GEOLOGY OF THE ORCHARD PEAK AREA, CALIFORNIA

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ABSTRACT

The Orchard Peak area includes 70 square miles at the southern end of the Diablo Range and lies principally in northwestern Kern County. The area is situated between the San Joaquin Valley on the northeast and the Temblor Range on the southwest.

Rocks in the area range in age from Late Jurassic (?) to late Miocene. More than 26,500 feet of marine sedimentary rocks are exposed, including about 6,300 feet of Eocene and Miocene beds, at least 16,500 feet of Upper Cretaceous, and about 3,700 feet of Lower Cretaceous (?) strata. The Eocene and Miocene beds are part of a transgressive marine overlap of Tertiary upon Cretaceous strata. Seven new Cretaceous formations are recognized and named. These are, in ascending order: the Badger shale, Risco formation, Johnson Peak formation, Aguila sandstone, Serpiente sandstone, Moonlight formation, and Red Man sandstone. In addition, an impressive but unmeasurable thickness of Upper Jurassic (?) shales (herein named the Hex formation) crop out, forming the core of a diapir fold. Large amounts of serpentine and other Franciscan-type rocks lie in fault contact with the Mesozoic and Tertiary strata.

Striking facies changes are characteristic of the Cretaceous formations. Fossils are very scarce or absent throughout most of the Cretaceous section, but locally they become abundant in the uppermost units where they include cephalopods, pelecypods, gastropods, hydrocorals, and foraminifers.

The Orchard Peak area, situated only 4 miles from the San Andreas rift, is one of the most complexly deformed Cretaceous terranes in California. Most of the mapped area comprises the upper plate of the Antelope Valley thrust which has moved at least 6½ miles south-

† *Doctoral thesis, Stanford University, 1954. Manuscript submitted for publication April 1957.*

* *Geologist, United States Geological Survey.*

ward, bringing Cretaceous rocks to rest upon Miocene strata. This upper plate has been broken by a second important fault, the Aido Spring thrust, which has brought Lower Cretaceous (?) beds to rest upon rocks of late Late Cretaceous age, producing a stratigraphic separation of nearly 3 miles. Serpentine has been intruded in a cold state along both thrust surfaces. Several lesser thrust faults cut the upper plate of the Antelope Valley thrust, forming an imbricate pattern. In addition to the southward-moving thrusts just mentioned, there are two thrusts in which movement was probably toward the west or southwest. Numerous right-lateral tear faults developed during the thrusting; one of these, the Polonio Pass fault, has a displacement of more than 5,000 feet. Two piercement anticlines occur within the mapped area, one with a core of serpentine, the other with a core of bentonitic clays containing belemnites of Late Jurassic (?) and Early Cretaceous age. Three of the six synclines in the area contain Eocene rocks which rest unconformably upon Cretaceous beds.

The deformation in the area is at least post-late Miocene, probably late Pliocene or early Pleistocene. Other workers have suggested that the San Andreas rift may have been caused by regional north-south compression. The writer believes that most of the structural features of the Orchard Peak area are likewise the result of north-south compression, although there is some indication that there was a later reorientation of the compression, at least locally, to produce the west- or southwestward-moving thrusts.

The Cretaceous sediments were apparently derived from several different sources, though probably in large part from the ancestral Sierra Nevada, and were deposited in a shallow sea whose bottom subsided in the manner of a geosyncline. Nearby land areas must have been well forested.

Petroleum prospects in the Orchard Peak area seem moderately good. The impermeable sole of the Antelope Valley thrust could trap petroleum in the Miocene beds of the lower plate, providing that structural and stratigraphic conditions in the lower plate were favorable. Several producing oil fields are situated close to the mapped area. Other products of possible economic interest include drilling mud and water.

INTRODUCTION

Location and Accessibility. The Orchard Peak area is situated in the southern Coast Ranges of California at the extreme southern end of the Diablo Range (fig. 1). This range forms the western margin of the San Joaquin Valley. The mapped area covers 70 square miles and occupies adjacent parts of four counties: Kern, San Luis Obispo, Monterey, and Kings. Parts of four 7½-minute topographic quadrangles are included: Pyramid Hills, Sawtooth Ridge, Annette, and Tent Hills (see plate 1).

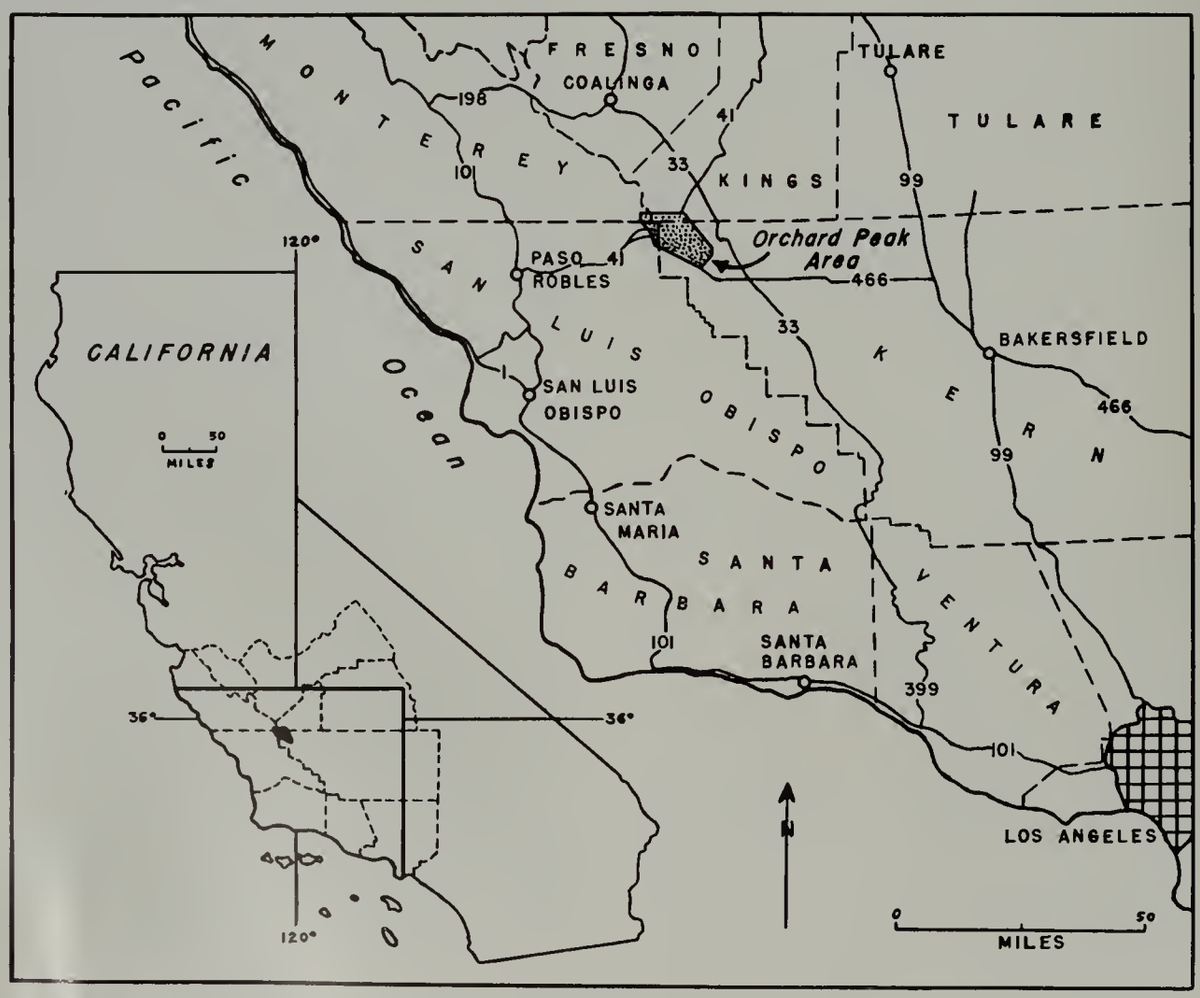


Figure 1. Index map showing location of Orchard Peak area.

U. S. Highway 466, which bounds the Orchard Peak area on the southwest, runs between Paso Robles (28 miles to the west) and Bakersfield (71 miles to the southeast). State Highway 41 cuts across the area along Cottonwood Canyon and links Paso Robles with Coalinga and Fresno. Numerous dirt roads, maintained by ranchers, provide access to many parts of the area.

Topography and Regional Setting. The Orchard Peak area lies at the southern end of the Diablo Range, which extends northward for 115 miles along the west side of the San Joaquin Valley. On the southwest the area is flanked by Antelope Valley and the Temblor Range, and on the northeast by McLure Valley. Maximum relief in the area is more than 2,300 feet; the highest point, Orchard Peak, is 3,125 feet above sea level. Avenal Ridge, a homocline trending west- to northwestward and having a precipitous south-facing scarp, forms the chief topographic feature in the southern two-thirds of the area. North of Cottonwood Canyon three folds which trend northwest form a series of ridges and valleys.

The Upper Cretaceous rocks which make up most of the Orchard Peak area are part of a band of such strata which extends northward for at least 320 miles along the west side of the Central Valley. Just north of the Panoche Hills, which lie about 70 miles northwest of the mapped area, these strata exceed 33,000 feet in thickness and constitute the thickest Upper Cretaceous section in North America (Briggs, 1953, p. 419).

Purpose and Scope of Report. The purpose of this report is to describe in detail the stratigraphy, structure, and paleontology of a little-known area of Cretaceous rocks and to deduce therefrom the geologic history of the region. Some tentative correlations of stratigraphic units with those of other regions will be discussed.

The Cretaceous rocks described in this report have been subdivided solely on the basis of lithologic differences. Because of the abrupt facies changes so characteristic of the California Cretaceous, most of the units could not be correlated outside of the area with any certainty. Accordingly, it has been necessary to introduce several new names.

Figure 2 indicates the subdivisions of the California Cretaceous by various authors. It should be noted that no specific correlations are implied on this chart between the Orchard Peak units and those of previous authors. Some tentative correlations are offered on a later page.

Field Work and Methods. Most of the field work was carried out during a 6-month period in 1953. Mapping was done on aerial photographs of scale 1:20,000. Geological data were transferred by means of a vertical sketchmaster onto a topographic base composed of portions of the following 7½-minute quadrangles: Tent Hills, Annette, Sawtooth Ridge, and Pyramid Hills—all published by the U. S. Army Corps of Engineers.

This composite base map has a scale of 1:31,680. These quadrangles are not marked off in sections, townships, and ranges; instead, the Army's thousand-yard grid

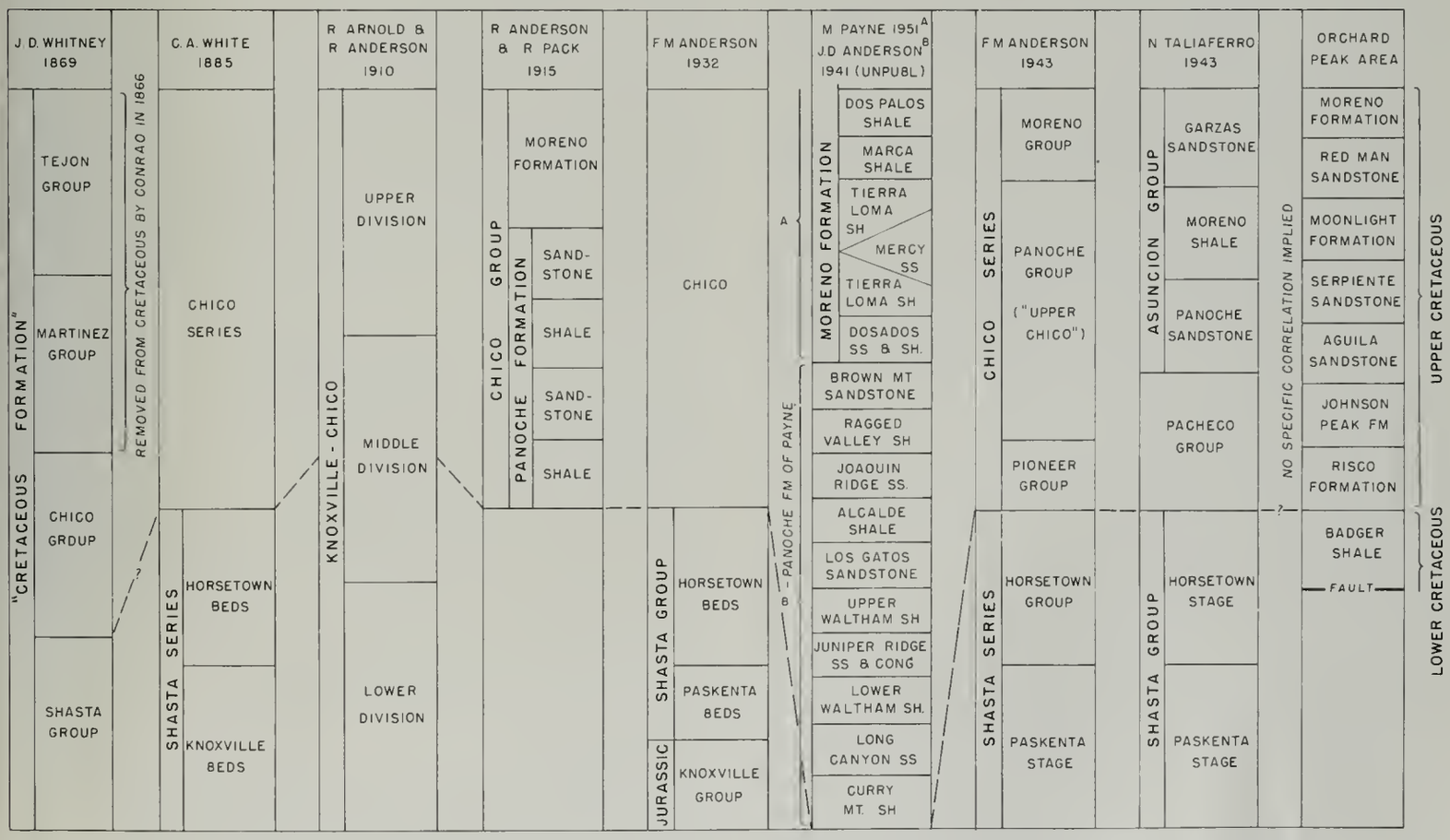


Figure 2. Cretaceous stratigraphic terminology.

system of coordinates is employed. When it is desirable to pin-point specific locations in the present report, this coordinate system (marked on the margins of the geologic map—see plate 1) will be used. In the geologic sections the theoretically most probable curvature of strata at depth was constructed geometrically. Stratigraphic sections were measured by hand-leveling.

Previous Work. In 1907 Arnold and Anderson (1910, pp. 31, 51, 55, plate 1) mapped a small portion of the Orchard Peak area as part of a regional study. This portion includes the eastern part of the Three Peaks anticline of the present report.

Arnold and Johnson (1910) visited the Orchard Peak-Devil's Den region in 1908 during a reconnaisance of California oil districts. They report that "the shales of the Knoxville formation predominate . . . " among the rocks of this region and that the conglomerate beds east of Orchard Peak "may locally mark the line between the Chico and Knoxville formations."

In 1916 English (1921, pp. 9-10) mapped the areal geology of northwestern Kern County at a scale of about 1:126,720. His map includes most of the Orchard Peak area and shows the Cretaceous strata as undifferentiated. Few structural features were shown on the map.

Taff's (p. 4, also fig. 1) geologic map, published in 1933 at a scale of 1:633,600, shows the southernmost portion of the Orchard Peak area as composed of undifferentiated Franciscan-Cretaceous and Eocene rocks.

In 1935 Clark (plate 89) published a map of the Mount Diablo and Coalinga areas (scale 1:126,720) which includes the Orchard Peak area. Clark shows the Cretaceous rocks near Orchard Peak as undifferentiated Shasta-Chico, the Eocene rocks of Devil's Den as Domengine, and the Miocene rocks northwest of Antelope Valley as Santa Margarita.

Taliaferro (1943a, p. 128, 133) noted the presence of "ash beds in the Lower Cretaceous . . . south of Orchard Peak" and states that there his Asuncion group lies unconformably on the Shasta group.

In 1947 Wagner mapped the Sawtooth Ridge quadrangle at a scale of 1:31,680 as part of a master's thesis. He also divided the Cretaceous rocks into Shasta and Asuncion. At Sawtooth Ridge and Devil's Den he found several diagnostic fossils. Wagner recognized the piercement nature of the Avenal Ridge anticline of the present report.

In 1949 the Tent Hills quadrangle was mapped by Herrera and the Annette quadrangle was mapped by Peryam, both as master's theses and at a scale of 1:31,680. Herrera, too, followed Taliaferro's divisions of the Cretaceous. Within the "Asuncion" Herrera recognized "five broad lithologic sequences" but was unable to decide whether they deserved formational status. His report gives good descriptions of the Cretaceous rocks, and at Red Rock Canyon he found several Upper Cretaceous fossils. Peryam's map shows the Cretaceous as undifferentiated; like Wagner and Herrera, his main interest lay in mapping the Tertiary units.

Acknowledgments. The writer is indebted to the Standard Oil Company of California for generous financial and technical assistance throughout the course of this investigation. Most of the microfossils listed in this report were identified by J. D. Bainton and his associates at the Company's micropaleontological laboratory. William Gealey and John Mann of the Exploration Department examined the field map at various stages. Louis Christian helped the writer collect a series of shale samples for microfossil analysis.

The Union Oil Company of California kindly provided comfortable living quarters in an inhospitable region over a period of 7 months. Thanks are especially due to Jennings Peterson, District Foreman of the Northern Pipeline Division, who made these accommodations available and rendered many other kindnesses.

The Shell Oil Company generously provided funds for illustrative material through its Grant for Fundamental Research.

The writer gratefully acknowledges the help of Dr. Myra Keen and Dr. Earl Packard of Stanford University in the identification of megafossils, and other assistance. Professor Leslie Bairstow of the British Museum (Natural History) and Dr. J. A. Jeletzky of the Geological Survey of Canada examined fragments of belemnites. Professors Colin O. Hutton and Robert R. Compton of Stanford University kindly examined several thin sections.

I am grateful to Alfred L. Bush of the U. S. Geological Survey for a careful, critical review of the report in the light of his penetrating geologic insight.

Especial appreciation is due Professor Siemon Wm. Muller of Stanford University for offering encouragement and invaluable advice throughout the investigation. Professor Muller spent a week in the field with the writer, helping to solve some of the more difficult structural problems.

RESUMÉ OF STRATIGRAPHY

The rocks of the Orchard Peak area (see fig. 3) are chiefly Upper Cretaceous; the maximum thicknesses of Upper Cretaceous formations total more than 16,000 feet. An additional 3,700 feet of strata may be Lower Cretaceous, although paleontological evidence is lacking. Eocene rocks occur in the troughs of three synclines, and Miocene beds crop out along the southwestern border of the area. The total thickness of the Tertiary section exceeds 6,300 feet.

Concretionary sandstone makes up about two-thirds, by volume, of the rocks exposed in the Orchard Peak area. The remainder consists of shale and minor amounts of conglomerate, tuffaceous material, chert, and serpentinized peridotite.

Because of facies changes and a scarcity of fossils, most of the Cretaceous rocks of the area could not be definitely correlated with recognized Cretaceous formations elsewhere. Consequently, it was necessary to distinguish and name seven new Cretaceous formations, some of which have been divided into members.

MESOZOIC ROCKS

Upper Jurassic (?)

Hex Formation

The name "Hex formation" is here proposed for a stratigraphic unit whose type locality is Hex Hill, just south of Devil's Den near the eastern edge of the mapped area (coordinates 1093/1419—see plate 1). The

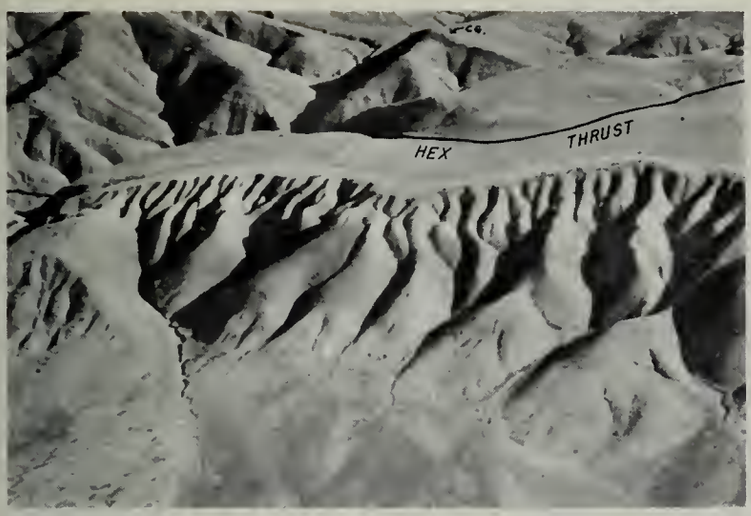


Photo 1. Bentonitic clays of the Hex formation at its type locality, Hex Hill. This unit occupies the core of the Avenal Ridge piercement anticline. Serpiente sandstone forming upper plate of Hex thrust in background.

name, meaning "witch" in some sections of the country, is suggestive of the peculiar, seemingly "bewitched" structural and stratigraphic aspect of these rocks.

The Hex formation crops out east of Orchard Peak as a single band about half a mile wide and more than 4 miles long, paralleling the base of the scarp formed by Avenal Ridge. The unit occupies the core of the Avenal Ridge piercement anticline. Apparently, the soft, plastic shales of the Hex formation, originally at an unknown depth below their present position, were squeezed up through the overlying formations during folding and thrust-faulting of the Avenal Ridge anticline. Because of this plastic deformation, the true thickness of the Hex formation cannot be determined.

The precipitous slopes of Hex Hill are strongly dissected to form a badland of sharp ridges and gullies (photo 1). The light gray, crumbly soil supports little vegetation. Numerous shallow basins up to 15 feet in diameter dot the alkali-incrusted surface of the ground.

At Hex Hill the dominant rock type is a lead-gray, bentonitic clay shale which weathers to light gray at the surface of the ground and to chocolate brown beneath. Locally the clay is sufficiently bentonitic that at one time it was mined for use as rotary drilling mud.

West of Hex Hill the topography becomes more subdued, and the bentonitic clay gives way to light blue tuffaceous shale which weathers brownish or grayish. Thin-section examination of this rock reveals shards of volcanic glass, fine-grained quartz and feldspar, and clays, mostly montmorillonite. Associated with the shale are thin plates, masses, or veins of gypsum up to 8 inches thick.

Scattered throughout the Hex formation are irregular masses of dark gray to grayish cream-colored limestone which weathers to white. The limestone is unfossiliferous. Locally it is oolitic. Less commonly limestone also occurs as discoidal or cannonball nodules, mostly septarian, up to one foot in diameter.

