GEOLOGY OF THE PRE-CRETACEOUS ROCKS IN A PORTION OF THE SANTA ANA MOUNTAINS

Thesis by

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ABSTRACT

The Santa Ana Mountains, a northern extension of the Penninsular Range, lie between the Elsinore Trough on the East and the costal plain on the West. The area concerned in this investigation is in a northern part of the range in Orange County, California. Both igneous and metasedimentary rocks are present. Metasediments include the Santa Ana formation, which has been subdivided into two members, and the Hough formation. The oldest rocks have been dated as Triassic. Unconformably overlying the Santa Ana is the Hough formation which is believed to be Jurassic in age. Igneous rocks of pre-Upper Cretaceous age are intruded into the metasediments and are largely responsible for their metamorphism. Overlapping the metasediments from the west are Cretaceous rocks, the basal unit of which is the Trabuco formation.

Structurally the Santa Ana Mountains resemble the Sierra Nevada, but on a smaller scale. They are essentially a tilted fault block. The older sediments were contorted into broad open folds late in Triassic time, but subsequent to this there has been little folding of consequence. Uplift of the east face of the mountains along the Elsinore fault occurred early in the Tertiary and has continued spasmodically up to the present. Later in the Tertiary there was normal faulting within the area which displaced Cretaceous and Triassic rocks.

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INTRODUCTION

Purpose and method of investigation

This problem was undertaken primarily to gain greater proficiency in geologic field work and to satisfy in part the requirements for the degree of Master of Science. The selection of the particular area was made on the basis of value to geologic science in general and for the instructive qualities it offerred. It is one of the few areas in Southern California where extensive masses of pre-Cretaceous sedimentary rocks are exposed. In this respect it appeared interesting, if not unique.

In recording observations, aerial photographs were utilized as a base map. The region was flown October 13th, 1939, by Fairchild Aerial Surveys, and contact prints of good quality were obtained. A scale of one inch equal to two thousand feet was suitable to the type of mapping desired. Displacement due to relief constituted the most serious inaccuracy in the photographs. Part of the Corona and Santiago Peak quadrangles served as a base for compilation of the data on a final office map.

All instrumental measurements were made with a Brunton Compass. Field work was started December 30, 1947, and was completed on April 19, 1948. During this period twenty full days were spent in the field. Laboratory work consisted of reviewing previous literature on the area, identifying specimens microscopically and megascopically, compiling data, and writing the report. The time spent on laboratory work was approximately half of that spent in the field.

Geography

The Santa Ana Mountains trend roughly north-south, and form the northern tip of the Penninsular Range. Figure 1 shows the area which is in a northern portion of the mountains, in Orange County, California. It is immediately west of the range divide and lies entirely within the Cleveland National Forest. Situated between Silverado and Santiago Canyons, it is easily reached on good surfaced highways. Access to some points within the area is difficult, however, and they can only be reached on foot after several miles of hiking. The area mapped is a rectangle nearly four miles on the western edge and 3½ miles on the northern edge, which has an area of approximately thirteen square miles.

Appreciable relief is present in most of the area. Slopes are as steep as forty degree in some cases, but the average is about fifteen to twenty degrees. Elevations above mean sea level range from 3600 feet on eastern edge of the area to 1100 feet at the mouth of Silverado Canyon. Santiago Peak, with an elevation of 5695 feet, is the highest point on the range divide.

The major streams through the area drain directly west to Santiago Creek. Minor streams generally intersect these at angles approaching ninety degrees. Some streams are clearly controlled

