THE GEOLOGY OF THE SOUTHERN PART OF THE INDIO QUADRANGLE, CALIFORNIA

BY

ROLLIN ECKIS

June 4, 1930

Thesis submitted June 4, 1930, to the Department of Geology Paleontology of the California Institute of Technology in partial fulfillment of the requirements for the degree of Master of Science.

INTRODUCTION

Spurs of the Peninsular Range of Southern California extend southeasterly into the Salton Sink at several places along its western margin, and thus produce a mountain front characterized by deep re-entrant valleys. The origin of these peculiar features has been much discussed, and with this problem in view the present investigation was undertaken.

A strip about 15 miles wide across the southern portion of the Indio Quadrangle, extending from the Salton Sea westerly to the upland area of the main Peninsular Range has been studied in some detail. Special attention has been given to the structure.

This area includes two spurs, the Santa Rosa and Coyote spurs, and two re-entrant valleys, Clark and Borego Valleys.

ACKNOWLEDGMENTS

The work was carried out with the encouragement and supervision of Dr. John P. Buwalda, who offered much helpful criticism and advice. The writer is indebted also to members of the Rift Club of Southern California for helpful suggestions made during a recent trip to the area.

PREVIOUS INVESTIGATION

Previous investigation includes no detailed work within the area. The only published geologic work of any importance that bears directly upon this region was done by John S. Brown (1923), who made a geologic reconnaissance of the area in connection with the preparation of a U. S. G. S. Water Supply Paper on the Salton Sea region. Carl Sauer (1929) has recently published a paper dealing with land forms of the Peninsular Range. This paper makes brief mention of the Borego Valley region.

CLIMATE

R. J. Russell (1926) has mapped the climate as transitional between mesothermal humid, in the western highland area, and hot desert, in the Salton Sea basin proper. Most of the area, including Borego and Clark Valleys, and the Coyote and Santa Rosa Mountain spurs, is classed as arid (Hot Steppe type).

No rainfall nor temperature records within this area are available, but the scant vegetation and the development of typical arid land forms confirms Russell's mapping and shows that general desert conditions exist over all but the extreme western edge of the area.

AREAL GEOLOGY

The Areal Geology will be treated briefly. The Basement Complex has been mapped as a unit; but the principal Tertiary and Quaternary divisions have been mapped separately. A hasty megascopic study of the rocks was made in the field. No petrographic work has been done.

The Basement Complex

The Basement Complex is composed of a series of metamorphic sedimentary and igneous rocks, completely intruded by a quartz-biotite diorite. The metamorphic rocks are chiefly quartz-feldspar-biotite gneisses, well banded and frequently varied by areas of limestone, quartzite and biotite schist. The intrusive quartz diorite is medium to coarse grained, and frequently gneissoid in structure. Although biotite is the chief accessory mineral, hornblende is not uncommon. Titanite, magnetite and even garnets are sometimes present also. The intrusive bodies are generally small and are everywhere closely associated with the older rocks. The whole mass is shot through with pegmatite dikes.

Nowhere within the area are the basement rocks overlain by rocks older than Tertiary. However, the character of the quartz diorite and its association with the metamorphic rocks so closely corresponds with the Jurassic (?) quartz diorite batholith described elsewhere in Southern California (Hanna 1926) that correlation seems safe.

These rocks cover the entire upland area, and the major portions of both the Coyote and Santa Rosa Mountain spurs. The structure is complex and is generally truncated by the topography.

The Tertiary Series

The Tertiary rocks are made up of a continuous series of sediments several thousand feet thick. Three distinct facies are represented: the Palm Wash Red Breccia, the Santa

Rosa Fanglomerate and the Borego Clay.

<u>The Palm Wash Red Breccia.</u> An earthy red breccia is exposed areally at two localities near the southeast end of the Santa Rosas. The exposures are small, totaling less than one half square mile, and lie about two miles apart on the east slope of the mountains.

The southernmost of the two localities will be taken as the type. The breccia is exposed in a cliff 200 feet high at the head of the north fork of Palm wash. It lies approximately one mile N 80° E of the promontory (elev. 2696) at the south tip of the Santa Rosa Mountains.