Here and there throughout the formation are thin Cretaceous-type sandstones, commonly overturned. These beds, many of which are thinly laminated arkosic sandstones, are probably part of the Serpiente sandstone

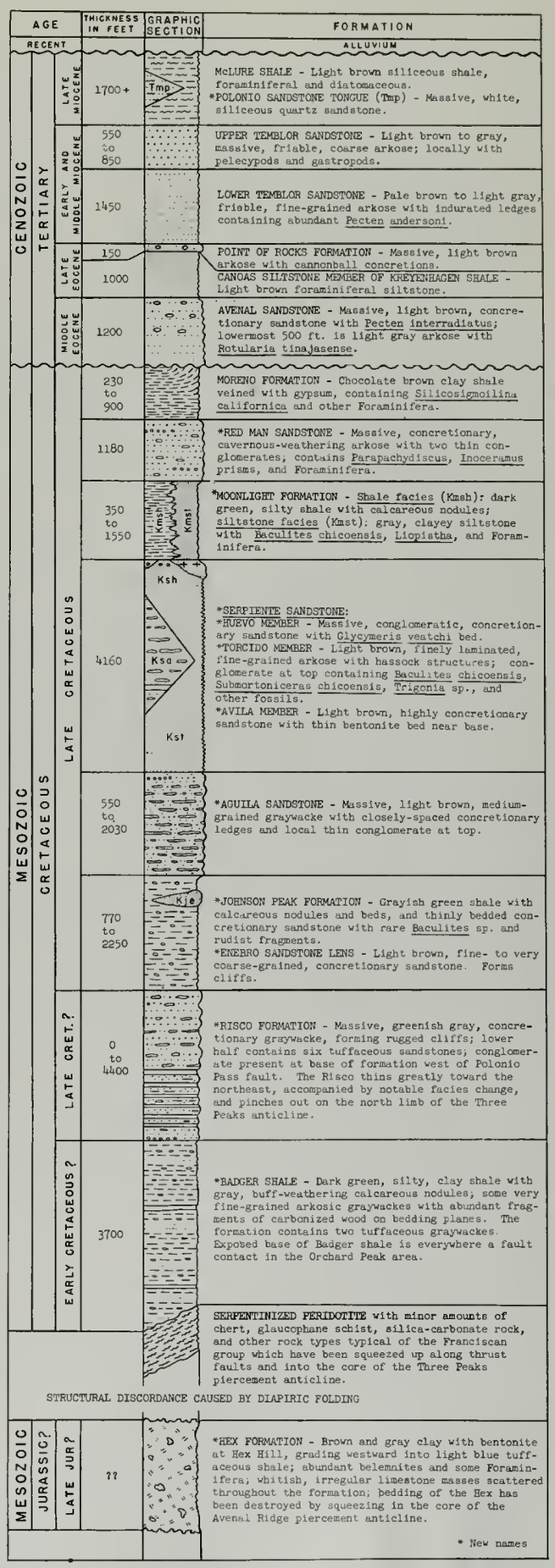


Figure 3. Composite geologic column, Orchard Peak area.

which has been engulfed by the diapiric Hex formation and are therefore not to be considered as part of the Hex.

Microfossils: The following microfossils * were recovered from the bentonitic clay:

South-central part of Hex Hill (1092.7/1419).[1]

Globorotalia cf. G. micheliniana VR [2]
Cyclammina? sp. VR
Haplophragmoides sp. VR
Bulimina? sp. VR
Nassellina sp. (radiolarian) VR
Cytherella cf. C. bullata (ostracod) VR

The radiolarian is of a type restricted to the Mesozoic, and a probable Late Cretaceous age is suggested by the general appearance of the fauna and by the comparative development of the *Globorotalia* and the *Cytherella*.

West end of Hex Hill—Standard Oil Company Loc. No. 5194 (1091.9/1418.9) and Loc. No. 5195 (1091.9/1419.2).

Glomospira cf. G. gordialis VR
Bathysiphon sp. C
Cribrostomoides (?) sp. C
Marssonella oxycona? VR
Haplophragmoides sp. VR

J. D. Bainton of the Standard Oil Company gives the following summary of these samples:

"The above samples contain only arenaceous foraminifera. *Glomospira gordialis* . . . ranges from the Austin chalk through the upper part of the Taylor marl in the Gulf Coastal region. In relation to Goudkoff's (1945, pp. 956-1008) stages and zones, *Glomospira gordialis* would have a range from the Upper Cachenian (G-1 zone) through the Upper Weldonian (F-1 and F'-1 zones). This would place these samples in the Panoche formation and possibly equivalent to the Joaquin Ridge sandstone or the Alcalde shale. The faunas . . . are not definitely definitive of age and therefore the age assignments . . . should not be considered conclusive."

Megafossils: Fragments of belemnites which have weathered out of the clay are the only megafossils which were found in the Hex formation. Prof. Siemon Wm. Muller and the writer collected a quantity of belemnite fragments and sent them to Prof. Leslie Bairstow at the British Museum (Natural History) for identification. After examining the fragments, Prof. Bairstow concluded:

"I can only state that the evidence is less adequate than I could wish, but that I suspect the belemnites to be Upper Jurassic. If it is legitimate to interpret *Cylindroteuthis* widely enough to include for example *Belemnites absolutus*, as Stolley did, perhaps the present specimens too may be considered to fall within the limits of *Cylindroteuthis*, though they are by no means typical of the genus. But, as I say, these conclusions are only provisional . . . ."

A belemnite fragment was also submitted to Dr. J. A. Jeletsky of the Geological Survey of Canada for examination. Dr. Jeletsky expressed the following opinion:

". . . the following suggestions are to be considered quite tentative. It would appear to me that the fragment belongs to large and sturdy *Belemnopsis* probably of the group of *Belemnopsis sulcatus* Phillips or *Belemnopsis gerardi* . . . . Its being of the group of Indo-Pacific *Belemnopsis gerardi* Oppel, 1863 . . . appears to be more probable . . . . Should the above assumption be correct . . . Upper Jurassic age would be indicated for the beds containing it."

John P. Wagner (1947) reports that several species of belemnites occur in the unit designated in the present report as the Hex formation, including *Acroteuthis winslowensis* Anderson, 1938. This form was identified by Prof. J. Wyatt Durham of the University of California at Berkeley; subsequently the identification was confirmed by Dr. J. A. Jeletsky who stated that the form should be "tentatively assigned to early to mid-Lower Cretaceous (not younger than the Barremian, though)."

Thus the fossils which have been collected from the Hex formation have been assigned tentatively to the Late Jurassic, Early Cretaceous, and Late Cretaceous. It is possible that all three ages are represented by the Hex, but this possibility cannot as yet be proved because none of the age assignments can be stated as being conclusive. For the sake of convenience, the Hex formation will be designated provisionally in this report as Upper Jurassic(?).

The contacts of the Hex with other formations are everywhere discordant. The unit rests in fault contact against the Badger shale, Risco formation, Serpiente sandstone, Moonlight formation, and probably the Red Man sandstone (contact concealed by alluvium).

Franciscan-Type Rocks

Rocks typical of the Franciscan group—chiefly serpentine and chert—occur abundantly along the traces of the Antelope Valley and Aido Spring thrusts and also in the core of the Three Peaks piercement anticline north of Cottonwood Canyon.

Serpentinized peridotite is by far the most abundant. The occurrence of the serpentine bodies along thrust faults strongly suggests that the serpentine was squeezed up in a cold state along the thrust surfaces by the orogenic pressures that produced the faults. This conclusion is corroborated by the complete absence of baking of the shale along the contacts and by the fact that in places most of the joint planes in the serpentine dip in the same direction as the thrust surfaces. The serpentine mass in the central part of the Three Peaks anticline was apparently squeezed up into the anticlinal core during the folding. Sedimentary strata along the axis were ruptured and overturned by the plastically flowing serpentine. This structure is only one of several such diapir folds which are found along the Diablo Range as far north as Mt. Diablo.

Numerous boulderlike masses of red and green chert, commonly up to 10 feet in diameter, are embedded in the serpentine at many places. In the Three Peaks anticline masses of dark red chert occur which are several tens of feet in diameter; here the chert is bedded in layers 1 inch to 6 inches thick. These large masses of bedded chert were probably torn from their normal position in the sedimentary series far down in the core of the anticline and carried upwards by the serpentine during the process of piercement.

Glaucophane schist, one of the rock types most characteristic of the Franciscan group elsewhere in California, occurs only at the extreme eastern end of the Aido Spring serpentine body.

Another minor rock type found in the area is silica-carbonate rock, formed by the hydrothermal alteration of serpentine (Knopf, 1906, pp. 425-430). A single small

* Except where otherwise stated, all microfaunal identifications and interpretations in this report were made by the staff at the micropaleontological laboratory of the Standard Oil Company of California.

[1] Coordinates of fossil localities, shown on the geologic map (plate 1).

[2] The following notations will be used in this report to indicate the frequency of occurrence of microfossils in the samples: VR = very rare, R = rare, C = common.

outcrop of silica-carbonate occurs in the northwest corner of the Orchard Peak area, on the trace of the Antelope Valley thrust (see geologic map, plate 1). This resistant knob is colored a rusty brown by iron oxides and consists principally of an intimate mixture of chalcedony and carbonates, probably magnesian. The rock is highly porous and irregular in texture, complexly criss-crossed with veinlets of chalcedony and carbonate, enclosing lenticular areas of chalcedony or carbonate or both. Just to the north of this knob the thrust trace is marked by a stringer of serpentine mixed with silica-carbonate rock.

Lower Cretaceous (?)

Badger Shale

South of Orchard Peak and to the northwest is a thick sequence of dark shales which previous workers have designated as "Shasta." In the present report this shale unit has been renamed the Badger shale in view of the fact that it does not conform to the original definition of Shasta. F. M. Anderson (1932, pp. 313-315) states:

> "According to its original definition . . . the Shasta group embraced strata ranging in age from the Gault to the Neocomian, as known in the European scale. We may now logically and with advantage adhere to this definition and accordingly exclude, as should always have been done, any strata not coming within its defined scope."

The only fossils which have been found in the Badger shale are arenaceous foraminifers, pelecypods, corals, and plant fragments—all indeterminable—which were collected by the writer, and some so-called "Icthyosaur" bones reported by N. L. Taliaferro.* These bones, which the writer examined at the California Institute of Technology, are extremely fragmentary and encrusted with calcite crystals. Mr. William Otto†, Preparator of Vertebrate Paleontology, considers the remains as "questionably saurian." Being unidentifiable, the bones cannot be used to date the enclosing shale. Without paleontological evidence as to age, then, the Shasta group as originally defined cannot be recognized in the Orchard Peak area.

* Oral communication.

Photo 2. Typical exposure of Lower Cretaceous (?) Badger shale, Risco Canyon, south of Orchard Ridge.

The Badger shale (photo 2) crops out in the southern and western parts of the area and in the core of the Three Peaks anticline to the north. Badger Ridge, 1½ miles west of Cottonwood Pass (map coordinates 1076.5/1427.8) is chosen as the type locality (see measured section B-B′, fig. 5). Measured section A-A′ (fig. 4) south of Orchard Ridge is supplementary to the type section, although both the upper and lower contacts in section A-A′ are thrust faults. Although the Badger is one of the thickest formations in the area—3,620 feet at Badger Ridge and 3,710 feet south of Orchard Ridge—its total thickness is not known, for its exposed base is everywhere a fault contact.

The formation consists of about 75 percent shale,* calcareous nodules, and siltstone; and about 25 percent arkosic graywacke. The shale is dark green, weathering to brown or dark gray. It is silty, quite hard, and noncalcareous. In places the shale fractures spheroidally. Joint surfaces weather a dark reddish purple.

Numerous dark gray calcareous nodules which weather buff or white are found throughout the Badger shale. These range in shape from oblate spheroids and circular or elliptical discoids half a foot to 3 feet in diameter to bluntly lenticular bodies up to 1 by 5 feet. At the type locality these nodules lie from a few inches to 2 feet apart along beds spaced 5 to 10 feet apart. In places the nodules appear to have "grown together," presenting a beaded aspect. The rock is exceedingly dense and fine grained.

Beds of calcareous siltstone from 2 to 12 inches thick also occur in the Badger. These resemble limestone and weather white or buff. Weathered surfaces of such beds commonly display delicate laminae of very fine light brown sand.

Throughout the formation are numerous thin arkosic graywackes which are light to dark gray with a faintly greenish cast, weathering to light brown. Typically these beds range from a fraction of an inch to 8 inches in thickness. Most of the graywackes in the Badger shale are very fine grained, well sorted, and exceedingly thinly laminated, implying deposition in quiet water. Bedding planes display a profusion of clay chips and carbonized wood fragments. Ripple marks, cross-bedding, graded bedding, and flow casts are common. At many places submarine flowage has produced small asymmetrical folds, a few up to 2 feet across.

The following is the composition of an arkosic graywacke in the Badger shale as estimated from a thin-section; it is typical except that glauconite is actually much more abundant in the graywackes than this thin-section would indicate:

† Oral communication.

* Most of the rocks referred to as "shale" in this report are actually massive mudstones or claystones; a true shale is either laminated or fissile (Pettijohn, 1949, p. 269). However, because long-established usage in California has extended the term "shale" to include massive, exceedingly fine-grained sedimentary rocks, this usage will be adhered to in the present report.

BADGER SHALE

Measured section A-A' Total thickness: 3710 feet
Annette quadrangle - Coordinates: 1084.0/1420.0; 1084.1/1421.6
Southwest of Orchard Peak

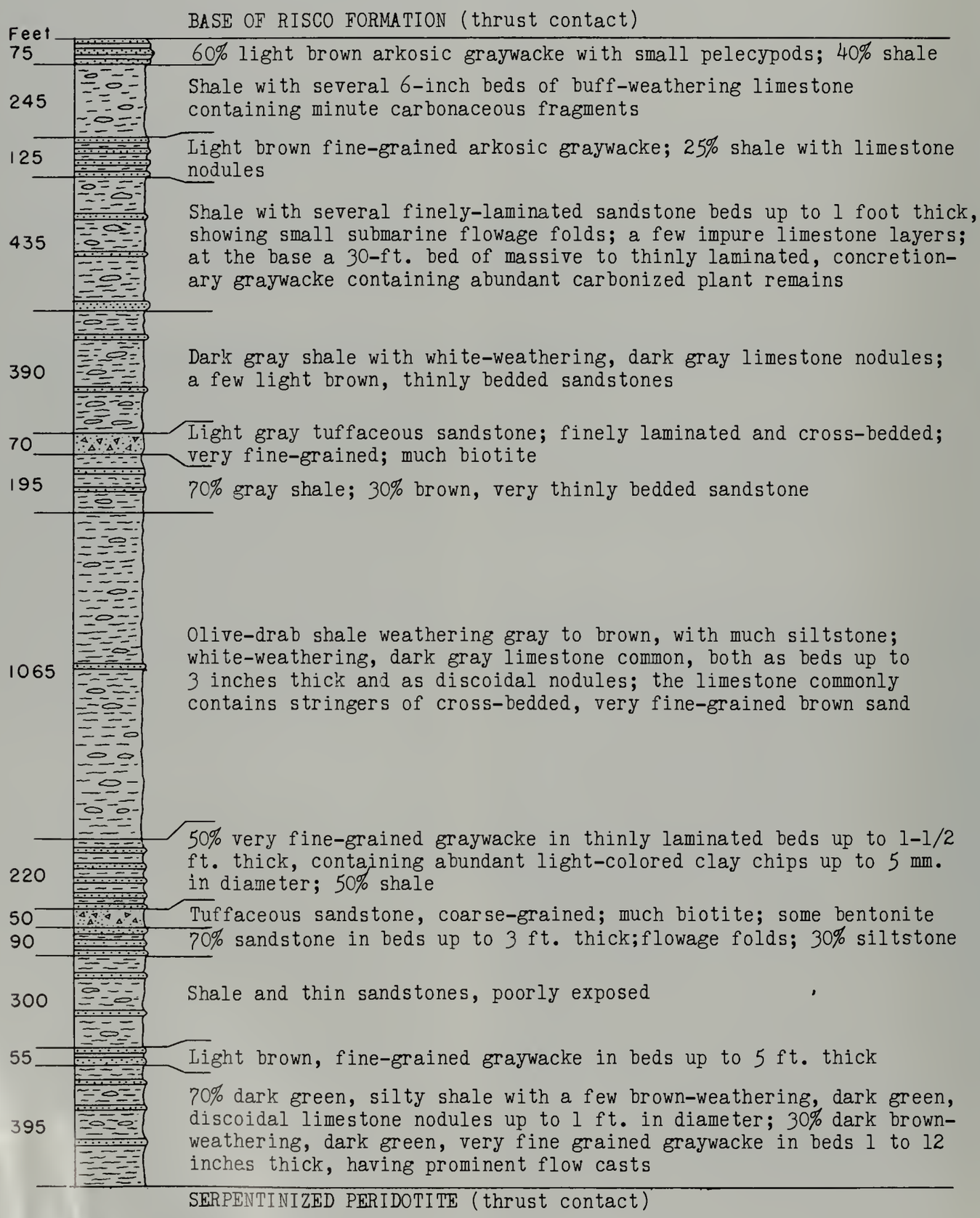
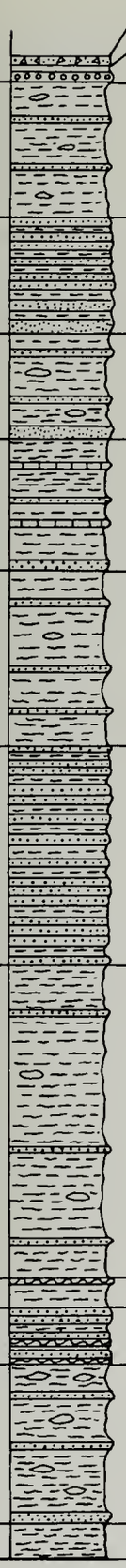


Figure 4. Measured section A-A' of Badger shale.

BADGER SHALE (Type Locality)

Measured section B-B' Total thickness: 3620 feet
Tent Hills quadrangle - Coordinates: 1077.0/1426.9; 1077.3 /1428.2
West of Cottonwood Pass



Feet	
15	Tuffaceous sandstone
23	Conglomerate - RISCO FORMATION (conformable contact)
340	Shale with a few beds up to 5 inches thick of very fine-grained, calcareous sandstone; poorly exposed
275	70% dark gray, very fine-grained arkosic graywacke in beds 1/4 to 6 inches thick; finely and evenly laminated; well sorted; glauconitic; 30% dark green shale
260	70% dark green shale with a few white-weathering discoidal limestone nodules up to 1 ft. in diameter; 30% very fine-grained sandstone in beds 2 in. thick, finely laminated
325	95% brown-weathering, finely jointed shale interbedded with buff-weathering, dark gray limestone in 3-inch beds spaced 3 to 6 ft. apart; 5% very fine-grained sandstone in beds 1 to 2 in. thick, finely laminated
435	Roughly 90% shale with 10% very fine-grained sandstone in beds up to 2 inches thick; poorly exposed
545	70% dark greenish gray, very fine-grained arkosic graywacke in hard, platy beds 1/4 to 6 inches thick, finely laminated; beds commonly occur in groups 8 inches thick; sandstone is well sorted and glauconitic; 30% dark gray shale without limestone nodules
775	Approximately 95% shale with 5% thin sandstones (upper 370 ft. poorly exposed); a 5-ft. sandstone bed near the middle has ripple marks (?) 3 to 6 ft. across; a few layers of dense, white-weathering limestone also occur, containing stringers of fine sand which displays small-scale cross-bedding and graded bedding
65	Shale with a 2-ft. limestone-nodular layer containing a breccia of dark igneous, metamorphic, and sedimentary rock fragments
140	80% sandstone in beds up to 1-1/2 ft. thick; two 3-ft. breccias as above; 20% shale
400	Dark gray shale with discoidal limestone nodules up to $1\frac{1}{2}$ ft. in diameter, both discrete and coalescing; interbedded with sandstone in beds 1 to 20 in. thick, spaced 1 in. to 3 ft. apart; ripple marks up to 2 ft. across; prominent flow casts; many carbonized plant remains
60	Dark green shale
	SERPENTINIZED PERIDOTITE (thrust contact)

Figure 5. Measured section B-B′ of Badger shale (type locality).

Quartz 20%
Feldspar 30%
Leucoxene (from sphene) 7%
Chlorite 7%
Epidote 5%
Calcite (detrital) 2%
Sphene 3%
Apatite < 1%
Biotite < 1%
Glauconite < 1%

Microgranular matrix 25%: clays, altered feldspar (sericite and clays), chert?, iron-rich chlorite or serpentine, and silica.

The Badger shale contains two tuffaceous graywackes with a minor admixture of bentonite. These marker beds crop out as conspicuous white bands running east and west across the countryside. South of Orchard Peak the uppermost volcanic bed lies two-thirds of the way above the base of the formation; it is 70 feet thick and can be traced continuously for more than 3 miles. About 1,500 feet lower in the formation is another tuffaceous bed, 50 feet thick, which can be traced continuously for nearly a mile and a half. Continuations of both beds, displaced northward along the Lupine and Polonio Pass faults, are found east of Blue Point Valley. These marker beds rise gradually in the section northwestward, until northwest of Cottonwood Pass the upper bed is found in the basal portion of the Risco formation; the lower bed, however, does not extend that far west. Assuming that the upper tuffaceous bed represents a time plane, the Badger shale evidently transgresses time lines, the shale beds south of Orchard Ridge having been deposited at a somewhat later time than their stratigraphic equivalents to the northwest.

Each of these tuffaceous graywackes comprises a series of thin beds which are up to 1 foot thick. The rock is light gray on fresh surfaces, weathering to pale lavender, pale yellow, or white. The beds are thinly and evenly laminated, although small-scale cross-bedding is common. The grains are very fine and have intergrown to produce an extremely dense, siliceous rock. Much bleached biotite is present. The following composition for one of the tuffaceous graywackes was estimated from thin-section:

Quartz 30%
Plagioclase, probably labradorite 25%
Volcanic glass shards (devitrified) 10%
Clays, including montmorillonite 10%
Chlorite (from alteration of biotite) 7%
Biotite 7%
Pyroxene 5%
Zircon < 1%
Apatite < 1%
Unidentified minerals in microgranular groundmass 5%

In the absence of diagnostic fossils, the designation of the Badger shale as Lower Cretaceous (?) can only be speculative. Lithologically the Badger shale of the mapped area resembles the Lower Cretaceous Horsetown and Paskenta shales of northern California; the shales of both areas are dark gray with calcareous nodules and thin interbeds of very fine-grained sandstone and siltstone. On the other hand, the Badger is quite different from the younger, lighter-colored shale units in the mapped area. However, this is not to be taken as a definite correlation with the Horsetown and Paskenta beds; further study is needed to establish any such equivalence.

The lower contact of the Badger shale is everywhere a fault, generally a thrust surface along which serpentine has been squeezed. South of Orchard Ridge the upper contact is likewise a thrust, although one of relatively minor displacement. A few Risco and Badger beds have been cut out by this fault (the Badger thrust), but otherwise the strata above and below the thrust surface are believed to be near their true stratigraphic position. Elsewhere in the Orchard Peak area the Badger shale appears to be conformably overlain by the Risco formation.

Upper Cretaceous (?)

Risco Formation

The Risco formation is a newly designated unit whose name, which means "crag" or "cliff" in Spanish, refers to the steep, craggy slopes typically underlain by the Risco. The type locality comprises the upper portions of both Risco Canyon (map coordinates 1085/1422, plate 1) and the next adjacent canyon to the west.

The Risco formation extends as a nearly continuous band of outcrop from the northwest corner of the Orchard Peak area southeastward, then eastward almost to Devil's Den where it ends abruptly against the Hex thrust. The Risco also crops out in the central part of the Three Peaks anticline.

At the type locality the Risco formation is 2,965 feet thick, and north of Antelope Pumping Station it attains a maximum thickness of about 4,400 feet. Northward it undergoes notable thinning and change of facies. In the Three Peaks anticline the maximum thickness of the Risco is 1,650 feet; only three-quarters of a mile to the northeast the unit has thinned to 430 feet, and a short distance farther north it pinches out altogether (compare measured sections C-C′, D-D′, and E-E′, figs. 6 and 7).

At the type locality the Risco formation is roughly divisible into three parts in the approximate thickness ratio (from bottom to top) of 2:3:5. The upper and lower portions consist of massive, concretionary, coarse sandstone, sandwiching a group of thin, finer-grained sandstones relatively free of concretions. Roughly the same ratio holds in the Three Peaks anticline, despite the thinning and facies change. At the head of Risco Canyon the formation consists of about 73 percent sandstone, 22 percent shale, and 5 percent tuffaceous material. In the Three Peaks anticline the Risco consists of 96 percent sandstone and 4 percent shale, with the tuffaceous beds altogether missing.

