THE SAN ANDREAS FAULT ZONE IN SAN GORGONIO PASS, CALIFORNIA

Thesis by

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ABSTRACT

In San Gorgonio Pass, 70 miles east of Los Angeles, a complex network of faults separates two of the highest mountain ranges of Southern California. The San Andreas fault, which forms a part of the network, exhibits several unusual features in this area. Among these are the absence of rift topography, absence of lateral stream offsets, an abrupt change in trend of the fault trace, seismic evidence for the predominance of thrusting over strike-slip movements, and a lack of great earthquakes in historic time.

Crystalline rocks of Mesozic and earlier age crop out over most of the map area. North of the pass, the San Gorgonio igneous-metamorphic complex comprises an old metamorphic terranc of intermediate to basic composition and probable igneous parentage, and Mesozoic(?) plutonic rocks of quartz monzonitic composition. These plutonic rocks have intimately intruded and in large part reconstituted the older metamorphic rocks. The resulting migmatitic gneiss is the most widespread rock of the area, and includes flaser gneiss, greenschist, and piedmontite-bearing gneiss as distinctive varietal types. Rocks of the San Jacinto Mountains south of San Gorgonio Pass are distinctly different from those to the north, and comprise texturally uniform granodioritic and tonalitic rocks that contain sparse inclusions and septa of metasedimentary rocks.

Nearly all of the sedimentary rocks in the pass area are of alluvial-fan or flood-plain origin, and they reflect a Quaternary and late

Tertiary history of recurrent deformation and deposition. The upper Miocene(?) Coachella fanglomerate is the oldest exposed sedimentary rock, and is overlain with marked angular unconformity by all younger units. Lower Pliocene(?) incursion of tropical marine waters into the Salton trough is represented by a thin stringer of Imperial formation which is conformably underlain and overlain by continental strata of the Hathaway and Painted Hill formations, respectively. All of these rocks are overlain with marked angular unconformity by Quaternary Cabezon fanglomerate, which probably is correlative with upper beds of the Pliocene-Pleistocene San Timoteo(?) formation in the western part of the map area. Other Quaternary deposits, each showing complex structural relationships to adjacent rocks, are the deformed gravels of Whitewater River, Heights fanglomerate, and Burnt Canyon breccia. Recent alluvium covers the floor of the pass. Flows and dikes of olivine basalt occur in the Coachella fanglomerate and Painted Hill formation. Lithology of clasts in the sedimentary rocks indicates derivation predominantly from rocks of the San Gorgonio igneous-metamorphic complex to the north.

Quaternary alluvial fans of Heights and Cabezon fanglomerate, which once buried a former rugged topography, are now being dissected along the north side of the pass. Surfaces of low relief and associated stream terraces resulting from this dissection are the Beaumont plain, Banning Bench, and Pine Bench surfaces. Upstream divergence of the Banning Bench surface from present stream levels is attributed in part to tilting. Farther east, the older Cabezon surface shows many effects of warping. This surface probably is correlative with an area of low relief at altitudes of 6500 to 8000 feet near Raywood Flat, and suggests Quaternary arching of the mountain range along a north-south axis.

Within San Gorgonio Pass, alluvial fans derived from areas to the north dominate those derived from the steeper San Jacinto scarp to the south. This unequal development of fans is attributed to greater flood-producing rainfall and larger drainage area on the north, together with more easily erodable rock in this area. Most of the faults that show Recent movement are well delineated by springs and vegetative contrasts. Other springs are caused by exposure of unconformities, and by superposition of streams onto the rugged pre-Cabezon topography.

The San Andreas fault is a continuous linear feature for a distance of more than 400 miles northwest from San Gorgonio Pass, but within the pass it curves abruptly southward and butts into the east-trending Banning fault at an angle of 45°. Recent strike-slip movement on this part of the fault probably amounts to less than one mile, and post-Mesozoic displacement probably has not exceeded a few tens of miles.

The Banning fault, a major break that delineates the north side of the pass, extends for a distance of more than 50 miles eastward from a point near Redlands through the pass into the Coachella Valley. Within the pass, it is a steeply north-dipping reverse fault except for a zone of low-angle thrusting between Millard and Whitewater Canyons. At least 5000 feet of vertical displacement has taken place on this fault since San Timoteo time, and a right lateral offset of 5 miles is suggested. Recent displacement is limited to the segment of the fault east of Millard Canyon. Pre-Pliocene lateral displacement may have been great, but is not demanded by evidence in this area.

The Mission Creek fault branches from the San Andreas fault north of Banning, and is a major north-dipping fracture that is continuous for at least 40 miles to the southeast. The Pinto Mountain fault diverges from the Mission Creek fault at a low angle, and probably is continuous for more than 50 miles to the east; in this interval it forms the southern boundary of the northwest-trending fault system of the Mojave Desert. The Mill Creek fault branches from the San Andreas fault north of San Bernardino, and has guided erosion along deep linear valleys in the high mountains; this fault apparently dies out eastward.

Within the San Bernardino Mountains all of the faults north of the Banning fault separate crystalline rocks of the same family; these rocks are similar in their migmatitic structural features, remnants of amphibolite, intrusion by quartz monzonite, and high content of titanium minerals. Thus post-Mesozoic lateral displacements of hundreds of miles along these faults seem to be precluded. Although lateral displacements of a few tens of miles are possible, no observed evidence appears to demand such movements. Late Tertiary and Quaternary vertical movements are suggested by the physiography of the mountains. No Recent movements have occurred on parts of the Mission Creek and Mill Creek faults.

Recent movements on both the Banning and San Andreas faults probably were caused by a stress system involving a generally north-south maximum principal stress, with an east-west least principal stress of only slightly lesser magnitude than the vertical stress. In the vicinity of San Gorgonio Pass, an older east-west line of weakness causes the east-west stress effectively to become the intermediate stress, so that thrust faulting predominates over strike-slip faulting in this one local area.

San Gorgonio Pass is bounded by a reverse or thrust fault on the north, and indirect evidence suggests a similar fault on the south. Quaternary and late Tertiary displacement on these faults, rather than erosion, is primarily responsible for the present physiography of the pass. Local conversion of San Andreas-type lateral strain into vertical displacements on the bounding faults is a reasonable explanation of both the pass itself and the unusually high peaks adjacent to it.