The deposit here is a well consolidated, earthy red breccia. Blocks range in size from several feet down to the fineness of an earthy matrix. The blocks are poorly sorted and slightly rounded, yet a fairly distinct bedded structure exists throughout the deposit. It is a fanglomerate, probably one in which mud flows were important agents of deposition, as in the case of the San Onofre breccia (A. O. Woodford, 1925).

The blocks consist of banded gneisses, metamorphosed porphyrys, limestones, quartzites and granitic rocks. No Tertiary sandstone blocks were observed in the deposit.

The northern deposit is in some respects similar to that just described. However, it is almost unbedded and the blocks seldom show any signs of water wear. One lens of waterlaid materials was seen with sandy matrix and bedded structure, surrounded by unsorted breccia. The breccia is well consolidated, with an earthy red or gray matrix.

Occasionally streaks of calcareous breccia occur, firmly cemented with lime. The composition of the blocks is similar to that described at the type locality, but the deposit has more the aspect of a talus or landslide breccia. At both localities the breccias must have originated from nearby crystalline masses.

Nowhere does the Palm Wash Breccia come in contact depositionally with the Tertiary fanglomerates. It lies depositionally upon the basement rocks and all of its other contacts are fault or landslide contacts.

An exposure one mile east of the northern outcrop of the Palm Wash Breccia suggests that the breccia forms the base of the Tertiary fanglomerate series. Here in the canyon bottom the lowest beds exposed at the axis of a small anticline have a brick red mud matrix very similar to that of the breccia. These red beds are conformable with the overlying gray fanglomerates. This bit of evidence together with the degree of consolidation and lithologic character of the breccia suggests that it differs from the Tertiary fanglomerates because it is not as far removed from the parent rock, rather than because of significant difference in age. It is therefore considered a part of the Tertiary series.

<u>The Santa Rosa Fanglomerate.</u> Folded Tertiary fanglomerates and transition sandstones form the southeastern point of the Santa Rosa Mountains. They are generally faulted down about the crystalline rocks of the main Santa Rosas, but locally their base is exposed in a faulted dome on the east slope of the promontory (elev. 2696) at the southeast tip

of the mountains (see geologic map). Here well consolidated sandy conglomerates overlie the basement complex. The section exposed here on the southeast flank of the hill (elev. 2696) will be taken as the type section of the Santa Rosa Fanglomerate. Its thickness in this section is several hundred feet. It grades down-dip into massive well consolidated sandstones. In places an unsorted breccia of the underlying crystallines, with a sandy or muddy matrix forms the base of the series and grades downward into brecciated basement complex. The two are almost indistinguishable in the field. The sediments are well consolidated and rather well bedded and sorted. Here the sand matrix is abundant and in places the rock becomes a sandstone or gritstone.

The maximum section is exposed north of the hill (elev. 2696). Here a section probably exceeding 2000 feet of coarse, poorly sorted, massive, unconsolidated fanglomerates is exposed. In the mountains these beds contain subrounded boulders three feet or more in diameter, but they grade rapidly down the dip eastward into clays at the mountains' edge.

The rock types of the fanglomerates are exactly those of the basement complex of the main Santa Rosa Mountains. The fragments are chiefly gneiss. Quartz diorite, quartzite, limestone, schist, porphyry, etc. are present also. The sand matrix is principally quartz, feldspar and biotite. Feldspar is probably the most abundant. The materials are generally fresh or only slightly decomposed. Red or yellow coloration is lacking. In fact the fanglomerates present a remarkably uniform gray massive appearance. Apparently climatic conditions during accumulation of these sediments did not differ greatly from the climate here today.

No fossils were found in any of these deposits, and owing to the small area studied it has been impossible to make satisfactory stratigraphic correlation with other sediments of knownage. From lithologic and structural characters it is obvious that the Santa Rosa Fanglomerate is a part of the great Tertiary section of the Salton Basin, part of which has been tentatively placed in the Pliocene (Kew 1914).

The Borego Clay. Pebbly sands, fine micaceous sands and silts interbedded with soft greenish gray and buff colored gypsiferous depositional clays form thick deposits which surround the southeast spur of the Santa Rosas. They extend for many miles to the south and east.

