5. THE SAN ANDREAS FAULT ZONE FROM SOLEDAD PASS TO CAJON PASS, CALIFORNIA*

By Levi F. Noble †

INTRODUCTION

The San Andreas fault, one of the dominant geologic features of southern California, defines a zone of rupture that extends more than 600 miles across the State from the coastal area north of San Francisco to the area south of the Salton Sea (fig. 1). This zone, the San Andreas fault zone or "San Andreas rift," is half a mile to a mile wide in most places. It has a curiously direct course across mountains and plains, with little regard for gross topographic features, and yet it influences profoundly the local topographic and geologic features within it.

The San Andreas fault is a part, perhaps a dominant part, of the great fault system of California, which has broken the rocks of the State into a mosaic of blocks. Some faults of the system branch from the San Andreas and may be closely related to it; others appear to have been cut off or displaced by the San Andreas, and their genetic relations to this master break are not at all clear. Still other faults are essentially parallel to the San Andreas, a few of them for distances of many miles. The San Jacinto fault, for example, lies parallel to and a few miles south of the San Andreas fault in much of the area described in this paper, but it diverges widely beyond this area to the southeast.

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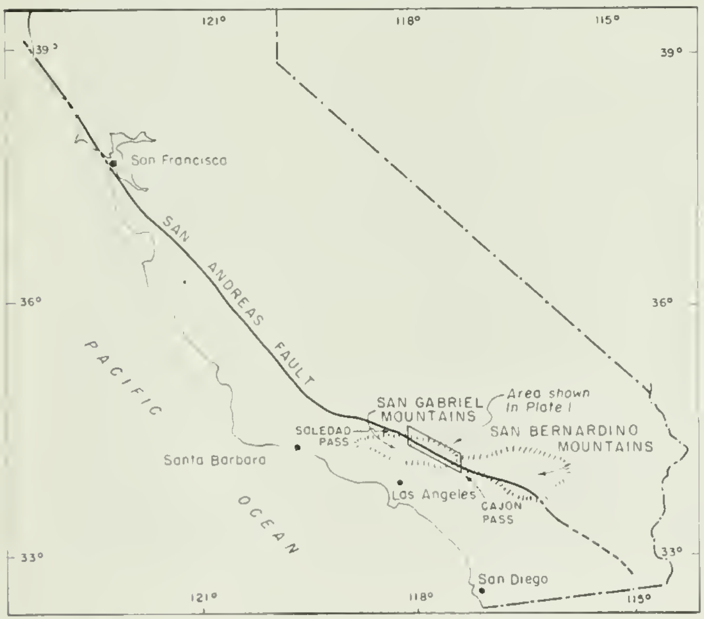

Figure 1. Sketch map showing course of San Andreas fault.

Although the area discussed in this paper was visited and the rock formations were accurately described by Blake (1856) as early as 1853, the San Andreas fault and its surface features were not recognized by a geologist until more than 40 years later, when Schuyler (1896-97, pp. 711-713) briefly described features of the "great earthquake crack" that had been formed by the Fort Tejon earthquake of 1857. These features were subsequently described in more detail by Fairbanks for the California Earthquake Investigation Commission (Lawson, et al., 1908, pp. 43-45). Simpson (1935) reported on the general character of the rocks and structural features of the Elizabeth Lake 30-minute quadrangle, which includes the western part of the area treated herein, and Wallace (1949) described in greater detail the features along a 19-mile strip of the fault zone just west of the area.

The writer has carried on a study of the 50-mile segment of the San Andreas fault zone between Soledad and Cajon Passes intermittently since 1910. Preliminary results of this work were briefly recorded more than 20 years ago (Noble, 1926, 1932, 1933); detailed descriptions of two areas along the fault zone have been published recently (Noble, 1953, 1954); and a fuller report on the structure and geology of this segment of the fault zone is in preparation.

Many geologists—among them H. E. Gregory, Charles Schuchert, W. M. Davis, Bailey Willis, A. C. Lawson, J. P. Buwalda, F. L. Ransome, W. C. Mendenhall, George and Anna Stose, P. B. King, and H. G. Ferguson—visited the writer during the course of his investigations and contributed valuable discussion and suggestions. The writer also is indebted to C. L. Gazin, who assisted with the field work in 1932, and to E. S. Larsen, Jr., and Charles Milton, who studied thin sections of various crystalline rocks from the fault zone and adjacent areas.

GEOLOGIC RELATIONS

General Features. The San Andreas fault extends in an east-southeasterly direction from points near the Palmdale area toward

FIGURE 2. San Andreas fault zone; view northwest toward Palmdale (middle distance). Trench of San Andreas fault is at left, and scarp of Little Rock fault is at right. Exposed in the block between these parallel faults are sedimentary rocks of Pliocene and Pleistocene age; the blocks that flank the fault zone are mainly granitic rocks, with some in-faulted slices of Tertiary sedimentary rocks. Note the concentration of vegetation in Little Rock Wash where it is crossed by the San Andreas fault. ***Photo by J. S. Shelton and R. C. Frompton.***

Cajon Pass, and in a general way separates the San Gabriel Mountains on the southwest from the western part of the Mojave Desert region on the northeast. Throughout this segment, the fault is marked by a straight and almost continuously traceable chain of scarps, ridges, and troughlike depressions, most of which involve Quaternary alluvial deposits and hence afford clear testimony to many earth movements earlier than those of historic record, yet geologically recent. In the western part of the area the San Andreas fault forms a trench and ridge that cut across the spurs and lines of northward drainage from the San Gabriel Mountains (fig. 2), and farther east its course is marked by Swartout Valley and Lone Pine Canyon (fig. 3).