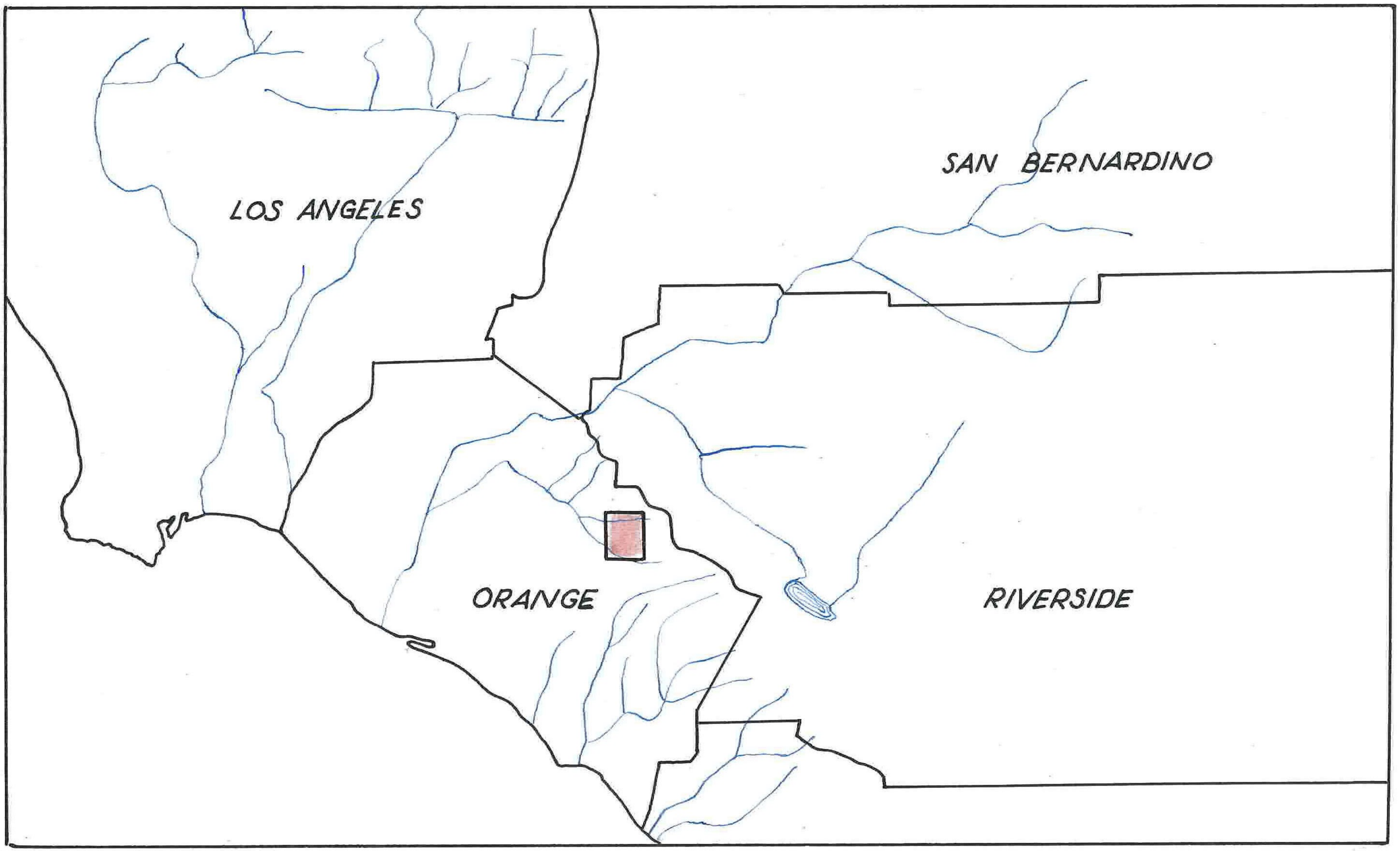


Figure 1 Location of the Area

by resistant strata, notably those disecting the Trabuco formation, and follow closely the strike of the beds. Groundwater is relatively abundant. Streams in the larger canyons continue to flow the year around, even during dry years. The water in most streams is hard. In Ladd Canyon and several others, the rocks in the stream beds are cemented together with calcium carbonate. The high lime content of the water apparently is due to derivation from the lenses of limestone in the Silverado formation, or possibly from unexposed limestone beneath the slate.

Vegetation is not different from that common to most of Southern California. The trees are confined almost entirely to the canyon bottoms, except for sparse growths of coniferous trees along the range divide. Approximately two-thirds of the area is covered by brush, generally very dense. The remainder is covered by grass and small bushes. Almost without exception the brush is present on the north or east sides of the ridges, whereas the opposite sides are grass covered. This relation is due in part to the northeast dip of the strata, which causes the groundwater to flow primarily in this direction.

A semi-arid climate comparable to that of most of Southern California is prevalent, and rainfall averages about twenty five inches per year. Exposures are good in areas of least vegetation and there is uncommonly more than a thin mantle of soil covering the rocks. The best exposures are in stream bottoms or on the steep faces of slopes. The dense brush masks many outcrops. Artificial exposures are rare, but those along several truck trails were found to be valuable. Cultural features are sparse, and are confined to Silverado Canyon and the lower reaches of Williams, Harding, and Santiago Canyons. They consist of small mountain cabins and several resorts. The small town of Silverado is in Silverado Canyon just above the mouth of Ladd Canyon.

Acknowledgments

The author would like to acknowledge the California Institute of Technology for making laboratory facilities available and the Institute staff for their many helpful suggestions and criticisms. In particular the cooperation of Mr. Shipment of the United States Forestry Service is appreciated for his aid in obtaining access to parts of the Cleveland National Forest.

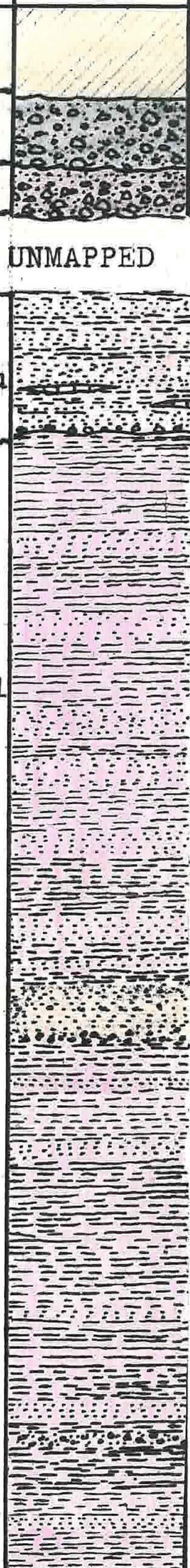
GEOLOGY

Stratigraphy and petrography

Rocks of the Santa Ana Mountains range in age from Mesozoic through Cenozoic, and include sedimentary, igneous, and metamorphic varieties. The older rocks outcrop at higher elevations, where erosion has exposed the core of the range and become progressively younger westward from the crest of the range. Only those of general pre-Cretaceous age are treated in this report. These include igneous and metasedimentary types. Both intrusive and extrusive igneous rocks were mapped. East and south of the area mapped, coarse-grained granodiorite is exposed and is related to the Southern California batholith. This igneous body has recently been investigated in considerable detail by Larson (2, page 134) and his description of this feature is very comprehensive. It is believed to be one of the main metamorphic agencies and will be discussed later in this respect.

The sediments have been metamorphosed to various degrees, and range from relatively unaffected sediments to rocks in which little of the sedimentary character remains. In general however, the sedimentary character is easily recognized. The most prevalent strike is fifteen to twenty degrees west of north. This is in accord with the structural trend in most of the older rocks of the Pacific Coast.

COLUMNAR SECTION



Age	Formation			Thickness	Discription
CRETACEOUS	Undivided		K		
					unconformity
CRETACEOUS?	Trabuco		Kt	400'	Weathered, red cgl.
					unconformity
JURASSIC?	Hough		Jh	270'	Metamorphosed cgl. & ss.
					unconformity
	UNMAPPED				
TRIASSIC	Santa Ana formation	upper member	T su	1750'	Interbedded ss., slates, and lenses of limestone
					unconformity ?
TRIASSIC	Santa Ana formation	lower member	T sl	2000'	Black slates and sandstone in thick beds
TRIASSIC	Santa Ana formation	lower member	Tsl'	300'	Resistant ss. and cgl.
TRIASSIC	Santa Ana formation	lower member	T sl	2900'	Black sandstone with conglomerate in thick beds of slate
			Sequence concealed		

Metasedimentary and sedimentary rocks

Santa Ana formation.

The oldest series of sediments is the Santa Ana formation. The name has been taken from the Santa Ana Mountains, where the rocks are well exposed. A more appropriate name is the Silverado formation, which has been used by B. N. Moore 1/

1/ B. N. Moore, Geology of portions of the Santa Ana Mountains: Calif. Inst. of Technology, unpublished thesis, page 6 (1930)

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but unfortunately this report was not published and the name has recently been applied to another formation in the literature. 2/ Moreover the term Santa Ana slates has long been

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2/ See U.S.G.S. - Oil & Gas Investigations, Preliminary Chart 12, 1945.

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used as a local name for these rocks. The type section is in Silverado Canyon where the most complete section and the best exposures are present. The section is not complete for two reasons. In the west the formation is overlapped by the Hough formation and Cretaceous beds which obscure the base of the Santa Ana formation. Also the sediments have been folded, uplifted, and most recent part of this formation has been eroded away.