The massive sandstones of the Risco formation are graywackes, characteristically gray-green to dark gray where fresh, weathering to light gray. The greenish color of the fresh rock is distinctive of the Risco. Light brown beds are also common. Typically, several sandstones 1 to 4 feet thick occur one above the other for 10 to 15 feet; these groups of sandstone beds are separated by intervals of shale. A few beds 10 to 20 feet thick are present in both the upper and lower parts of the formation. The sandstone is indistinctly bedded, friable to moderately hard, and exhibits conspicuous exfoliation, producing rounded forms up to 6 feet in diameter. At the type locality the sandstones in the upper half of the formation (i.e., the uppermost of the three divisions mentioned above) become progressively thicker toward the top of the unit, culminating in a thick, craggy bed which forms the crest of Orchard Ridge. The top of this bed is the upper contact of the Risco.

The graywackes are silty and medium grained to very coarse. Some of the medium-grained beds contain irregu-

RISCO FORMATION (Type Locality)

Measured section C-C' Total thickness: 2965 feet
Annette quadrangle - Coordinates: 1083.6/1422.0; 1084.5/1422.7
West of Orchard Peak

JOHNSON PEAK FORMATION (conformable contact)

Feet	
375	Light yellow-brown, fine-grained graywacke, forming massive, craggy outcrops, well sorted; elliptical concretions up to 4-1/2 ft. in diameter are spaced 10 to 15 ft. apart along the bedding, forming layers up to 50 ft. apart; concretions are medium- to very coarse-grained, poorly sorted, with clay chips and very abundant black chert and bleached biotite
115	Shale, weathering brown to gray
260	Very coarse-grained graywacke in beds 1 to 4 ft. thick, forming prominent ledges; tabular, continuous concretionary layers 1 to 2 ft. thick are common; a few discrete subspherical concretions occur up to 7 x 4 x 2-1/2 ft.; 2% gray shale
125	Sandstone beds up to 10 ft. thick, topped by concretionary layers varying from 1-1/2 to 2-1/2 ft. thick along strike: 5% shale
85	80% thin graywackes, a few up to 1 ft. thick; 20% shale
50	Massive sandstone bed topped by concretionary layer 2 to 3 ft. thick
140	Greenish gray to light brown, fine-to coarse-grained, massive, concretionary graywacke
115	Approximately 50% graywacke, 50% shale
140	Greenish gray to light brown, massive graywacke with much biotite
155	60% shale; 40% fine-grained, massive to very thinly laminated graywacke, containing a 1-ft. bed of sandy limestone with minute pelecypods and abundant carbonized wood fragments
35	Tuffaceous sandstone, light gray, very fine-grained; much biotite
150	70% shale with 30% sandstone in beds up to 1 ft. thick and 1-ft. calcareous breccia with minute pelecypods and carbonized wood
35	Tuffaceous sandstone, light gray, hard, with a little bentonite
130	70% light brown, very fine-grained, massive graywacke with abundant carbonized plant fragments; 30% gray shale
15	Tuffaceous sandstone with abundant bentonite
215	65% light brown, thinly bedded sandstone, well sorted; glauconitic; abundant carbonized plant remains; tabular concretionary layers up to 1 ft. thick; 35% shale
30	Tuffaceous sandstone, gray, fine-grained, finely laminated; much biotite
120	90% dark gray shale with rare limestone nodules; 10% laminated sandstone
10	Tuffaceous sandstone with some bentonite; poorly exposed
665	95% greenish gray to light brown graywacke in thin, laminated beds (fine-grained) and massive beds up to 5 ft. thick (medium- to very coarse-grained, pebbly); grains well sorted, angular to subangular; greenish clay pods up to 2 in. long; concretionary layers 1 to 3 ft. thick, spaced 5 to 35 ft. apart; also discrete ovoid or lens-shape concretions up to 14 x 3 ft.; concretions weather dark brown and have coarse, angular grains; no concretionary layers in lower 165 ft.; a thin tuffaceous sandstone, very poorly exposed, lies 390 ft. above the base; 5% shale

BADGER SHALE (thrust contact)

Figure 6. Measured section C-C' of Risco formation (type locality).

RISCO FORMATION

Measured section D-D' Total thickness: 1650 feet
Tent Hills quadrangle - Coordinates: 1082.1/1430.3; 1082.7/1429.9
Three Peaks anticline

JOHNSON PEAK FORMATION (conformable contact)

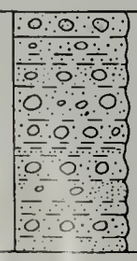
Feet	
690	Light brown, faintly greenish graywacke, weathering to brownish gray; coarse- to locally medium-grained; indistinctly bedded in structureless beds 1 to 3 ft. thick (a few up to 20 ft. thick); consists of poorly sorted, angular to subangular grains of quartz, feldspar, very abundant black chert, and some bleached biotite; also present are cream-colored clay chips and small rock fragments; dark lavender-brown cannonball concretions, very coarse-grained and averaging 1-1/2 ft. in diameter, are spaced every 5 ft. or so along bedding planes, forming rows of concretions 10 to 20 ft. apart stratigraphically
480	Light brown, very fine-grained arkosic sandstone in finely laminated beds 1/4 to 6 inches thick; very well sorted; few dark minerals; limonitized plant remains locally common; no concretions; rare 2- to 4-inch beds of limy conglomerate occur, with pebbles and angular rock fragments up to 5 mm. in diameter, a few shell fragments, and abundant carbonized wood; 5% light brown shale
480	Same as upper third of formation, except that here the sandstone is coarse-grained with abundant very coarse grains up to 3 mm. in diameter.

BADGER SHALE (conformable contact)

RISCO FORMATION

Measured section E-E' Total thickness: 430 feet
Tent Hills quadrangle - Coordinates: 1082.9/1431.1; 1083.0/1431.1
Three Peaks anticline (3/4 mile NE of section D-D')

JOHNSON PEAK FORMATION (conformable contact)



430	Same as upper third of measured section D-D', with 1% dark green shale

BADGER SHALE (conformable contact)

Figure 7. Measured sections D-D' and E-E' of Risco formation.

lar stringers of coarse, pebbly sandstone. The graywackes are, for the most part, poorly sorted, made up of angular to subangular grains. White chert and especially black chert, as well as other dark rock fragments are abundant. Bleached biotite is also plentiful. The rock is usually somewhat glauconitic. Greenish mud chips, carbonized wood fragments, and limonitized plant remains are common.

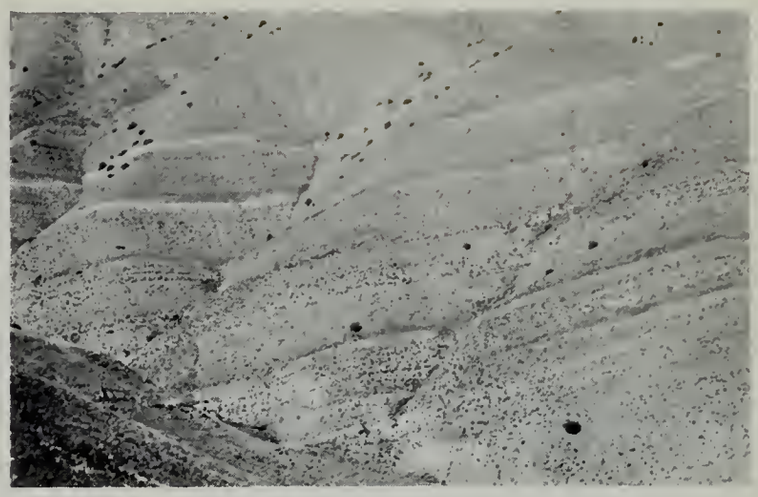
At the type locality the massive sandstones contain two kinds of concretions: (1) continuous tabular layers capping sandstone beds and varying along strike from 1 to 3 feet in thickness; and (2) discrete concretions of various shapes—ellipses, discoids, and cannonballs 1 foot to 4 feet in diameter and crudely rectangular masses up to 3 by 14 feet. In general, the discrete concretions are spaced from 10 to 15 feet apart along the bedding, the layers themselves being spaced vertically from 10 to 35 feet apart. The concretions of the Risco weather dark reddish-lavender to reddish-brown and are light to dark gray on fresh surfaces. They are strongly indurated with calcite. In other respects they are identical with the massive graywackes which enclose them.

In contrast with the lower and upper parts of the Risco, the middle portion of the formation is finer grained, much more thinly bedded, and relatively lacking in concretions. In the Three Peaks anticline these strata range in thickness from a fraction of an inch to 6 inches. They are composed of well sorted, very fine-grained arkosic sandstone, faintly and finely laminated, which is deficient in dark minerals. These rocks are light brown on both fresh and weathered surfaces. Locally these thin beds were much contorted by submarine flowage prior to consolidation.

The Risco formation contains at least four, and probably more, 1-foot layers of fossiliferous, impure, sandy to pebbly calcareous rock which is a dirty brownish-gray color, weathering dark red or grayish. Surfaces are much pitted by weathering. At the type locality these layers occur at the base of laminated sandstone beds. Abundant fragments of minute pelecypods, too poorly preserved to be identified, are scattered throughout the rock. One small coral was noted, also unidentifiable. Most plentiful of all, however, are bits of carbonized wood up to an inch long.

South of Orchard Ridge the lower half of the Risco formation contains six thin tuffaceous sandstones (four of which are shown in photo 3) similar to those in the Badger shale. These ash beds were noted by Taliaferro (1943a, p. 128) who states that: "As far as is known, these thin beds constitute the only record of contemporaneous submarine volcanism during the Cretaceous [in California]."

Although these tuffaceous beds crop out in only a few places, their presence elsewhere is indicated by grassy saddles of light-colored, soft soil which is usually littered with blocks of extremely hard tuffaceous sandstone. Gopher holes reveal an admixture of bentonite. The sandstone is gray, finely and evenly laminated, and fine- to very fine-grained. Much bleached biotite is present. The thickness of the volcanic beds increases upward from bed to bed, the lowermost being 10 feet, the uppermost 35 feet thick, suggesting a sort of crescendo of volcanic activity over a period of time. Northwest of Cottonwood Pass only four of these tuffaceous beds are present. At



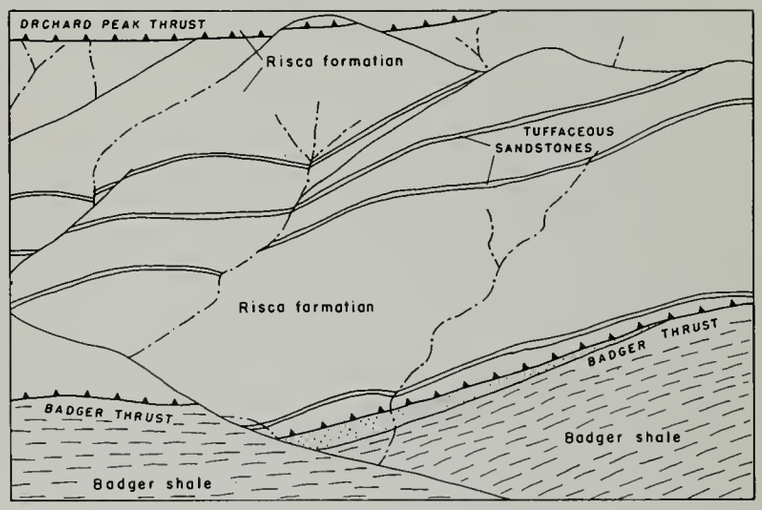


Photo 3. *A*, Risco formation containing thin tuffaceous sandstones, thrust southward (toward observer) upon the Badger shale. Note truncation of sandstone ledge by Badger thrust. Upper Risco Canyon (type locality of the Risco formation), 2 miles northeast of Antelope Pumping Station. *B*, Diagrammatic sketch of area of *A*, showing disposition of structural features.

Cottonwood Peak a short distance to the south, a 15-foot ash bed occurs in the lowermost beds of the Risco; this bed is probably the equivalent of the uppermost of the two ash beds in the Badger shale south of Orchard Ridge. At Cottonwood Peak this bed is a highly lenticular pyroclastic breccia of coarse grain size, containing abundant fresh biotite and fragments of tuff up to 1 inch long.

Where the Risco formation overlies the Badger shale along an apparently normal sedimentary contact, the base of the Risco is commonly marked (except in the Three Peaks anticline) by lenses and stringers of conglomerate (see geologic map, plate 1). West of Cottonwood peak the conglomerate attains its maximum thickness of 300 feet; east of this peak it abruptly thins and divides into two thin stringers each about 23 feet thick. In general appearance it resembles the conglomerate which caps Sawtooth Ridge except for the absence at Cottonwood Peak of shell fragments. Pebbles, cobbles, and boulders of many types of plutonic, volcanic, metamorphic, and sedimentary rocks are enclosed in a matrix of dark greenish brown, coarse sandstone. These include numerous pods of yellowish dolomite(?). The largest elements in the conglomerate are 1½-foot greenish chert boulders probably derived from rocks of the Franciscan

group. Thin slabs of finely laminated sandstone up to 10 by 13 inches are common; such tabular pieces could hardly have been transported very far without being broken up. The metamorphic and plutonic rocks, on the other hand, probably came from a considerable distance away, possibly from the Sierra Nevada region. Thus, this conglomerate was probably derived from both nearby and distant sources.

No diagnostic fossils were found in the Risco formation, although the following assemblage was recovered from shale samples: *Gyroidina* sp. (one specimen), indeterminable arenaceous Foraminifera, limonitic plant remains, and limonitic diatoms?—all very rare in the samples. If these last are actually diatoms, this is the lowest stratigraphic occurrence of diatoms so far reported in California. To the writer's knowledge, no diatoms have previously been reported below the uppermost Cretaceous formation, the Moreno.

In the absence of diagnostic fossils, no definite age can be assigned to the Risco formation. The writer found a *Baculites* sp. 230 feet above the top of the Risco, in the Johnson Peak formation; thus, rocks at least this low in the section are Upper Cretaceous. Lithologically, the Risco much resembles the Johnson Peak formation, especially the Enebro sandstone member of the Johnson Peak. Based on this resemblance and on the stratigraphic proximity of definite Upper Cretaceous strata, the Risco is herein regarded as Upper Cretaceous(?).

West of the Polonio Pass tear fault and in the Three Peaks anticline the lower contact of the Risco formation appears to be conformable. East of the fault the contact is a thrust fault marked by local discordance of beds (photo 3). The upper contact appears to be conformable except possibly near Polonio Peak where it may also be a thrust surface.

Upper Cretaceous

Johnson Peak Formation

The Johnson Peak formation is here named for Johnson Peak (map coordinates 1083.7/1429.8, plate 1), the highest summit in the mapped area north of Cottonwood Canyon. The formation crops out mainly east and northwest of Orchard Peak and in the Three Peaks anticline. Measured section F-F′ (fig. 8) which runs through Johnson Peak is the type section; here the formation attains its maximum thickness of 2,250 feet. Near its western limit of outcrop the unit is on the order of 800 feet thick; and at its eastern limit, near Devil's Den, it is about 950 feet thick.

Approximately 65 percent of the formation at Johnson Peak consists of pale green to dark green silty shale which weathers light brown. Locally the shale contains a profusion of fine carbonaceous particles. A few thin layers of yellowish-green siltstone are also present. Limestone nodules and thin limestone beds are common throughout the shale. These are light to dark gray where fresh and rust-brown, dark gray, buff, or white where weathered. The nodules occur as elliptical or lens-shaped bodies up to 1½ by 4 feet, closely spaced along bedding planes 5 to 20 feet apart.

Thinly bedded arkosic sandstones make up about 35 percent of the formation at Johnson Peak. These beds are gray, weathering to light brown, and range in thickness from ½ inch to 3 feet, although most are less than 6 inches thick. The sandstones are typically very fine grained and well sorted, containing abundant biotite and some glauconite. Clay chips are also plentiful. Locally graded bedding is common, with grains ranging from fine to very coarse. Flow casts and cross-bedding are fairly common. Oscillation ripple marks occur up to 8 inches across. Plant remains and rare shell fragments lie along bedding planes.

Enebro Sandstone Member. About 200 to 300 feet below the top of the Johnson Peak formation there is a prominent lens of massive to thinly bedded, concretionary graywacke (see figs. 8 and 9) which attains a maximum thickness of about 380 feet northeast of Orchard Peak. This lens is here named the Enebro sandstone member (Spanish for "juniper") in reference to the numerous junipers that thrive on its sandy soil.

The lenticular nature of the Enebro member is most apparent in the Three Peaks anticline where it pinches out both northward and westward, bringing the underlying and overlying shales together. The massive sandstone of the Enebro member forms sharp peaks and precipitous cliffs. The rock is light brown to light yellowish gray or greenish gray on both fresh and weathered surfaces. Beds 1 foot to 3 feet thick are typical. The grain size ranges from very fine to very coarse, although the latter is exceptional; the grains are angular. A distinctive feature is the profusion of biotite, generally bleached. Black chert grains are also common. Both the bedded sandstone and the concretions contain angular pieces up to half an inch long of green, gray, white, or tan siltstone and claystone.

The larger concretions in the Enebro member—up to 2 by 6 feet—are roughly rectangular-lenticular in shape; the smaller ones, up to 8 inches in diameter, tend to be elliptical or spherical. These concretions are spaced 5 to 15 feet apart along the bedding and occur in layers 10 to 20 feet apart stratigraphically. They are light gray on fresh surfaces and weather dark reddish brown.

East of Johnson Peak there is a 140-foot interval of sandstone beds (fig. 8) about midway in the formation; it was not considered sufficiently well exposed and extensive to be mapped as a separate member.

Although the sandstones of the Enebro member and the Risco formation are rather similar, the Enebro is typically light brown rather than greenish where fresh, tends to be better sorted, and contains more clay chips than the Risco.

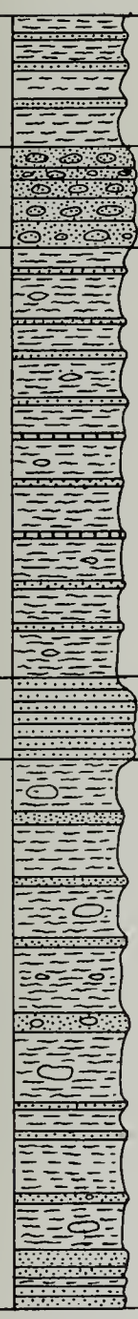
Several indeterminable arenaceous Foraminifera were found in shale samples from the Johnson Peak formation. A single *Baculites* sp. was found in an 8-inch bioclastic sandstone bed 1.3 miles northwest of Orchard Peak, 230 feet above the base of the formation. The specimen is about the size of a thick pencil lead and exhibits sutures which are well preserved. Numerous fragments of rudistids and other pelecypods, as well as a few gastropods were also found—all too fragmentary for identification. The *Baculites*, however, is sufficient to indicate a Late Cretaceous age for the Johnson Peak formation. Similar thin, fossiliferous beds were observed in the Enebro member at two other localities.

Except where faulted, the Johnson Peak formation rests conformably upon the Risco; it is everywhere conformably overlain by the Aguila sandstone.

JOHNSON PEAK FORMATION (Type Locality)

Measured section F-F' Total thickness: 2250 feet
Tent Hills quadrangle - Coordinates: 1083.0/1430.1; 1084.0/1429.8
Three Peaks anticline

AGUILA SANDSTONE (conformable contact)



Feet

225 — 70% light brown-weathering, pale green silty shale; 30% dark reddish-brown-weathering, dark gray, fine- to very fine-grained sandstone in finely laminated beds up to 6 inches thick; calcareous

175 — ENEBRO SANDSTONE MEMBER: light brown to gray, fine-grained sandstone in beds averaging 1-1/2 feet thick, well sorted, containing much biotite; concretions up to 2 x 6 feet are spaced from 5 to 15 feet apart along the bedding, forming layers 10 to 20 feet apart stratigraphically; concretions are light gray on fresh surfaces and are medium-grained

750 — 80% green shale, weathering to brown, containing dark gray, finely laminated limestone layers 4 inches thick which weather to reddish brown; also a few gray, elliptical limestone nodules up to 6 inches in diameter; 20% sandstone in beds up to 6 inches thick with rare flow casts

140 — Gray-weathering, light brown, medium-grained sandstone in laminated beds 1/2 to 2 feet thick; well sorted except for abundant clay chips up to 1 mm. in diameter; a few ripple marks 8 inches across

960 — Roughly 70% greenish, brown-weathering shale containing a few buff-weathering pods of sandy limestone up to 1-1/2 x 3 ft.; roughly 30% dark gray to light brown, very fine-grained sandstone in beds 1 to 12 inches thick; glauconitic; in a few places subspherical, biotite-rich concretions occur up to 1 ft. in diameter; 100 ft. above base of formation is a 5-ft. bed of light brown, thinly laminated sandstone with oscillation ripple marks 8 inches across and containing fragments of shells and carbonized wood on bedding planes; lowermost 100 ft. is 70% sandstone and 30% shale; lower 960 ft. of formation not well exposed

RISCO FORMATION (conformable contact)

Figure 8. Measured section F-F' of Johnson Peak formation (type locality).

JOHNSON PEAK FORMATION

Measured section G-G' Total thickness: 2050 feet
Tent Hills quadrangle - Coordinates: 1083.1/1431.0; 1083.6/1431.3
Three Peaks anticline

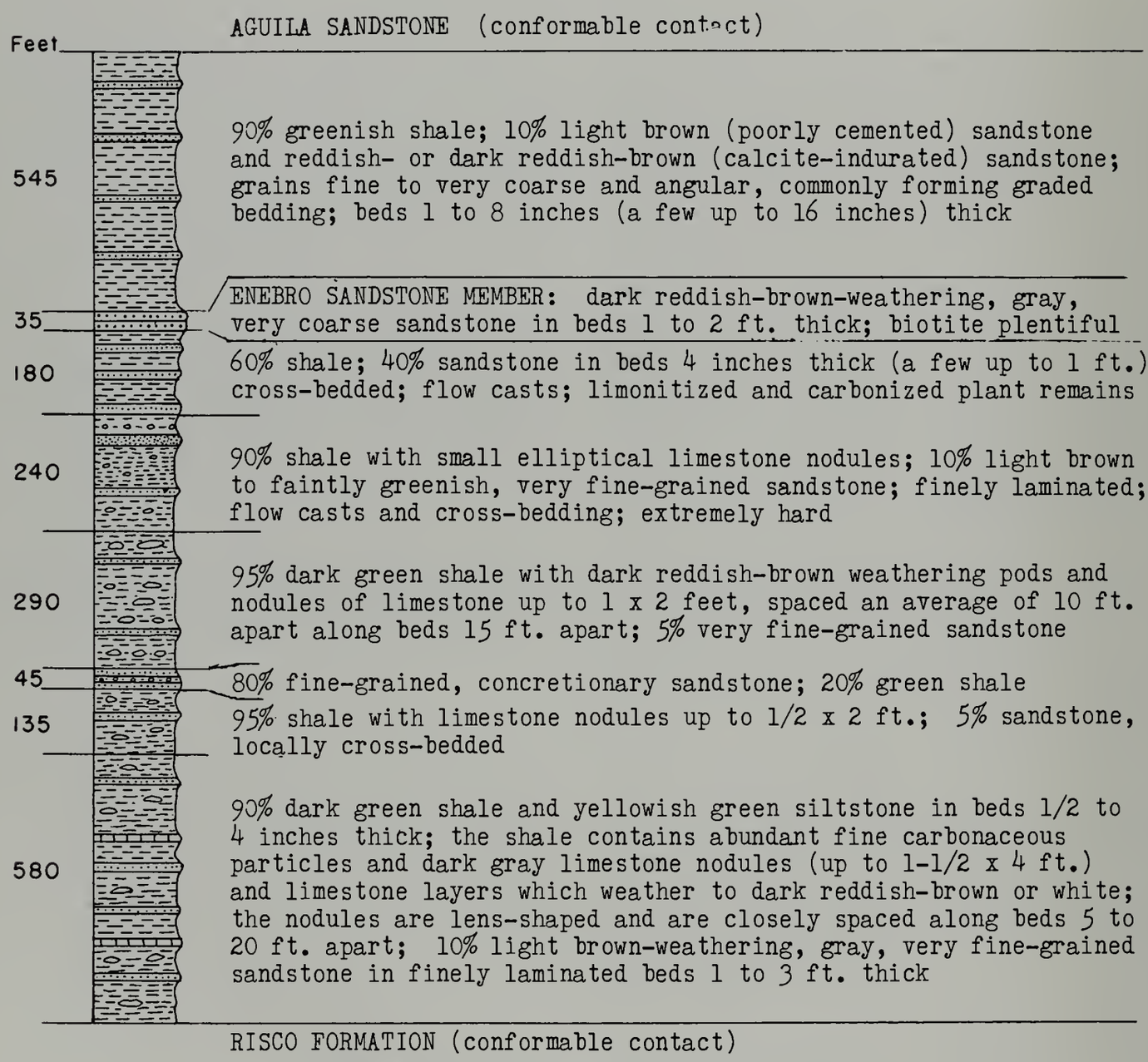


Figure 9. Measured section G-G' of Johnson Peak formation.