A second major fault, the San Jacinto, is essentially parallel to the San Andreas from Cajon Creek to a point near Little Rock Creek where it curves northward and merges into the San Andreas fault zone. These two master breaks are 2 to 4 miles apart in most places, and together they define an elongate tectonic belt of extreme structural complexity (plate 5). Flanking this belt are major blocks that consist mainly of crystalline basement rocks in which the structure is less complex.

As shown in plate 5, many other faults lie on each side of the San Andreas fault. Some of these are secondary only in magnitude to the San Andreas and like it show evidence of recent movements in the Quaternary deposits and large displacements in the older rocks. Unlike the San Andreas, however, they do not constitute major lines of discontinuity between markedly dissimilar formations. Most are not continuously straight but instead are arranged en echelon or are characterized by numerous subparallel branches. Many of the individual breaks are separated by zones of intense crushing in the pre-Quaternary rocks.

Although most of these faults are parallel to the San Andreas and San Jacinto faults, or diverge from them at low angles, a few major breaks diverge abruptly and have an almost due westerly trend; some of these faults may well be cut off or offset by the San Andreas and San Jacinto faults. Typical examples are the Soledad fault, which extends westward into the Soledad basin (see Bailey and Jahns, Contribution No. 6, Chapter II) from a point near Little Rock Creek; the Fenner fault, which trends westward across Pinyon Ridge; the Cleghorn fault, which extends eastward into the San Bernardino Mountains from Cajon Creek; and the San Gabriel fault zone, which extends westward into the San Gabriel Mountains from Lytle Creek (plate 5).

The rocks of the San Andreas fault zone and the adjacent major blocks can be grouped into four types: (1) the Pelona schist and associated rocks, a metamorphosed sedimentary and volcanic sequence of probable pre-Cambrian age; (2) widespread plutonic rocks, for the most part of Mesozoic age, that generally range in composition from quartz diorite to granite; (3) several Tertiary formations, including volcanic rocks and both marine and nonmarine sedimentary rocks, mostly confined in their extent to the fault zone; and (4) Quaternary alluvial-fan, stream, and playa deposits. In the eastern half of the area mapped, all Tertiary rocks lie north of the San Andreas fault; in the western half of the area, they lie south of the fault or within the fault zone. The pre-Tertiary rocks are different on opposite sides of the San Andreas fault. All these rocks are noted in the following discussions of the fault zone, but for an integrated presentation of their distribution, nature, and sequence the reader is referred to the legend in plate 5.

Area North of San Andreas Fault. The structural block north of the San Andreas fault is underlain by a batholith of granitic rocks and the injected rocks of its contact zone. The injected rocks contain a large amount of limestone, metamorphosed to marble. The batholith is of wide extent in the western Mojave Desert region. In Holcomb Ridge it encloses elongate, steeply dipping roof pendants of marble oriented parallel with the San Andreas fault. In the Table Mountain ridge the injected rocks include marble, dioritic gneisses, mica schist, and migmatite, all intricately intruded by the granitic rocks.

The granitic rocks are Mesozoic, perhaps Cretaceous, in age (Woodford, 1939, p. 257), and the included limestone probably is late Paleozoic in age (Noble, 1932, p. 356). Farther east, in the San Bernardino Mountains, the crystalline rocks were not studied, but they include large bodies of granitic plutonic rocks, schist, gneiss, crystalline limestone, and several kinds of hybrid rocks.

In the drainage area of upper Cajon Creek are many spectacular exposures of upper Miocene conglomeratic sandstone forming bold upturned ledges. Interbedded with the sandstone are siltstone, gypsiferous shale, and a few limestone beds. These strata, which have long been known locally as the "Cajon beds," are at least in part correlative with the Punchbowl formation farther west and on the opposite side of the San Andreas fault. The section is more than 8,000 feet thick and has been dated by means of vertebrate fossils (C. L. Gazin and Chester Stock, personal communications). It lies upon the granitic basement rocks at a few places; elsewhere it is faulted against them (plate 5). At one place it lies upon the Vaqueros formation and at another upon the Martinez formation; these unconformable contacts are too small to show upon the map.

Four small patches of fossiliferous basal beds of the marine Vaqueros formation of early Miocene age lie upon a high hill of

FIGURE 3. San Andreas fault zone; view west-northwest from Cajon Canyon into the San Gabriel Mountains. The main fault extends up Lone Pine Canyon. Near the mouth of the canyon are a sag pond and a small stream offset caused by shifts along the fault. The nearly parallel San Jacinto fault extends up Lytle Canyon in left distance. San Antonio Peak is at the upper left corner of the view. *Photo by R. C. Frampton and J. S. Shelton.*