The Santa Ana Formation is exposed throughout this area, and is in contact with every other rock unit mapped. Although it is fractured and generally breaks into small particles, it nearly everywhere forms steep slopes. Some of the more resistant beds have distinct topographic expression, and form breaks in the general slope. This of great advantage in tracing them, expecially in areas of dense brush. These beds are not abundant, however, and between them are large gaps where determination of structure must rest entirely on measurements of the attitudes of bedding planes. A slaty cleavage which dips steeply east, commonly parallels the bedding. When the intervening angle is small it obscures bedding features. The formation is composed of slate, shale, sandstone, quartzite conglomerate, and lenses of limestone.

On the basis of lithology, the portion of the formation that was mapped has been divided into two units, termed lower and upper members. The lower is exposed in Ladd, Silverado, Williams, and Harding Canyons. It is largely slaty beds and subordinate sandstone, but also contains considerable conglomerate and a little limestone.

Lower member in Silverado Canyon

The lowest beds exposed are black slates that weather to a buff or rust color. They are thinly laminated, and range from an inch up to a foot or more in thickness. Most of the slates here are relatively pure but many contain arenaceous material. The slaty cleavage is best developed in the purer material, as there is little evidence of it in the sandy slates and sandstones. Original lithologic structure is generally obliterated, but these same beds in Ladd Canyon show evidence of ripple marks.

Beds of sandstone as much as ten feet in thickness are interlayered with the slates, and increase in quanity in the upper portion of the member. The arenaceous rocks range from fine-grained sandstone to conglomerate. The average is medium sand, angular to subangular and in general well sorted. These beds contain fifteen to twenty percent arkosic material and about two percent heavy minerals. The remainder is quartz. The sandstone is cemented chiefly with silica, and is well indurated. Its color is commonly black, but the rock weathers to a dull brown.

Conglomerate beds are less numerous than sandstone, but are not rare. The average particle size is small, being either granules or pebbles. They are moderately well sorted and have a subangular shape. The particles are felsite, quartzite, and slate. A matrix of quartz sand constitutes nearly half of the rock. On the north slope of Silverado Canyon about two thirds of mile above the junction of Ladd Canyon is an unusual conglomerate. It consists entirely of limestone cobbles as much as eight inches in diameter. They are subangular and show no sorting. This bed is twenty feet thick.

A resistant bed crosses Silverado Canyon about 1 3/4 miles above the junction of Ladd Canyon. It has a thickness of two hundred feet, and was mapped across a portion of the area. There seems to be a thinning to the south, and it was lost in upper Williams Canyon. The base is a granule conglomerate, with particles from eight to a half inch in diameter, and contains an equal amount of coarse sandy matrix. Under the microscope this rock shows some interesting relationships. It is extensively fractured, with some of the fractures cutting through both matrix and granules in a continuous line. These fractures are filled with quartz, calcite, and an opaque mineral, possibly pyrolusite, which is probably associated with the mineralization in this region. The quartz was introduced first. These seams are offset and cut by fractures filled with calcite. From similar relations the opaque mineral was apparently intermediate between the quartz and calcite.

This conglomerate grades into a sandstone, which is the major constituent of the resistant unit. In the upper part of the member the sandstone decreases, and several hundred feet above this stratigraphically, slates predominate. Continuing to rise in the section, the slates contain numerous thin beds of sandstone, and only in a few places is a thicker bed encountered.

Summary of the lower member

2900 feet of black slates with a few beds of hard, black sandstone an inch to ten feet or more in thickness. Conglomerate beds one to twelve feet thick less numerous than sandstone.

300 feet of resistant conglomerate and sandstone, grading into beds predominantly slate.

2000 feet of black slates containing about twenty percent of sandstone in thin beds.

Upper member in Silverado Canyon

By the term "upper member", the author does not wish to imply that this unit is made up of the youngest rocks in the Santa Ana formation, but only that it overlies the lower member. The upper portion of the formation was not mapped in this investigation, thus it is not known whether this member includes all the remaining rocks or whether another overlying unit or units can be distinguished. In either event, it must be understood that there are rocks included in the Santa Ana formation which lie above the limit of those mapped in this report.

At the base of the upper member there is a thick group of sandstone beds that contain conglomerate in the lower part and thin slate beds throughout. The sandstone is black, weathering to brown. It varies in size from very coarse to very fine grains in different beds. On the divide between Silverado and Ladd Canyons it is two hundred and fifty feet thick, but thins to the south. It was not identified south of Silverado Canyon, and may either lense out completely or lose its identity by including more slate.

Directly above this sandstone unit lies the main body of the upper member, illustrated in Figure 2. It is composed of interbedded sandstone and slate. The sandstone is fine grained, and occurs in beds half an inch to a foot in thickness. Its color is the usual black and it weathers to brown. It consists largely of quartz, with a little arkosic material. Due to fracturing perpendicular to the bedding planes, the rock tends to break into small blocks and hence offers relatively little resistance to erosion. Beds of slate a half to six inches thick occur between the thin beds of sandstone. The slate appears similar to that already described, except that the beds are marked by many thin laminations. In the lower part, sandstone is slightly dominant over slate. Stratigraphically higher the slate is more abundant, and beds of sandstone are thinner and even finer grained. The contacts between individual beds do not appear as sharp here. Small lenses of limestone also occur in this member. Figure 3 shows one of these lenses in the lower left corner of the photograph.

Summary of the upper member

250 feet of sandstone and conglomerate, with a minor amount of slate in thin beds.

1500 feet of thin, alternating beds of sandstone and slate, with lenses of limestone.

The total thickness of that part of the Santa Ana formation which was mapped is 6950 feet. This does not include the lowest

Figure 2

Interbedded sandstone and slate upper member, Santa Ana formation in Silverado Canyon

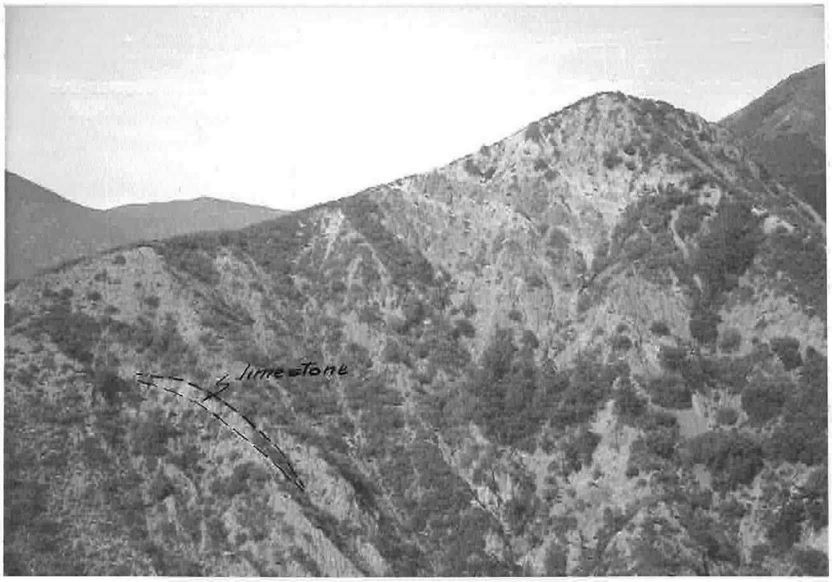

Figure 3

A limestone lens in upper member of Santa Ana formation. Looking toward northeast side of Silver Canyon portion of the formation which is overlapped and hidden by Cretaceous rocks, or that stratigraphically above the limit of mapping. The accuracy of this figure is limited, by the occurence of a fault that has duplicated some of the beds. Displacement along this fault cannot be determined directly. Further, the true thickness of the upper member is uncertain, owing to the amount of minor folding it has undergone.