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I. INTRODUCTION

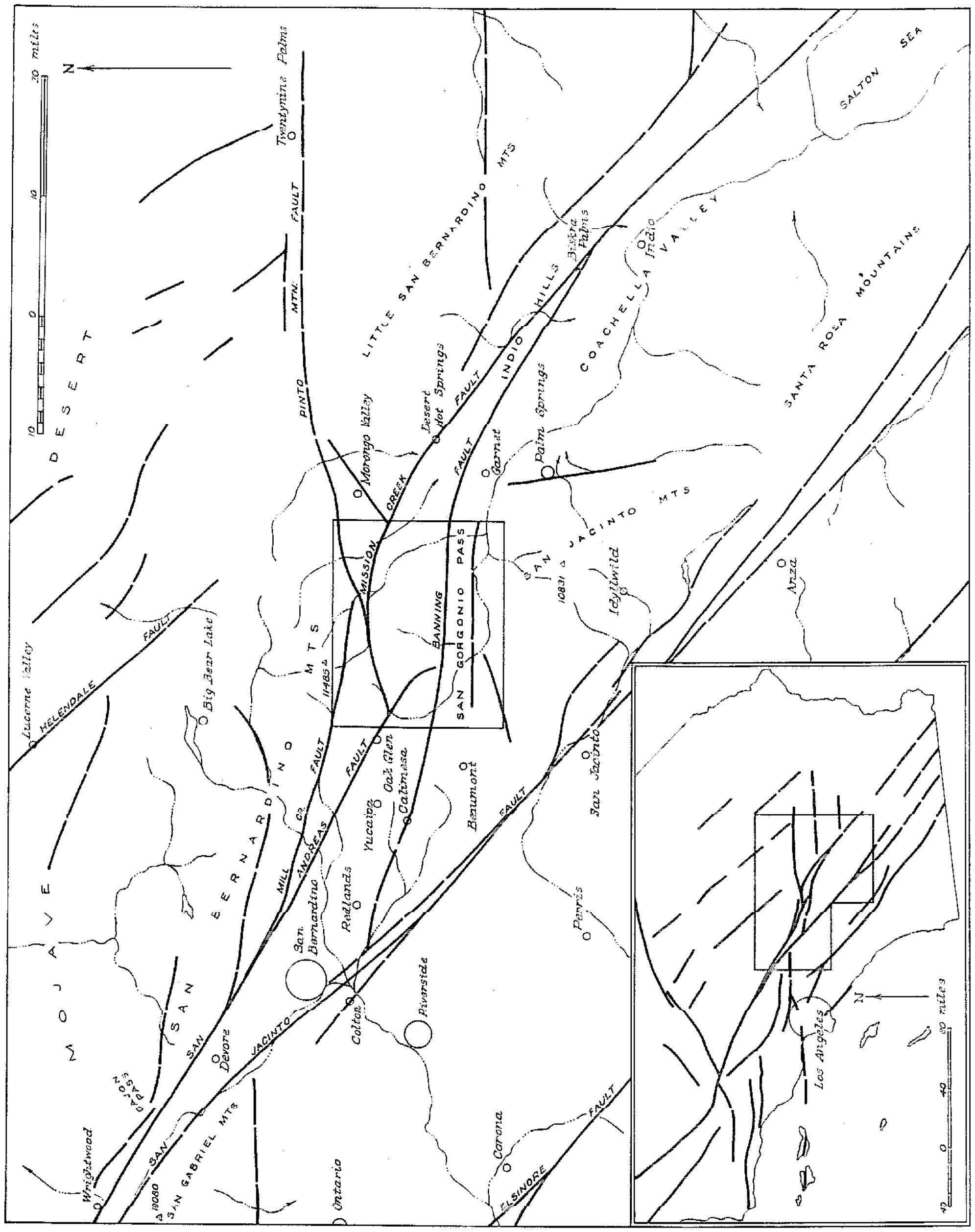
BACKGROUND OF INVESTIGATION

The investigations described in this paper were aimed mainly at increasing the knowledge of a part of the San Andreas fault system of California. The many unanswered and significant tectonic problems relating to this fault have been summarized in a recent contribution by Hill and Dibblee (1953), which includes a bibliography of most earlier studies. These investigators have stimulated further field work by their suggestion that the total lateral displacement on the San Andreas fault zone may be as much as 350 miles, in sharp contrast to previous suggestions of 20 to 30 miles (Noble, 1926) and less than one mile (Taliaferro, 1943).

The San Gorgonio Pass area, 70 miles east of Los Angeles (fig. 1), has held particular promise for studies of the San Andreas fault zone because the rugged topography affords excellent exposures, and because Tertiary marine beds are known to crop out on both sides of the supposed trace of the fault. On the other hand, several anomalous features, unlike those along the San Andreas fault zone in most other areas, have given added interest to the San Gorgonio Pass area. These include:

(1) Rift topography is absent along much of the supposed trace of the San Andreas fault. Potato Canyon (fig. 2), just northwest of San Gorgonio Pass, was recognized by H. W. Fairbanks (in Lawson, et al., 1908, p. 45) as "the last of the longitudinal depressions of any

Figure 1. Index map, showing relation of faults in the San Gorgonio Pass area to those of adjacent regions. Area outlined by rectangle is shown on plate 1. Inset shows location of index map relative to Los Angeles and larger features of Southern California.


MOJAVE DESERT
SAN BERNARDINO MTS
LITTLE SAN BERNARDINO MTS
SAN JACINTO MTS
SANTA ROSA MOUNTAINS
COACHELLA VALLEY
SALTON SEA
INDIO HILLS
SAN GABRIEL MTS
SAN ANDREAS FAULT
SAN JACINTO FAULT
MILL CR. FAULT
MISSION CREEK FAULT
BANNING FAULT
INDIO FAULT
PINTO MTN. FAULT
HELENDALE FAULT
ELSINORE FAULT
SAN GORGONIO PASS
Lucerne Valley
Big Bear Lake
Twentynine Palms
Morongo Valley
Desert Hot Springs
Garnet
Palm Springs
Indio
Idyllwild
Anza
San Jacinto
Beaumont
Calimesa
Oak Glen
Yucaipa
Redlands
San Bernardino
Colton
Riverside
Devore
Wrightwood
Ontario
Corona
Perris
10831
11485
10080
Los Angeles
N
miles