Aguila Sandstone

The Aguila sandstone is a newly designated formation named for Aguila Canyon on the north limb of the Stoker Canyon syncline (map coordinates 1081.3/1429.8, plate 1). Aguila is Spanish for "eagle." The formation is principally exposed in the Three Peaks anticline and in the Stoker Canyon syncline, although a thin band extends southeastward from Cottonwood Canyon, north of Orchard Peak. At its type locality the Aguila is 2,035 feet thick (fig. 10).

The Aguila sandstone typically forms prominent ridges and spurs thickly covered with bushes and a few junipers. The sandstone is a light brown to greenish gray, massive, obscurely bedded graywacke (photo 4). Although the thickness of individual beds is usually difficult to determine, where best exposed they reach a maximum of 4 feet. In addition, thin beds of finely laminated sandstone up to 3 inches in thickness occur in subordinate amount.

Where weathered the massive sandstone is friable, and there is some tendency to weather spheroidally. The rock is chiefly medium grained with a large amount of detrital matrix, the grains being sharply angular and poorly sorted. Biotite and black chert are both plentiful and characteristic. In places numerous small white clay chips are scattered throughout the rock.

The most striking aspect of the Aguila sandstone is its massive concretions which rib slopes and spurs with conspicuous dark ridges (photo 5). Most commonly these concretions are continuous along the bedding and range in thickness along strike up to a maximum of 3½ feet, giving a somewhat beaded effect. Also common are discrete concretions of various sizes, ranging from 1 foot to 12 feet in diameter and exhibiting a variety of shapes from cannonballs and lens-shaped bodies to roughly rectangular forms. These individual concretions are spaced from a few inches to 20 feet apart along beds which are 10 to 50 feet apart stratigraphically. These rocks weather dark reddish brown and are gray on fresh surfaces, with grains ranging from fine to very coarse in size.

Roughly 15 percent of the Aguila consists of interbedded light greenish brown shale which weathers to light brown or gray and contains much fine-grained mica.

The Aguila sandstone rests with apparent conformity upon the Johnson Peak formation and at most places is conformably overlain by the Serpiente sandstone.

AGUILA SANDSTONE (Type Locality)

Measured section H-H' Total thickness: 2035 feet
Tent Hills quadrangle - Coordinates: 1080.7/1429.6; 1081.1/1430.6
Stoker Canyon syncline

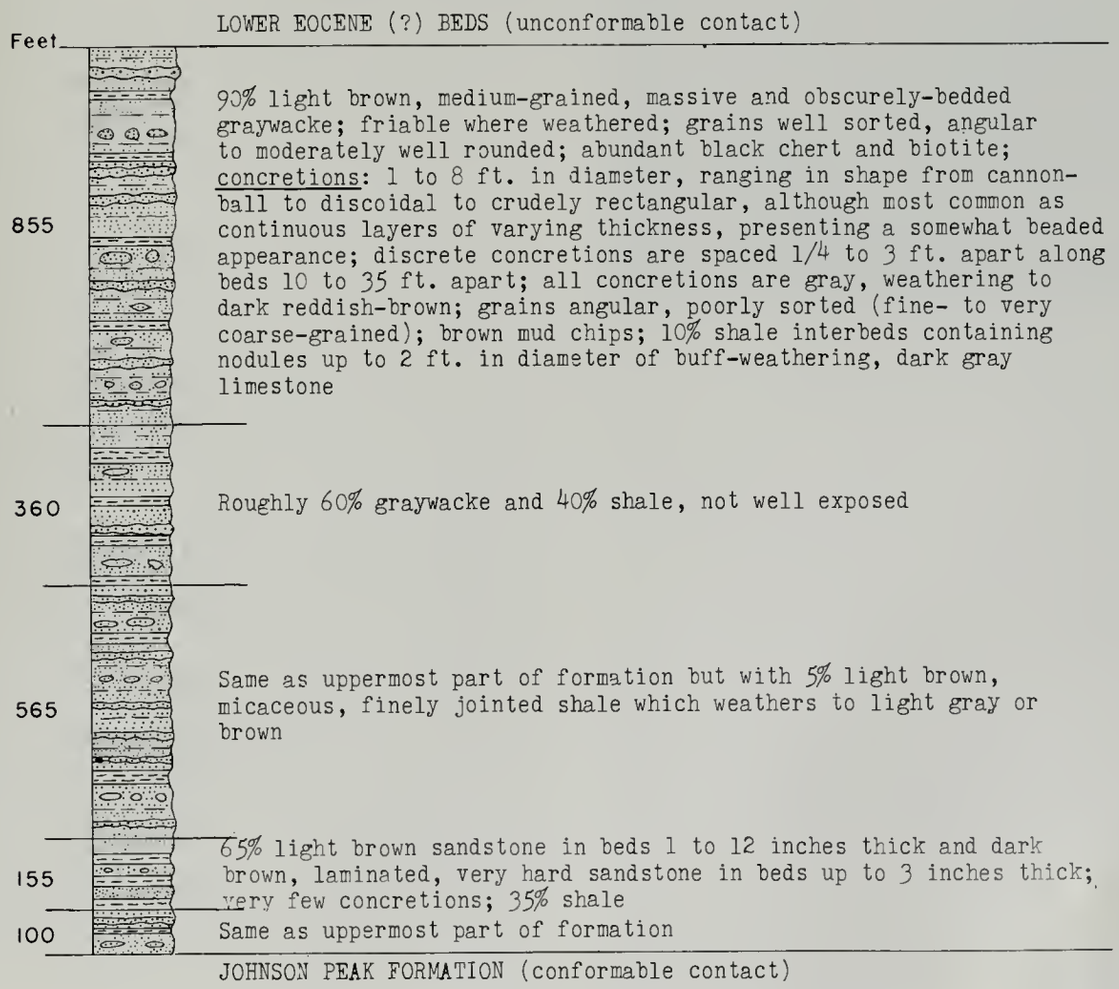


Figure 10. Measured section H-H' of Aguila sandstone (type locality).

Photo 4. Typical exposure of massive concretionary Aguila sandstone in Avila Canyon.

Photo 5. Monoclinally folded Aguila sandstone on south limb of Three Peaks anticline. Dark lines are concretionary ledges. Highway 41 crossing McLure Valley in distance.

Along the south limb of the Stoker Canyon syncline, however, perhaps as much as 8,000 feet of Upper Cretaceous strata have been removed by erosion; and the Aguila sandstone is unconformably overlain by the Avenal sandstone of middle Eocene age. Along the north limb of the syncline the Aguila is overlain by two units which do not appear to be represented elsewhere in the Orchard Peak area. These units may be of early Eocene age.

Although no fossils of any kind were found in the Aguila sandstone, the formation is Upper Cretaceous, for it is underlain and overlain by stratigraphic units containing Upper Cretaceous fossils.

Serpiente Sandstone

The Serpiente sandstone is a newly designated unit whose name, which means "serpent" in Spanish, is suggestive of the commonly contorted nature of the strata. The type locality is Serpiente Ridge and vicinity; this ridge lies 2 miles northwest of Devil's Den (map coordinates 1087.5/1424.7, plate 1).

The Serpiente is principally exposed as a nearly continuous belt paralleling McLure Valley along the eastern side of the Orchard Peak area. The thickest section of the formation—4,160 feet—is at the type locality (fig. 11).

The Serpiente sandstone is divided into three members: (1) the Torcido, most widely distributed of the three members; (2) the Avila tongue within the Torcido member; and (3) the Huevo member which occurs locally at the top of the formation. These are all new names. Because of its very restricted distribution, the Huevo member is not represented on the measured sections (figs. 11 and 12).

As a whole the formation consists of about 85 percent arkosic sandstone and 15 percent shale. The sandstones of the Serpiente are composed of well-sorted, angular grains cemented with limonite, clays, and some calcite to form a moderately hard rock. Glauconite grains are fairly plentiful throughout the sandstone.

The Serpiente contains fewer dark minerals and less fossil wood than the underlying Cretaceous formations. Moreover, the Serpiente represents a complete change from the graywackes of the older Cretaceous units to arkose. The Johnson Peak formation, containing both graywacke and arkose, may be considered as a transitional phase between the two types of sedimentation. Arkoses are considered to be the product of granitic terranes, whereas graywackes are derived from erosion of sedimentary and metamorphic rocks (Pettijohn, 1949, p. 261). It is possible that during the deposition of the Risco and earlier Cretaceous formations, erosion in the Sierra Nevada had not yet penetrated to the granitic Sierran batholith. Consequently, these formations may be composed, at least in part, of reworked metamorphic rocks derived from the pre-Cretaceous fold mountains of the Sierran region. Later as the basement was breached, granitic detritus was carried westward by streams draining the region, ultimately to form (in the Orchard Peak area) the arkoses of the Serpiente sandstone and overlying Cretaceous formations.

At the type locality the lower part of the Serpiente sandstone contains a 430-foot interval of dark green shale which weathers gray. The remainder of the formation has about 5 percent shale distributed throughout as thin partings and interbeds.

Torcido Member. The name of this member (Spanish for "contorted") refers to the commonly contorted bedding of its sandstones, the most distinctive feature of this unit.

The sandstones of the Torcido member (fig. 12) are light brown, weathering to brown or gray. The thin bedding contrasts strikingly with that of the other, more massive units in the Orchard Peak area (photo 6). Beds in the Torcido range from 1 inch to 3½ feet in thickness, and most of them are very finely laminated. Commonly the laminae separate upon weathering. A distinctive feature of the Torcido member is the abundance of small folds and contortions—from gentle warping to the most complex crumpling (photo 7). Most numerous are "synclinal" folds from 6 to 12 inches across. Commonly the upper portion of a bed is closely folded, whereas the

lower portion is unaffected. These structures were probably produced by slumping of the sediments down a submarine slope prior to complete consolidation. Not uncommonly the bent strata are truncated by the uncontorted overlying layers, indicating that slumping was followed by slight scouring before deposition resumed. Also characteristic of the Torcido member are prominent flow casts, small-scale cross-bedding, and ripple marks.

The sandstones of the Torcido are arkoses. Generally they are fine to very fine grained, although locally very coarse-grained beds occur containing well-rounded grains up to 2 mm. and greenish clay chips up to 5 mm. in diameter. Finely broken shell fragments are locally abundant in these coarser beds.

Dark red-weathering concretions are not uncommon in the Torcido member. These range from thinly laminated tabular bodies 1 foot thick to cannonball concretions up to 2 feet in diameter.

About 140 feet below the upper contact of the Serpiente sandstone along the south limb of the Devil's Den syncline the Torcido member contains a conglomerate which is as much as 75 feet thick (see fig. 12) and which can be traced for more than 2 miles. The conglomerate consists of well-rounded pebbles, cobbles, and boulders of chert, quartzite, conglomerate, and porphyritic volcanic and other igneous rocks, as well as concretions (up to 5 feet in diameter), calcareous nodules, and angular slabs of sandstone. These constituents are mixed together with no trace of sorting in a matrix of yellowish brown, medium- to very coarse-grained arkose. That at least some of the constituents are of intra-Cretaceous or possibly Jurassic origin is indicated by the occurrence of *Inoceramus* prisms in some of the boulders. The presence of numerous boulders of an earlier conglomerate and the well-rounded condition of even the hardest rocks indicate that this is at least a second-cycle conglomerate.

In places the conglomerate divides into thin, somewhat lenticular stringers separated by massive, yellowish brown sandstone. Locally the sandstone interbeds are fossiliferous, containing *Submortoniceras chicoensis*

Photo 6. Typical ledge of thinly bedded Serpiente sandstone at crest of Avenal Ridge.

Photo 7. Submarine flowage fold in Serpiente sandstone.

Trask (collected by R. E. Cook at 1092.3/1419.7) and other fossils including *Baculites chicoensis* Trask, *Trigonia* sp., echinoid spines, gastropods, and numerous pelecypods which could not be identified owing to poor preservation (collected by the writer at 1093.1/1419.7, geologic map, plate 1). On the basis of the two ammonites the conglomerate is judged to be of late Late Cretaceous age.

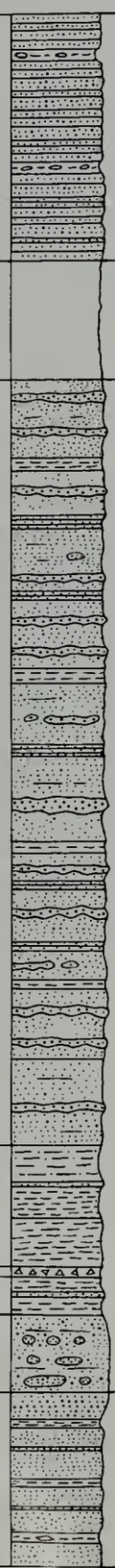
Avila Member. The Avila member is a large tongue of concretionary sandstone, 2,710 feet thick as measured along section I-I′ (fig. 11), which lies between the upper and lower portions of the Torcido member of the Serpiente. To the north the Avila member extends outside the mapped area for an undetermined distance; at its southern end the tongue tapers and pinches out about half a mile south of Avila Canyon, for which it is named.

The Avila member is characterized chiefly by the nature and abundance of its concretions and by its stratigraphic position. The Avila tongue is distinguished from the Torcido member which encloses it by the abundance of prominent concretionary layers in the Avila. The Huevo member is also distinguished by its large concretions; but the Huevo occupies the uppermost, rather than the middle, part of the formation and does not crop out in the same part of the area as the Avila member. Moreover, the Huevo contains a higher proportion of discrete concretionary masses and cannonball concretions than does the Avila member.

The concretions of the Avila are more or less continuous along the bedding and range in shape from irregular masses to lens-shaped bodies. These layers are ordinarily about 3 feet thick, although they range in thickness from 1 foot to 10 feet. Stratigraphically they are spaced an average of 28 feet apart at the type locality of the formation. A few concretionary layers are tabular in form and unevenly but distinctly laminated, displaying small-scale cross-bedding and scour-and-fill structures. Such tabular layers do not exceed about 4½ feet in thickness.

The concretions of the Avila member are dark reddish brown where weathered and are gray on fresh surfaces. Most are medium-grained, although some layers are fine grained and others very coarse grained. A distinctive

SERPIENTE SANDSTONE (Type Locality)
Measured section I-I' Total thickness: 4160 feet
Pyramid Hills quadrangle - Coordinates: 1087.1/1424.1; 1088.9/1426.5



Feet

ALLUVIUM of McLure Valley

660 — TORCIDO MEMBER: 95% light brown, very fine-grained, finely laminated arkose in beds 1/2 to 6 inches thick; some beds weather to sheaves of separate plates 1 mm. thick; fairly hard; no concretions; numerous large, well-formed flow casts; some submarine flowage folds; oscillation ripple marks; 5% gray shale with buff- to white-weathering limestone nodules up to 6 inches in diameter, both discoidal and spherical

320 — Concealed by alluvium

A

2055 — AVILA MEMBER: (extends from A to B)- 80% light brown (fresh and weathered), fine-grained, massive, concretionary arkose with interbeds averaging 1/2 inch thick of very fine-grained arkose; abundant bleached biotite; concretions: most distinctive feature of the Avila member; these are irregular to lens-shaped, forming more or less continuous layers along the bedding and averaging 3 ft. in thickness, though ranging from 1 to 10 ft. in thickness; these layers are spaced an average of about 30 ft. apart stratigraphically; some are unevenly but distinctly layered and tabular in shape; all the concretions are gray, weathering dark brown, and are made up of medium, angular grains; much jointed.

20% gray-weathering, dark green to dark gray shale with a few beds of buff-weathering limestone up to 6 inches thick, occurring as thin interbeds, but chiefly concentrated in the interval between 20 ft. and 655 ft. above the base of the Avila member; this shale interval contains a 20-ft. bentonite bed; basal 205 ft. of member exposed along measured section I-I', consists of light brown, medium-grained, massive arkose with cannonball concretions

Note: The Avila member is a tongue within the Torcido member.

325

20

105

205

B — Hex thrust (a few feet or a few tens of feet may have been cut out)

470 — TORCIDO MEMBER: 85% light brown, friable arkose in beds 1/2 to 2 inches thick; 5% indurated arkose in beds 1/2 to 1 ft. thick, spaced 10 to 35 ft. apart; very fine- to very coarse-grained; very thinly laminated; many pelecypod shell fragments; 10% dark gray shale with limestone nodules

AGUILA SANDSTONE (conformable contact)

Figure 11. Measured section I-I' of Serpiente sandstone (type locality).

SERPIENTE SANDSTONE (TORCIDO MEMBER)
Measured section J-J' Total thickness: 2634 feet
Sawtooth Ridge quadrangle - Coordinates: 1091.0/1419.4; 1091.4/1420.3
Avenal Ridge, southwest of Devil's Den

Feet	
	MOONLIGHT FORMATION (conformable contact)
140	Light brown sandstone, poorly exposed
75	Conglomerate composed of sedimentary, igneous, and metamorphic rocks, very poorly sorted (1/2-inch pebbles to 5-ft. concretions); some highly fossiliferous boulders (mostly oysters, some Inoceramus)
1160	Light brown (fresh and weathered), very fine-grained arkose in finely laminated beds 1 ft. thick; strata are greatly crumpled, both by original submarine flowage and by later tectonic folding; well sorted; much bleached biotite; locally indurated; a few flow casts; 5% dark green gray-weathering shale with buff-weathering limestone nodules
455	Light brown, thinly bedded concretionary arkose with submarine flowage folds; these thin strata occur in groups of beds up to 14 ft. thick; concretions: these are more or less tabular, continuous concretionary layers averaging 1-1/2 ft. thick and spaced about 50 ft. apart; composed of dark brown-weathering, very fine- to coarse-grained sandstone containing abundant fragments of gastropods and pelecypods
325	Same as the 1160-ft. interval described above
480	Gray shale with fragments of buff- to white-weathering limestone
	HEX FORMATION (thrust contact)

Figure 12. Measured section J-J' of Serpiente sandstone.

feature of these concretions is the abundance of subangular to subrounded grains of black chert.

The sandstone in which the concretions are embedded is a light grayish brown arkose, very fine-grained with a few coarse-grained beds. The rock ranges from massive, obscurely bedded sandstone to thinly bedded sandstone with individual strata averaging half an inch in thickness. Much black chert and bleached biotite are present.

About 20 percent of the Avila member consists of dark green to gray shale, some as thin interbeds but most concentrated near the base of the member (see fig. 11). Near the head of Avila Canyon the member contains a thin conglomerate of various volcanic and metamorphic rocks in well-rounded pebbles and cobbles up to 8 inches in diameter. Near the base of the member south of Cottonwood Canyon a 20-foot bentonite bed can be traced from Avila Canyon northwestward for more than 2 miles before it is cut out by the Hex thrust.

Although the Avila member of the Serpiente bears considerable resemblance to the Aguila sandstone, the latter can be distinguished by its more massive bedding; the faint, though definitely greener color of the fresh rock; and its larger concretions which are less commonly laminated and tend to occur in more closely spaced layers than those of the Avila member of the Serpiente.

Huevo Member. In contrast to the Torcido and Avila members of the Serpiente, the lenticular Huevo member (Spanish for "egg", in reference to its rounded concretions) has a very restricted distribution. The Huevo crops out only at three localities: in White City Canyon, along the axis of the Devil's Den syncline, and on the north and south limbs of the Sawtooth Ridge syncline. At all three places the Huevo constitutes the uppermost part of the Serpiente sandstone.

The most striking feature of the Huevo member is its concretions (photo 8) which range in shape from irregular or "flattened" masses 1 foot to 3 feet thick and more or less continuous along the bedding, to cannonballs up to 8½ feet in diameter. These concretions are dark reddish brown, dark gray where fresh, and are composed of angular grains of fine to very coarse, pebbly sand, locally conglomeratic and highly fossiliferous. Biotite and black chert are abundant.

South of Sawtooth Ridge the Huevo occurs as a thin, asymmetric lens 2.4 miles in exposed length, the thickest portion (500 feet) being near its eastern extremity at Huevo Ridge. Along this outcrop belt the Huevo member contains numerous thin stringers and lenses of conglomerate up to 3 feet thick, composed of well-rounded pebbles, cobbles, and boulders of metamorphic, porphyritic volcanic, and sedimentary rocks up to 15 inches in diameter. Among these are quartzite, granite, and sandstone slabs with shell fragments. Most abundant of all are well-rounded slabs of limestone and dolomite (?) up to 2 inches thick and 8 inches long which weather yellow. These conglomeratic constituents are larger and more numerous toward the center of the outcrop belt. They are embedded in a matrix of massive yellow sandstone medium- to very coarse-grained, which locally shows conspicuous cavernous weathering.

The most fossiliferous zone in the Orchard Peak area occurs near the top of the Huevo member south of Sawtooth Ridge. The most characteristic fossil is *Glycymeris veatchii*. Smith (1945, pp. 35-44) distinguishes several

Photo 8. Concretions in Huevo member of Serpiente sandstone southeast of Sawtooth Ridge.

related forms, with *G. veatchii sensu lato* ranging from "lower Chico" at Redding through Meganos at Mt. Diablo, or Upper Cretaceous to lower Eocene. *G. veatchii sensu stricto* appears to be limited to the Upper Cretaceous. Also represented in this fossiliferous horizon are other (unidentifiable) pelecypods, nautiloids, and a very abundant hydrocoral which occurs as branched, cabbage-like masses up to 6 inches in diameter. Most of these fossils are poorly preserved. This fossiliferous bed can be traced from a point at coordinates 1091.7/1416.4 (see geologic map, plate 1) westward for a distance of 1.2 miles. Near its eastern end exposures of the bed have been repeated by overturned folding.

The Serpiente sandstone rests conformably upon the Aguila sandstone northeast of Johnson Peak and for a distance of 2.3 miles northwest of Avila Canyon. At all other places in the area an undetermined thickness of the basal part of the formation is missing where it has been thrust upon other units.

In the Sawtooth Ridge and Devil's Den synclines the Serpiente sandstone is overlain conformably by the Moonlight formation. Elsewhere its upper contact is a fault separating it from the Red Man sandstone. Both of these overlying formations are of late Late Cretaceous age; the Serpiente sandstone is also late Late Cretaceous, as proved by the fossils found in the conglomerate within the Torcido member.

Moonlight Formation

The Moonlight formation is a new name here proposed for a lithologic unit in the Orchard Peak area which is equivalent to the "*Pachydiscus* silt" or "Ragged Valley shale" of the Coalinga area and elsewhere.