Certain evidence indicates that there is an unconformity between the lower and upper members. No confirmation of this was noted at the contact between the two, but this contact is rarely well exposed, and thus hinders direct observation of the feature. One factor that supports this conclusion is the difference in dip between the base of the upper member and beds in the lower member. Attitudes of individual beds do not give a broad picture because of the crushing and minor folding, but the base of the upper member is seen to have a low dip by its topographic intersection. This can be observed in Figure 4. In contrast attitudes indicate that the lower member is dipping more steeply, even immediately adjacent to the contact. This same relationship is indicated by the difference in horizontal separation between a given bed in the lower member and the base of the upper, at different topographic levels. In addition, the conglomerate at the base of the upper member indicates a change in depositional conditions which may be related to an unconformity.

Relations of the Santa Ana formation to the underlying older rocks are not known, as the base is not exposed. Two

Figure 4

Contact between the two members of the Santa Ana formation, north of Silverado Canyon sedimentary units overlie it in this area. These are the Hough and Trabuco formations. Both are unconformable with respect to the Santa Ana formation. These unconformities and relations to the various igneous bodies will be discussed later in this report.

The origin of the Triassic sedimentary rocks is doubtful, but two factors are helpful in this determination. Wherever thinning of the coarse sediments occurs, it appears to be in a southward direction. This would indicate that the sediments were deposited from a northern direction. Further, Trassic sediments to the east of the Santa Ana Mountains show that this area was covered by the sea. Conversely, the lack of sediments to the northwest indicates that this region stood as a land mass. These lines of evidence make it appear most likely that the sediments were derived from the north or northwest. There is little doubt that the source was nearby, as testified by the subangular limestone conglomerate already mentioned. It seems highly improbably that these limestone pebbles could be transported very far, even if they were not of subangular shape. The lithology and relations of this formation also indicate that the sediments were deposited in a shallow basin of the sea and that fluctuations of depositional conditions were frequent, expecially during the later part of Santa Ana time.

The age of these rocks is generally agreed to be Triassic, or at least in part Triassic. This, however, is not entirely certain. Unfortunately the sediments are practically unfossiliferous, due mainly to the later metamorphis. More than fifty years ago Fairbanks (1, page 115) recovered a pelecypod, brachiopod, and coral from a limestone lens in upper Ladd Canyon. These were identified at the time as being of Carboniferious Age. Several years later J. P. Smith (6, page 776), studying these same fossils, stated that the beds were "almost certainly Lower Triassic". This view was based on the pelecypod Pseudomonotis, aff. clairi, Mendenhall (3, page 505) also found fossils in Ladd and Bedford Canyons. These were identified by Stanton as "probably upper Triassic". The exact age of the Santa Ana formation is thus rather uncertain, largely because the faunal assemblage is so limited. It appears, however, that it is Triassic, and probably it is middle or lower Triassic. All of the fossils came from approximately the same horizon in the section. This horizon seems to lie just above the contact between the lower and upper members, and thus there is a great thickness of rock both above and below these localities, some of which may be of a different age. The author has attempted to obtain additional fossils from Fairbanks' original locality, and to find new localities, but without success. A limestone lens in Pine Canyon yielded what was apparently a brachiopod, but metamorphism has obliterated its characteristics.

The slates of the Elsinore metamorphic series, which are exposed north of Elsinore and in Railroad Canyon, and those of the Southern Santa Ana Mountains are apparently related to the Santa Ana rocks, and may be the same formation. E. S. Larsen (2) has called these rocks the Bedford Canyon formation in his recent paper. From an advanced copy of the report which was made available to him, it is noted that all of these slates are assigned to this one formation and referred to as Triassic.

Hough formation

In the lower part of Ladd and Silverado Canyons there is an unusually interesting conglomerate. It crops out over a very limited area, and according to Moore (4, page 20) it is found at no other locality in the Santa Ana Mountains. He has named it the Hough formation after the Hough property where it is exposed. It is very well indurated, and forms imposing walls and cliffs where erosion has disected it in Ladd Canyon. A persistant joint system commonly gives it an igneous appearance in these cliffs. The color is dark gray to black where fresh, but it is most often seen as a weathered brown. It contains subangular particles ranging from coarse sand to boulders four feet in diameter. Its lack of sorting can be seen in Figure 5. The geology pick is in a granitoid boulder more than two feet in diameter.

The rock contains large, light-colored plutonic boulders similar to those mentioned above, as well as moderately large gray andesitic boulders. Smaller pebbles and cobbles are composed mainly of black slate. The gray andesites and black

Figure 5

Exposure of Hough conglomerate

in Ladd Canyon

slates can be seen in the foreground of Figure 5. The conglomerate also contains some quartzite and felsite fragments in a matrix of coarse sand. In Silverado Canyon it grades upward into sandstone. Evidence of bedding is rare, but its altitude was determined in several places where thin sandstone beds were included in the conglomerate. Except for its greater degree of metamorphism, the bed bears a striking similarity in lithology and structure to lower portions of the Trabuco formation. Detailed study of the two conglomerates might bring out some interesting facts as to its age or possibly as to the age of the Trabuco. In Ladd Canyon the Hough is closely associated and intermixed with andesite. There are all gradations from conglomerate to pure andesite. In some localities the conglomerate is cut by dikes and in others the andesite contains fifty percent or more stream-rounded pebbles and boulders. Thus it is often difficult to decide in some places whether to map the rock as igneous or sedimentary. Several of these boulders in an igneous groundmass are shown in Figure 6. An exceptionally large one can be seen in the center of the photograph.

The thickness of the Hough formation in Silverado Canyon, where it is not so intimately associated with the andesite, is about 270 feet. In Ladd Canyon the thickness if much greater, but a large part of this is igneous rock, and the proportion is difficult to determine.