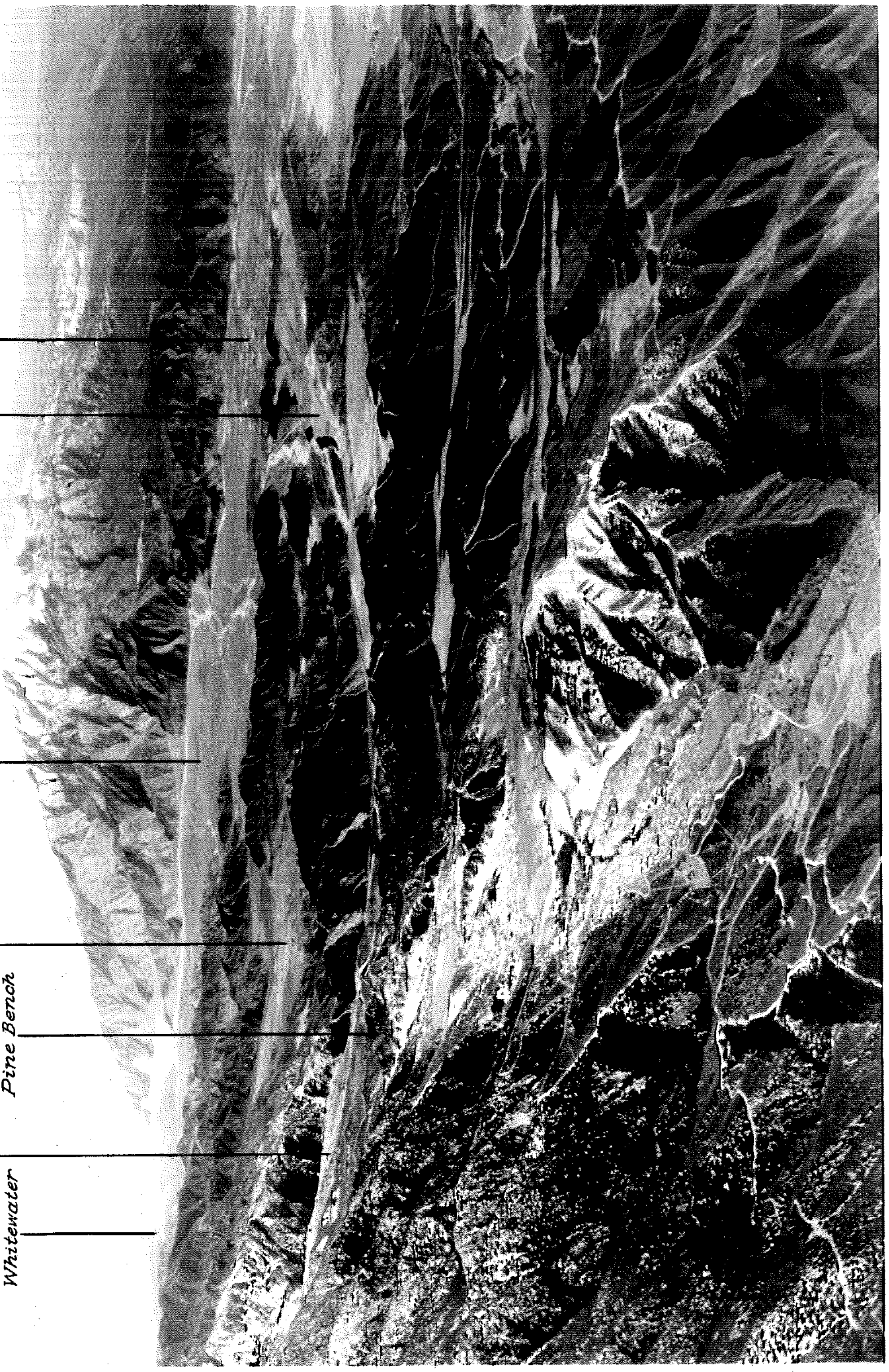
size marking the line of the rift." Fairbanks ascribed the lack of rift topography in the pass area to rapid erosion caused by "recent disturbances." Vaughan (1922), who first mapped the geology of this area, interpolated a segment of the fault between Pine Bench and the mouth of Stubby Canyon (fig. 3, pl. 1) despite the admitted absence of good physiographic and structural evidence for faulting between these two points.

(2) Lateral stream offsets, caused by strike-slip displacements, are among the most typical features of the San Andreas fault zone over most of its course, yet such offsets appear to be lacking in the pass area. Indeed, examination of air photos reveals no undisputable stream offsets southeast of Devore (fig. 1), nor are lateral stream offsets visible in the Indio Hills southeast of San Gorgonio Pass. These observations are difficult to reconcile with historically known strike-slip movements and geodetic confirmation of San Andreas-type strain both northwest and southeast of the pass.

(3) As mapped by Vaughan (1922), the San Andreas fault on the north side of San Gorgonio Pass makes an abrupt change of trend amounting to 35 degrees in 8 miles. Nowhere else along the fault is such a sharp bend known. The only other major change in trend, at the south end of the San Joaquin Valley, is associated with marked structural complications in adjacent rocks (Buwalda, Gazin, and Sutherland, 1930; Crowell, 1950; Hill and Dibblee, 1953), and analogous features should be expected in the San Gorgonio Pass area.

Figure 2. View southeast into San Gorgonio Pass from near Yucaipa. Banning and Cabazon lie on the floor of the pass, the summit of which is just off the picture to the right. The San Andreas fault enters the pass area through Potato Canyon, center foreground.

Photo by Fairchild Aerial Surveys.


Whitewater
San Gorgonio Canyon
Pine Bench
Burro Flat
Cabazon
San Jacinto Pk
Banning Bench
Banning

(4) A recent study by Dehlinger (1952), in which fault displacements in Southern California are correlated with initial motions of transverse earthquake waves, indicates the predominance of thrusting over strike-slip faulting in the San Gorgonio Pass area near Cabazon. Dehlinger (1952, p. 171) states:

> Along the San Andreas fault and northeast and southeast from Riverside, transcurrent displacements trending northwesterly occur. In addition, east-west trending reverse or thrust faults may exist east of Riverside. In this region, where the San Andreas fault briefly strikes east-west, displacements may have large vertical components instead of being primarily horizontal. Initial motions of a series of aftershocks from this region [north of Cabazon] are consistent with reverse or thrust movements.

(5) No great earthquakes are known from the pass area, and probably none has displaced the surface in historic time. This is in contrast to seismic activity along most of the San Andreas zone. The nearby San Jacinto fault (fig. 1) is characterized by frequent seismic shocks; those of 1899 and 1918 were of intensity X in San Jacinto, and perhaps were associated with surface disruptions (Wood and Heck, 1951, pp. 16, 22). The writer doubts the contention of H. O. Wood (1954) that the 1857 earthquake fissure on the San Andreas fault extended through San Gorgonio Pass into the Colorado Desert.

Aside from Vaughan's pioneer geologic work in the San Bernardino Mountains, which was of a reconnaissance nature, no areal geologic studies of the north side of San Gorgonio Pass have yielded a published record. Nor have comprehensive reports been published on any immediately adjacent areas, except for the San Jacinto quadrangle south of the pass (Fraser, 1931). On the other hand, numerous studies have been made on various specific aspects of the geology, paleontology, and physiography of this and nearby regions, and the pass area has been discussed briefly in more general studies of the regional geology of southeastern California. References to these studies are made in the text of this paper.

FIELD WORK

Field mapping by the writer was done during 1952 and 1953, and represents about 150 days in the field. Air photographs, mostly at a scale of 1:18,000, were utilized. South of latitude 34°00', geology was transferred to base maps that had been enlarged and modified from the Palm Springs and Banning quadrangles (1:62,500) of the Corps of Engineers, U. S. Army. North of latitude 34°00', some map coverage is provided by the 1902 San Gorgonio quadrangle (1:125,000), but it is unsuitable for detailed geologic work. In this area, a planimetric base map (pl. 1) was constructed on a scale of 1:62,500 from aerial mosaics (although even their degree of control is questionable), and 500-foot contours were adapted from the San Gorgonio quadrangle. These contours should be considered as generalized form lines, rather than accurate markers of elevation. Near Pine Bench and at Red Dome, vertical control was established by hand-levelling in the field, and was used in making more detailed maps at larger scales.