The term "*Pachydiscus* silt" (Jenkins, 1943, p. 251) has been used as a field term for a member of the Panoche formation. *Pachydiscus* was reported from the area long ago (Arnold and Anderson, 1910, p. 60) and paleontologists have referred to the 'siltstone with *Pachydiscus*' for a long time without using it as a formal stratigraphic name. Vokes (p. 27) proposed the term "Ragged Valley shale" in 1939 to designate An-

derson and Pack's Clay Shale member of their Martinez (?) (Eocene). In 1941 J. Q. Anderson used the same name for the shale unit below the Upper Cretaceous Brown Mountain sandstone of the Coalinga area. Thus the same term has been used for both Eocene and Cretaceous units.

The type locality of the Moonlight formation is Moonlight Valley (map coordinates 1091/1421, see plate 1) which runs along the south limb of the Devil's Den syncline, just north of Avenal Ridge. The unit also occurs along the north and south limbs of the Sawtooth Ridge syncline and along the north side of Antelope Valley.

At its type locality the formation attains its maximum thickness of 1,550 feet. However, 1.2 miles to the southwest in the Sawtooth Ridge syncline the formation is only about 375 feet thick, suggesting that the Moonlight formation may be a tongue which pinches out toward the south. Because of the extremely poor exposures, it was not considered worthwhile to attempt to measure a section of the formation.

The Moonlight formation consists of two facies: a light-colored siltstone facies in the Devil's Den and Sawtooth Ridge synclines and a dark gray clay shale west of Sawtooth Ridge syncline. The transition between these two facies occurs rather abruptly, near the west end of the Sawtooth Ridge syncline.

Siltstone Facies. Because the siltstone facies of the Moonlight formation is soft and clayey, it occupies trough-like lowlands along the base of the scarps formed by the resistant Red Man sandstone. Its light-colored soil supports only short grass, and many patches are entirely barren of vegetation. Small mudcracks are characteristic. Nowhere does the fresh rock crop out; even gullies incised to a depth of 5 feet fail to reveal anything but crumbly earth.

The fresh rock, obtained by digging, is a very faintly greenish, light-gray, clay-rich siltstone which readily slakes in water. The siltstone occurs as crudely rounded joint fragments about 1 inch long. A powdered sample, when stirred up with water, expanded to 175 percent of its original volume, owing to the presence of montmorillonite. Microscopic examination of the siltstone confirms the presence of large amounts of montmorillonite. Possibly the clay has been derived from the breakdown of volcanic glass. The high index of refraction of this clay mineral suggests that it is an iron-rich variety, approaching nontronite. Grains of quartz and of a carbonate, possibly siderite, are also present.

Three types of calcareous rocks are associated with the siltstone facies. One is a gray, impure limestone which weathers white and occurs as small, irregular pods or masses containing ammonites and pelecypods. A second type is a brown to orange-brown dolomite (?) which weathers to pale yellowish brown or orange-brown. This rock is likewise in the form of irregular, much-jointed masses; some of these reach 4 feet in diameter. A third type is found as layers of dark brown to orange-brown fibrous calcite up to 3 inches thick. This rock exhibits a striking cone-in-cone structure, some of the larger cones having a diameter of 2 inches.

At Devil's Den the lower portion of the Moonlight formation contains a few coarse-grained arkosic sandstones up to 6 feet in thickness. These strata are structureless to thinly bedded. The rock is light brown where fresh but turns dark brown upon weathering and contains much fresh biotite.

The straight ammonite *Baculites chicoensis* Trask is locally abundant in calcareous pods within the siltstone facies of the Moonlight formation and was collected at the following localities:

	Map coordinates (see plate 1)
Sawtooth Ridge	1090.2/1417.1
syncline	1089.6/1417.3
Devil's Den	1092.2/1420.2
syncline	1093.2/1419.8

Baculites chicoensis is a guide fossil for the uppermost part of the Upper Cretaceous. A fragment of an unidentified coiled ammonite was also collected.

Two pelecypods are associated with these ammonites, one unidentified, the other *Liopistha (Psilomya)* cf. *L. hardingensis* (Packard). According to Packard (1922, p. 423), the latter species (which he described as *Homomya hardingensis*) occurs in the "Chico group, *Acateonella oviformis* zone."

The following Foraminifera, all arenaceous and indicative as a whole of a shallow-water environment, were collected by the writer from the middle portion of the siltstone facies at the type locality of the Moonlight formation in Devil's Den (map coordinates 1093.5/1419.8, plate 1):

Standard Oil Company Locs. No. 5213 and 5214

Ammodiscus sp. VR
Bathysiphon perampla R
Bathysiphon sp. VR
Cribrostomoides cretacea (?) C
Cyclammina sp. VR
Gaudryina (?) sp. VR
Marssonella sp. VR
Silicosigmoilina californica R
Spiroplectammina sp. VR
Trochammina cf. T. globigerinaformis VR
Trochammina (?) sp. VR

The micropaleontological laboratory of the Standard Oil Company of California suggests that this assemblage "...may *possibly* represent lower *Pachydiscus* silt, or *possibly* upper Joaquin Ridge time." This would place the assemblage approximately in the upper part of the Senonian.

Shale Facies. West of Sawtooth Ridge the Red Man sandstone rests upon a dark green, silty, clay shale instead of upon the light-colored siltstone which underlies it elsewhere. This shale unit is found within the mapped area only as a narrow outcrop band south of Orchard Ridge, and nowhere is the base exposed. In appearance this unit much resembles the Badger shale, even to its calcareous nodules.

Just south of the Aido Spring serpentine body and northwest of F. Owen's ranch (map coordinates 1084.9/1419.2, plate 1) a sample of the shale facies was collected which yielded the following Foraminifera:

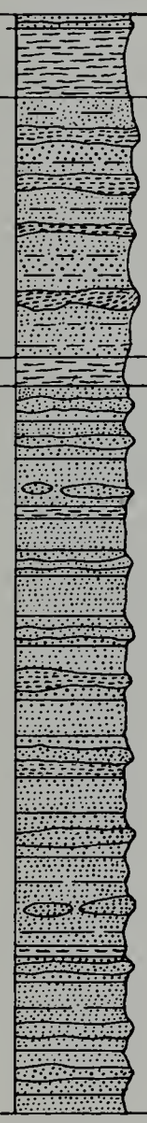
Standard Oil Company Loc. No. 5202

Bathysiphon sp. R
Cribrostomoides (?) sp. C
Gaudryina sp. R
Silicosigmoilina californica R

The Standard Oil Company's micropaleontologists interpret this assemblage as follows: "Upper Cretaceous;

RED MAN SANDSTONE (Type Locality)
Measured section K-K' Total thickness: 1180 feet
Sawtooth Ridge quadrangle - Coordinates: 1092.9/1420.1; 1093.3/1420.6
South limb of Devil's Den syncline

MORENO FORMATION (conformable contact)



Feet	
80	Light blue, soft, tuffaceous shale
310	Light brown, very fine- to very coarse-grained concretionary arkose, very thinly bedded and finely laminated; concretions: light gray, brown-weathering, laminated, tabular layers which are moderately indurated and show much small-scale channeling and cross-bedding; weathered surfaces are felted with an extreme abundance of *Inoceramus* prisms aligned east-west along the bedding; many well-preserved Formaninifera also occur on these surfaces
30	Light blue tuffaceous shale
755	Very light yellowish brown (fresh and weathered), very fine-grained, concretionary arkose in beds 1 to 3 ft. thick; beds are finely and evenly laminated; well sorted; much interstitial limonite; concretions: dark gray on fresh surfaces, weathering dark reddish brown; very fine-grained; occurring mostly as tabular, more or less continuous layers 1 to 3-1/2 ft. thick, spaced 10 to 60 ft. apart stratigraphically; thinly laminated, through commonly structureless in appearance; locally containing clay chips up to 3 mm. across; 1 to 5% light gray shale containing nodules of white- to brown-weathering, dark gray, impure limestone up to 1 ft. in diameter, much fractured; gypsum fragments up to 1 inch across also occur in the shale

MOONLIGHT FORMATION (conformable contact)

Figure 13. Measured section K-K′ of Red Man sandstone (type locality).

Tracian? and/or older? of Goudkoff...thought to be equivalent to the lower Ragged Valley shale (*Pachydiscus* silt) or older."

Thus, based on paleontological evidence and similar stratigraphic position, the dark green shale and the light-colored siltstone which make up the Moonlight formation appear to be facies equivalents. Except where faulted, the Moonlight formation conformably overlies the Sespiente sandstone and underlies the Red Man sandstone.

Red Man Sandstone

Along the northeast border of the Orchard Peak area and in the Sawtooth Ridge and Devil's Den synclines a craggy sandstone unit crops out which is probably equivalent to the "Brown Mountain sandstone," a term first used informally in a talk by J. Q. Anderson (1941).

The type locality of the Red Man sandstone is the south limb of the Devil's Den syncline. About 2 miles northwest of the synclinal axis this formation crops out in prominent crags which are here named Red Man Rocks. The shallow caves carved by weathering in the sandstone were formerly inhabited by Indians, probably of the Yokut tribe, who left numerous pictographs and corn-grinding mortars to mark their stay. The Red Man sandstone is named for these crags.

At its type locality the formation is 1,180 feet thick (fig. 13). A comparable thickness is exposed at Red Man Rocks, but since here the upper part of the formation is

concealed by alluvium, the maximum thickness of the unit may be somewhat greater.

The formation consists of about 90 percent sandstone and 10 percent shale. At Sawtooth Ridge the unit also contains a conglomerate. The sandstone in the Red Man is typically a light, yellowish-brown arkose which in places is massive and obscurely bedded and elsewhere occurs in beds 1 foot to 3 feet thick. Commonly it is faintly laminated, and locally it is cross-bedded. The sandstone is generally much jointed. North of Devil's Den cavernous weathering is conspicuous. The sandstone is dominantly very fine grained, less commonly medium grained, and is composed of well sorted, angular grains of quartz and feldspar, with abundant biotite. Although few dark minerals except biotite are present, locally there are small amounts of glauconite and black chert. The light brownish color of the sandstone is due to a coating of iron oxides on the grains. In the Sawtooth Ridge syncline the Red Man sandstone undergoes several changes upward in the section: the color grades to grayish white and the rock becomes quite friable, very thinly bedded, and evenly laminated.

The most conspicuous feature of the Red Man sandstone is the abundance of dark reddish brown concretions. On fresh surfaces they are dark gray. These concretions are distributed every 2 to 8 feet apart along bedding planes spaced from 10 to 50 feet apart throughout the formation. There is a complete gradation in shape from tabular bodies half an inch to 12 inches thick, through "beaded," or coalescing rounded masses 1 foot to 5 feet thick, to cannonball concretions ranging from the size of tennis balls to giant spheres 9 feet in diameter. Although usually structureless in appearance, many of the concretions are actually thinly laminated; and locally these laminæ have been separated by weathering. The rock is very fine to very coarse grained, strongly indurated with calcite, and in places contains clay chips up to 1 inch long. Fresh biotite is plentiful.

Conglomerate. The serrate crest of Sawtooth Ridge is composed of a lenticular bioclastic conglomerate (photos 9 and 10) which is 32 feet thick at the highest part of the ridge and thins eastward and westward to a thickness of about 10 feet at each end of the exposure. Still farther in each direction it probably pinches out beneath the cover of alluvium. Although this conglomerate can be traced for 2 miles along the south limb of the syncline, it is absent from the north limb; and therefore it must also pinch out northward, probably somewhere near the synclinal axis. The conglomerate lies nearly 800 feet above the base of the Red Man sandstone. It has been offset by more than a dozen cross faults.

The conglomerate is grayish brown where fresh and weathers to yellowish brown. The matrix consists of very coarse sandstone, chiefly angular grains of quartz and some feldspar, cemented by limonite, calcite, and clays. Finely broken shell fragments are extremely abundant. These are mainly pelecypods, although remains of gastropods, small corals, and other organisms were also found. None of these, however, could be identified except for needle-like fragments of *Inoceramus* sp.

The conglomeratic elements (photo 10) are mainly chunks and slabs of sedimentary rocks—buff-colored dolomite(?); light gray limestone; and light brown, laminated, very fine-grained sandstone. A single slab of sandstone, for example, measured 26 by 26 by 3 inches; it is doubtful whether such large tabular pieces could have been transported very far without breaking up. On the other hand, cobbles of metamorphic (chiefly quartzite) and porphyritic igneous rocks up to 6 inches in diameter are present in lesser amount; and these must have been transported from a considerable distance away. Thus both nearby and distant sources are indicated for these constituents. Many of the slabs are arranged in an imbricate pattern which clearly indicates

Photo 9. Bioclastic conglomerate in Red Man sandstone at crest of Sawtooth Ridge which forms south limb of Sawtooth Ridge syncline. Looking southeast.

Photo 10. Closeup of conglomerate in Red Man sandstone at top of Sawtooth Ridge, showing chunks and slabs of limestone and fine sandstone and shell fragments.

that the current which deposited them flowed from northeast to southwest. The direction of torrential cross-bedding near the west end of Sawtooth Ridge supports this conclusion. Westward the slabs and cobbles become less numerous until near the western end of the conglomerate they are present only in thin stringers and as isolated fragments. Shell fragments, too, are much less plentiful here. Veins of calcite as much as 6 inches thick cut the conglomerate at several places.

At the exposed (faulted) base of the Red Man sandstone northeast of Johnson Peak a different type of conglomerate occurs which can be traced northwestward for 1½ miles before it passes outside the Orchard Peak area. This conglomerate is about 20 feet thick and consists of pebbles, cobbles, and boulders up to 1 foot in diameter of igneous and metamorphic rocks embedded in a scanty matrix of dark gray, coarse to very coarse, indurated sandstone in which biotite is very plentiful. Also present are chunks of white-weathering limestone up to 8 inches in diameter.

Besides minor amounts of dark green shale throughout the formation, the upper portion of the Red Man sandstone at Devil's Den and in the Sawtooth Ridge syncline contains a light blue tuffaceous shale similar to that which is characteristic of the Hex formation. At the type section of the Red Man this blue shale occupies two intervals, one 30 feet thick, the other 80 feet thick (see fig. 13), where it forms interbeds between the sandstones and also occurs as an original constituent in some of the sandstone beds. Fragments of gypsum are generally associated with this tuffaceous shale, and composite veins of gypsum up to 8 inches thick cut the sandstones at Devil's Den.

Previous workers have mapped the conspicuous craggy sandstone at Red Man Rocks (map coordinates 1090/1425, plate 1) as Eocene, usually as the Point of Rocks formation whose type locality lies 4 miles southeast of Devil's Den. On the other hand, the craggy sandstone unit in the northeast corner of the Orchard Peak area has been regarded as Cretaceous. The writer carefully compared these two exposures and is convinced that they are lithologically identical. Both are mapped in this report as the Upper Cretaceous Red Man sandstone.

A shale sample collected from the exposure in the northeast corner of the area and examined for microfossils was found to contain a few *Inoceramus* prisms, indicating that these rocks are Mesozoic. William K. Gealey of the Standard Oil Company of California found a *Baculites* in this same outcrop belt 4½ miles to the northwest, outside the Orchard Peak area. Thus these rocks are established as Upper Cretaceous.

Several months after the writer had left the area, Gealey did some surface mapping and paleontological work northeast of the Orchard Peak area. In a letter dated January 14, 1954, he states:

> "We have found what we consider the base of the Eocene to [illegible] the neighborhood of a half mile to the northeast of the out[illegible] at Red Man Rocks]. Our present opinion is that the out[illegible] question is a continuation more or less unbroken of the B[illegible] Mountain sand [i.e., Red Man sandstone] to the south."

Fossils and Age: Numerous well-preserved Foraminifera may been seen on the weathered surfaces of concretions in the upper one-third of the Red Man sandstone at Devil's Den. These include the following assemblage, indicative of a neritic environment:

Bulimina aspera Cushman and Parker
Bulimina aff. B. prolixa Cushman and Parker
Bulimina sp.
Dentalina basiplanata Cushman
Dentalina cf. D. catenula Reuss
Dentalina cf. D. consobrina d'Orbigny
Dentalina aff. D. legumen Reuss
Dorothia sp.
Frondicularia cf. F. cordata Roemer
Frondicularia inversa Reuss
Marginulina sp.
?Neoflabellina cf. N. interpunctata (Wedekind)
Neoflabellina or Frondicularia sp.
Pseudoglandulina sp.
Robulus sp.

Dr. Stewart Edgell who made the above identifications at Stanford University gives the following analysis of the assemblage:

> "*Frondicularia cordata* = upper Austin and Taylor; *F. inversa* = from upper Austin to Navarro; *Bulimina aspera* = mostly upper Taylor. On this rather inadequate basis a correlation is suggested with the Taylor of the Gulf Coast which is known to be equivalent to the Lower Maestrichtian and Campanian of Europe."

The surfaces of the Foraminifera-bearing concretions mentioned above have a peculiar felted texture due to a great profusion of *Inoceramus* prisms which are aligned along the bedding in an east-west direction. Echinoid spines and fish teeth were also found in these rocks.

Concretions in the Red Man sandstone northeast of Antelope Pumping Station (map coordinates 1084.4/1419.5, plate 1) also contain Foraminifera, including *Planularia* sp. and *Dentalina* sp., as well as a profusion of *Inoceramus* prisms.

J. P. Wagner (1947) of the Union Oil Company found a large ammonite, *Parapachydiscus* cf. *P. caterinae*, along the axial trace of the Sawtooth Ridge syncline at its extreme western end. This ammonite is dated as Maestrichtian (uppermost Cretaceous).

The Red Man sandstone rests conformably upon the Moonlight formation in the Sawtooth Ridge syncline, along the south limb of the Devil's Den syncline, and west of Sawtooth Ridge. Elsewhere it is faulted against other units.

Moreno Formation

In 1915 Anderson and Pack (pp. 46-47) designated Moreno Gulch on the east flank of the Panoche Hills as the type locality of the Moreno formation. The Panoche Hills lie about 70 miles northwest of the Orchard Peak area, along the west side of the San Joaquin Valley.

In 1951 Payne (p. 3) divided the Moreno into four members which are, in ascending order: the Dosados sand and shale, the Tierra Loma shale, the Marca shale, and the Dos Palos shale.

In the Orchard Peak area the Moreno formation crops out only as a single arcuate band of brown shale in the Devil's Den syncline. This is the southernmost known surface exposure of the formation in California*. It is not known which of Payne's members is represented at Devil's Den. Within the mapped area the maximum exposed thickness of the Moreno formation—900 feet—is

* Written communication from William K. Gealey, Standard Oil Company of California geologist, November 21, 1956.

reached on the north limb of the Devil's Den syncline. Southeastward the formation thins until near the eastern end of the outcrop belt it is only about 230 feet thick. This thinning is interpreted by the writer as indicating an angular unconformity between the Upper Cretaceous Moreno formation and the overlying upper Eocene Canoas siltstone member of the Kreyenhagen shale.

At Devil's Den the Moreno formation underlies smooth, concave slopes sparsely covered with grass. The rock is almost entirely a soft, clay-rich, chocolate-brown shale. Commonly the shale carries many well-rounded, dark clay pellets, a few of which are as much as 3 mm. in diameter, forming a clay-granule conglomerate. Excavations reveal the shale to be intricately veined with gypsum; pieces of gypsum are also common on the surface of the ground. Locally, the rock is much streaked with powdery yellow jarosite (hydrous potassium iron sulfate) along joint surfaces. A few light gray limestone nodules which weather to white are present in the shale.

Shale samples from the Moreno, collected at map coordinates 1094/1420.3 (plate 1), yielded the following arenaceous Foraminifera:

Bathysiphon sp. VR
Cribrostomoides cretacea (?) VR
Dorothia sp. VR
Haplophragmoides sp. R
Silicosigmoilina californica R

J. D. Bainton of the Standard Oil Company of California interprets this assemblage as follows:

> "Based on the fauna and the lithology it is thought that this sample represents the Moreno shale. It is suggested that this sample is no younger than Upper Ciervian and no older than Upper Ingramian (Goudkoff's stages)."

In other words, the Moreno at Devil's Den appears to be equivalent in time to the lower portion of the Moreno formation at its type locality as redefined by Payne.

In the Orchard Peak area the Moreno formation lies conformably upon the Red Man sandstone and is overlain by the upper Eocene Canoas siltstone member of the Kreyenhagen shale. Consequently, there is a stratigraphic hiatus in which the Paleocene and lower and middle Eocene are missing. Southeastward from the north limb of the Devil's Den syncline there is a loss of more than 670 feet of section in a little over a mile along the outcrop belt. The writer interprets this thinning as the result of an angular unconformity because in the northwest part of the Orchard Peak area Eocene beds progressively bevel Upper Cretaceous strata. At Red Rock Canyon the middle Eocene Avenal sandstone rests upon the Upper Cretaceous Risco formation; at Stoker Canyon about 2 miles to the southeast the Avenal rests upon younger Upper Cretaceous beds, the Aguila sandstone. This interpretation does not agree with the opinion of Reed and Hollister (1936, p. 58) who state that "... at Devil's Den, the Cretaceous-Eocene contact seems to be merely disconformable."

Correlation of Cretaceous Formations

On the basis of fossils and stratigraphic position, at least the following formations in the Orchard Peak area are equivalent in age to the Late Cretaceous Panoche formation of the Panoche Hills, which lie about 70 miles northwest of the mapped area in western Fresno County: Johnson Peak formation, Aguila sandstone, Serpiente sandstone, Moonlight formation, and Red Man sandstone. A few of these units may correlate with some of the informal divisions of the Upper Cretaceous (see fig. 2) which J. Q. Anderson (1941) set up for the Coalinga area in 1941. Thus, the Serpiente sandstone may probably be correlated, at least in part, with his "Joaquin Ridge sandstone" (Weldonian stage, Goudkoff, 1945, pp. 962, 985-991); the Moonlight formation with his "Ragged Valley shale" (="*Pachydiscus* silt") (Tracian and lower Ingramian stages); and the Red Man sandstone with his "Brown Mountain sandstone" (upper Ingramian stage). Diagnostic fossils were not found in the Badger shale or the Risco formation, so these units cannot as yet be correlated with assurance. Precise correlation of all the Cretaceous units in the Orchard Peak area must await further detailed study.

CENOZOIC ROCKS

Lower Eocene (?)

Above the Aguila sandstone along the northeast limb of the Stoker Canyon syncline are two thin stratigraphic units (see geologic map, plate 1) which do not appear to be represented elsewhere in the Orchard Peak area. The lower unit is about 300 feet thick and consists of light gray siltstone with calcareous nodules; this is overlain by about 700 feet of brown sandstone with large, dark reddish-brown concretions. These units appear to be absent from the southwest limb of the syncline where the Upper Cretaceous Aguila sandstone is unconformably overlain by the middle Eocene Avenal sandstone. Thus, there is a stratigraphic hiatus in which the upper part of the Upper Cretaceous, the Paleocene, and the lower Eocene are missing.

It is possible that the two units of uncertain age along the northeast limb of the syncline are remnants of lower Eocene beds which elsewhere in the Orchard Peak area were removed by erosion prior to the deposition of the Avenal sandstone. A possible, though inconclusive, confirmation of this interpretation is the discovery by William Gealey of an assemblage of smaller Foraminifera believed to be lower Eocene at map coordinates 1079/1431.6 (plate 1). The rocks at this locality may be part of a fault sliver derived from the lower of the two units of uncertain age in question. The direction and extent of movement along the Stoker Canyon tear fault are such as could easily have caused this postulated fault sliver to be dragged many hundreds of feet northward from its original position within the syncline. Unfortunately, exposures were too poor to permit recognition of this fault sliver in the field, and accordingly it is not shown on the geologic map. The following species of Foraminifera were found at this locality:

Anomalina cf. A. coalingensis
Anomalina dorri
Globigerina triloculinoides
Globorotalia sp.
Marginulina mexicanus var. nudicostat s
Nodosaria latejugata
Robulus sp.
Tritaxalina cf. T. colei
Vulvulina sp.