The Hough rests on the Santa Ana formation with an angular

Figure 6

Stream rounded boulders

igneous matrix in Ladd Canyon

unconformity of seventy to eighty degrees. This unconformity can be seen in Figure 7 as the continuous notch across the middle of the photograph. Overlying the Hough there is an effusive breccia separating the formation from the Trabuco.

Sediments of the Hough probably originated in the east. It contains rather angular particles of the Santa Ana formation and so it seems that the sediments, at least in part, did not travel any very great distance. The igneous materials also are very similar to rocks in this region. It is difficult to tell whether the unit is marine or subaerial, as no fossils have been found in it. Because of this lack of fossils, the age also is very uncertain. The rock is known to be later than the Santa Ana formation (presumably Triassic) and younger than the Cretaceous rocks which overlie it. Moore (4, page 21) has stated that he thinks the age is probably Triassic. For two reasons the author believes that it is more likely to be Jurassic. First, it bears a much closer relationship in lithology and structure to the Trabuco (presumably Cretaceous) than to the Santa Ana formation. Second, its relations with the andesite discussed, suggest that this intermingling was performed at a time when the sediments were as yet unconsolidated to any appreciable degree. Thus if this andesitic igneous activity was during the Jurassic, as it is thought to be, the sediments were probably deposited during Jurassic time.

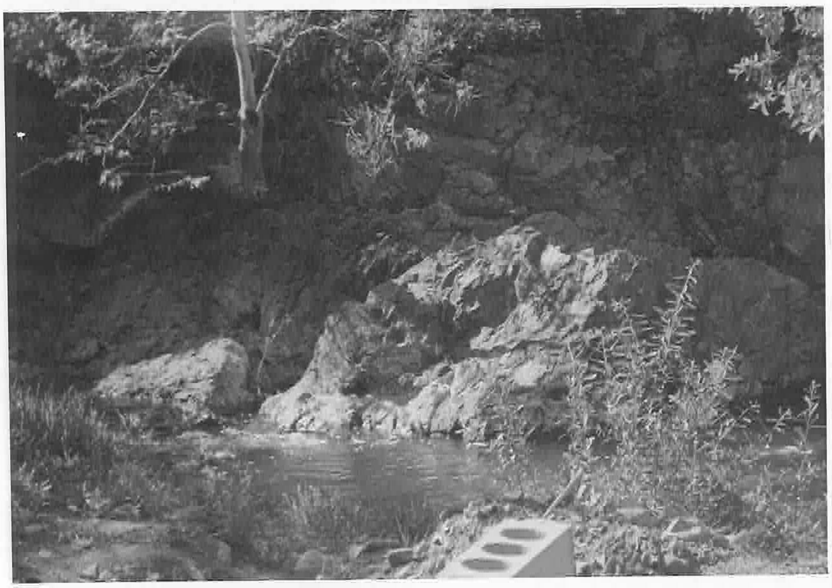

Figure 7

Unconformity between Santa Ana and Hough formations in Silverado Canyon. The unconformity is shown as notch across middle of photograph.

Trabuco formation

The Trabuco formation was first distinguished by Packard,[3] who named it from exposures in Trabuco Canyon. It is

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[3] Packard, Univ. Cal. Bull Geol. Dept. Vol 8, No. 11 pp 137-159 (1914)

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exposed across the entire western side of the area, and is in some places faulted down into the Triassic slates. The formation probably once extended over the entire area, but has been removed by erosion. Owing to its deeply weathered condition, it is easily reduced by erosion wherever it is exposed, and is usually recognized on the aerial photographs by its characteristic topography. Figure 8 shows the erosional depression of the Trabuco in Santiago Canyon.

The formation consists largely of massive red conglomerate with thin lenses of arkosic sandstone. Near the base its color changes to gray. The conglomerate is composed of rounded, unsorted, particles of quartzite, slate, limestone, cherts, plutonics and abundant andesites. In general slates, cherts and limestone are of smaller size, whereas the plutonic rocks constitute the boulders.

As bedding is absent except for short lenses of arkose, reliable attitudes are difficult to obtain. Assuming conformity with the overlying Cretaceous beds the average thickness is about 400 feet.

Figure 8

Erosional depression of Trabuco formation. The resistant Baker conglomerate form the cliffs in the background.

Popenoe[4] has made a detailed study of this conglomerate

4/ W.P.Popenoe, An analysis of the Trabuco and Baker Conglomerates of the Santa Ana Mountains, Unpub. Thesis, Calif.Inst.Tech.

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in conjunction with the overlying Baker member of the Williams formation.. He concludes that there can be no differentiation of the two conglomerates on the basis of texture or composition. It is his belief the Trabuco represents coastal floodplain deposits and the Baker a basal conglomerate laid down by a transgressing sea. The difference in the degree of induration is explained by deep weathering of the Trabuco before it was covered by the sea.

The Trabuco overlies the Santa Ana formation with a profound angular unconformity, amounting to nearly ninety degrees in most places. The hiatus represented here was of great duration, and included at least one great period of igneous activity. The unconformity between the Trabuco and Hough appears less profound but may be great. Because of the total lack of fossils the age of the Trabuco is not definitely known. It is closely related structurally to the overlying Baker member of the Ladd formation, and for this reason Popenoe (5, page 170) classes it as nearly Upper Cretaceous or later Lower Cretaceous.

Although the formation was not studied in detail, it was included in this report because of its structural relationship with the Santa Ana formation.

Igneous Rocks

Several different types of igneous rock found throughout the area are attributed to a single broad period of igneous activity. A granodiorite, not mapped in this study is exposed in the adjacent area to the north and east. Fragments of it are abundant in the later sediments. Presumed to be related to the Southern California Batholith, this rock is thought to be the main metamorphic agency in this area. Although smaller igneous bodies plainly show zones of contact metamorphism at their boundries, these are not extensive. A few hundred feet away the sediments show little variability in the degree of metamorphism for great distance.

Williams series

The Williams series is a group gentically related rocks of andesite, dacite, and rhyolite. It has been named from Williams Canyon, where all three types are exposed. The oldest is an andesite porphyry, followed by a dacite porphyry, and finally by a rhyolite porphyry. The series thus shows a distinct succession from basic to acidic composition.

Andesite porphyry

Exposed in Silverado and Harding Canyons is the oldest and most widely distributed rock of this series. It occurs in dikes, stocks, and extrusive flows, largely in Silverado Canyon. An extrusive facies of this rock separates the Cretaceous from older rocks at the mouth of Silverado Canyon. South of the canyon it is uniform in composition, but to the north it contains xenoliths of slate and sedimentary pebbles. Some of its facies are extrusive breccia. Two thousand feet north is another small body of this andesite, which probably represents the extrusive vent. It trends north across Ladd Canyon, and probably coalesces with the extrusive in this direction. The andesite has been intruded between the Santa Ana and the Hough, probably under great pressure. Dikes of this rock are found in the slates and all through the Hough conglomerate. From its intimate relationship with the conglomerate, which has been discussed previously, it appears to underlie all of the immediate vicinity at a shallow depth.