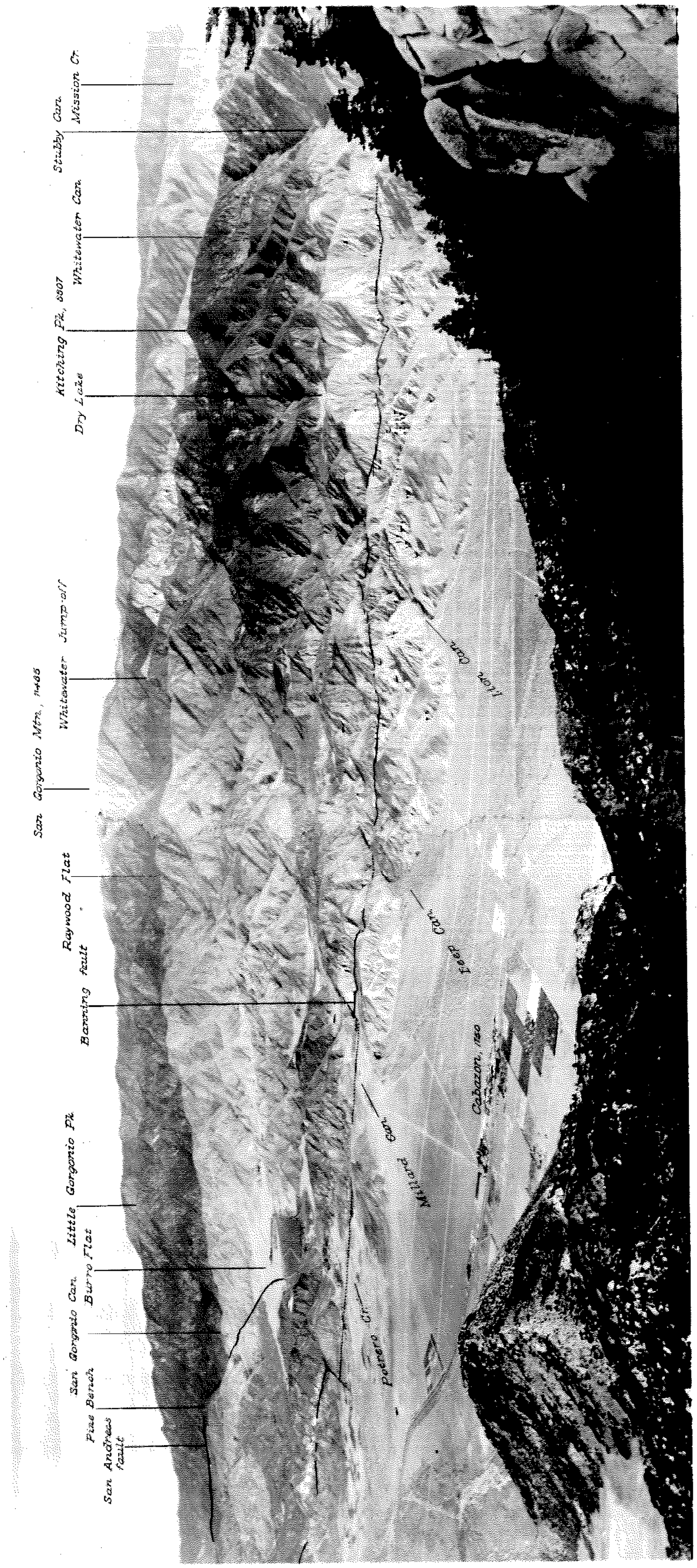
The detail of field mapping was varied according to the nature and significance of the geology encountered. Thus geology along the San Andreas and Banning faults (pls. 2, 3, 4) is shown at scales of two and four inches to the mile, whereas a scale of one inch to the mile was used in mapping the remainder of the area (pl. 1). Mapping in the crystalline rocks north of the Banning fault (pl. 1) was strictly reconnaissance in nature.

GEOGRAPHY

In its setting between two of the highest and most rugged mountain peaks of Southern California, San Gorgonio Pass is a spectacular physiographic feature (figs. 2, 3). Despite its narrowness, the pass is the greatest break in the ring of mountains that surrounds the coastal valleys of Southern California, and since early times it has been a strategic line of communication.

San Gorgonio Pass is essentially a tectonic feature rather than a simple erosional divide as the term "pass" might imply. From the relatively high plains near Beaumont, it appears as a deep, narrow notch that cuts through the mountains into the Colorado Desert below. Its unusual form is reflected in the fact that the name San Gorgonio Pass usually is applied to the narrow easterly part of the notch near Cabazon, where it is flanked by the high peaks, rather than to the gentle and indistinct summit of the pass at Beaumont, 12 miles farther west (fig. 2). Further physiographic confusion is caused by easterly stream drainage from Beaumont (Potrero Creek), which does not continue on

Figure 3. View north across San Gorgonio Pass to the San Bernardino Mountains, taken from the 7500-foot level on San Jacinto Peak. Most of this area is shown on the geologic map, plate 1.


San Andreas fault
Pine Bench
San Gorgonio Can.
Burro Flat
Little Gorgonio Pk.
Banning fault
Raywood Flat
San Gorgonio Mtn.
Whitewater Jump-off
Dry Lake
Kitching Pk.
Whitewater Can.
Stubby Can.
Mission Cr.
Potrero Cr.
Millard Can.
Cabazon
Deep Can.
Lion Can.

"down" the pass into the desert, but instead cuts through the south wall of the pass and thence westerly into the Lake Elsinore drainage system. Only near Banning is desert drainage (Smith Creek) established. This and other aspects of the regional geography have been discussed by Russell (1932).

The area covered in this report (pl. 1) ranges in altitude from 1000 feet near Whitewater to 10,000 feet north of Raywood Flat. Geographic contrasts consequently are great, not only because of the topographic differences themselves, but also because the mountain range north of the pass forms a meteorologic barrier that effectively separates the semi-arid coastal valleys from the truly arid Colorado and Mojave Deserts farther north and east. Mean annual rainfall varies from about 6 inches at Whitewater to 35 inches at Raywood Flat, only 12 miles to the northwest (pl. 1, fig. 3). Temperature contrasts are likewise great.

Yucca, cacti, and native palms are common near Whitewater, whereas at Raywood Flat the predominant vegetation is fir, yellow pine, cedar, and buckthorn. Thick growths of chaparral cover most of the intermediate country. Practically all of the map area has high watershed value, but there is little other constructive land use except near Banning and Beaumont, where there is much fruit growing and cattle raising. The foothills area on the north side of the pass is readily accessible, but geologic mapping in much of the intermediate and higher country is made difficult by a scarcity of roads and trails, by a heavy brush cover, and by extremely rugged topography.

The time and space distribution of rainfall in the pass area has particular geologic significance, inasmuch as stream erosion and deposition are almost wholly confined to periods of infrequent floods. Floods in the mountains of Southern California are associated with some of the world's greatest recorded short-period rainfalls (Jennings, 1950; U. S. Weather Bureau, 1953), most of which occur during winter storms of cyclonic origin. These storms follow a fairly typical pattern, and usually produce heavy precipitation over a period of several days. Records in the pass area for several such periods of excessive precipitation are given in Table 1, together with maximum recorded precipitation for 24-hour periods. Whitewater and San Gorgonio Canyons still show conspicuous scars from the flood of 1938, and it is significant that for these two streams the discharges per square mile of drainage area during this flood were exceeded by only three other streams in Southern California, all of which have much smaller drainage areas. These discharge figures seldom have been exceeded in the United States.