In a letter dated July 27, 1954, Mr. Gealey states:

"This fauna is not entirely definitive as it might be either basal upper Eocene or low in the lower Eocene. Our interpretation is that it is indeed a lower Eocene fauna similar to that found in Hondo shale of the Devil's Den area. The fact that it appears to lie just above Cretaceous at Stoker Canyon and below the Discocyclinas which you found, leads us to consider the lower Eocene determination to be more probable."

In the East Coalinga field, about 22 miles northwest of the Orchard Peak area in southern Fresno County, the Hondo shale is at the base of the Gatchell sandstone which is equivalent to the Avenal sandstone (middle Eocene) of Kettleman Hills in southwestern Kings County.

Middle Eocene

Avenal Sandstone

In 1905 Anderson (pp. 164-168) proposed the name "Avenal Sandstones" for a series of fossiliferous, concretionary sandstones about 400 feet thick which makes up the lower portion of the Eocene series in Reef Ridge, about 8 miles north of the Orchard Peak area. The formation is named for the Avenal wells (Tar Springs) where it is well exposed.

In the Orchard Peak area the Avenal sandstone crops out only in the central parts of the Red Rock and Stoker Canyon synclines. In the former it attains a thickness of about 1,200 feet, in the latter about 900 feet.

The upper two-thirds, approximately, of the Avenal sandstone forms rugged outcrops of massively bedded light-brown sandstone. The beds range in thickness from 1 foot to more than 4 feet. The rock is hard, very fine-grained, and silty. Locally it is coarse-grained, with abundant flakes of fresh biotite. Some layers are strongly indurated with calcite and exhibit large, well-formed flow casts. Numerous chocolate-brown concretions, spherical to ellipsoidal in shape, occur throughout the upper two-thirds of the formation. The strata are separated by partings of brownish shale, and at places wood fragments lie along the bedding planes.

The lower 500 feet of the Avenal sandstone consists of light gray (locally light brown), fine- to very coarse-grained arkose. The soil, however, is a peculiar greenish-yellow color. The rock is very friable, which may explain its subdued topographic expression. The beds are 1 foot to 2 feet thick and indistinctly bedded. Rare igneous pebbles up to 1 inch in diameter and unidentifiable shell fragments are scattered throughout the sandstone. Small spherical concretions 3 to 6 inches in diameter are common in the friable sandstone.

Fossiliferous ledge-forming beds 2 to 5 feet thick, indurated with calcite, occur here and there throughout the lower 500 feet of the Avenal sandstone. Some of them are cross-bedded. These beds are composed of very coarse-grained sandstone, mostly well-rounded grains of quartz and some black chert.

Fossils and Age. Beds of coarse Avenal sandstone on the southwest limb of the Stoker Canyon syncline (map coordinates 1079.4/1428.9, plate 1) contain abundant *Discocyclina* sp., as well as *Lenticulina* sp. and cf. *Quinqueloculina* sp. The large foraminifer *Discocyclina* is restricted to rocks of Paleocene and Eocene age. Hitherto the beds in the Stoker Canyon syncline have been considered to be Cretaceous.

Small, planispirally coiled, calcareous tubes of the annelid worm *Rotularia tinajasense* (Hanna and Hertlein) were found at two localities in the Avenal sandstone. One is on the southwest limb of the Stoker Canyon syncline (map coordinates 1079.4/1428.9, plate 1), and the other is in the northeastern part of the Red Rock syncline (map coordinates 1074.9/1431.9, plate 1), in the indurated ledges of the lower part of the formation. According to Dr. Myra Keen * of Stanford University, "The range of the species in California is lower to middle Eocene." *Rotularia* is commonly misidentified as "*Spiroglyphus.*" Dr. Keen states: "The type species of *Spiroglyphus* may possibly be an annelid worm but is more likely a gastropod . . . In any case, the name applies to a Recent form and is not appropriate for the Eocene Annelida to which it has been applied."

In the trough of the Red Rock syncline, about 500 feet above the base of the formation, the Avenal sandstone contains the minute, delicately ribbed *Pecten (Propeamusium) interradiatus* Gabb which ranges from middle to upper Eocene. This locality is at map coordinates 1075.2/1430.5, plate 1.

Surprisingly, Upper Cretaceous Foraminifera were found in shale interbeds in the lower part of the Avenal sandstone at two localities in the Stoker Canyon syncline. Apparently these fossils were reworked; that is, eroded from Cretaceous rocks and redeposited in the Eocene beds.

At Red Rock Canyon in the northwest corner of the mapped area the Avenal sandstone rests unconformably upon the Risco formation of early Late Cretaceous (?) age. On the order of 10,000 feet of Upper Cretaceous strata must have been removed by erosion before deposition of the Avenal sandstone at Red Rock Canyon. In the Stoker Canyon syncline the Avenal sandstone rests unconformably upon the Upper Cretaceous Aguila sandstone along the southwest limb of the syncline and upon lower Eocene (?) strata along the northeast limb. Within the mapped area the Avenal sandstone is not in contact with any of the younger rocks.

Upper Eocene

Canoas Siltstone Member of Kreyenhagen Shale

In 1942 Cushman and Siegfus (p. 391) published a report on the Foraminifera of the Kreyenhagen shale. They recognized ten lithologic divisions of the Kreyenhagen at Garzas Creek, about 11 miles north of the Orchard Peak area. They named the lowest unit the Canoas siltstone member and designated Garzas Creek as the type locality.

The following year Van Couvering and Allen (1943, p. 499) published a geologic map of the Devil's Den oil field. They recognized two new Eocene formations between the uppermost Cretaceous beds and the upper Eocene Point of Rocks formation. The lower unit they called the Mabury formation and the upper, the Gredal formation; together these two units are equivalent to the Canoas siltstone member of the Kreyenhagen shale in the present report. Because the siltstone unit at Devil's Den is lithologically and faunally equivalent to the earlier-named Canoas siltstone member as defined by Cushman and Siegfus, the writer prefers to follow their usage in deference to the rule of priority.

The Canoas siltstone member crops out in the mapped area as a single arcuate band in the Devil's Den syncline

* Written communication November 27, 1956.

where it is approximately 1,000 feet thick. The light color of the siltstone contrasts strikingly with the dark Cretaceous formations which underlie it. The clayey, mud-cracked soil of the Canoas is almost bare of vegetation.

At Devil's Den the Canoas siltstone member is light brown, weathering to light greenish-gray or light brown. It is much jointed, forming subspherical kernels averaging half an inch in diameter. The siltstone is soft and readily slakes in water. Large numbers of foraminifers are present. Locally, gypsum is abundant in the soil.

Near the base of the Canoas siltstone member are several sandstone beds 1 foot to 2 feet thick which are indistinctly bedded and contain coiled calcareous tubes of the Eocene annelid worm *Rotularia tejonensis.* The sandstone is brown to purplish where weathered and light brown where fresh. The grains, ranging from fine to very coarse, are subangular to well-rounded and consist mostly of quartz cemented with iron oxides. Locally these sandstones are conglomeratic, containing poorly sorted dark igneous pebbles up to 1 inch in diameter. In places shell fragments, mostly of oysters, are plentiful.

Two samples of the siltstone were examined for Foraminifera and yielded a large microfauna as follows:

Standard Oil Company Locs. No. 5209 and 5210—(map coordinates 1092.7/1421.1—see plate 1).

Ammodiscus cf. A. incertus VR
Anomalina crassasepta R
Anomalina dorri R
Anomalina garzaensis VR
Asterigerina crassiformis R
Bathysiphon sp. R
Bulimina sp. R
Bulimina denticulata VR
Buliminella grata R
Cibicides martinezensis R
Cibicides pygmaea C
Cyclammina cf. C. pusilla R
Dorothia sp. VR
Eponides umbonata VR
Globigerina spp.
Globorotalia spp.
Globorotalia cf. G. naussi C
Glomospira charoides VR
Gyroidina orbicularis planata VR
Various Lagenidae C
Marginulina asperuliformis (?) VR
Pleurostomella sp. VR
Pullenia quinqueloba VR
Robulus cf. R. inornatus VR
Silicosigmoilina californica R
Spiroplectammina clotho VR
Spiroplectammina cf. S. richardi R
Tritaxilina colei R

Micropaleontologists of the Standard Oil Company correlate this fauna as follows:

> ". . . a prolific fauna which is definitely Canoas. The Canoas fauna (basal A-2 zone of Laiming 1940, pp. 1923-1939) is a repetition or recurrence of the lower Lodo fauna (C zone of Laiming) with some elements of the Kreyenhagen shale (A-2 zone of Laiming) present."

In other words, the Canoas siltstone member at Devil's Den is dated as lower upper Eocene.

At Devil's Den the Canoas siltstone member rests with angular unconformity upon the Upper Cretaceous Moreno formation. According to Van Convering and Allen (1943, p. 499), there is also an unconformity between the Canoas siltstone member (the portion equivalent to their Gredal formation) and the overlying Point of Rocks formation. The Point of Rocks crops out only in a small part of the mapped area. The writer found no fossils or other evidence in this exposure either to support or refute the presence of a supposed unconformity between the Point of Rocks and the Canoas.

Point of Rocks Formation

The Point of Rocks formation was named by Van Couvering and Allen (1943, p. 496) for a group of crags by that name about 4 miles southeast of Devil's Den. However, they did not publish a detailed description of the unit.

In the Orchard Peak area the Point of Rocks formation occurs only as a small patch of sandstone about 150 feet thick in the central part of the Devil's Den syncline. Within the mapped area it is not overlain by any of the younger rocks. This exposure is lithologically identical and continuous with the Point of Rocks formation at its type locality 4 miles to the southeast. The soil derived from the unit supports sparse grass and numerous bushes, many of which were still green at a time when bushes elsewhere had dried up, testifying to the water-retaining properties of the sandstone.

The Point of Rocks formation is a light yellowish arkose, consisting almost entirely of medium-grained quartz and feldspar cemented with limonite. The rock is massive and obscurely bedded and extremely friable. Biotite is rare but some muscovite was noted, as well as a small amount of black chert. The grains are angular to subrounded and fairly well to poorly sorted.

The most conspicuous feature of the Point of Rocks formation is the abundance of concretions. Most of these are spherical in shape, although forms ranging from oblate and prolate spheroids to irregular masses are common. These concretions are light to dark brown and are mostly quite hard, although some are friable. They range from 3 inches to 4 feet in diameter (averaging 2 or 3 feet) and are spaced 3 to 15 feet apart along the bedding, with successive concretionary horizons from 6 to 50 feet apart. The grains are angular and medium to very coarse with some pebbles. Patches of dark brown limonite are characteristic. The concretions are generally much jointed.

No fossils of any kind were found in the Point of Rocks formation within the mapped area.

Lower and Middle Miocene

Temblor Formation

The name "Temblor Beds" was given by Anderson (pp. 168-187) in 1905 to "the entire series of sands and shales below the Monterey Shales" at Carneros Springs on the east flank of the Temblor Range, Kern County, California.

Within the mapped area the Temblor formation occurs only in scattered outcrops along the western border; here it has been overridden, and in places overturned, by the Antelope Valley thrust. For the purposes of this report the Temblor has been mapped as two divisions, the upper Temblor sandstone and the much thicker lower Temblor sandstone.

Lower Temblor Sandstone. This sandstone unit is at least 1,450 feet thick. The rock is pale brown where fresh, usually with a faint greenish tinge, and weathers light brown to light gray. It is a massively bedded arkose, fine

to very fine grained and well sorted. Highly fossiliferous beds of indurated, ledge-forming sandstone are numerous throughout the lower Temblor, ranging in thickness from 6 to 24 inches along a given bed. These strata are a darker brown than the more friable sandstone between them and weather to residual boulders. Locally the indurated beds give way to lenticular concretions up to 6 by 12 feet. By far the most abundant fossil in these beds is *Pecten (Plagioctenium) andersoni* Arnold, but there are also a few poorly preserved pelecypods of other types. Arnold (1906, p. 83) states that "*Pecten andersoni* ranges from the lower to the middle (and probably upper) Miocene. In the Devil's Den country, Kern County, *P. andersoni* is found with *P. crassicardo* in beds of probable lower Miocene (Vaqueros) age."

The base of the lower Temblor sandstone is not exposed in the mapped area. The unit is overlain conformably by the upper Temblor sandstone.

Upper Temblor Sandstone. This member is about 850 feet thick and is composed of white to brownish gray arkose which weathers to light brown. It is massively and obscurely bedded. Although locally fine grained, the member is typically composed of coarse to very coarse, friable, well-sorted sandstone. The grains are angular, mostly quartz with some black chert and almost no mica. Locally there are concentrations of pebbles of igneous, metamorphic, and sedimentary rocks exceptionally as large as 2 inches in diameter; these include green and black chert and angular fragments of brown, very fine-grained sandstone which may have been derived from Cretaceous outcrops. Veins and pods of calcite occur sporadically throughout the unit. The upper Temblor also contains light gray concretions indurated with calcite, up to a foot and a half in diameter and ovoidal in shape.

Several types of fossils occur both in the concretions and in the friable matrix. These are mainly calcareous worm tubes, a few barnacles, gastropods, and various pelecypods including razor clams and *Pecten (Lyropecten) crassicardo* Conrad. Arnold (1906, p. 73) gives the range of *Pecten crassicardo* at Devil's Den as lower to middle Miocene.

The upper Temblor sandstone lies conformably above the lower Temblor sandstone and below the McLure shale.

Upper Miocene

McLure Shale

In 1930 Henny (p. 404) proposed the name "McLure shale" for the "brown shale" of the southern Coalinga region, Fresno and Kings Counties, which Arnold and Anderson (1910, p. 92) had previously mapped as the Santa Margarita (?) shale. Henny states that in this region the McLure shale overlies the Santa Margarita sandstone (upper Miocene) with angular unconformity and is in turn overlain with angular unconformity by the Etchegoin sandstone (Pliocene). Henny designated a canyon crossing Tent Hills south of Avenal Creek near the west line of sec. 6, T24S, R17E as the type locality of the McLure shale, a name taken from McLure Valley which bounds the Orchard Peak area on the northeast. The type locality thus lies about 3 miles north of the mapped area.

Gester and Galloway (1933, p. 1175) point out that it is not clear whether Henny intended to include in his McLure shale both the Reef Ridge shale* and the underlying siliceous shales, or merely the latter. These authors restrict the term "McLure shale" to the brown siliceous shales which at Kettleman Hills (10 miles northeast of the Orchard Peak area) lie unconformably below the Reef Ridge shale and unconformably above the Temblor formation. This is reasonable, as there is no Reef Ridge shale at the type locality of the McLure.

Henny (1930, p. 409) states that "In the Devil's Den area the McLure shale is situated unconformably on the Monterey shale, and no Santa Margarita is present between the two formations." Careful examination by the present writer of the siliceous shale exposures in the Orchard Peak area (6 miles west of Devil's Den) revealed no lithologic distinction which could be used to distinguish Henny's McLure shale from the "Monterey shale" referred to in his statement. Accordingly, these outcrops have all been mapped as McLure. As a matter of fact, the U. S. Geological Survey regards the McLure shale as a member of the Monterey shale and assigns it a late Miocene age (Wilmarth, 1938, p. 1258).

Within the Orchard Peak area the McLure shale crops out as a continuous belt along the western border of the area. Small, scattered outcrops are also found to the southeast in Antelope Valley. In general these Miocene beds dip northeastward, and in Antelope Valley they are overlain by Upper Cretaceous strata along the Antelope Valley thrust. At least 1,700 feet of McLure shale is exposed in the mapped area.

The siliceous shales of the McLure are very resistent to erosion, as indicated by the high, steep-sided hills which they form (photo 11). Characteristic vegetation is sparse grass and oak trees.

The shale is light chocolate-brown on fresh surfaces, weathering to light gray. The bedding has been obscured by extreme jointing which has broken the rock into blade-like fragments averaging 2 inches in length. The rock is fairly hard. Diatoms and Foraminifera are abundant throughout the shale. Locally, "beaded" lenticular layers of impure diatomite up to 3 inches thick, composed of marine diatoms, are found in the McLure. Interbedded with the siliceous shale are beds of dark tan porcellanite which weathers to white. In a few places, layers and pods of dark orange-brown, iron-stained dolomite 1 foot to 3 feet thick occur among the shales; these weather to yellow and contain diatoms.

Polonio Sandstone Tongue. A large tongue of siliceous sandstone was mapped within the McLure shale. This tongue, here named for Polonio Pass at the head of Antelope Valley, enters the Orchard Peak area from the northwest. The member thins southeastward and pinches out just northwest of Hughes Ranch (see geologic map, plate 1) near the head of the valley. The Polonio sandstone tongue comprises alternating beds of siliceous quartz sandstone and interbeds of siliceous shale in approximately equal amounts. The massive sandstones crop out as prominent ledges and range in thickness from 1

* A name proposed by W. F. Barbat and F. L. Johnson in 1933 (p. 239) for an upper Miocene blue shale which weathers brown, exposed on Reef Ridge, Fresno and Kings Counties, between the siliceous shales (undoubted McLure of Henny) below and the Etchegoin sandstone above.

Photo 11. Cottonwood syncline in upper Miocene McLure shale, overturned southwestward by Antelope Valley thrust whose trace can be seen in distance (arrow).

foot to 36 feet. Ten-foot-thick beds are common. Where fresh the rock is white or light gray, weathering light gray, but commonly tinged with orange, brown, pink, or pale yellow. The rock is very hard to extremely friable and consists of very fine-, medium-, and very coarse-grained, well-sorted quartz sand in angular to subangular grains. Dark minerals are very scarce.

The beds are much broken by vertical, closely spaced joints. A characteristic feature of this sandstone is the intricate crisscrossing of thin siliceous veinlets which weather into relief as sharp ridges. Locally, cavernous weathering is conspicuous. In places the sandstones are cross-bedded.

Approximately every 20 feet or so along the bedding there are light gray-brown, lenticular concretions up to 3 by 5 feet which weather to brown. These are not distinctly separated from the matrix except in color.

Several poorly preserved internal casts of *Uvigerina* and/or *Uvigerinella* were recovered from a shale interbed in the Polonio sandstone tongue at map coordinates 1079.1/1423.4 (plate 1), suggesting an age for these beds of middle or late Miocene. No attempt was made to identify the diatoms in the McLure shale. These are chiefly of a discoidal, marine type, possibly *Coscinodiscus*.

Just east of Antelope Pumping Station (map coordinates 1083.3/1419.2, plate 1) a flattened pelecypod, *Phacoides* sp., was collected from the siliceous shale. In California, this genus ranges from Eocene to Pliocene and is therefore of little value in dating Tertiary units.

In the Orchard Peak area the McLure shale rests with apparent conformity upon the Temblor sandstone. It is not overlain by younger rocks in the mapped area.

Transgressive Tertiary Overlap

South or southeastward from the northern part of the Orchard Peak area there appears to be a transgressive overlap of Tertiary formations upon Cretaceous beds. At Red Rock and Stoker Canyons, Upper Cretaceous beds are unconformably overlain by the Avenal sandstone (middle Eocene). The Avenal sandstone evidently pinches out a few miles southeast of Stoker Canyon; for at Devil's Den, Upper Cretaceous beds are unconformably overlain by the Canoas siltstone member of the Kreyenhagen shale (upper Eocene). Six miles south of Devil's Den the upper Eocene Point of Rocks formation, which normally overlies the Canoas siltstone member, rests upon the Cretaceous. Seven miles farther south, on the northeast side of Cedar Canyon, the upper Santos shale member of the Temblor formation (Gester and Galloway, 1933, pp. 1161-1193) (lower Miocene) lies unconformably upon Cretaceous strata (Heikkila and MacLeod, 1951, plate 1). Thus, each of these Tertiary formations pinches out in a south- or southeasterly direction and in turn is overlapped by the next younger formation, indicating an advance of the Tertiary seas across the beveled Cretaceous surface. A regional study would be required to establish the configuration of this overlap and the precise direction of marine transgression.

STRUCTURE

The entire Orchard Peak area, except for a narrow margin along the southwest border, is underlain by the upper plate of the Antelope Valley thrust. Movement from north to south along this thrust has brought Cretaceous rocks to rest upon strata of Miocene age. These strata have been warped into six large folds broken by a multitude of faults, most of which appear to fall into an orderly pattern implying a common origin. Evidently these subsidiary folds and faults represent adjustments to the same regional compression—probably acting roughly north-south—that produced the Antelope Valley thrust.

The faults are of two principal kinds: (1) imbricate thrusts trending west or northwest; and (2) tear, or strike-slip, faults trending north or northwest. The great majority of the tear faults are displaced right laterally (see tectonic map, fig. 14). Not only the stratigraphic units but also the thrust faults are offset right laterally along the tears. This indicates that successive north-south segments of the Antelope Valley thrust sheet, going from west to east, were displaced progressively farther southward. Possibly the western part of the thrust sheet was impeded in its movement, perhaps by some obstacle in the basement; whereas the more easterly portions, not so obstructed, were able to advance farther. However, evidence is lacking, and any guess as to ultimate causes must be entirely speculative.

The thrust faults of the Orchard Peak area fall into two groups: (a) those in which movement was from north to south, and (b) those in which thrusting was toward the southwest or west. Of the four southward-moving thrusts, two have pushed older rocks up over younger (thrust plane dips more steeply than beds) and two represent a movement of younger beds over older (thrust plane dips less steeply than beds). The two thrusts of the second group—namely, those whose movement was toward the southwest or west—have also moved younger beds upon older.

Thrust Faults

Southward-Moving Thrusts

Antelope Valley Thrust: The trace of the Antelope Valley thrust roughly parallels the southwest border of

the Orchard Peak area. This fault can be followed for 13 miles within the mapped area. Two miles west of Cottonwood Pass the thrust is cut off by a vertical east-west fault; north of this fault the thrust is probably present under the alluvium of the valley. As the Antelope Valley thrust continues beyond the borders of the area both to the north and south, its total extent is undetermined. Northwest of Antelope Valley the thrust trace is marked by fault slivers of serpentine, chert, and other rock types which presumably originated from the Francisan group at depth.

Along the thrust in Antelope Valley the Upper Cretaceous Moonlight formation and Red Man sandstone rest upon the upper Miocene McLure shale. Northwest of Antelope Valley the Cretaceous Badger shale rests upon overturned beds of the Temblor formation, dated as early and middle Miocene.

With presently available information it is not possible to determine the net slip of the Antelope Valley thrust. A minimum figure, however, may be obtained in the following manner. Near where State Highway 41 crosses the thrust, Badger beds rest upon upper Temblor sandstone along the fault. Here the stratigraphic throw is at least 11,000 feet and probably considerably more. Owing to facies changes, structural complexities, and other factors, it is extremely difficult to obtain a reliable figure. Since it is apparent that the net slip along a fault must be at least as great (usually greater) than the stratigraphic throw, the net slip at this place must be something more than 11,000 feet. Eastward from where Highway 41 crosses the thrust the upper plate has been displaced progressively farther south along numerous right-lateral tear faults. By adding up the offsets along these tear faults, the relative displacement can be calculated between the segment of the upper plate in the northwest corner of the mapped area and that portion of the upper plate at Orchard Peak. The amounts of displacement along the tear faults are accurately indicated by the offsetting of numerous distinctive volcanic ash beds which can be traced for nearly 9 miles across the area. The cumulative horizontal displacement of these marker beds is about 25,000 feet. By adding together the two figures obtained above (11,000 and 25,000 feet), a minimum net slip is obtained for the Antelope Valley thrust sheet on the north side of Antelope Valley. This minimum figure is 36,000 feet, or almost 7 miles. The actual net slip of the Antelope Valley thrust on the north side of Antelope Valley is probably much greater than this.