This clay series will here be designated the Borego Clay. It is typically developed in the badlands three miles east of Borego Valley, near the south edge of the Indio quadrangle. This area will be taken as the type locality. Here the south limb of a broad EW syncline is exposed, showing a good section. The beds are chiefly buff colored, poorly consolidated, rather thinly bedded clays. Occasional gray, pale green or light brown micaceous sand beds occur. These sometimes contain pebbles and cobbles. Gypsum occurs in thin discontinuous bands parallel to the bedding, and in veins transverse to it. Both the veins and the bands are usually less than one inch thick. The buff clays grade laterally to the north into greenish gray clayey silts containing many pebbles and cobbles. The same gradation can be seen east of the Clark Fault (see geologic map). Here however, the clays can be traced directly into the sandstones and fanglomerates at the south tip of the Santa Rosa Mountains.

Although no section was measured, the exposed thickness of these beds within the area mapped appears to be about 4000 feet. This represents only a small part of the total thickness exposed in the Salton Basin.

The poor sorting, the wide but sparse distribution of gypsum, and the fact that the Borego clays can be traced laterally into the Santa Rosa fanglomerate strongly indicates that they are of continental origin. They probably accumulated under conditions similar to those existing in the Salton Sink today.

No definite age correlation can be made with the data at hand. The lower members differ only in facies from the Santa Rosa Fanglomerate. The Tertiary section in this area may well be contemporaneous with the Carrizo Creek beds, (Mendenhall 1910),(Kew 1914), (Vaughan 1917), but without more definite evidence a correlation will not be attempted.

STRUCTURE

Fault systems dominate the structure and divide the region into distinct structural blocks. John S. Brown (1923) has pointed out two systems of faults, namely: N10°W faults (older system); N45°W faults (younger system).

There are several faults in the area that cannot be grouped directly with either of Brown's systems. These will be discussed separately.

Faults of the N 10° W System

The west side of Borego Valley, the west side of Clark Valley and the east side of the Santa Rosa Mountains are bounded by faults which strike north or a few degrees west of north. These faults will be called: Borego, Dry Lake and Coachella faults respectively.

No exposures of Borego Fault or Dry Lake Fault have been seen, but in both cases bold scarps front valleys under which Tertiary sediments occur. Coachella Fault is exposed at several places near its southern end. It is a normal fault with an approximate attitude of N 10° W, 67° E. Coarse, rather poorly consolidated fanglomerates are faulted down against the basement complex of the mountains. There is no evidence of recent movement along this fault. It everywhere exhibits fault-line features, and its scarps where present are erosion scarps. Recent elevation of the Santa Rosa block has evidently not occurred along this line.

N 45° W Fault System

The N 10° W fault system is intersected by two fault zones of the northwest system. One, the San Jacinto system, follows down the course of Coyote Creek into Borego Valley. The other strikes about N 60° W across the northeastern part of Clark Valley into the Peninsular Range. It will be called the Clark fault. Both are vertical or nearly vertical strike-slip faults, movement along which is probably measurable in miles.

The San Jacinto fault zone is exposed in the SW 1/4 of the SE 1/4 of sec. 14, T9S, R5E. Here a slice of Santa Rosa Fanglomerate has been faulted down against and northeast of the basement complex. The contact is practically vertical and the fanglomerate beds have been dragged up so that they are nearly vertical along the fault. The basement rock is crushed for a distance of 100-200 feet from the contact. A fresh furrow suggests recent movement. Many small, usually normal faults leave the main fault at sharp angles. The Santa Rosa Fanglomerate slice averages about one half mile in width and is about seven miles long. It is bounded on the northeast by a normal fault roughly parallel to the San Jacinto and dipping into it at angles of 60 to 70 degrees. This fault is probably not active. The elevated erosion surface crosses the normal fault without displacement. Locally, however, the fault plane has been exhumed by Coyote Creek and its tributaries. The steep scarp on the northeast side of Borego Valley is probably the exhumed scarp of this fault rather than a recent fault scarp of the San Jacinto Fault.