Despite the cyclonic origin of most flood-producing storms in this area, rainfall distribution is markedly affected by local topography, and south and southwest facing slopes of the frontal ranges bear the brunt of the heavy rainfall (Troxell, 1942, p. 49-54; Hamilton, 1944). The north side of San Gorgonio Pass therefore is in an especially vulnerable position, and it is noteworthy that 24-hour precipitation of 5 inches was equalled or exceeded at Raywood Flat twenty-six times between 1921 and 1945. Furthermore, infiltration capacity is a surprisingly important factor in flood runoff from such terrains (Anderson, 1949; Bailey, 1941; Troxell, 1953), and the steep, barren slopes carved in the Mill Creek fault zone along Mill Creek and Whitewater River (fig. 12) contribute to the unusually high runoffs from these two drainage areas (Troxell, 1942, p. 315).

Although the mean annual precipitation at similar altitudes north and south of San Gorgonio Pass is not strikingly different, flood-producing rainfalls appear to have been more intense on the north side (Table 1). This probably is an important factor in the relative magnitude of alluvial-fan production by streams draining the two walls of the pass. The high precipitation at Decker Ranch, as compared to that at other stations south of the pass, is explained by its location on a steep southwest-facing slope of one of the spurs of San Jacinto Peak.

		Elevation in feet	Mean annual precipitation	Max. 24-hr.	18-22 Dec. 1921	13-17 Feb. 1927	27 Feb. - 4 Mar. 1938	22-23 Jan. 1943
north of pass	Seven Oaks	5000	27.37	9.76	18.55	18.21	18.22	13.51
	Forest Home (Mill Cr. Intake)	5000		9.20+			22.12	
	Raywood Flat	7200	35.35	13.50	22.45	26.60	24.33	17.49
	Powerhouse No. 2	4500		12.15+			20.65	
in pass	Banning	2330	19.12	7.00+	9.56	10.59	8.11	
	Cabazon	1785	12.83	5.09				6.11
south of pass	Snow Creek Upper	1925	12.45	8.33+	8.69	9.27	12.50	9.66
	Hurley Flat	3600	22.28	9.45+	11.45	16.71	12.33	8.75
	Decker Ranch	5550	38.30	12.00+	17.62	23.63	15.97	
	Idyllwild	5390	28.05	4.37+			12.12	
	Hemet Reservoir	4400		6.01			8.94	

Table 1. Mean annual and selected short-period precipitation figures for stations near San Gorgonio Pass. All precipitation figures are in inches. Sources: Troxell (1942); Jennings (1952); Banning Water Company; U. S. Weather Bureau.

II. CRYSTALLINE ROCKS

INTRODUCTION

The crystalline rocks of the San Gorgonio Pass area can be logically grouped into two distinct categories. The rocks north of the pass, herein termed the San Gorgonio igneous-metamorphic complex, have been mapped in reconnaissance in this study; the distinctly different intrusive and metasedimentary rocks of the San Jacinto Mountains south of the pass have been studied by Fraser (1931), Miller (1944), and Larsen (1948). In his mapping of the crystalline rocks north of San Gorgonio Pass, Vaughan (1922) distinguished only "heterogeneous plutonic rocks" and "undifferentiated schists" in the south part of the range. The writer's investigations indicate that Vaughan was more realistic in this seemingly oversimplified classification than one might imagine.

SAN GORGONIO IGNEOUS-METAMORPHIC COMPLEX

GENERAL FEATURES

The bulk of the crystalline rocks of the south and east flanks of San Gorgonio Mountain are hybrid types of varying composition and transitional boundaries. In general, an old metamorphic complex of intermediate or basic composition has been intimately intruded by, and in large part reconstituted by, plutonic rocks of quartz monzonitic composition. In the foothills north of the pass, the intrusive rocks are represented by numerous pegmatite dikes and lit-par-lit injections.

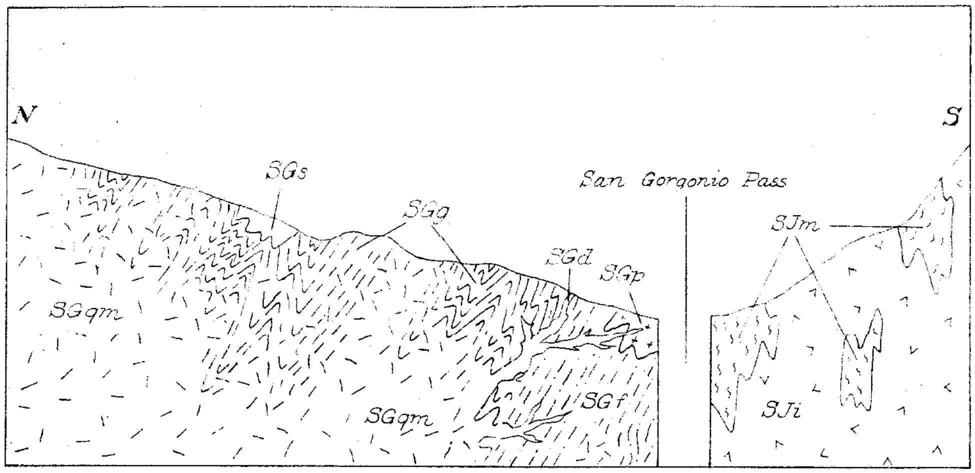


Figure 4. Schematic cross-section of San Gorgonio Pass, showing relations of principal crystalline rock types. Faults have been omitted. Rocks of the San Gorgonio igneous-metamorphic complex (left) are: SGqm--Cactus(?) quartz monzonite; SGg--migmatitic gneiss; SGf--flaser gneiss; SGs--greenschist; SGp--piedmontite-bearing gneiss; SGd--pegmatite dikes. Crystalline rocks of the San Jacinto Mountains (right) are: SJi--intrusive rocks; SJm--metasedimentary rocks.

Northward in the range, more pervasive introduction of granitic material has given rise to contorted injection gneisses and migmatites. Still farther north, the predominant rock is plutonic quartz monzonite with included fragments of metamorphic rocks in all degrees of assimilation. Unfortunately, several east-west faults that cross the south flank of San Gorgonio Mountain make it difficult to determine whether an actual lateral transition is exposed, or whether rocks from different depth zones merely have been brought into juxtaposition by vertical movements on the faults.

The most appropriate name that can be applied to the diverse gneissic rocks of the igneous-metamorphic complex is migmatitic gneiss. Important varietal types, differentiated on plate 1 and discussed separately below, are flaser gneiss, greenschist, and piedmontite-bearing gneiss. In three places intrusive quartz monzonite forms units large enough to differentiate on the map.

