, northeast of the Franklin fault, by Lawson (1914). Hall (1958, p. 14–15) described a calcareous unit—the Tolman Formation—from the Pleasanton area and assigned the unit to the Eocene.

Eocene strata in the Berkeley Hills, though now faulted, possibly were once continuous with exposures in the Las Trampas Ridge, Walnut Creek, and Briones Valley quadrangles. As Eocene beds are petroleum and gas producers elsewhere in this part of California, the whole area between the Berkeley Hills and the exposures of Eocene strata near the Franklin and Sunol faults farther east must be considered a potentially productive province.

Contact relations of Eocene strata with the Monterey Group are obscure. The contact is an inferred fault—the San Leandro Creek fault—on the northeast, but the slope along which the contact must run is heavily covered with redwood and eucalyptus trees and chaparral, and exposures are exceedingly sparse. Many investigators have postulated an angular unconformity between the Cretaceous or lower Tertiary beds and the Monterey Group, but no conclusive evidence of this was found in the area mapped. Hall (1958, p. 44) and Robinson (1956) presented evidence that beds of the Monterey Group overlie Cretaceous beds with angular unconformity.

Age and correlation.—On the basis of the invertebrate fauna at localities B8005, B8007, B8008, B8009, B8010, B8012, B8013 (Case, 1963, app. 19), M2057, and M2058 (F. S. MacNeil, written commun., 1961), the Eocene strata in the Berkeley Hills is of Capay or Domengine age, the best collections indicating Capay, according to J. W. Durham and F. S. MacNeil (see Case, 1963, app. 19). These beds are thus equivalent to parts of the Capay Shale or Las Juntas Shale in the Martinez district (Weaver, 1949, p. 47–53; 1953, p. 21–35). Microfossils at localities MF536, MF800, and MF801 indicate that part of the sequence is Ynezian, according to M. C. Israelsky (written commun., 1961, 1964).

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