The Clark Fault brings Santa Rosa Fanglomerate on the southwest against crystalline rocks on the northeast, near the mouth of Rockhouse Canyon. The fault is buried under the alluvium in Clark Valley, but hills of the Borego Clay protruding through the alluvium in the valley floor, together with the extensive section of Borego Clay exposed south of Clark Valley, suggest that the Tertiary section is continuous beneath the valley floor. It is probably faulted against the crystalline rocks of the Santa Rosa Mountains along the northeast.

The Structure Adjacent To Clark Fault

A series of en echelon folds on each side of Clark Fault was mapped (see geologic map). They strike N 60° W to N 80° W, and continue southeast from Clark Valley as far as the Borego Clay is exposed. The anticlines generally flatten and die out within one or two miles of the fault zone. As they approach it they become crushed, and vertical dips are common. The anticlinal and synclinal axes tend to be convex toward the fault plane and thus to align themselves with it as they approach it. Exposures within a zone one-fourth mile wide at the fault show steeply dipping beds (70 to 90 degrees) whose strikes closely approach that of the fault.

The competent sandstones and fanglomerates of the Santa Rosa formation at the southeast tip of the mountains form a broad dome with the long axis striking a few degrees north of east. Two nearly parallel reverse faults, confined to the dome, cut it. The average strike of the more prominent one is N 70° E. Its dip, about 70 to 85 degrees south at the margins of the dome, flattens to 35 degrees south at the crest.

Recent erosion has cut away the top and a part of the northeast side of the dome. Here a few feet of brecciated basement complex, beneath competent members of the basal Santa Rosa, are thrust northward over red breccia. The fualt plane has been warped by the doming process so that its dips, though steeper, correspond to those in the Santa Rosa beds above. This warped fault is cut by the two above mentioned faults (see section AA).

The down faulted north side of the dome exposes poorly consolidated, coarse, massive Santa Rosa fanglomerates in whcih structure is not very evident. These are in turn faulted down against the basement rocks of the Santa Rosa Mountains along a normal fault. Its strike is variable but averages about N 60° E. Dips were measured ranging from 43° S to 83° S. No consistent scarp is present on the upthrown side although throw on the fault exceeds 2000 feet. Evidently movement on this fault preceded development of the topographic forms, and is probably not related to the deformations accompanying movement on the northwest fault system.

The Santa Rosa Mountains form a block uplifted by a fault along the southwest side and tilted toward the Salton Sink (see section BB). Some differential movement may have occurred on the Coachella Fault, or on a buried fault out in the valley, but probably relief on the east side of the mountains is due to differential erosion.

The fault bounding the Santa Rosas on the southwest will be called the Santa Rosa Fault. It meets Clark Fault at a sharp angle near the southeast end of Clark Valley. Its strike is about N 30° W. Several miles northwest it swings around nearly parallel to the Clark Fault. Although no exposure of the fault plane has been seen , its trace, together with the very fresh facets of the fault scarp, indicate that it is a normal fault. Within the area mapped, throw on the Santa Rosa Fault varies greatly. Its throw is zero where it meets the Clark fault, and judging from the displaced erosion surfaces it reaches a maximum of about 4000 feet, a few miles northwest.

The block between Clark Fault and San Jacinto Fault has been tilted down toward Clark Fault (see section BB) northwest of Clark Valley. Santa Rosa fanglomerates faulted against Clark Fault dip about 15 degrees toward it. They have been stripped from the higher southwest side of this block. The physiography indicates a similar relation for the block between Clark fault and Santa Rosa Fault (tilted down toward Santa Rosa Fault).

STRUCTURAL RELATIONSHIPS

So far as is known all of the earlier faults (NS system, etc.) are normal faults. That they bounded the Tertiary Salton Basin is shown by the presence of coarse Santa Rosa Fanglomerate grading laterally into Borego Clay, on the downthrown sides of the faults. They formed a more or less continuous NS line along the east side of the Santa Rosas, Coyote Mountain and the present Peninsular Mountains west of Borego Valley. This line was complicated somewhat by a later cross fault striking northeast across the southeastern part of the Santa Rosas, and by the outlying triangular Fish Springs Fault Block.