MIGMATITIC GNEISS

Lithology--Biotite-hornblende-quartz-andesine gneiss* with varying amounts of potash feldspar is the most widespread crystalline rock on the north side of San Gorgonio Pass. Textural variations are marked, and the common rock types are (1) massive, relatively uniform gneiss with ill-defined foliation; (2) layered gneiss, with contrasting

*In this report, rock names include minerals that are present to the extent of more than 5 percent of the rock; last-named minerals are most abundant.

dark-colored biotitic-amphibolitic layers and light-colored pegmatitic layers; (3) contorted gneiss, showing sparse ptygmatic folding, with much injected igneous material and little consistent foliation; (4) angular, unoriented fragments of reconstituted metamorphic rock in a matrix of pegmatitic or granitic material, much like the agmatite of Sederholm (1926, pp. 17-27). The latter two types are most abundant northward in the range, and are gradational with the intrusive rocks.

The least-altered gneiss appears to be that in the southeast part of the range. North of the mouths of Cottonwood and Stubby Canyons, the rock is relatively uniform in composition, and foliation is consistent over distances of several miles. Although interlayered pegmatitic material is abundant even here, the rock is generally amphibolitic. Dark biotitic schists are common as inclusions in the more granitic gneisses throughout the mapped area, and angular fragments of hornblendite as much as several feet in diameter, "immersed" in a matrix of pegmatite, are widespread near Little Gorgonio Peak and north of the Mission Creek fault in the eastern part of the area.

A rock typical of the least-altered gneiss (specimen SGo-10b) has a tonalitic composition, and contains 40 percent of andesine, 30 percent of quartz, 15 percent of biotite, and 15 percent of blue-green hornblende. Common accessory minerals are apatite, clinozoisite, and sphene. A nearby rock (SGo-11b), however, has 45 percent of orthoclase and only 2 percent of andesine. Such wide variation in the proportions of light minerals is compatible with the field observations, which suggest pervasive permeation of the older rocks by granitic material. Recrystallized quartz in small blebs is everywhere abundant, and locally constitutes as much as 60 percent of the rock.

Garnet is almost completely absent from rocks in the map area, except (1) in piedmontite-bearing gneiss near Stubby Canyon, (2) in migmatitic gneiss on the ridge between San Gorgonio and Mill Creeks, and (3) in migmatitic gneiss north of the Mission Creek fault in the vicinity of Mission Creek. Potash feldspar is represented by both microcline and orthoclase, the latter commonly occurring as augen in the somewhat sheared rocks. Albite is locally abundant north of the San Andreas fault in the Burro Flat area, although it also occurs sparsely south of the fault. The albite typically appears as altered white porphyroblasts, which give the rock a knotty appearance. The albite is associated with increased proportions of epidote and chlorite.

The prominent rock of Painted Hill is a tourmaline-bearing hematite-muscovite-plagioclase-microcline-quartz schist. Five miles to the north, the crystalline rocks include a distinctive biotite-quartz-oligoclase-orthoclase gneiss in which saussuritization of the plagioclase gives the rock a dark green color, despite the presence of large, flesh-colored porphyroblasts of orthoclase. These rock types show evidence of extensive deuteric activity, perhaps genetically associated with the pervasive pegmatite of this area.

Pegmatite dikes north of the mouth of Cottonwood Canyon and along the west wall of Whitewater Canyon are strikingly rich in ilmenite, some of which occurs as masses more than an inch across. Gneisses as far west as Millard Canyon contain abnormal concentrations of ilmenite, apparently as a result of permeation by such titanium-rich solutions. North of the Mission Creek fault in this same region, sphene is abundant near areas of pegmatitic intrusion, and locally constitutes as much as 10 percent of the amphibolitic gneiss. It is possible that this mineral assemblage represents the same titanium-rich permeation into a more calciferous environment; independent evidence suggests that some of these metamorphic rocks are of sedimentary origin. Many titaniferous rocks from north of the Mission Creek fault have a "spotted" appearance owing to the presence of quartz-feldspar aggregates that form bunches in a more mafic matrix. This texture is characteristic of sphene-rich rocks from the San Jacinto Mountains, and it is perhaps significant that rocks of the San Jacinto and eastern San Bernardino Mountains are alike in their high content of titanium minerals.

Of particular structural significance is the widespread extent of migmatitic gneiss throughout the area. Although definite discontinuities in rock types and in attitudes of the foliation in these rocks occur at most faults, all of the migmatitic gneisses belong to the same "family" of rocks--the San Gorgonio igneous-metamorphic complex. This is significant in that one of the most characteristic features of the San Andreas fault northwest of this region is the marked difference between the crystalline rocks on opposite sides of the fault.

Structural features of the gneiss--Foliation is pronounced in most of the migmatitic gneisses of San Gorgonio Mountain, although this foliation is so contorted and variously oriented that efforts to define major faults by means of discontinuities in trend of foliation proved disappointing. Only in the southeastern part of the map area do the gneisses have a consistent regional trend; foliation in this area strikes north and dips steeply east. At many other places local continuity precludes the existence of major faults, but it is difficult to prove the existence of faulting in areas of seemingly discontinuous and contorted foliation.

Origin--The presence of amphibolitic layers, biotite-rich schist inclusions, and hornblendite fragments within the partially reconstituted gneisses suggests a parent rock of intermediate to basic composition. This conclusion presupposes, of course, that the rocks were formed by arteritic migmatization (injection from without). The occurrence of veinitic migmatization (segregation of indigenous constituents) cannot be discounted completely, at least not on the basis of the very limited field and laboratory work of this study, but it does seem less likely.

Nowhere in the migmatitic gneisses south of the Mission and Mill Creek faults are there marble lenses or continuous layers of distinctive composition that suggest or denote a sedimentary ancestry. The "altered pebble conglomerate" reported from north of Banning by Vaughan (1922, p. 345) appears merely to be a flaser gneiss with large porphyroblasts of andesine and orthoclase. North of the Mill Creek fault, 2 miles east of Fallsvale (pl. 1), is a limestone lens one-half mile long and locally 50 to 60 feet thick (Logan, 1947, pp. 292-293). Although not studied in detail by the writer, this rock may well be metasedimentary. Further evidence of sedimentary ancestry of at least a part of the migmatitic gneisses of this northern area is given by Vaughan (1922, p. 348). For most of these gneisses in the San Gorgonio igneous-metamorphic complex, however, the most probable parent is an igneous rock of dioritic or gabbroic composition.

Although several individual episodes of pegmatite intrusion are evident in the migmatitic gneisses, as shown by successively cross-cutting relations, there seems to be no evidence that these pegmatites represent more than one general period of igneous intrusion. Material injected lit-par-lit in the Chuckwalla complex of the nearby Little San Bernardino Mountains, thought to be "older pre-Cambrian" by Miller (1946, p. 519), recently has been assigned an age of 124 million years by using the Larsen method with zircon crystals (David Gottfried, personal communication, Jan. 25, 1954). All pegmatites and granitic rocks of the San Gorgonio Pass area are presumably of Mesozoic age, although this by no means has been proved.