FIGURE 4. Hogbacks (Inface Bluffs) of Quaternary gravel, sand, and silt (Shoemaker gravel) derived from the San Gabriel Mountains; view east toward San Bernardino Mountains. Beds of the Pleistocene Harold formation underlie the low area between the hogbacks and the north slopes of the Table Mountain ridge at right. Mescal Wash in middle distance. *Photo by J. S. Shelton and R. C. Frampton.*

granodiorite that rises north of the San Andreas fault at Lone Pine Canyon; the hill is a wedge of basement rock pushed up through strata of the Punchbowl formation (plate 5). The fossils have been described by Woodring (1942, pp. 78-83). The relation of these beds to other outcrops of the Vaqueros formation in California has remained a puzzle since their discovery in 1929, for the nearest rocks of the Vaqueros north of the San Andreas fault lie in the San Joaquin Valley, 90 miles northwest of Cajon Creek, and the nearest strata of the Vaqueros formation south of the fault lie in the Santa Ana Mountains, 40 miles to the southwest. However, a small block of unfossiliferous beds that are lithologically like the Vaqueros in the Cajon area is faulted into granodiorite south of the San Andreas fault 2 miles west of the Valyermo quadrangle. These beds are correlated tentatively with the Vaqueros formation by the writer (plate 5).

Two disconnected outcrops of basal beds correlated with the marine Martinez formation of Paleocene age lie near Cajon Creek just north of the San Andreas fault (plate 5); the steeply dipping beds in one of these outcrops are well exposed in cross-section in a road cut on U. S. Highway 66. The beds in both outcrops lie unconformably upon granodiorite, are folded and intricately faulted, and are overlapped at one place by the Punchbowl formation. A thin wedge of crushed basement rock and sandstone of the Punchbowl (concealed beneath alluvium) separates the blocks of Martinez from the San Andreas fault. No other Martinez strata crop out north of the San Andreas fault nearer than the San Joaquin Valley.

In an earlier paper of the writer (Noble, 1933, pp. 12, 17) the outcrops of the Martinez formation just described were incorrectly stated to be Vaqueros and were incorrectly labeled Miocene in the legend of the accompanying map (Noble, 1933, plate 3); however, they are correctly labeled on an airplane view (Noble, 1933, plate 4B) accompanying the paper.

As traced northward down a gently sloping pediment toward the floor of Antelope Valley, the granitic rocks of Holcomb Ridge are overlain by gravel, sand, and silt of the Harold formation of Pleistocene age. The pediment is an exhumed feature that represents a surface of erosion formed at the beginning of the time of deposition of the Harold formation. This erosion surface is widespread in the area mapped but has been dislocated at many places by faulting and warping. The north slope and the crest of the San Bernardino Mountains at Cajon Pass are parts of it, as are the even crests of the ridges (fig. 3) in the San Andreas-San Jacinto tectonic belt. It is spectacularly exposed in the Punchbowl trough at the Devil's Punchbowl (fig. 7). The surface represents an angular unconformity at the base of the Harold formation that bevels all Tertiary and pre-Tertiary rock formations and all the complex structure in the San Andreas fault zone.

The Harold formation is 1,200 feet thick at Cajon Pass but thins westward and is only 200 feet thick in the west half of the area mapped. Everywhere the lower part of the formation is finer grained than the upper part, suggesting that the San Gabriel Mountain arch did not begin to rise until after the lower part of the Harold had been laid down.

The Pleistocene age of the formation is established by fossils found by C. L. Gazin in the Pearland quadrangle (Noble, 1953). In the Cajon Creek area, several beds in the basal part of the Harold section contain scattered vertebrate remains that, according to Gazin (1932, personal communication), are upper Miocene of the stage indicated by fossils in the underlying Punchbowl formation nearby. On the basis of this evidence, the writer erroneously assigned the Harold formation of the Cajon Creek area to the upper Miocene in two former papers (Noble, 1932, p. 356; 1933, p. 13). Subsequent