Under the microscope it is seen to contain nearly fifty percent andesine with a small amount of orthoclase and quartz. Some residual traces of hornblende and magnetite were noted, but these have been almost obliterated. Hydrothermal alteration is extensive, and has transformed most of the hornblende and magnetite to chlorite and hematite, respectively. Chlorite composes about twenty percent of the rock, magnetite much less. The section was interesting for the large amount of calcite that it contained (15-20 percent). It is distributed throughout the rock, and it appears that most of it was introduced by later solutions. Some of the calcite is euhedral, and exhibits good polysynthetic twinning, which suggests that it was recrystalized by later metamorphism. The rock is holocrystaline, with euhedral phenocrysts of andesine that are $2\frac{1}{2}$ millimeters in their long demension. Subsequent stress on the rock is shown by extensive fracturing and wavy extinction of the quartz.

The zone of metamorphism about the intrusive portion is only about fifty feet in width, and in some places is not evident at all. Where it is well shown the slates are seen to have been baked to a gray color, but with no apparent mineralogical change.

Dacite porphyry

On the divide directly north of Williams Canyon, this rock is exposed in the form of a stock. It crops out east from the Cretaceous contact, and underlies these beds to the west for an undetermined distance. On a fresh fracture, its appearence is very similar to the first member of this series, but on weathering its color changes to brown. The dacite has not been noted in any dikes, but because of its megascopic resemblence to the andesine, some of it may have been overlooked. Its composition is similar to that of the andesite, except that it contains more quartz and orthoclase, and the plagioclase is more sodic (oligoclase). Phenocrysts are not generally as large or as numerous, and alteration is less extensive.

This was the largest igneous body mapped, and its effect on the surrounding sediments has been more pronounced. The zone of contact metamorphism is several hundred feet wide on the north side. Here the black slates have been baked almost white and might be taken for a vocanic tuff if the lithologic structure did not persist. On the south the slates appear to be affected very little. Where the dacite is intrusive into the upper member of the Santa Ana Formation it has caused many minor but acute contortions. On a slope south of Silverado Canyon the beds have been folded into a small anticline, which is attributed to this intrusion.

Rhyolite porphyry

This rhyolite is associated with the already described members of this series, and in every occurrence it is found at their margins or nearby in the sediments. In Silverado Canyon it occurs as dikes in the slates adjacent to the andesite intrusion. These dikes are thirty to fifty feet thick. On the divide between Harding and Silverado Canyons the rock is present in much thicker dikes between the dacite and sediments, and also nearby entirely within the sediments. About a mile and a half above the mouth of Williams Canyon it is in contact with both slates and andesite in a thick dike or small stock. The contact with the slates is a fault, shown in figure 9.

In thin section it was found that quartz and orthoclase compose a large part of the rock, with only a minor amount of oligoclase. A little hornblende and magnetite also are present in phenocrysts. The groundmass, which constitutes sixty five percent of the rock, is largely quartz and orthoclase. Although the rock is holocrystaline, the groundmass is very

Figure 9

Fault contact between rhyolite and the Triassic slates in Williams Canyon.

fine grained, with grains less than a tenth of a millimeter in diameter. The feldspar phenocrysts are corroded, but the rock shows only moderate alteration. It appears both in the field and under the microscope to be the freshest of the three types in the series.

The age of the Williams series is post-Hough and pre-upper Cretaceous. It probably represents some of the earlier phases of igneous activity that occurred presumably during the Upper Jurassic in this region.

Glen Ivy diabase

The Glen Ivy diabase was named by Moore (4, page 45) for its occurence near Glen Ivy Hot Springs. Only a small irregular body, in the bottom of Harding Canyon two miles above its mouth, was exposed in this area. There are, however, other exposures of this same rock in the Santa Ana Mountains. One of the largest is above Glen Ivy Hot Springs, where the type section is located. In thin section the rock is holocrystaline, with a diabasic texture. The grains are seriate, with an average diameter of two millimeters. Other facies in this same locality are both coarser and finer grained. Composition of the rock is largely sodic labradorite, with fifteen to twenty percent augite and a small percentage of uralite. The augite and uralite are anhedral, and surround euhedral grains of labradorite. There is extensive hydrothermal alteration of augite and uralite to chlorite, and labradorite to calcite, sericite, and kaolin. In addition, there has been a moderate percentage of calcite introduced by latter solutions. The rock has been classified as an intrusive gabbro diabase.

As the diabase is intruded into the Santa Ana formation, its age is known to be post-Triassic. By correlating this rock with a diabase in the Puente Hills, Moore (3, page 50) has called it Miocene, and appears to have little doubt about this. From observations the author has made with the microscope, it appears improbable that the rock could be Tertiary, and it seems almost surely pre-batholithic. On studying the calcite in the section, it was observed that there are large grains with well developed cleavage and polysynthetic twinning. Furthermore, there are individual pieces, separated by feldspar, that show the same crystallographic orientation. It seems unlikely that solutions could deposit calcite in this manner. The author has therefore attributed this to later metamorphism. This same sequence was noted in the andesite porphyry previously discussed. Evidence for the diabase having undergone metamorphism clearly dates the intrusion as previous to the emplacement of the granodiorite batholith. The age has thus been placed as Jurassic, probably a little younger or in part contemporaneous with the Williams series.

Geologic structure

The Santa Ana Mountains, viewed broadly, form a tilted fault block similar to the Sierra Nevada. The Elsinore fault system bounds the east side of the range and separates the mountains from the Elsinore Trough. Cretaceous and Tertiary sediments overlie the metamorphic and igneous rocks on the west side of the range. These post-Jurassic beds dip to the west at an angle of 45 to 55 degrees, but become less steep westward. The initial tilting of the block presumably took place in early Tertiary time. Evidence of recent movement is strong, and displacements are known to have occurred during middle Tertiary time, so that there apparently has been repeated uplift throughout the Cenozoic Era. As a consequence of the tilting, erosion has exposed the rocks investigated in this report.