Two lines of evidence indicate that Clark and San Jacinto Faults have displaced the southwestern part of this basin margin northwest along their strikes many miles. An examination of the geologic map shows a similar distribution of Tertiary rocks on the two sides of Clark Fault, but displaced northwest ten or eleven miles on the southwest side. Borego

Clay in Clark Valley, faulted against crystalline rocks that produced the Santa Rosa Fanglomerates northeast of Clark Fault, can hardly be explained except by horizontal movement on Clark Fault. The Tertiary sediments do not appear at the surface southwest of San Jacinto Fault within the area mapped (except locally just north of Borego Valley) but just south of the map, Santa Rosa Fanglomerate faulted against the scarp at the west side of Borego Valley grades eastward into Borego Clay. These Tertiaries undoubtedly underlie the Quaternary alluvium northward to the head of Borego Valley. If this is true, then the scarp west of Borego Valley and that on the west side of Clark Valley were once continuous, and have been displaced eight or nine miles by the San Jacinto Fault.

Application of the strain ellipsoid to the structures adjacent to Clark Fault shows that they have resulted from strain with a large tangential component, stress being applied southeast on the northeast side of the fault and northwest on the southwest side of the fault (see figure 1).

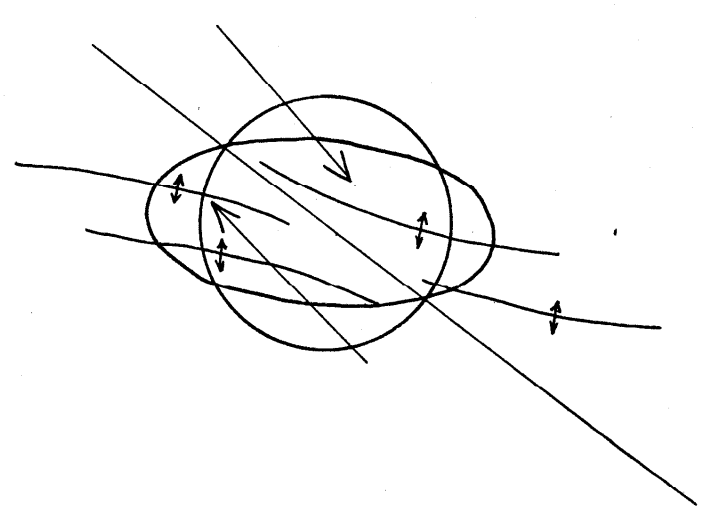

Fig. 1 Application of strain ellipsoid to structures adjacent to Clark Fault.

En echelon folds have developed normal to the axis of greatest shortening. This axis which is NS at distances of two or three miles from the fault has been rotated so that it strikes about N 30° E near the fault. This rotation is reflected by the strike of the folds. Several miles from the fault they strike about EW but gradually swing around toward the northwest as the fault is approached. This rotation is accompanied by greatly increased shortening toward the fault.

The domed and faulted competent Santa Rosa fanglomerates and sandstones at the southeast end of the Sana Rosa Mountains exhibit features which place them in the same structural system. Here instead of a group of en echelon folds, a single anticlinal dome with an easterly trending axis has been developed. The two reverse faults cutting the dome are manifestations of NS shortening. These structures which strike a little north of east may do so because they have not been rotated or dragged in the manner of less competent clays.

The probably normal Santa Rosa Fault has suffered recent movement and has a general northwesterly trend. These two facts tend to associate it with the northwest system. It is difficult to reconcile normal faulting of this magnitude with the obvious NS shortening along the Clark Fault. Movement is probably complicated by three-dimensional components of strain. The normal fault paralleling the San Jacinto Fault along the northeast side of Borego Valley may be the result of local adjustment to irregularities of strike along the adjacent shear plane.

Conclusions

Two fault systems and their accompanying features are the dominant structures in the southern portion of the Indio Quadrangle.

The older NS system bounds the Miocene or Pliocene Salton Basin, and is characterized by normal faulting. Probably no appreciable post-Tertiary movement has occurred on these faults.