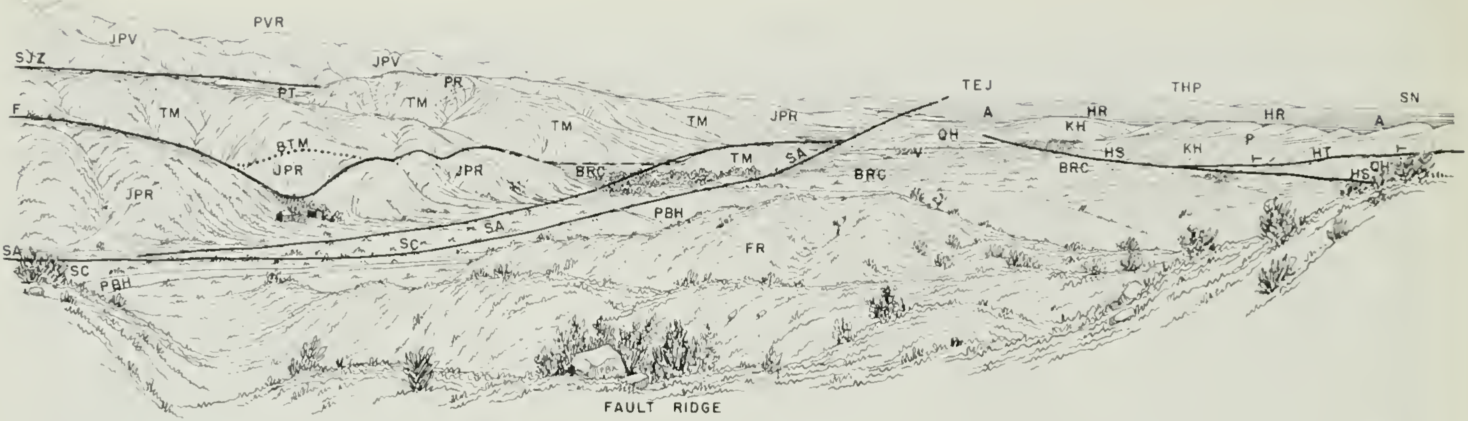

FIGURE 5. San Andreas fault zone; view west across Valyermo Ranch. At right are Holcomb Ridge (HR) and exhumed pediment (P), with Antelope Valley (A), Tehachapi Mountains (THP), and Sierra Nevada (SN) beyond. The Holcomb thrust fault (HT) and Hidden Springs fault (HS) bound the San Andreas fault zone on the north. Beyond and to the left of the fault ridge (FR) in foreground is the San Andreas fault (SA), which defines Shoemaker Canyon (SC), crosses Big Rock Creek (BRC), and extends west-northwestward toward Tejon Pass (TEJ). In the distance at left are Pinyon Ridge (PR), the Punchbowl trough (PT), the San Jacinto fault zone (SJZ), and Pleasant View Ridge in the San Gabriel Mountains (PVR).
Major rock types, from left to right, include Pleasant View complex (JPV) of the San Gabriel Mountains, Martinez formation (TM) with its unconformable contact (BTM) on the Pinyon Ridge granodiorite (JPR), Harold formation (QH), and Holcomb quartz monzonite (KH).
Valyermo Post Office (V) and Pearblossom Highway (PBH) lie in trough of San Andreas fault zone. *Sketch by Philip B. King.*

examination of the locality has led to the conclusion that the remains are detrital material eroded from the underlying Punchbowl beds, and the Harold formation has since been assigned to the Pleistocene.

The Harold formation at Cajon Pass is overlain by 200 feet to as much as 900 feet of gravel, sand, and silt derived from the San Gabriel Mountains to the south. These younger deposits are now exposed in a series of hogbacks that extend eastward for many miles along the base of the Table Mountain ridge (fig. 4) to Cajon Pass, where they form infacing bluffs and have been known as the "inface gravels." They are now termed the Shoemaker gravel (Noble, 1954). They are everywhere overlain by alluvial-fan and stream deposits washed from the San Gabriel Mountains (Noble, 1933, pp. 17, 19) before the valley of Cajon Creek was excavated.

Area South of San Andreas Fault. South of the San Andreas fault pre-Tertiary basement rocks form the San Gabriel Mountains, which stand at altitudes of 4,000 to 10,000 feet in the area under discussion. In the western part of the area, the block between the San Andreas and San Jacinto faults comprises many smaller fault-bounded blocks, some of which consist in part of Tertiary sedimentary rocks. Farther east, in contrast, the block between the two main faults consists wholly of basement rocks, and forms part of the high ground of the San Gabriel Mountains (plate 5).

The oldest of the crystalline rocks is the Pelona schist, a thick sequence of quartz-mica schist, feldspathic quartz-mica schist, chlorite-rich schist, actinolite-mica schist, and minor amounts of quartzite, crystalline limestone, and amphibolite. It probably is pre-Cambrian in age. Younger members of the basement complex include anorthosite and associated gabbroic rocks, hornblende-rich diorite, plutonic rocks of quartz dioritic to granitic composition, numerous hybrid schists and gneisses, and dike rocks among which amphibolite, pegmatite, and aplite are widely represented. Some of these rocks, including the anorthosite, may well be as old as pre-Cambrian, but most of the plutonic types probably are Jurassic or Cretaceous in age (Miller, 1934, pp. 61-65; Simpson, 1935, p. 384; Woodford, 1939).

The Pelona schist borders the San Andreas fault throughout the eastern half of the area mapped, where it underlies Blue Ridge, Pine Mountain, and the ridge between Lone Pine Canyon and Lytle Creek. It does not crop out in the western half of the area. Younger plutonic rocks are in fault contact with the schist in many places, especially in the San Andreas-San Jacinto tectonic belt, and in some places they are intrusive into the schist. They are separated from the schist in the highest part of the San Gabriel Mountains by the widespread Vincent thrust fault, which is spectacularly ex-

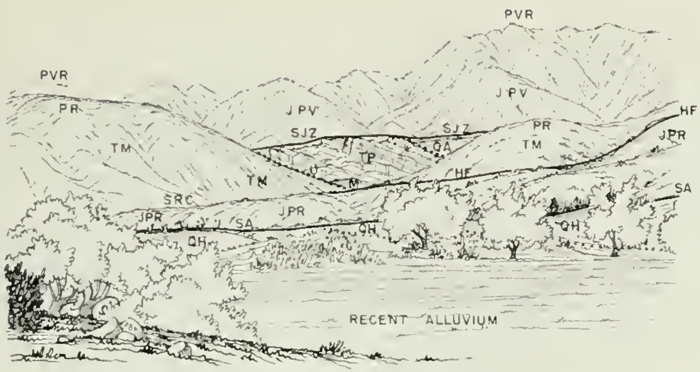

FIGURE 6. Pinyon Ridge (PR) and San Gabriel Mountains; view south up Sandrock Canyon (SRC) from Valyermo Ranch. Beds of the Harold formation (QH) form the ridge (Earthquake Hill) on the near side of the San Andreas fault (SA), immediately beyond which is a higher ridge of granodiorite (JPR). The Martinez formation (TM) underlies the part of Pinyon Ridge here shown, and visible through the gap in this ridge are the gently dipping beds of the Punchbowl formation (TP) on the north limb of the Punchbowl syncline. Quaternary older alluvium (QA) overlies the Punchbowl formation, which in turn rests unconformably upon the Martinez formation. A red megabreccia (M) of Martinez blocks lies immediately above this unconformity (U). Beyond the Punchbowl trough are the San Jacinto fault zone (SJZ) and the crystalline rocks (JPV) of Pleasant View Ridge (PVR). *Sketch by Philip B. King.*