Aido Spring Thrust. The second most important thrust in the Orchard Peak area, in terms of displacement, is the Aido Spring thrust which runs southeastward from the Maxey ranch (map coordinates 1075.9/1427.7, plate 1) north of State Highway 41, parallel to the trace of the Antelope Valley thrust. East of the Stoker Canyon tear fault and east of the Polonio Pass tear fault the Aido Spring thrust trace is offset southward many thousands of feet. At Polonio Pass (at the head of Antelope Valley) the Aido Spring and Antelope Valley thrusts merge to form a single fault for a short distance. East of Polonio Pass the two thrusts diverge from each other, the Aido Spring thrust running eastward along the north side of Antelope Valley at least as far as Aido Spring. East of Aido Spring there is a steeply dipping fault within the diapiric Hex formation which lines up with the thrust, but the precise relationship of these "two" faults is not certain.

Along nearly its entire extent the Aido Spring thrust is marked by fault slivers of serpentinized peridotite, chert, and other Franciscan-type rocks. Where Highway 41 crosses this fault, a zone of caliche-like rock 65 feet thick is exposed in the roadcut.

On the north side of Antelope Valley movement along the Aido Spring thrust has brought the Lower Cretaceous (?) Badger shale into contact with the Red Man sandstone and Moonlight formation of late Late Cretaceous age, producing a stratigraphic throw on the order of 15,000 feet.

Taliaferro (1943b, p. 206) gives a different interpretation of the Aido Spring serpentine body:

> "Along the north side of Antelope Valley . . . there is a long belt of serpentine squeezed into either Knoxville or Paskenta shales and sandstones along the crest of a faulted anticline."

Both the lithology and fossil content of the rocks, however, indicate that the Aido Spring serpentine body does not occupy the core of an anticline but instead has been squeezed up along a thrust fault of considerable magnitude. The rocks south of the fault are neither lower Lower Cretaceous (Paskenta) nor Jurassic (Knoxville) but are late Late Cretaceous (Senonian and Maestrichtian stages) as proved by microfossils and megafossils (listed in this report under discussion of Moonlight formation and Red Man sandstone). The shales on the north side of the fault, although lithologically similar to those on the south side, are actually much older, as indicated by the stratigraphic separation mentioned above. Furthermore, there is no Red Man sandstone north of the fault to correspond with the Red Man beds on the south side, as would be required by an anticline.

Badger Thrust. South of Orchard Ridge and east of the Polonio Pass fault the contact between the Badger shale and the Risco formation is a thrust fault. West of the Polonio Pass fault the thrust surface—whose trace has been offset on the order of 5,000 feet to the north—climbs rapidly in the section from near the base of the Risco to a position about two-thirds of the way up from the base. West of the Stoker Canyon fault the Badger thrust could not be detected, owing either to the poor exposures or to its absence there. The southeastward trend of the thrust trace west of the Polonio Pass fault, in contrast to its eastward trend east of the Polonio Pass fault, may be attributed to drag along the Stoker Canyon and Polonio Pass tear faults which undoubtedly produced a strong couple acting on the segment of the Risco formation between them. One and a half miles east of Orchard Peak the Badger thrust is abruptly cut off by the overriding Hex thrust sheet.

Between the Polonio Pass and Stoker Canyon tear faults roughly 2,300 feet of the Risco formation appear to have been cut out by the thrusting. East of the Polonio Pass fault the thrust surface bevels the Badger shale so gently that over much of its extent it is very difficult to perceive its trace in the field, especially where the fault parallels bedding planes. Locally, however, truncation of Badger beds by the thrust may be observed, as along the east side of Risco Canyon (see photo 3). Even where the Badger thrust follows bedding

planes, its presence, although not its precise location, is demonstrated by indirect evidence. For example, about a mile west of Orchard Peak the tuffaceous sandstones in the Risco formation have been offset northward about 3,300 feet by the branching faults at the southern terminus of the Three Peaks tear fault. Yet the upper ash bed in the Badger shale, running directly across the path of these vertical faults a short distance to the south, has not been offset at all by them, indicating that the Three Peaks fault system is confined to the upper plate of a thrust. This same reasoning may be applied at several other places to confirm the presence of thrust faults.

Evidence of thrusting is readily apparent just east of the Stoker Canyon tear fault, where beds of the upper plate are cut off by those of the lower plate. Even more striking is the truncation of lower plate beds by upper plate beds—both overturned—just west of the Polonio Pass fault. Here the two sets of strata abut against each other at an angle of 65°.

The trend of the tear faults in the upper plate of the Badger thrust indicates that thrusting was from north to south. The thrust surface apparently dips about 10° northward.

Orchard Peak Thrust. Near the top of the steep scarp south of Orchard Peak there is a distinct angular discordance of beds in which the uppermost exposed sandstones of the Risco formation are overlain and truncated by the more gently dipping strata of the Johnson Peak formation. Hitherto this discordance has been considered by Wagner (1947) and others to be an angular unconformity, separating Lower from Upper Cretaceous. The writer is convinced, however, that this discordance has been caused by thrusting and is not an angular unconformity, as proved by several lines of evidence:

(1) Southwest of Orchard Peak the thrust is compound; that is, it consists of two small thrust faults, one 200 feet above the other. Sandwiched between them is a fault sliver of Risco beds which are inclined westward more steeply than the strata above or below and in such a manner as to be truncated both upward and downward by the two thrust surfaces. The downward truncation cannot be explained by an angular unconformity.

(2) Elsewhere in the mapped area the Risco-Johnson Peak contact appears to be both concordant and conformable. The Orchard Peak discordance is a very local feature; in the case of an angular unconformity, one would expect the discordance to extend over a greater area and also that there be a greater stratigraphic hiatus.

(3) The Johnson Peak formation of the upper plate abuts against the Risco formation along a vertical tear fault half a mile northwest of Orchard Peak. There has been about 4,000 feet of horizontal movement along this fault, as shown by the right-lateral offsetting of the basal contact of the Enebro sandstone member. Unless there were a zone of thrusting near the top of Orchard Ridge, a vertical fault of this magnitude could not fail to have cut and offset the four volcanic ash beds which run along the scarp immediately below and directly in its path. These marker beds, however, have not been offset at all.

An approximate figure for the total amount of horizontal movement of the upper plate with respect to the lower plate can be obtained by adding the horizontal displacement of the tear fault just discussed (i.e., 4,000 feet) to that of a second right lateral tear fault 0.9 mile west of Orchard Peak. This latter fault marks the western limit of the Orchard Peak thrust sheet. There has been 900 feet of horizontal movement along this fault. Thus, the total horizontal displacement of the upper plate with respect to the lower plate is about 4,900 feet.

Southwest- or Westward-Moving Thrusts

Along the east side of the Orchard Peak area there are two faults—the Hex and Devil's Den thrusts—whose movement seems to have been toward the west or southwest, rather than toward the south as in the case of the other thrusts described above. These two faults might be termed "scissors thrusts," for their displacements increase progressively from a few feet near one end to several thousand feet just before the faults leave the mapped area. Their "hinge points," however, lie at opposite extremes from each other. The "hinge point" of the Hex thrust lies east or northeast of the Three Peaks anticline; that of the Devil's Den thrust lies near the axis of the Devil's Den syncline. The rotational movement of the Hex thrust was in a clockwise direction, whereas that of the Devil's Den thrust was in a counter-clockwise direction.

Hex Thrust. In the northern part of the Orchard Peak area the Serpiente sandstone overlies the Aguila sandstone in, or close to, its normal stratigraphic position. But 3 miles south of Cottonwood Canyon the Serpiente swings abruptly southward across the strike of older formations—successively the Aguila, Johnson Peak, Risco, and the Hex formation (see geologic map, plate 1). The cause of this striking discordance is the Hex thrust whose trace can be followed for nearly 10 miles southeastward from a point east of Johnson Peak to the east end of Hex Hill. In the southeast corner of the Orchard Peak area this thrust has pushed the upper Upper Cretaceous Moonlight formation over upon the Upper Jurassic (?) clays of the Hex formation.

The contrast between the regionally discordant southern portion of the Hex thrust sheet and the concordant-appearing northern part can perhaps be partially explained by a steepening of the thrust surface from south to north. Southwest of Devil's Den the thrust surface dips about 5° NW; southwest of Red Man Rocks it dips about 13° NE; and at the head of Avila Canyon the thrust surface also dips NE, perhaps on the order of 30-40°.

The trace of the Hex thrust is marked in places by strong brecciation of overridden strata, fault gouge, carbonate zones, saline springs, overturned beds both above and below the thrust, and prominent drag structures. The latter are especially numerous between the Devil's Den syncline and Cottonwood Canyon. Here massive concretionary sandstones of the upper plate have in places been rotated as much as 90° from their normal position. These steeply dipping beds commonly abut against gently dipping strata of the lower plate, producing an angular discordance of a sort opposite from that which characterizes an angular unconformity.

Just north of Aido Spring there is a klippe of Serpiente sandstone three-quarters of a mile long and a quarter of a mile wide, irregular in outline. It is evidently an erosional remnant of the formerly more extensive Hex thrust sheet which must have advanced west- or southwestward at least this far, with a probable minimum horizontal displacement of about 2 miles. Along its southwestern edge the Serpiente is in contact with the Badger shale; on the northeast side of the klippe the Serpiente lies against the Hex formation. The flaggy Serpiente sandstones are overturned toward the south, as proved by flow casts and cross-bedding.

Devil's Den Thrust. A thrust fault extends northwestward from Devil's Den along the eastern border of the Orchard Peak area, crosses the mouth of Cottonwood Canyon, and continues northward for an unknown distance beyond the boundary of the area. The upper plate of this thrust is composed of Red Man sandstone and probably younger formations, although the latter are covered by alluvium of McLure Valley. As northward the thrust cuts deeper and deeper into the section, the Red Man is brought successively into contact with basal Moonlight formation, the Torcido member of the Serpiente, and the Avila member of the Serpiente. Northwest of Devil's Den, Red Man beds are overturned along the thrust.

Tear Faults

Of the numerous tear faults produced by thrusting in the Orchard Peak area—most of which are right lateral—only the four most important will be discussed here.

Stoker Canyon Tear Fault. One of the longest high-angle faults in the Orchard Peak area is the Stoker Canyon tear fault which can be traced for more than 6 miles northward from near Polonio Pass to the northern border of the area, beyond which it continues for an undetermined distance. There has been about 3,900 feet of right lateral horizontal displacement along this fault. Nearly a mile from its southern end the fault has a vertical component (northeast side down) on the order of 200 feet. The Stoker Canyon fault marks the western limit within the mapped area of the Stoker Canyon syncline; to the west the synclinal character is no longer discernible owing to folding and faulting. Prominent drag folds occur at various places along both sides of the break.

The Stoker Canyon fault appears to be the only tear fault in the Orchard Peak area which cuts both the lower and the upper plates of the Antelope Valley thrust. At the east end of Blue Point Valley it contains thin fault slivers of serpentine, suggesting that it extends downward to considerable depths—at least deep enough to tap the Franciscan group as a source for the serpentine.

Polonio Pass Tear Fault. The Polonio Pass fault, which trends northwestward then northward from Hughes ranch near the head of Antelope Valley, has the largest horizontal displacement of any tear fault in the mapped area—more than 5,000 feet. The fault may be traced northward for 4½ miles before it disappears on the south limb of the Stoker Canyon syncline. For 2 miles along its southern part the Polonio Pass fault separates Tertiary from Cretaceous rocks. Drag folds at its northern end indicate that the fault also had a vertical component of movement in which the west side went down an unknown distance relative to the east side.

[illegible]ne Tear Fault. Just west of Polonio Peak there is [illegible]h-trending tear fault of large horizontal displa[illegible] which can be traced from the edge of the Badger [illegible]rust to Cottonwood Canyon. The six tuffaceous sandstones in the Risco formation have been offset right laterally about 4,100 feet along this fault. Conspicuous fault slivers of Risco occur along the fault north of Polonio Peak.

Three Peaks Tear Fault. The Three Peaks anticline is cut by a vertical fault which enters the area from the north and continues southward across Orchard Ridge to the margin of the Badger thrust sheet. South of Orchard Ridge it branches out into three small right-lateral faults.

Horizontal displacement along the northern part of the Three Peaks fault has been about 4,200 feet. At the southern end of the fault the total displacement has been about 2,750 feet; this movement has been distributed along three branch faults as follows (from east to west): 850 feet, 1,400 feet, and 500 feet. Nevertheless, near the middle of the Three Peaks fault, beds have been offset horizontally only about 600 feet. One way to explain this paradox would be by postulating a strong vertical component near the middle of the fault—down about 750 feet on the southwest (see structure section IV-IV′, plate 2)—which resulted from the net slip being oblique at this place. That is, assuming an average apparent dip for the beds of 30° in the plane of the fault, the net slip could have taken place along a line which dips about 20° to the northwest. The 600-foot horizontal offset of beds near the middle of the fault would actually be the result of a horizontal component of movement of nearly 1,900 feet, because here the beds dip north or northwest—the same direction as that in which the net slip occurred.

Another peculiar feature of the Three Peaks fault is that in the Three Peaks anticline, despite a horizontal displacement of 4,200 feet, the southern contact between the Badger shale and the serpentine appears not to have been displaced at all (see geologic map, plate 1). Evidently the serpentine was intruded sometime after the development of the Three Peaks fault. The apparent slight offset of the northern contact may be due to a stringer of serpentine having been blocked by the plane of the fault at the time of intrusion.

Drag folds, overturned beds, contorted strata, springs, carbonate zones, and red, oxidized zones occur along the Three Peaks fault.

Normal Faults

The few normal faults which occur in the Orchard Peak area are practically confined to two parts of the area—east of Orchard Peak and west of Stoker Canyon syncline. Because of their similar sense and trend, these faults may be considered as a single group or set of faults which probably formed at about the same time and in the same manner. Most of them trend within 30° of north, and in nearly every case the eastern block dropped down with respect to the western block (see tectonic map, fig. 14). One of these normal faults, which cuts northeastward across White City Canyon, has a vertical displacement of about 240 feet.

The writer believes that the folds, thrusts, and tear faults in the Orchard Peak area formed essentially at the same time and that the normal faults did not come into being until some time later—how much later is not known. Field observations by many geologists in regions of both thrust and normal faulting, such as the Great Basin of Nevada, support the thesis that commonly an episode of thrusting (horizontal compression) is followed by normal faulting ("relaxation"). The empirical evidence is supported by theoretical considerations.

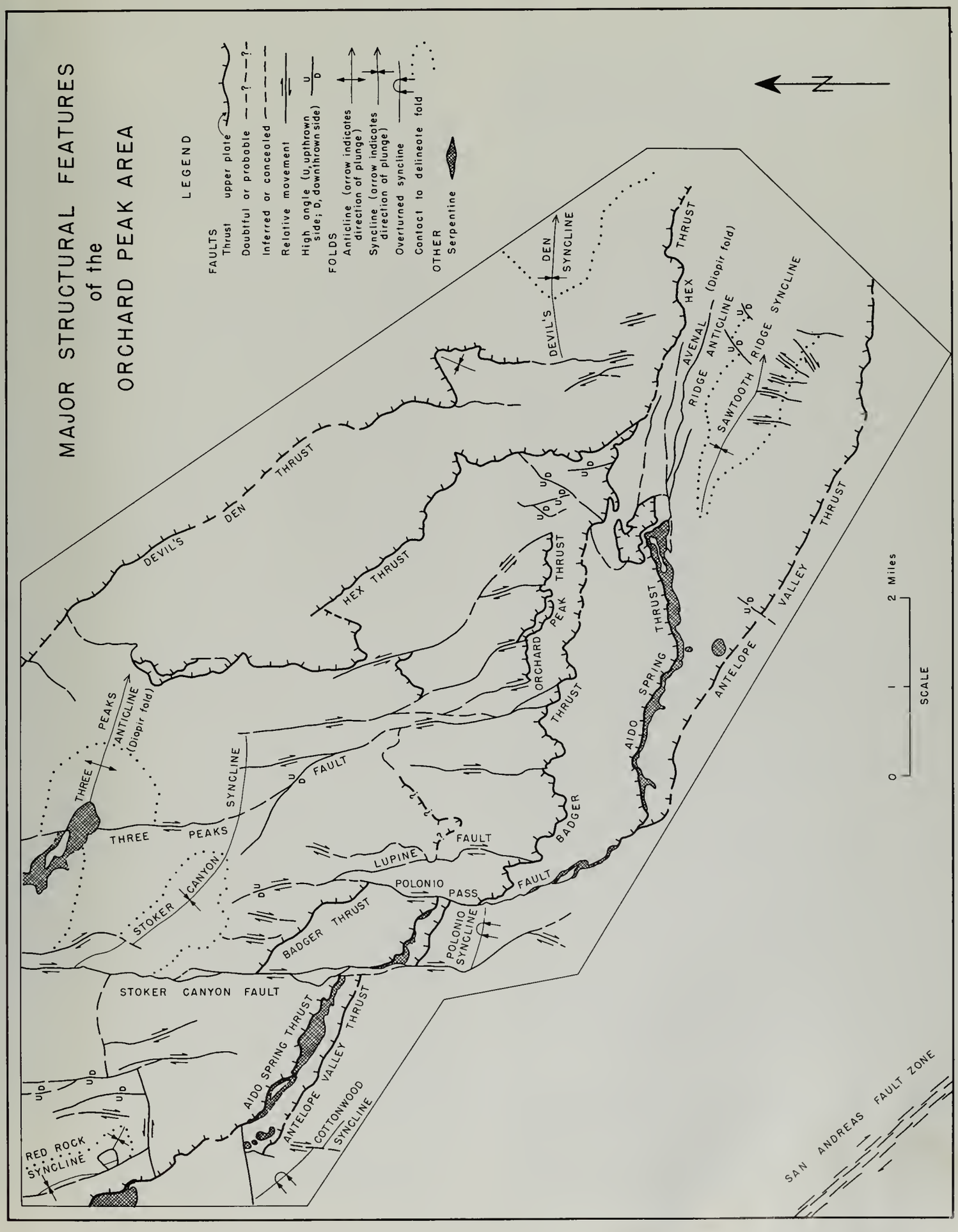

MAJOR STRUCTURAL FEATURES
of the
ORCHARD PEAK AREA
LEGEND
FAULTS
Thrust upper plate
Doubtful or probable
Inferred or concealed
Relative movement
High angle (U, upthrown side; D, downthrown side)
FOLDS
Anticline (arrow indicates direction of plunge)
Syncline (arrow indicates direction of plunge)
Overturned syncline
Contact to delineate fold
OTHER
Serpentine
N
DEVIL'S DEN THRUST
DEVIL'S DEN SYNCLINE
HEX THRUST
HEX THRUST
AVENAL RIDGE ANTICLINE (Diapir fold)
SAWTOOTH RIDGE SYNCLINE
ORCHARD PEAK THRUST
THREE PEAKS ANTICLINE (Diapir fold)
THREE PEAKS SYNCLINE
STOKER CANYON
FAULT
FAULT
LUPINE
POLONIO PASS
FAULT
BADGER THRUST
BADGER THRUST
POLONIO SYNCLINE
STOKER CANYON FAULT
AIDO SPRING THRUST
AIDO SPRING THRUST
ANTELOPE VALLEY THRUST
ANTELOPE VALLEY THRUST
COTTONWOOD SYNCLINE
RED ROCK SYNCLINE
SAN ANDREAS FAULT ZONE
0 1 2 Miles
SCALE

Figure 14

In their discussion of wrench-fault tectonics, Moody and Hill (1956, p. 1211) state that:

> "Normal faults require that the maximum stress be vertical, which means that the horizontal stresses are smaller than the vertical stresses. This requirement obviates the syngenetic development of normal faults with wrench or thrust faults except where normal faults are a secondary effect to local deformation, [that is,] in areas of local positive uplift, as in salt domes and igneous intrusive masses."

Folds

Three Peaks Anticline. North of Cottonwood Canyon there is a large southeastward-plunging anticline which Arnold and Anderson (1908, p. 67) named the "Diablo anticline." Because of possible confusion with the geologically similar Mount Diablo anticline, which is also situated in the Diablo Range (east of San Francisco), it is proposed that the fold in the Orchard Peak area be renamed the Three Peaks anticline after the three crags by that name as shown on published maps.

The Three Peaks anticline is one of several diapiric folds with cores of serpentine which are found in the Diablo Range as far north as San Francisco. This serpentine probably originated in the Franciscan group far beneath the range and was squeezed up into the axial portion of the anticline during the folding. The large body of serpentine which occupies the central portion of the Three Peaks anticline contains masses of bedded chert measurable in tens of feet, probably also derived from the Franciscan group. The pressure of the rising serpentine apparently tore off these blocks of chert, as well as masses of shale, and carried them upward, overturning many strata near the serpentine contact. The Three Peaks anticline is a tight fold whose axial plane dips southwest (see structure section IV-IV′, plate 2). The south limb of the anticline has been bent into a monocline (photo 5) whose axis roughly parallels that of the major fold.

Avenal Ridge Anticline. A second diapir fold, also trending southeastward, lies between the Devil's Den and Sawtooth Ridge synclines. It is here named for the prominent ridge which forms its northeast limb and which makes up the southern end of the Diablo Range. The core of the Avenal Ridge anticline is occupied by an extensive mass of clay, bentonite, and tuffaceous shale which makes up the Hex formation of Late Jurassic (?) age. Serpiente and Badger beds near the Hex contact have been overturned, probably as a result of upward pressure of the mobile core. This upward pressure was apparently also responsible for the formation of the two small hinge faults which cut the north limb of the Sawtooth Ridge syncline. One of these faults has offset formational contacts about 900 feet, yet beds running across the path of the fault near the synclinal axis do not appear to be displaced.

Stoker Canyon Syncline. Along the south side of the Three Peaks anticline there is a large syncline whose axis swings northwestward as it approaches the Stoker Canyon fault, probably due to drag between this fault and the Three Peaks fault. The north-trending Stoker Canyon tear fault abruptly cuts off the western end of the Stoker Canyon syncline; west of this fault the synclinal character within the mapped area has been destroyed by complex faulting and small-scale folding. The central part of the syncline is occupied by beds of the Avenal sandstone of middle Eocene age.

Devil's Den Syncline. In the easternmost part of the Orchard Peak area lies a broad, gentle syncline which plunges eastward. This fold is unique within the mapped area in that its axis trends due east rather than southeastward. A possible explanation for this is offered below. The Devil's Den syncline is composed of Upper Cretaceous and upper Eocene formations separated by a probable angular unconformity.

Sawtooth Ridge Syncline. The only syncline in the area composed entirely of Cretaceous rocks is the southeastward plunging Sawtooth Ridge syncline. The beds of the south limb, being close to the margin of the Antelope Valley thrust, are much broken by cross faults; and south of Sawtooth Ridge they are crumpled into small folds, many of them overturned.

Red Rock Syncline. In the extreme northwest corner of the Orchard Peak area there is a northwestward plunging syncline composed of rocks of the middle Eocene Avenal sandstone. It is here named for Red Rock Canyon which transects the fold. The syncline has been somewhat disrupted by faulting, so that for almost half a mile part of the southwest limb is missing; the northern part of this limb is apparently cut by the Antelope Valley thrust. The axis of the syncline has been broken into three segments which have been rotated out of line with each other (see geologic map, plate 1).

Polonio and Cottonwood Synclines. Two synclines which have been overturned toward the southwest by the advancing Antelope Valley thrust sheet occur in the McLure shale just south of the thrust trace in the western part of the area. The Polonio syncline lies northwest of Polonio Pass, between the Stoker Canyon and Polonio Pass tear faults. The Cottonwood syncline lies about a mile west of Cottonwood Pass.