The northwest fault system is represented here by two great shear planes. The older fault system and the Tertiary rocks have been displaced (the southern portions northwest with respect to the northern portions) a total of probably nineteen miles along the strike of these shear planes. Throw on these faults is local, irregular and generally small. It appears to represent local adjustment to irregularities of strike along the shear planes. The measured horizontal displacement has probably been chiefly or entirely Quaternary.

These major strike-slip displacements give positive evidence to support the general hypothesis that the region southwest of the San Andreas Fault is moving northwest with respect to the continent notheast of the fault.

GEOMORPHOLOGY

Land forms in this area show in the main typical desert or marginal features. Steep rugged mountain fronts flanked by alluvial fans that flatten out into broad alluviated valleys are characteristic.

Intense recent tectonic activity together with the fact that this region marks the transition from the peninsular highland to the Salton Basin has resulted in a variety of topographic forms, and many discordant surfaces. For convenience the area will be divided into four elevated blocks as follows: Peninsular, Coyote, Rockhouse, and Santa Rosa; and three depressed blocks: Borego,Clark, and Salton(see map of surfaces). Surfaces of similar origin and stage will be grouped together in the following discussion.

THE UPLAND SURFACES

Each of the four elevated blocks shows remnants of an upland surface of old age. This surface is almost gone from the southern portion of the Santa Rosa block. A few narrow mesa-like remnants with eastward slopes are all that remain.

The upland surfaces slope eastward on both the Coyote and Rockhouse blocks, forming terraces against the southwestern facing scarps of Clark and Santa Rosa faults. Tectonic activity has displaced drainage lines, caused alluviation, and tilted these surfaces to such an extent that they are recognizable only by their relatively low relief. It is significant, however, that the low relief surface of Coyote Block cuts across the eroded edges of the down faulted wedge of Santa Rosa Fanglomerates northeast of San Jacinto Fault, thus dating it as post Santa Rosa.

The mesa-like rolling top of the Hot Springs Block shows the best characteristics of this old surface. It has been described rather fully by Carl Sauer (1929). Sauer believes that the various surfaces of low relief occurring on elevated blocks in this general region have developed independently and are the result of the physiographic history of the block upon which they occur. This postulates activity on the bounding faults during development of the surfaces of low relief, producing surfaces of somewhat different relief on the different blocks. It follows that activity on the bounding faults had increased recently, producing scarps about the margins of the elevated blocks.

The geologic evidence does not seem to bear out the hypothesis of independent origins for low relief surfaces on different blocks. Development of these surfaces independently should have resulted in local alluvial deposits on the relatively depressed blocks around the margins of the elevated ones. Such deposits should have been deformed by accelerated movement recently, and the modern alluvium should be unconformable upon such deposits. These conditions do not generally exist. The Santa Rosa Fanglomerate has been shown to be directly related to uplift on the older NS fault system. Its accumulation is not related to the later faulting along the NW faults, which has produced the present elevated blocks.

The unconformity between the Santa Rosa Fanglomerate and Quaternary alluvium represents a long period of tectonic rest, during which an extensive surface of low relief must have been developed. Otherwise alluviation on the depressed blocks should have continued from Santa Rosa time until the high and low blocks were redistributed by intense activity along the NW faults. Evidence presented under the

STRUCTURE showed that the old erosion surface probably extended across the deformed Santa Rosa Series, and that Quaternary activity along faults of the NW system (probably accompanied by a general warp of the Peninsular region) initiated a new erosion cycle. Breaking up of the old surface, and alluviation along the lower sides of the active NW faults must have accompanied this activity.

From the foregoing evidence, it seems probable (1) that the isolated elevated regions of low relief are parts of a once continuous old age surface, separated by intense Quaternary tectonic movements; and (2) that the great thickness of Tertiary sediments on the western side of the Salton Basin represents an erosion cycle on the Peninsular Block, which reduced fault scarps of the NS system and produced the old age surface of the present summit areas.