posed on the bold faces of Mount Baden-Powell and San Antonio Peak (plate 5 and fig. 8). This fault commonly dips southwestward at angles less than 45°, but locally it is folded or warped. It is marked at many places by considerable thicknesses of mylonite. It cannot be younger than Mesozoic in age, as it is cut by the youngest intrusive rocks of the late Mesozoic igneous complex.

At the western edge of the mapped area are scattered exposures of the Vasquez formation, a thick sequence of coarse-grained continental strata with associated andesite and basalt. The sedimentary rocks probably are Oligocene in age, but may extend into the earliest Miocene. They are unconformably overlain by fossiliferous lower Miocene beds in areas farther west (Jahns, 1940, p. 170). The Vasquez formation in this area is preserved as erosional remnants in downfaulted blocks and in general is separated from the crystalline rocks of the San Gabriel Mountains by the Soledad fault.

San Andreas Fault Zone. In the western half of the area mapped, the San Andreas fault zone is a wide depression whose floor consists for the most part of broad alluvial surfaces diversified by low ridges that parallel the depression (figs. 2, 5). In the eastern half of the area nearly all alluvium occupies a narrow trough that encloses the San Andreas fault, and most of the surface of the zone is bedrock (fig. 3). The fault zone, which is structurally a depressed area, contains numerous fault-bounded masses of Tertiary and pre-Tertiary rocks. These masses, as well as others that flank the zone, represent slices and lenses that have been raised or depressed with respect to adjacent blocks by movements within the zone. Some of the ridges are sharp anticlines in Quaternary deposits.

Perhaps the most striking features in the fault zone are numerous large wedges of granitic basement rock that have been pushed up through the Punchbowl formation of upper Miocene age near Little Rock Creek south of the San Andreas fault and near Cajon Creek north of the fault. Some of the faults that border the wedges dip steeply beneath them, suggesting that the wedges taper downward as well as laterally and have been dragged along or squeezed up.

A wedge of crushed granitic basement rock, commonly concealed beneath Quaternary deposits and at many places so intricately fractured that it resembles fault gouge, borders the San Andreas fault throughout the area mapped. Thin slivers of extremely disordered upper Miocene strata of the Punchbowl formation border the wedge and at places are intricately involved in it by faulting. This belt of crushed rocks is believed to mark the break along which large strike-slip movements took place in pre-Quaternary time.

A particularly interesting feature of the major block between the San Andreas and San Jacinto faults is the Punchbowl trough south and southwest of Valyermo. In this structurally depressed area is more than 6,000 feet of marine shale, arkosic sandstone, and conglomerate of the Martinez formation, of Paleocene age (Dickerson, 1914). This formation comprises two members that are everywhere in fault contact. The lower member and underlying granodiorite have been thrust over the upper member along the Pinyon fault.

Both the Martinez formation and the Pinyon thrust fault were folded and eroded prior to deposition of the overlying Punchbowl formation of late Miocene age, which consists of nonmarine conglomerate, sandstone, siltstone, and gypsiferous shale. This section contains scanty vertebrate remains that appear to be related to the Barstow fauna of the Mojave Desert region (Chester Stock, personal communication; see also Savage and Downs, Contribution No. 6, Chapter III) and probably is in part correlative with the Mint Canyon formation of the Ventura basin to the west (Jahns, 1940, pp. 171-172). The Punchbowl strata have been folded into a broad syncline and are well exposed in a spectacular basinlike area known as the Devil's Punchbowl (fig. 6). The Punchbowl and San Jacinto faults bound this area on the south, and on its north side is the easily recognized unconformity between the Martinez and Punchbowl for-

FIGURE 7. The Devil's Punchbowl; view northwest along axis of Punchbowl syncline from Devil's Punchbowl trail. From left to right, sketch shows Pleasant View Ridge (PVR), the San Jacinto fault (SJF), the crush zone (SJZ) between the San Jacinto fault and the Punchbowl reverse fault (PF), beds of the Punchbowl formation (TP), the canyon of Punchbowl Creek (PC) through Pinyon Ridge (PR), the San Andreas fault zone (SAZ), and Holcomb Ridge (HR). Antelope Valley is in the far distance. The crystalline rocks of the San Gabriel Mountains (JPV) are separated from the Punchbowl strata by a crush zone in which white aplite and dark metadiorite are prominent. Quaternary older alluvium (QA) lies on an erosion surface that bevels the Punchbowl formation, and a Quaternary fault (QF) cuts this alluvium on line of the Punchbowl fault. The unconformity (U) between the Punchbowl formation and the underlying Martinez formation (TM) is clearly shown along the base of Pinyon Ridge. *Sketch by Philip B. King.*

mations (fig. 7). The Punchbowl beds were laid down in a northwest-trending structural trough coinciding with and at places overlapping the San Andreas-San Jacinto tectonic belt. The trough has been intermittently under intense compression since before the deposition of the Punchbowl strata, with attendant episodes of faulting and synclinal folding.