Folding

Sediments of the Santa Ana formation were folded into a broad syncline early in their history. The axis of this fold lies to the east of the area mapped and is near the range divide. In Ladd Canyon and other localities, small drag folds in the slaty beds also are in accordance with this structure. This deformation is known to be pre-Cretaceous. From its relations with the Hough, it is also demonstrably earlier than this formation, which is assigned to the Lower Jurassic. It would appear, then, that an Upper Triassic date for this deformation would probably be correct. The preservation of this early folding is remarkable, when we consider the extensive and repeated folding in the Coast Ranges immediately to the north. This is only one of several factors which demonstrate that structurally the Santa Ana Mountains are not an extension of the Coast Ranges, but acted instead as a more simple block during Tertiary time.

The Triassic beds consistently dip to the east. In only one place on the north slope of Silverado Canyon is there a reversal of dip large enough to map. In contrast to this seemingly monotonous structure, the upper member, and to a smaller extent the lower member, are contorted into many small folds and faults. The axes of these minor folds generally trend in a northern direction, but are not consistent in this respect. The minor folding and fracturing is believed to be due to igneous intrusions, and is generally found to be more extensive near instrusive bodies. No evidence of folding could be detected in the Hough, but several joint systems were noted. The most prominent has a northerly trend and dips sixty degrees east.

Faulting within the area

Appreciable faulting was found to be concentrated in the western part of the area. It is possible that similar faults occur further east, but do not offset any recognizable bed. In a broad view, these appear to be local structures not related to any major faults in the region. Two roughly parallel faults were mapped, which have a general strike of thirty degrees west of north. These are sinuous, however, and vary as much as thirty degrees in each direction. At very few places was the actual fault zones observed, which necessitated mapping primarily by displacement of stratigraphic units. From the topographic relationship, it appears that they dip steeply to the east and are normal faults. Figures 10 and 11 show two views of the faults. On their southern portions movement has been only several hundred feet. The displacement increases northward and on the largest attains a maximum of nearly 4000 feet at the Silverado-Williams divide. The fault apparently continues across Silverado Canyon, as there is another patch of Trabuco on the north slope. A large part of the displacement at this end has been taken up by an intersecting fault which parallels Silverado Canyon. Thus displacement to the north of the Canyon has been reduced to about 2000 feet. The dropping of the east side in conjunction with later erosion has produced isolated blocks of Cretaceous sediments completely surrounded by older rock.

Figure 10

Fault cutting across the Silverado-Williams Canyon divide. The right block has dropped down.

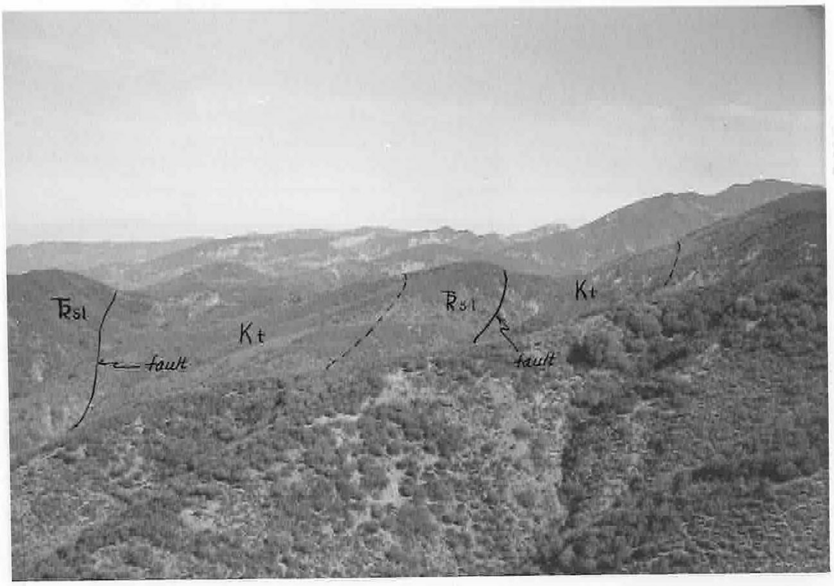

Figure 11

Two parallel faults crossing the Williams - Harding Canyon divide. Block on right has dropped down in each case.

Geomorphology

The Silverado-Santiago Canyon area presents an interesting view of the broad physiographic history of the Santa Ana Mountains. Tilting of the mountain block has had a pronounced effect on drainage and erosion. Thus it is advisable to treat the subject in a sequencial manner, beginning with the initiation of the tilting. Before faulting, the region was flat lying and probably connected to the area that is now the Perris Plain. With uplift of the east face of the block and associated tilting, the drainage was directed westward. The streams that were consequent on the tilted surface are now exemplified in this area by Silverado, Williams, and Harding Creeks. These are all strikingly parallel, and flow directly west. The subsequent tributaries of these main streams are controlled by structure and differential resistance of the rocks. They join the main streams generally at right angles, and produce a rectangular drainage patter in the lower part of the canyons. There is an obvious change to dendritic pattern in the upper part of the canyons. This is best illustrated in Silverado Canyon as shown in Figure 12. Headward erosion is believed to have originated at points where the pattern is transformed.

The uplift and tilting of the block was not continuous. Terraces near the mouth of Silverado and Ladd Canyons illustrate at least two cycles of this periodic tilting and erosion.

Immediately to the west of the area, the course of Santiago Creek can be observed. At once it will be noticed, that this