<u>Intensity of metamorphism</u>--Nowhere in the area studied does the mineral assemblage of the migmatitic gneisses suggest regional metamorphism more intense than that of the amphibolite facies. The widespread association of quartz, microcline, biotite, blue-green

hornblende, and andesine is characteristic of Turner's cordierite-anthophyllite subfacies (1948, p. 77). The chlorite-hornblende-quartz-albite gneisses on the borders of the greenschist areas of San Gorgonio Canyon represent the intermediate albite-epidote-amphibolite facies, as do many other epidote-rich gneisses of the area.

Correlation and age--No other rock units definitely have been proved correlative in lithology and implied geologic history to the migmatitic gneisses of the San Gorgonio igneous-metamorphic complex, owing primarily to the lack of geologic mapping in adjacent areas, but several correlations are possible. The Baldwin gneiss of the north side of the San Bernardino Mountains, named and described by Guillou (1953, p. 6), has many features in common with the gneiss 20 miles to the south, including similar augen structure, injection by Cactus quartz monzonite, and similar composition and degree of metamorphism. The two units probably are correlative. Miller's Pinto gneiss (1938, pp. 424-428), presumably a part of his more extensive Chuckwalla complex (Miller, 1944, pp. 16-18), is strikingly similar to the San Gorgonio gneisses, and further work in the intervening area of the Little San Bernardino Mountains may demonstrate their equivalence.

Evidently also a part of Miller's Chuckwalla complex are rocks of the Berdoo and Thermal Canyon series, named and described by MacLellan (1936) from exposures in the Little San Bernardino Mountains 30 miles east of Whitewater. Although MacLellan (1936, p. 18) considered these rocks to be "definitely more highly metamorphosed than the undifferentiated schists of the San Bernardino Mountains," the characteristic mineral assemblage of oligoclase-andesine, biotite, orthoclase, cordierite, blue-green hornblende, and quartz does not suggest a degree of metamorphism strikingly different from that of the San Gorgonio migmatitic gneisses.

The San Gabriel formation (Miller, 1934, pp. 49-56), a widespread igneous-metamorphic complex of the San Gabriel Mountains, has many features in common with the San Gorgonio gneisses, but correlation between these units would be difficult to demonstrate.

Metamorphic rocks south of San Gorgonio Pass are largely metasedimentary types, and thus are unlike most of those to the north. Larsen (1948, p. 16, pl. 1) has grouped metamorphic rocks north of the Banning fault near Beaumont together with the Mississippian(?) schists and quartzites that are abundant farther south in the Elsinore quadrangle. Although the Beaumont locality was examined only hastily by the writer, Larsen's correlation is questioned because of the general absence of metasedimentary rock types here.

The gneisses within the area of this study must be regarded as pre-Jurassic, on the basis of injection by Cactus(?) quartz monzonite. If they are equivalent to the Baldwin gneiss, which seems likely, they can be dated more specifically, because this gneiss is overlain by pre-Carboniferous quartzites. Guillou states (1953, p. 7): "On the basis of the recognizable complex pre-Mississippian history of the Baldwin gneiss, it is assigned an early Paleozoic or pre-Cambrian age."

FLASER GNEISS

In the foothills north of the Banning fault, many of the gneisses of the igneous-metamorphic complex show distinctive structure developed by deep-seated cataclastic metamorphism. These rocks range from slightly sheared augen gneisses to highly pulverized and lenticularly layered rocks, and these types grade into one another.

A thin-section cut from one of the most highly sheared rocks (SGo-14) shows distinct fluxion structure. Eye-shaped porphyroclasts, white in hand-specimen, constitute about 50 percent of the rock and consist of (1) fine-grained aggregates of quartz and orthoclase, (2) altered plagioclase, probably andesine, or (3) orthoclase. The orthoclase porphyroclasts, though least common, have the most striking appearance in hand-specimen, and Carlsbad-twinned crystals 2 inches long have been observed. The generally idioblastic outline of many of the sheared crystals suggests that the orthoclase is of porphyroblastic origin.

The remaining comminuted portion of the gneiss is holocrystalline, and consists of fine-grained (.03 to .10 mm.) recrystallized quartz, with minor biotite and orthoclase(?). Some of the quartz has recrystallized as plates parallel to the foliation. Likewise, the small flakes of recrystallized biotite are aligned in lenticular streaks. Biotite, though a minor constituent, gives the matrix a gray to black color in hand-specimen. Following E. B. Knopf (1931, p. 13) and Buddington (1939, p. 253), this rock is termed a flaser gneiss, rather thana mylonite, on the basis of the abundant porphyroblasts and the almost complete recrystallization of the comminuted paste.

The foliation of the augen and flaser gneisses generally trends east-west. Rocks of this type occur in an area of right-triangular shape, with the hypotenuse extending from the mouth of Cottonwood Canyon to the western edge of the map area south of Pine Bench, and with the right-angle on the Banning fault at the western edge of the map (pl. 1). That the flaser gneisses cannot be an expression of present-day faulting is indicated not only by textural characteristics of deep-seated origin (e.g. recrystallized matrix, coherence, growth of orthoclase porphyroblasts), but also by their intense folding and contortion, together with field evidence of contemporaneous and post-shearing injection by granitic material.

The Banning fault is more nearly parallel than the San Andreas fault to the zone of the cataclastic rocks. It seems reasonable, therefore, that either (1) the Banning fault is very old, so that its early "roots" are now exposed, or (2) the course of the Banning fault has been determined by the zone of east-west weakness that is defined by the much older sheared rocks.

Flaser gneisses, identical in appearance to those near the Banning fault, locally crop out along the Mission Creek fault at the Tunnels (pl. 1), but similar cataclastic rocks are not widespread elsewhere along this fault.

GREENSCHIST

Lithology--A highly distinctive and localized body of quartz-actinolite-albite-epidote schist is exposed on the north side of San Gorgonio Canyon for three miles above the San Andreas fault, which cuts off the unit on the southwest. On the north, the greenschist is faulted against the gneisses of Little Gorgonio Peak, and the Raywood fault appears to cut it off on the south. To the east, near the junction of Black and Mill Canyons, the greenschist appears to be transitional with the migmatitic gneisses. The greenschist is structurally significant, not only because of its anomalous position among rocks of a seemingly different type, but also because it has contributed distinctive clasts to the Cenozoic sedimentary rocks that lie south of the San Andreas fault.

In hand-specimen the greenschist is dark blue-green, has well-developed foliation, and contains many porphyroblasts of white albite which give the rock a distinctive knotty appearance. In thin-section, the most typical greenschist (SGo-15) shows fluxion structure, with eye-shaped, sheared porphyroblasts of both albite and epidote in a matrix of actinolite needles. These needles have orientations that reflect the eye-shaped outline of the sheared porphyroblasts. The rock comprises 40 percent of epidote, 30 percent of untwinned albite (with strung-out inclusions of actinolite, clinozoisite, and quartz), 20 percent of actinolite, 5 percent of chlorite, and 5 percent of quartz, with accessory magnetite. A second specimen (SGo-38) from the greenschist 3 miles northeast of the SGo-15 locality, appears similar in hand-specimen, but has 30 percent of albite, 30 percent of quartz, 20 percent of epidote, and 20 percent of actinolite.