LATERAL DISPLACEMENT ALONG THE SAN ANDREAS FAULT

In the following description the writer offers quantitative evidence for pre-upper Pleistocene right-lateral movement of at least 30 miles on the segment of the San Andreas fault extending from the western border of the Pearland quadrangle (long. 118°06′) to Cajon Creek (long. 117°26′), a distance of 42 miles. Discussion is confined to the San Andreas fault, and possible additional lateral movement on sub-parallel faults is not taken into account.

Because the record of movements on the San Andreas fault is fairly plain in the youngest formations and becomes progressively more obscure in older formations, this account begins with the latest events and proceeds to the earliest, the reverse of the usual historical order.

Several lines of evidence, none in itself conclusive but all pointing in the same direction, indicate that the total horizontal displacement on the San Andreas fault was of great magnitude. No accurate analysis is possible, and the estimated displacement of 30 miles since late Miocene time is considerably less than the estimate given by Hill and Dibblee (1953, pp. 447-448) for movement on a more northerly part of the fault during this same period. It should be noted, however, that the figure given here applies only to the San Andreas fault itself. If the speculation offered by Hill and Dibblee (1953, p. 453), that the San Gabriel and San Jacinto faults may be ancestral portions of the San Andreas fault can be proved correct, it is possible that the aggregate movement on these faults, could it ever be determined, would bring the estimates more nearly into accord. Movement on the Fenner fault, a third possible ancestor, ceased before the Punchbowl formation was deposited.

Recent Displacements. Almost everywhere along the San Andreas fault the younger alluvium is deformed into low ridges, small sinks, and discontinuous scarps. At many places in the fault zone it is warped into low anticlinal domes and undrained shallow depressions. Elsewhere, however, it is undisturbed.

Just east of the Pear Blossom Highway bridge over Big Rock Creek, a recent uplift of the creek gravel has produced a scarp that faces upstream; this scarp probably was formed during the Fort Tejon earthquake of 1857. Before the earthquake, Big Rock Creek crossed the San Andreas fault 600 feet east of its present channel and flowed north through Mountain Brook Ranch; the old channel is still traceable. It had been shifted to that position by right-lateral movements on the San Andreas fault amounting to 600 feet, prior to the Fort Tejon earthquake. The 1857 uplift across the channel diverted the stream back to a course in line with its original channel on the southwest side of the fault.

Where the San Andreas fault crosses Pallett Creek a recent uplift of the younger alluvium has produced a scarp that faces downstream. This scarp also was probably formed during the 1857 earthquake. As a result of the uplift, Pallett Creek is rapidly deepening its channel and dissecting a peat deposit that accumulated in Recent time in a depression south of the San Andreas fault ridge.

Although the San Andreas fault dislocates the younger alluvium in the fault trench, the trench itself is an older feature, for the alluvium was deposited in the trench after it was formed. The San Andreas fault ridge also is an older feature, for parts of it are buried under younger alluvium. Yet the ridge is younger than the older alluvium, because at places this older alluvium is involved in the faulting that formed the ridge. Clearly the trench and the ridge are the result of recurrent movements.

The older alluvium is cut by many faults in the San Andreas fault zone. All these breaks are expressed topographically and are readily traceable on air photographs; their scarps are degraded, however, and most of the fault trenches are floored with younger alluvium. On many faults the displacement of the surface is reversed abruptly from place to place along the fault trace, indicating a dominant horizontal component.

Three gaps in Holcomb Ridge represent stream valleys whose upper courses have been offset by the San Andreas fault. The easternmost, Bob's Gap, is the offset valley of Big Rock Creek; the middle gap, now occupied by the combined stream courses of Big Rock Creek and Pallett Creek, is the offset valley of Pallett Creek; and the westernmost gap, unnamed, is the offset valley of an unnamed large stream course northwest of Valyermo. Each of these offsets indicates a horizontal or strike-slip movement of more than a mile on the San Andreas fault, the land on the southwest side of the fault having moved relatively northwest. The offsets are of the same order of magnitude as those of Little Rock Creek and other large stream courses in the Pearland quadrangle (Noble, 1953) and of Cajon Creek in the Hesperia quadrangle (Noble, 1932, p. 357; 1933, p. 17).

The fact that Big Rock Creek now flows northwest in the San Andreas fault zone and passes through the middle gap in Holcomb Ridge is seemingly anomalous. Actually the stream could not long have maintained its course through Bob's Gap against the rising