Scarps of the NS Fault System

In discussing scarps of the NS system the question at once arises as to whether they are fault scarps or fault-line scarps (Blackwelder 1928). The bulk of evidence tends to show that they are the result of differential erosion. We know that soft clays underlie the low blocks (Borego, Clark, and Salton blocks). Steep, high portions of the scarps are in hard rocks, where the structure is favorable for such development, The irregular surface of the Tertiary rocks near the scarps furnishes the best evidence that the scarps have been and are still being exhumed. In the southwestern part of Borego Valley the scarp is relatively low and Santa Rosa Fanglomerate appears so high in front of the scarp as to largely obscure it. The east side of the Santa Rosa Mountains, however, offers the most positive evidence of fault line features. Here the NS Coachella Fault is terminated on the south by a N 30° E fault whose topographic expression obviously is due to differential erosion. The same features are developing along Coachella Fault just north of the area mapped. Santa Rosa Fanglomerate (on the downthrow side of the fault) extends high up on the mountain front. The outlying mountain of crystalline rocks just west of Fish Springs is bounded on at least two sides by faults (see geologic map), but it stands high today because the soft downfaulted Borego clays have been eroded away from around its eastern portion. To the west its steep fronts disappear as the soft clays at its base grade into more resistant Santa Rosa Fanglomerate.

If the NS faults are exhumed Miocene or Pliocene faults, then the present differential height between mountain and basin blocks (accentuated by erosion) is probably due to an upwarp of the Peninsular Block or tilt of its eastern portion toward the Salton Basin. In the case of the Santa Rosa Mountains uplift along the Santa Rosa Fault appears to have been accompanied by a tilt toward Salton Basin. The Borego clays east and southeast of the Santa Rosa Mountains are undergoing sub-aerial erosion almost to the Salton Sea itself. Quaternary alluviation in this region is local and occurs chiefly as a thin veneer.

Similar tilts are indicated for the Rockhouse and Coyote Blocks (see section BB), but no conclusive evidence of a tilt of the Hot Springs Block has been obtained.

In spite of evidence of exhumed scarps along the NS fault system, it may well be that movement recurred on some of these old lines during Quaternary time. Should this be true the scarps are composite scarps.

Scarps of the NW Fault System

In contrast to the mature dissection and well integrated drainage systems of the NS scarps, those developed along faults of the NW system are generally steep, with poorly developed, ungraded, rugged drainage lines.

With the exception of Santa Rosa Fault scarp, the scarps of the NW system are generally composite. Owing to the horizontal character of the movement they have developed chiefly as the result of offset topography. Such is probably the case along the northeast side of Borego Valley where the steep fresh scarp of the San Jacinto or parallel fault can be seen. Horizontal movement on the San Jacinto Fault probably produced a scarp which has retreated to the plane of the parallel normal fault.

In the Peninsular Mountains the San Jacinto and Clark Faults are fronted by escarpments 500 to 1500 feet high. Their height is irregular and in places has undoubtedly been accentuated by stream erosion along the fault lines. This is especially evident in Coyote Canyon. A component of throw may account in part for these scarps, but since the Peninsular Range rises to the northwest along these faults, these scarps are probably the result of horizontal offset.

The dominant component of movement on the Santa Rosa

Fault has probably been throw. A steep, straight, moderately dissected scarp 2000 to 4000 feet high, extends northwest from Clark Valley along the northeast side of this fault.

ORIGIN OF THE TRIANGULAR VALLEYS

John S. Brown (1923) has suggested that such valleys as Collins and Borego Valleys are depressed blocks between faults of the NS system and the NW system. Data presented in the foregoing pages indicates that Borego and Clark Valleys have been exhumed from soft Tertiary sediments faulted against crystalline rocks along NS faults at their west margins. The northeast side of Borego Valley has probably resulted from horizontal movement, which has separated Clark Valley from Borego Valley along the line of the San Jacinto Fault. Clark Valley fails to have a typical triangular shape apparently because a block between Clark Fault and Santa Rosa Fault has been dropped down, thus adding a fourth corner to the valley.

Collins Valley may be a triangular depressed wedge as Brown suggests or it may be an old alluviated northeast draining canyon, dammed across the northeast side by a fault scarp branching from the San Jacinto Fault at the head of Collins Valley. The evidence is inconclusive.