Relation of Structure to the San Andreas Rift

The Orchard Peak area lies only 4 miles from the San Andreas rift, one of the world's largest faults.* Within the mapped area horizontal compression, rather than vertically acting forces, has evidently been the principal deforming agent; for the great majority of the faults are thrusts and associated tears. The major faults and folds of the area exhibit an orderly pattern and a spatial relationship to the San Andreas rift which strongly suggest that most of the structural features of the mapped area were formed at about the same time and by the same tectonic forces which concomitantly produced movement along the San Andreas. As mentioned earlier, the primary structural features of the Orchard Peak area fall into three groups as follows: (1) generally north-trending, vertical, strike-slip faults (tear faults) offset right laterally; (2) thrusts whose traces trend west to northwest; and (3) folds whose axes (except for the Devil's Den syncline) trend northwest.

* According to Mason L. Hill and T. W. Dibblee, Jr. (1953, p. 457), the San Andreas rift can be traced for about 600 miles from Point Arena southward into Mexico. They state that the total amount of right lateral movement along this fault has been many tens of miles and may have been as much as 350 miles.

In an article on wrench-fault tectonics, Moody and Hill (1956, pp. 1207-1246) present an analysis of stress relationships in the vicinity of large wrench faults † (also called strike-slip or transcurrent faults). They conclude that thrust faults, wrench faults, and anticlinal folds can be produced "as a result of movement on a large wrench fault, such as the San Andreas of California." According to Moody and Hill, local reorientation of the compressional stresses which caused the major fault may result in second and third order stress directions; these new stresses produce second and third order drag folds and wrench faults which are oriented with respect to the new stress directions at angles which fall between certain theoretical limits.

A possible first-order drag fold within the Orchard Peak area is the Devil's Den syncline whose axis trends east-west, for this is the orientation of first-order drag folds associated with the San Andreas as postulated by Moody and Hill. These authors regard the Three Peaks anticline* as a second-order drag fold. The Sawtooth Ridge syncline, Avenal Ridge anticline, Red Rock syncline, and Stoker Canyon syncline are probably also second-order drag folds. The axes of all but the Stocker Canyon syncline make small acute angles with the direction of the San Andreas fault, within the 5-30° range cited by Moody and Hill as being that most commonly observed for second-order drag folds. The axis of the Stoker Canyon syncline would probably also fall within this range except for its having been rotated by drag between the Stoker Canyon and Polonio Pass tear faults. The average trend of the larger tear faults within the mapped area compares favorably (within about 8°) with Moody and Hill's theoretical direction for second-order, right-lateral wrench faults.

Moody and Hill (1956, pp. 1215, 1217) state that the greater part of the San Andreas fault has a characteristic strike of N.40° W. and that this orientation "requires a nearly north-south direction for the principal stress axis (i.e., direction of regional horizontal compression), or possibly a little west of north, to give right lateral movement." The orientation of most of the structural features in the Orchard Peak area suggests that they were formed by compressional forces acting in this same direction. Two exceptions are the Hex and Devil's Den thrusts in which movement was toward the west or southwest. Apparently after the other major structures in the area had been formed, there was a shift, at least locally, in the direction of compression. The Hex thrust (and presumably the Devil's Den thrust as well) was evidently produced later than the other major faults, because the Hex thrust sheet has overridden the Badger and Aido Spring thrusts.

Time of Deformation

The Three Peaks diapiric anticline is one of several such structures in the Diablo Range which have cores of serpentine. Although similarity of structure does not necessarily prove contemporaneous origin, it seems likely that these diapir folds may have been formed at approximately the same time in the geologic past. If this be true, the following statement by Taff (1935, p. 1096) regarding the age of the Mount Diablo piercement is also pertinent to the Orchard Peak area:

> "Following the close of Pliocene time, Coast Range mountain building was accelerated with increased uplifting, folding, and faulting. At this stage the Mount Diablo uplift began, and during its progress, continuing probably into late Quaternary, the Franciscan complex was thrust up through the Cretaceous in the apex of the structure."

Clark (1935, p. 1077) concurs as to the date of the orogeny, saying that "most of the folding took place either in late Pliocene or in early Pleistocene time, the latter being the more probable."

The youngest beds cut by faulting in the Orchard Peak area are those of the late Miocene McLure shale, displaced by the Stoker Canyon tear fault. This fault must therefore have formed sometime after late Miocene. As most of the other faults in the region appear to fit into a system implying a common origin, they too probably came into existence after late Miocene time. As mentioned earlier, the west- or southwestward-moving thrusts are apparently somewhat younger than the southward-moving thrusts—but how much younger it is as yet impossible to say. Movement of the former appears to have been more uniform than that of the latter; for the Hex and Devil's Den thrust plates are not broken by tear faults. Although there seems to be no way to set an upper age limit to the faulting in the Orchard Peak area, reasonable assumption might place this deformation, too, in the late Pliocene or early Pleistocene, a time of exceptional orogenic activity in California.

GEOLOGIC HISTORY

Late Jurassic (?). At this time the Orchard Peak area was covered by a sea in which were deposited the clays and shales of the Hex formation. Marine life included belemnites, foraminifers, ostracods, and radiolarians. Land areas were either low-lying and thus incapable of supplying coarse sediments or were situated a considerable distance away. Volcanic eruptions occurred. Franciscan rocks may also have been formed in the area at this time.

Cretaceous. The meager evidence available suggests that the Cretaceous sediments in the Orchard Peak area came from several different directions at different times —probably mainly from the ancestral Sierra Nevada, but perhaps also from nearby islands in the Cretaceous sea. That this sea was shallow is suggested by the presence of neritic Foraminifera, rapid lateral variation of lithology, coarseness and poor sorting of conglomerates, abundance of ripple marks, and profusion of wood fragments. These indications of shallow-water deposition occur throughout the Cretaceous sequence, yet at least 16,000 feet of sediments were deposited in Late Cretaceous time alone. It seems certain, therefore, that the Cretaceous sediments of the Orchard Peak area must have been deposited in a geosynclinal basin; for only by concurrent subsidence of the depositional basin could such a great thickness of sediments have accumulated in a shallow sea.

Pettijohn (1949, pp. 444-446) considers the following sedimentary features to be typical of the geosynclinal

† Moody and Hill (p. 1208) define wrench faults as "ruptures in the earth's crust in which the dominant relative motion of one block to the other is horizontal and the fault planes essentially vertical." The tear faults described in the present report are a special type of wrench fault.

* Shown in their figure 7 as "Orchard anticline."

facies; these features also characterize the Cretaceous rocks of the Orchard Peak area: (1) great thickness of sediments, (2) abundance of graywackes, (3) increase in percentage of sand upward in the section, (4) uniform, well-marked, and rhythmic bedding of arenites, (5) numerous slump structures, (6) absence of carbonate rocks except as nodules, and (7) scarcity of fossils.

During the early (?) part of the Cretaceous period, relief of source areas remained low enough, or source areas were remote enough, to permit the accumulation of 3,700 feet of clay shale and very fine-grained sandstone. Two volcanic eruptions occurred during the deposition of the shale, the second more prolonged than the first. Nearby land areas were probably well forested, for wood fragments are plentiful in the Badger shale.

Early in Late Cretaceous (?) time uplift of land areas to the northeast may have accounted for the change from shale to the conglomerate and graywacke of the Risco formation. Occasional volcanic outbursts at this time are recorded as thin ash beds in the Risco. Somewhat later the graywackes characteristic of the earlier part of the period gave way to arkosic sediments, implying, perhaps, that in the Sierran region erosion had finally penetrated through the metamorphics to the granitic basement complex. The uniformity, fine grain size, and delicate laminations of the Serpiente sandstone imply stability in the source area. Renewed but temporary uplift probably occurred, however, just before the Moonlight formation began to be deposited; for the conglomerate at the top of the Serpiente contains boulders eroded from earlier Cretaceous outcrops. During most of the Late Cretaceous, marine life apparently continued to be greatly restricted, probably in part by the rapidity of sedimentation. Not until late Late Cretaceous time did conditions apparently become favorable enough for animal life to flourish in moderate abundance.

Tertiary. If the two units of uncertain age along the northeast side of the Stoker Canyon syncline are indeed lower Eocene, there must have been considerable uplift and erosion in that part of the area before Eocene time; for besides an unknown thickness of Paleocene strata, at least 9,000 feet of Cretaceous sediments were removed. The region may even have been mountainous. Possibly between early and middle Eocene, uplift and tilting of the Devil's Den district resulted in the removal of lower Eocene and Paleocene beds and beveling of the Moreno formation. Except for the lower Eocene (?) remnants just alluded to, these strata, where present, were entirely removed from the remainder of the Orchard Peak area. Probably the entire region was emergent at this time.

Beginning with the middle Eocene and continuing at least into the middle Miocene, the sea gradually advanced south or southeastward across the region, its deposits forming a marine transgressive overlap. The fine grain size of the Canoas siltstone member of the Kreyenhagen shale implies that land areas in early late Eocene were either low-lying or distant. Before the deposition of the Point of Rocks formation there was apparently a brief interval of erosion.

The late Miocene ushered in a very different type of sedimentation in which chemical sediments became predominant. Siliceous shales and sandstones were widely deposited. The water may have been rather cold, for diatoms and foraminifers were prolific.

Sometime probably in the late Pliocene or early Pleistocene the orogeny began which produced the complex folding and faulting in the Orchard Peak area. The rocks were folded by regional compression, in two cases forming piercement anticlines. Thrusting from north to south occurred, accompanied by the formation of numerous tear faults. Later, thrusting occurred toward the west or southwest.

Finally, a long period of erosion, lasting into Recent times, sculptured the Diablo Range to its present form, carving terraces at different levels along the canyons and blanketing the foot of the range on all sides with alluvium.

ECONOMIC GEOLOGY

Petroleum. Evaluation of the petroleum prospects in the Orchard Peak area may be divided into two considerations: the upper plate of the Antelope Valley thrust, composed chiefly of Cretaceous rocks; and the lower plate whose upper portion is probably made up dominantly of Tertiary strata.

The chances of finding oil in the upper plate do not appear to be good. In the first place, Cretaceous rocks in California have generally been poor producers of petroleum compared to the rich Tertiary section. In the second place, although the upper plate consists of alternating permeable and impermeable formations, much faulted, the relations between the faulting and the dip of the beds are not such as would be expected to provide traps with adequate closure.

On the other hand, the possibility of oil being trapped in the lower plate seems better for two reasons: (1) probably much of the upper part of the lower plate consists of Miocene strata, rocks whose rich production elsewhere testifies to their excellence as reservoirs and perhaps as source beds, and (2) the base of the Antelope Valley thrust sheet is composed of impermeable shale which could effectively seal in any oil, preventing its escape upward from the Tertiary beds. Furthermore, petroleum is currently being produced within a few miles of the Orchard Peak area—for example, from the Devil's Den, Lost Hills, and Kettleman Hills fields.

Four wells were drilled in the southeastern part of the Orchard Peak area, but none was ever productive. Two of these were drilled in Antelope Valley (see geologic map, plate 1) by the Amerada Petroleum Corporation, but information on these two wells is not available for publication. The other two wells are both located on the south limb of the Devil's Den syncline. One of these (map coordinates 1091.2/1420.8, plate 1) starts in the Moonlight formation; the other (at coordinates 1093.2/1420.8) starts in the Moreno formation. E. H. Musser,* State Oil and Gas Supervisor, states that his department has only a map location of the former well but no well records. The latter well he believes was probably C. T. Dougherty well No. 1, but he is unable to supply further information about it.

During the summer in which the field work for the present report was carried out, a well was drilled in Antelope Valley about 2 miles northwest of Keck's Corners, just south of Highway 466. Musser * gives the following information on this well:

* Letter dated July 2, 1954.

"This is Frank A. McDonald well No. "Mabury-Still" 1, Sec. 11, T26S, R17E, M. D. B. & M. This well was drilled to a total depth of 2938′ in 1953 and abandoned during the same year. Top of the Santos shale was found at 1260′ and the bottom of the well was in the Lower Miocene."

Drilling Mud. The Hex formation at Hex Hill in the southeastern part of the area contains a considerable amount of bentonite. When a powdered sample was placed in water it expanded 172 percent. The bentonitic clay was once mined on a small scale for rotary drilling mud, but the operation was discontinued. A fairly sizable deposit still remains and should be investigated as to its commercial value. The deposit is readily accessible by car or truck from Highway 116 which is about half a mile away.

Water. In arid regions such as the San Joaquin Valley, water is always at a premium. Small springs of good water are numerous throughout the Orchard Peak area, indicating that many of the Cretaceous sandstones are good aquifers. Moreover, many rocks which normally have low porosity may well have been rendered porous by brecciation as a result of the extreme amount of faulting in the area. As the regional dip south of Cottonwood Canyon is to the northeast, wells sunk for water in McLure Valley should have the best chance for success. The axial portion of the Stoker Canyon syncline would be another favorable site for drilling water wells.

APPENDIX

Geographic Names

The following geographic names are in local use but are not shown on published maps. Locations are given in map coordinates as shown on the geologic map, plate 1.

Avila Canyon (1090/1424)—Named for an early settler who lived in the vicinity.

Bee Canyon (1084/1428)—So called because of several beehives there. It is also known as Sulphur Spring Canyon, from the occurrence there of two sulfur-bearing springs. However, as a canyon through Reef Ridge a few miles to the north also bears this name, Bee Canyon is preferable.

Gomes Canyon (1086/1429)—Named for an old homesteader who resided in section 34 around 1890.

Gooseberry Canyon (1083/1425) — Presumably named for an abundance of gooseberries growing in the canyon.

Orchard Ridge (1085/1422.8)—That part of Avenal Ridge extending eastward from the Polonio Pass fault and including Orchard Peak.

White City Canyon (1091/1422) — In 1900 J. D. Spreckels drilled for oil in this canyon; his encampment of white tents was called the "White City."

The following are new names proposed in this report for geographic features in the Orchard Peak area.

Aguila Canyon (1081.3/1429.8) — A canyon on the north limb of the Stoker Canyon syncline, taken as the type locality of the Aguila sandstone. The name means "eagle" in Spanish.

Badger Ridge (1076.5/1427.9)—A ridge at the type locality of the Badger shale north of Blue Point Valley.

Blue Point Valley (1077/1426)—Named for the group of serpentine rocks known as Blue Point.

Hex Hill (1093/1419)—Type locality of the Hex formation. The name, meaning "witch" in German and local American usage, refers to the "bewitched" appearance and peculiar stratigraphic relations of the hill.

Huevo Ridge (1091.6/1416.4)—The Huevo member of the Serpiente sandstone is best developed on this ridge. The name is suggestive of its large concretions, many of them egg-shaped; "huevo" means "egg" in Spanish.

Red Man Rocks (1090/1425)—A group of boldly outcropping rocks containing several caves once used as dwellings by Indians. The Red Man sandstone is named for these rocks.

Risco Canyon (1085/1422)—Type locality of the Risco formation. The name means "cliff" or "crag" in Spanish and refers to the rugged outcrops of massive sandstone in the canyon.

Serpiente Ridge (1087.5/1424.7)—A ridge at the type locality of the Serpiente sandstone, near the mouth of Cottonwood Canyon. The name means "serpent" in Spanish.

Moonlight Valley (1092/1420.5)—Type locality of the Moonlight formation. A small valley along the south limb of the Devil's Den syncline.

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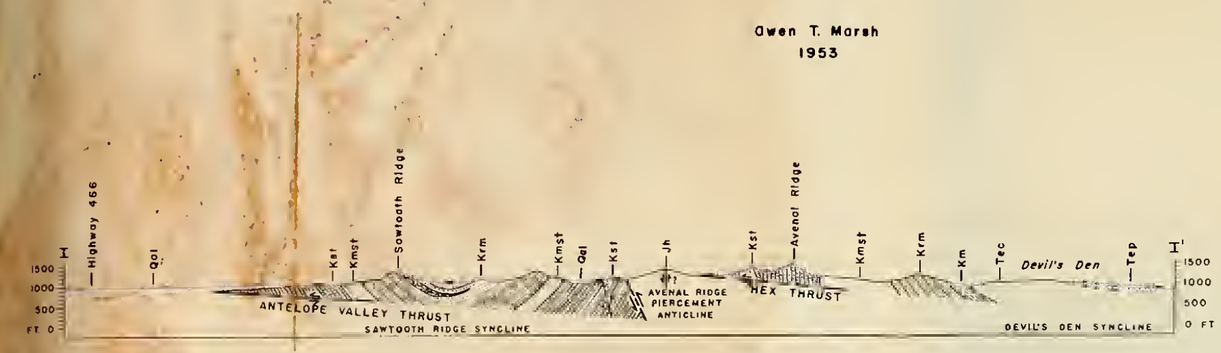
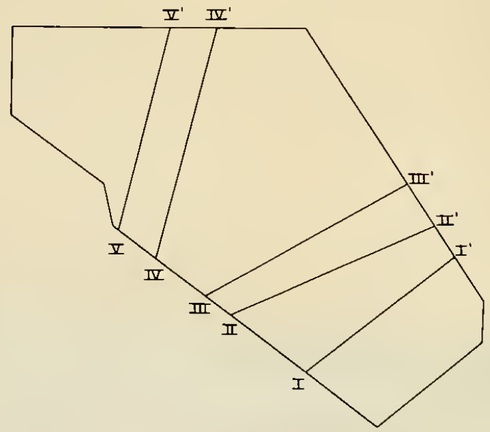
STRUCTURE SECTIONS ACROSS

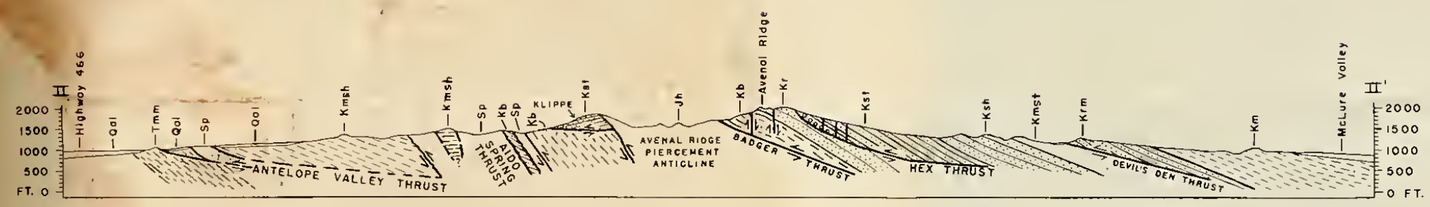
THE ORCHARD PEAK AREA

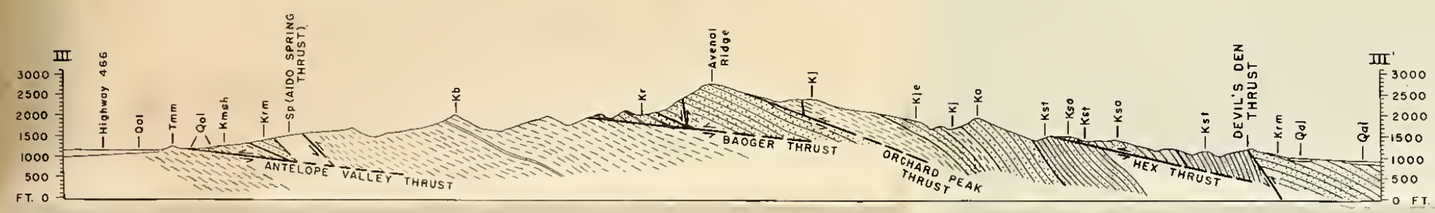
KERN, SAN LUIS OBISPO, MONTEREY, AND KINGS COUNTIES, CALIF.

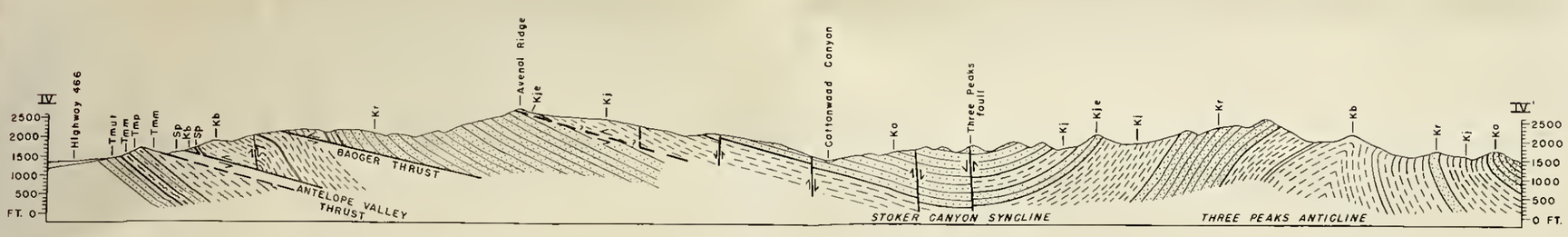
Owen T. Marsh
1953

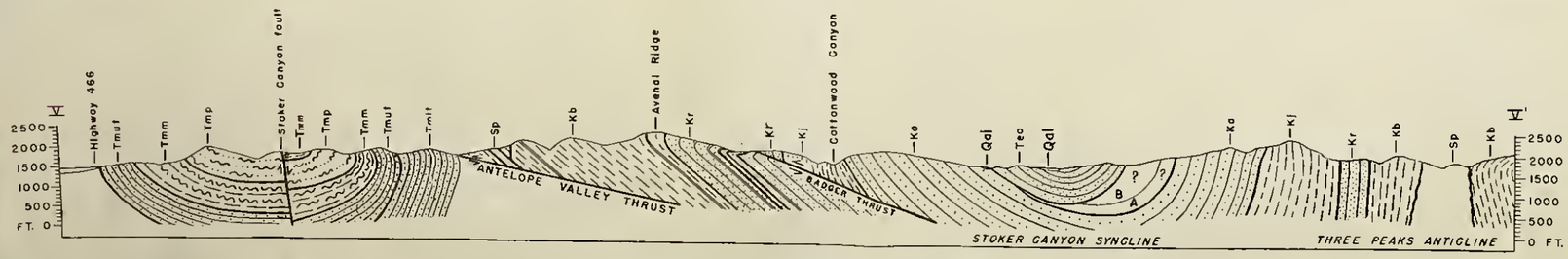












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NATURAL SCALE

LEGEND

CENOZOIC

- **Quaternary** — Recent
  - Qal — Alluvium

UNCONFORMITY

- **Tertiary** — Upper Miocene
  - Tmm / Tmp — McLure shale with Polonio sandstone tongue
- Lower and Middle Miocene
  - Tmut — Upper Temblor sandstone
  - Tmlt — Lower Temblor sandstone
- Upper Eocene
  - Tep — Point of Rocks formation
  - Tec — Conoas siltstone member of Kreyenhagen shale
- Middle Eocene
  - Teo — Avenal sandstone

UNCONFORMITY

- Lower Eocene ?
  - ? B, ? A — Units of uncertain stratigraphic affinities apparently not represented elsewhere in the Orchard Peak area; occurring only as erosional remnants. A – Gray siltstone; B – Concretionary brown sandstone.

UNCONFORMITY ?

MESOZOIC

- **Cretaceous** — Upper Cretaceous
  - Km — Moreno formation
  - Krm — Red Man sandstone with thin conglomerate
  - Kmsh / Kmst — Moonlight formation: Shale facies (Kmsh), siltstone facies (Kmst)
  - Ksa / Ksh / Kst — Serpiente sandstone: Huevo member, Torcido member with conglomerate, and Avilo tongue
  - Ko — Aguilo sandstone with thin conglomerate
  - Kje / Kj — Johnson Peak formation with Enebro sandstone lens
- Upper Cret.?
  - Kr — Risco formation with thin tuffaceous sandstones
- Lower Cret.?
  - Kb — Bodger shale with thin tuffaceous sandstones
- **Jurassic** — Upper Jur.?
  - Jh — Hex formation

- Sp — Serpentine with minor amounts of chert, glaucophane schist, and other rock types typical of the Franciscan group

Conglomerate
Sandstone
Siltstone
Shale
Tuffaceous sandstone
Siliceous sandstone
Siliceous shale