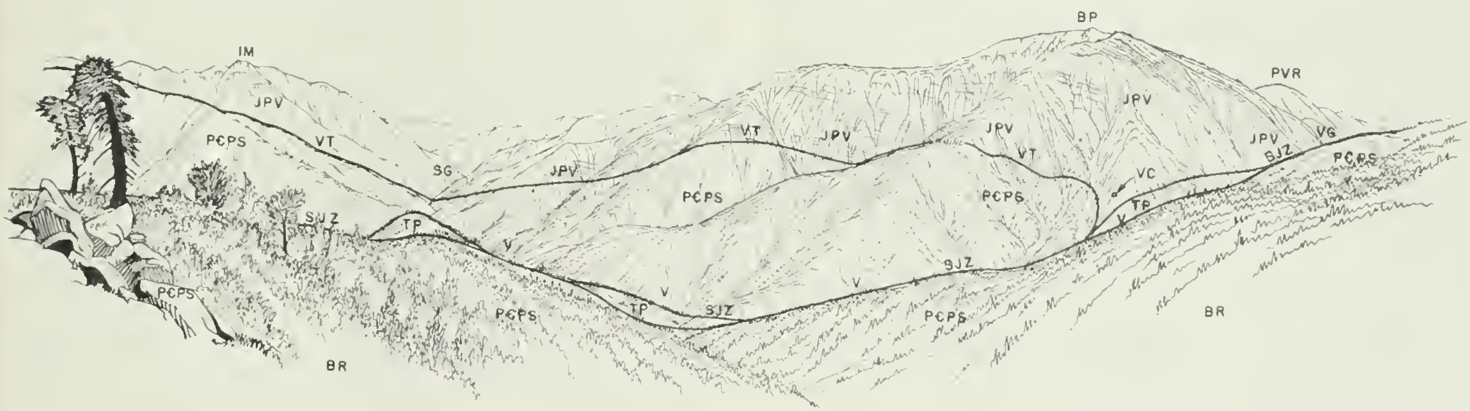

FIGURE 8. The Vincent thrust (VT); view down the canyon of the San Gabriel River (SG) in the San Gabriel Mountains from Blue Ridge (BR). A complex of heterogeneous plutonic rocks (JPV), which underlies Iron Mountain (IM), Mt. Baden-Powell (North Baldy) (BP), and Pleasant View Ridge (PVR), rests with thrust contact upon Pelona schist (PCPS). The thrust is truncated in Vincent Gulch (V) by the San Jacinto fault zone (SJZ) near Vincent Cabin (VC). Wedges of the Punchbowl formation (TP) occupy parts of the fault zone eastward from Vincent Gap (VG). *Sketch by Philip B. King.*

scarps of the Recent Hidden Springs and Holcomb faults and against the strong northwesterly tilt of the San Andreas fault trough on the flank of the rising San Gabriel Mountain arch.

An area of older alluvium north of the San Andreas fault between Pallett Creek and the Valyermo Ranch has no counterpart directly opposite on the south side of the fault, but the material is lithologically identical with the older alluvium south of the fault near the west border of the Valyermo quadrangle. In both areas the gravel consists chiefly of cobbles derived from the San Gabriel Mountains, without admixture of granodiorite from Pinyon Ridge nearby. The existing relation indicates a horizontal offset of the older alluvium of 1 to 2 miles.

Late Pleistocene Displacement. Toward the end of Harold deposition in late Pleistocene time, upwarp of the basement rocks of the northern San Gabriel Mountains into a broad arch caused them to shed debris northward in coarse alluvial-fan deposits all along the steepening northern flank of the mountains from the Palmdale-Little Rock area eastward to Cajon Pass, where the Shoemaker gravel forms the infacing bluffs at the summit of the pass (Noble, 1926, p. 419; 1933, pp. 18, 20). A check of precise levels run northward across Cajon Pass from the San Andreas fault in 1906, 1924, and 1944 shows that at least a segment of the arch is still rising, apparently at the rate of 20 inches per century (Gilluly, 1949, pp. 562-565). Some erosion may have intervened prior to deposition of the Shoemaker gravel, but no unconformity can be detected in most places, where the boundary between the Harold formation and the overlying gravel is essentially a change from finer to coarser material.

Movements after Harold time and before the older alluvium was deposited are indicated by the fact that the Harold formation and the Shoemaker gravel are more deformed than the older alluvium. Both lie flat in some places and dip gently in others, but locally they are considerably warped and folded, and in the San Andreas fault ridge they are violently disturbed. Both formations are cut by many faults that are parallel to the San Andreas or branch from it at low angles.

During this period the Harold formation may have been displaced as much as 5 miles by horizontal movements. Rocks of the Harold formation exposed north of the San Andreas fault west of Valyermo are lithologically similar to Harold strata exposed south of the fault 2 to 5 miles farther west, indicating a displacement similar to that of the same formation in the Pearland quadrangle (Noble, 1953).

Displacement Indicated by Anaverde Formation. Within and northwest of the area shown in plate 5, all exposures of the Anaverde formation of early to middle Pliocene age lie north of the San Andreas fault. In the Pearland quadrangle, at a point 3 miles west of Little Rock Creek, the formation lies unconformably upon quartz monzonite. The constituent materials of the formation are almost entirely quartz monzonite without admixture of material from sources on the south side of the San Andreas fault, whereas those of the juxtaposed Punchbowl formation on the south side of the San Andreas fault are derived exclusively from rocks that crop out on that side of the fault. The Anaverde formation, which is younger than the Punchbowl, should contain material from the Punchbowl formation or from the rocks south of the San Andreas fault zone if it had been deposited in the position that it now occupies, for cobbles weather out easily from the Punchbowl formation and are incorporated in great abundance in the Pleistocene Harold formation wherever it overlies the Punchbowl.