DISSECTED QUATERNARY ALLUVIUM AND DISSECTED PEDIMENTS

Dissected Quaternary surfaces or, probably more properly, dissected pediment surfaces (Kirk Bryan 1922) surround the east and south bases of the Santa Rosa Mountains, and occur along the south side of Clark Valley. The pediments are covered by 10 to 20 feet of alluvial gravels. Streams draining the mountains trench these pediment surfaces to depths of 100 feet or more at the mountains' edge. The trenches gradually die out down stream and at distances of five to eight miles from the mountains they coincide with the pediment surfaces. This deep trenching is confined to streams draining the soft Tertiary rocks of the southeastern end of the Santa Rosas. Probably the pediment was first cut into the soft Tertiaries as the mountain front receded, then as the mountains were worn down farther, the feebler streams were underloaded upon emergence onto the pediment surface and thus were able to pick up material from the pediment. The previously wandering streams thus became confined to channels, and immediately cut gorges in the pediment head (Eckis 1928). That these trenches developed normally in some manner is strongly indicated by the fact that their extensive development does not compare with the much less extensive development of such features elsewhere within the area studied.

RESUME OF THE CHIEF EVENTS IN THE TERTIARY AND QUATERNARY HISTORY OF THE REGION

1. NS faulting was initiated in Miocene or Pliocene time to form the western margin of the Salton Basin.
2. Deposits of fanglomerates and clays exceeding 4000 feet in thickness accumulated as uplift along these faults continued.
3. Uplift died out and the mountains were gradually worn down to an old age surface. Erosion was very extensive, and

probably destroyed some of the Tertiary sediments.

4. Probably some time in early or middle Pleistocene time tectonic activity was resumed. The Peninsular block was warped or tilted toward the east, the Tertiaries were folded and two great shear planes striking northwest developed.
5. The intense Quaternary tectonic movements produced a total of nearly 20 miles horizontal offset on the two NW shear planes. It has been accompanied by alluviation along the bases of newly formed scarps. During this period of diastrophism the elevated soft Tertiary clays have been removed, producing fault line scarps along the old faults of the NS system.

BIBLIOGRAPHY

Blackwelder, Eliot. "The Recognition of Fault Scarps," Jour. Geol. Vol. XXXVI (1928) pp. 289-311

Brown, John S. "The Salton Sea Region, California, a geographic, geologic, and hydrologic reconaissance, with a guide to desert watering places," U.S.Geol. Survey Water Supply Paper 497 (1923) pp. xv 292.

Bryan, Kirk. "Erosion and Sedimentation in the Papago Country, Arizona," U.S. Geol. Survey Bull. 730 (1922) pp. 19-90.

Eckis, Rollin. "Alluvial Fans of the Cucamonga District, Southern California," Jour. Geol. Vol. XXXVI (1928) pp. 224- 247.

Hanna, Marcus A. "Geology of the La Jolla Quadrangle, California," Univ. of Cal. Pub. Bull. Dept. of Geol. Sci. Vol. 16 (1926), pp. 187- 246.

Kew, W.S.W. "Tertiary Echinoids of the Carrizo Creek Region in the Colorado Desert," Univ. of Cal. Publ. Bull. Dept. of Geol. Sci. Vol. 8 (1914) pp. 39-60.

Mendenhall, W.C. "Notes on the Geology of Carrizo Mountain and Vicinity, San Diego County, California, " Jour. Geol. Vol. XVIII (1910) pp. 336-355.

Russell, R.J. " Climates of California," Univ.of Cal. Pub. in Geog. Vol. 2 (1926) pp. 73-84.

Sauer, Carl. " Land Forms in the Peninsular Range of California as Developed about Warner's Hot Springs and Mesa Grande," Univ. of Cal. Pub. Geog. Vol. 3 (1929) pp. 199-290.

Vaughan, T.W. " The Reef Coral Fauna of Carrizo Creek, Imperial County, California, and its Significance," U.S. Geol. Survey Prof. Paper 98,(1917) pp. 355-395.

Woodford, A.O. " The San Onofre Breccia, its Nature and Origin," Univ. Cal. Pub. Bull. Dept. Geol. Sci. Vol. 15 (1925) pp. 159-280.