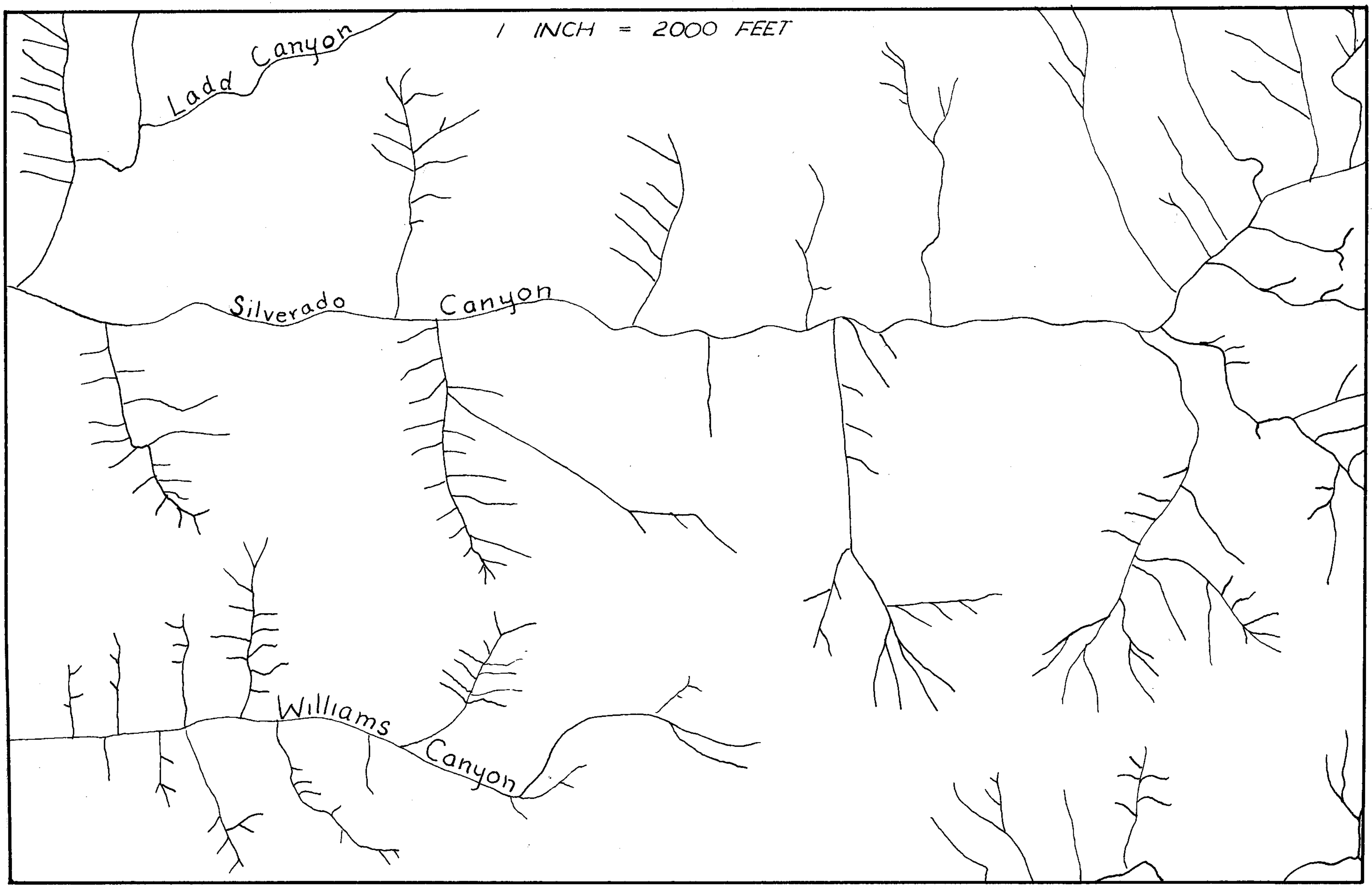

Figure 12
Silverado Canyon Drainage Pattern

stream does not conform to the general pattern. It flows northeast along the west face of the high mountains, and drains the streams of this area, as well as some which flow in opposition to the tilting, producing two divides on the same structural block. Due to this peculiar relationship of a stream flowing perpendicular to the direction of tilting with no structural control, it seems the Santiago is an older stream antecedent to the mountain deformation. This origin is argued by Moore (4, page 132) and others who have more data than those obtained during this limited investigation.

Geologic history

The geologic history of this area has encompassed a long and eventful period. It has disclosed valuable information of Mesozoic history in Southern California. The first decipherable event was the deposition of the Santa Ana formation during early Triassic time. Sediments were laid down in a shallow basin, which continued to subside throughout this time. A postulated landmass to the northwest was nearby, but attained only moderate elevations. The rate of deposition was not slow, but the time of deposition was rather long, as is shown by the great thickness of sediments that accumulated. After a retreat of the seas and initiation of erosion, there was a period of orogeny that folded the rocks into broad synclines and anticlines. Accompanying or following this orogeny was minor amount of igneous activity.

Renewed transgression of the seas established conditions for the deposition of the Hough formation. Little can be postulated as to conditions during this time, owing to the limited exposure of the present sediments. In the initial stages, however, there appears to have been high land nearby to produce the large subangular boulders in the conglomerate. The seas retreated early in Jurassic time, and a long period of erosion ensued. During this hiatus most of the Hough was removed and the agencies of erosion again attacked the earlier Triassic rocks. There was uplift and gentle tilting but no period of folding that altered the structure of the deposits.

Although pronounced orogeny was absent, there was a vigorous period of igneous activity. This began with intrusion of dikes and small stocks of andesite porphyry, and the extrusion of andesitic lavas and breccias. Almost contemperaneous with these events, but following them was the intrusion of the dacite porphyry apparently differentiated from the same magma. This was succeeded by further differentiation and the intrusion of thin dikes of rhyolite porphyry. The intrusions produced small contortions and induced only minor metamorphism in the rocks which surrounded them. A later intrusion of diabase seems to be related to these early rocks. There may have been a period of quiescence, but the volcanic activity was only a forerunner to the much greater igneous activity that was to follow. This was the emplacement of the large granodiorite bodies and related granitic rocks. The granodiorite is part of the Southern California Batholith which is assigned to Lower Cretaceous time, by Larsen (2, page 136) and others. With the granitic intrusion came the majority of the metamorphism which changed the sediments to their present character.

During the latter stages of this erosional interval, the Trabuco formation had been accumulating as a floodplain deposit. With another transgression of the sea, it was covered by the Baker conglomerate.

Later events of stratigraphy are not decipherable from sediments of this area. They involved the deposition of a series of beds both subaerially and by advances of the sea.

Certain structural events however are recorded and close the long chapter of geologic history in this region.

During Tertiary time uplift was probably initiated on the Elsinore fault system to the east, which caused a tilting of the mountain block. This imparted a westward dip to the post-Jurassic sediments and initiated the present drainage. A subsidiary deformation worthy of note was the normal faulting within the area. This probably occurred late in the Tertiary, and dropped Cretaceous sediments down into the Triassic slates. Erosion, at present active, has removed later sediments and exposed the core of the mountain range in its present form.

BIBLIOGRAPHY

(1) Fairbanks, H. W. - Geology of San Diego: also of portions of Orange and San Bernardino Counties: Calif. State Min. Bur: Rept. 11, pp 76-102 (1893)

(2) Larsen, E. S. - The batholith and associated rocks of Corona, Elsinore, and San Luis Rey quadrangles, Southern California: Geol. Soc. Amer., Mem.--in press 1948

(3) Mendenhall - Geology of United States (Triassic Rocks of Southern California): U.S.G.S., PP 71, p. 505 (1912)

(4) Moore, B. N. - Geology of portions of the Santa Ana Mountains: Calif. Inst. of Technology, unpublished thesis (1930)

(5) Popenoe, W. P. - Upper Cretaceous of Southern California: A.A.P.G., Bull, Vol 26, pt. 1, pp. 162-187 (1942)

(6) Smith, J. P. - Trias of California: Jour Geol. Vol 6, pp. 776-786, (1898)