The evidence suggests that at the time the Anaverde formation was deposited, rocks other than those now adjacent were present on the south side of the fault. Thirty-five miles northwest of Palmdale, the Liebre quartz monzonite described by Crowell (1952a, p. 11), probably the equivalent of the quartz monzonite from which the Anaverde was derived, crops out south of the San Andreas fault.

Displacement of Punchbowl Formation. In the Valyermo area the strata of the Punchbowl formation north of the San Andreas fault do not match lithologically those of the same formation exposed in the Punchbowl trough directly opposite them to the south; but some of them match beds in the facies of the Punchbowl formation exposed south of the fault from a point 5 miles west of Valyermo to the Pearland quadrangle, several miles beyond. As interpreted by the writer, these relations indicate that the two facies of Punchbowl rocks have reached their present juxtaposition by horizontal movements along the fault.

A combination of geologic features north of the San Andreas fault within an area several miles square bordering Cajon Creek corresponds remarkably with a combination of geologic features south of the fault within and west of the Valyermo area (Noble, 1926, p. 420). On both sides of Cajon Creek, just north of the San Andreas fault, marine beds of littoral origin are lithologically similar to and correlated with the Paleocene Martinez formation of the Valyermo area and overlie basement rock similar to the granodiorite of Pinyon Ridge, in the Valyermo area. The Martinez beds at Cajon Creek are complexly folded and faulted, and, as in the Valyermo area, are overlain unconformably by less complexly folded and faulted upper Miocene strata similar in lithology to the lower member of the Punchbowl formation of late Miocene age in the Valyermo area. Both at Cajon Creek and in the Valyermo area these overlying beds contain vertebrate remains that, according to Chester Stock (written communication, 1950), indicate an age of late Miocene near that of the Barstow formation, with a possibility that the fauna of the Valyermo quadrangle may be slightly younger than the fauna of the beds at Cajon Creek. The beds in both areas contain cobbles of volcanic rocks of the Vasquez formation, the only apparent source of which lies 4 to 10 miles west of the Valyermo area and south of the San Andreas fault. This offset of cobble-bearing beds from the source area of the cobbles is similar to that described by Crowell (1952b) as indicating large lateral displacement on the San Gabriel fault.

Although the basal part of the Punchbowl formation is in juxtaposition with Pelona schist for several miles along the San Andreas fault in Lone Pine Canyon, the Punchbowl contains very little material of the Pelona. If these formations had been deposited in or near their present position, they should be crowded with material of the Pelona schist; where they lie with depositional contact upon Pelona schist just southeast of the Valyermo quadrangle, they are rich in schist debris. The evidence suggests that, at the time the Punchbowl formation was deposited, rocks other than the Pelona schist now adjacent were present on the south side of the San Andreas fault.

Beds of limestone are rare in the Punchbowl formation. Three miles southwest of Cajon Pass a bed of algal limestone crops out on the north side of the San Andreas fault. A similar bed crops out south of the fault about 4 miles west of the Valyermo area.

Two miles southwest of Cajon Pass, and north of the San Andreas fault, a thin seam of lignitic material that has been prospected for coal is interbedded with yellowish and buff sandstone and dark shale in the upper part of the Punchbowl formation. A similar seam, also interbedded with yellowish and buff sandstone and dark shale, crops out in the upper part of the Punchbowl formation south of the San Andreas fault, just west of the Valyermo area; it also has been prospected for coal.

The relations just described suggest that the upper Miocene rocks north of the San Andreas fault near Cajon Creek have been displaced at least 30 miles relative to those on the south side of the fault (Noble, 1926, p. 420).

Displacement of Punchbowl Fault. It seems possible that the Punchbowl fault also has been offset 30 miles or more by the San Andreas fault. At a point 4 miles west of Cajon Creek the Cajon Valley fault (Noble, 1933, pl. 3) diverges northwestward from the San Andreas fault for several miles (plate 5). The Cajon Valley fault closely resembles the Punchbowl fault, in that it is a reverse fault with southwest dip and northwest trend, and, as along the Punchbowl fault, shattered basement rocks injected by quartz monzonite are faulted against the folded Punchbowl formation.

Pre-Upper Miocene Displacement. The faults and folds in the Martinez formation record a major disturbance that took place before the Punchbowl formation was laid down. Although the relation of these movements to the San Andreas fault is a matter of conjecture, the alignment of the faults and folds of the Martinez and of the structural trough in which the Punchbowl formation was deposited indicate that these structures are closely related to movements on the San Andreas. It seems probable that the ancient seaway in which the Martinez and Vaqueros formations are assumed to have been deposited also coincides with this trough, implying that it too was structural in origin and was related to movements on the fault. If this interpretation is correct, the San Andreas fault or its ancestral equivalent was in existence as a major structural feature at least as early as the beginning of Tertiary time.

The difference in the pre-Tertiary basement rocks on opposite sides of the San Andreas fault in the Valyermo area and throughout the 50-mile segment studied by the writer (Noble, 1926, p. 420) suggests that horizontal movements greater than those already described may have taken place on the fault in early Tertiary or even in pre-Tertiary time. It is even conceivable (Noble, 1932, pp. 356, 357) that horizontal movements on the San Andreas fault totaling more than 50 miles have pulled the similar rock masses of the San Gabriel and San Bernardino Mountains apart (fig. 1), but if evidence of this movement is to be forthcoming it must await a detailed study of the basement rocks that border the San Andreas fault.

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