Origin--The composition of the most typical greenschist (SGo-15), with an estimated silica content of 52 percent, indicates origin as a rock of gabbroic composition, subjected to greenschist facies intensity of metamorphism. The marked increase in quartz content toward the east (SGo-38 contains about 70 percent of silica) suggests that granitic material locally has permeated the rock in much the same manner as in the adjacent amphibolitic gneisses. Although the greenschist has been at least partly faulted into its present position, gradational rock types occur not only eastward but also across the Raywood fault to the south. On the ridge south of the Raywood fault near Power House No. 1 (pl. 1), "spotted" rocks (e. g. SGo-39), grouped together with the migmatitic gneisses in the mapping, contain porphyroblasts of white albite-oligoclase, and hornblende that is partly altered to chlorite and epidote. Rocks of similar appearance crop out south of the San Andreas fault near Oak Glen (fig. 1), although no true greenschists are known south of the fault in this region.

On the basis of admittedly sparse evidence, it is tentatively suggested that the greenschist represents a locally retrogressed and little-injected phase of the widespread amphibolites. This hypothesis certainly has not been proved, but it does emphasize the fact that postulation of large lateral movements on the nearby faults is not entirely necessary to account for the present location of the greenschist. The difference in intensity of metamorphism in the two rock types might be explained by vertical movements on the faults (bringing rocks of different depth zones into juxtaposition), together with localization along these faults of shear stress and hydrothermal activity. Shear stress has been emphasized as a factor in retrogressive metamorphism by Turner (1948, pp. 299-304), and the action of hydrothermal solutions has been emphasized by Schwartz and Todd (1941). Further mapping in this area should be fruitful.

Correlation--Rocks identical in appearance and composition with the greenschists of San Gorgonio Canyon occur in the Pelona schist of the San Gabriel Mountains and in schist of the Orocopia Mountains, north of the Salton Sea. These rocks have been discussed in detail by Hill (1939), and the idea has been entertained that they might be parts of a formerly continuous rock body that has been offset 160 miles along the San Andreas fault (Hill and Dibblee, 1953, p. 450). Despite their highly distinctive appearance, however, such greenschists represent neither peculiar metamorphic conditions nor rocks of unusual parentage. The present state of knowledge of the "basement" rocks of Southern California does not permit a comprehensive statement of the regional significance of rocks with Pelona schist lithology, but it might be suggested that the localization of greenschists along the highly sheared San Andreas fault zone is more than an accident.

PIEDMONTITE-BEARING GNEISS

Stubby Canyon locality--One mile west of the mouth of Stubby Canyon is a localized mass of piedmontite-bearing gneiss that is a highly distinctive rock type within the otherwise normal migmatitic gneisses of the foothills area. Particular significance is attached to exposures of this unusual rock because they have contributed clasts to sedimentary accumulations south of the Banning fault; the distribution of these clasts, as compared with distribution of the source rocks, provides evidence of the amount of subsequent displacement along this fault. The piedmontite-bearing rocks of Stubby Canyon are limited to an area of about one by one-half mile just north of the Banning fault, and lie almost entirely within the headwaters of Second and Third Canyons (pl. 3).

The piedmontite-bearing gneiss is associated with pegmatite intrusions into the older metamorphic rocks; the largest piedmontite crystals occur within and near the borders of pegmatite dikes. The average gneissic rock is a piedmontite-ilmenite-quartz-microcline gneiss with accessory biotite, apatite, sphene, garnet, amphibole, and pyroxene. Altered oligoclase-andesine is present in widely varying amounts. The piedmontite occurs as euhedral crystals as much as three-fourths inch long, and constitutes as much as 5 percent of the rock. Many crystals show zoning, and the intensity of pleochroism varies with geographic location, probably reflecting variations in manganese concentration. Disseminated ilmenite constitutes about

5 percent of the rock, although several miles to the east, near the mouth of Cottonwood Canyon, ilmenite masses several inches across form a major part of the otherwise-barren pegmatite.

The gneiss is rich in sphene, which forms euhedral crystals as much as one-fourth inch long. Bright yellow garnet of undetermined composition is locally abundant; spessartite garnet of identical color and index has been described from manganese-rich areas of Japan (Yosimura, 1939, pp. 387-396). A distinctive mineral of the pegmatite and border rocks is a clove-brown, iron-poor, calciferous hornblende(?) that forms euhedral crystals as much as one-half inch long. In thin-section, this hornblende(?) appears to be an alteration product of an iron-poor calciferous augite that is closely associated with the piedmontite. The optical properties suggest that manganese may be present in both the hornblende(?) and augite. Biotite is locally abundant, and its light color, very weak pleochroism, and relatively high optic angle of 20° to 25° suggest that it, too, is an iron-poor variety.

Whitewater Canyon locality--A second occurrence of piedmontite-bearing gneiss is on the west wall of Whitewater Canyon, between the trout farm and Red Dome (pl. 1). The following description is based upon megascopic examination of stream float; the actual outcrop was not visited.

In most respects the Whitewater occurrence is similar to the one at Stubby Canyon, about 4 miles away, in that the piedmontite is associated with ilmenite-rich pegmatite, and the most common rock type is piedmontite-ilmenite-quartz-microcline(?) gneiss with a characteristic pink-gray color. Piedmontite occurs both in the pegmatite and in the adjacent gneiss. Contorted gneisses from this area have high concentrations of granular-appearing piedmontite in pegmatite associated with the apices of sharp folds. Yellow-green epidote is particularly abundant here, and it appears to be the major constituent in some of the rock.

A schistose rock from the first canyon south of Red Dome contains a light pink mica that probably is alurgite, the manganiferous muscovite. Needles of piedmontite as much as one-half inch long are intergrown with the alurgite(?). Alurgite(?) occurs in clasts of the San Timoteo(?) formation north of Banning, and undoubtedly was derived from the eastern end of the range; a more thorough search probably would disclose its presence in the Stubby Canyon locality, as well as near Red Dome. Alurgite is closely associated with piedmontite in the San Gabriel Mountains (Hill, 1939, pp. 93-96; Webb, 1939b).

Other occurrences and significance--A minor occurrence of piedmontite associated with pegmatite was observed in a tributary of the East Branch of Millard Canyon, three-tenths mile north of Big Tree. Similar small occurrences probably are common in the eastern part of the range between the Banning and Mission Creek faults, but an examination of stream gravels from all the canyons draining the north side of San Gorgonio Pass failed to reveal evidence of any major outcrops other than those at Stubby and Whitewater Canyons.

Piedmontite has been described from numerous localities in Southern California (Murdoch and Webb, 1948, pp. 230-231), although the only previous report of this mineral from the San Bernardino Mountains concerned piedmontite-bearing clasts from sedimentary rocks near Painted Hill. Hill (1939, pp. 93-96) describes several occurrences of piedmontite in quartz-rich rocks of the Pelona schist, which is interesting because these rocks crop out on the south side of the San Andreas fault 50 to 60 miles northwest of the San Gorgonio Pass locality. According to Hill (1939, p. 109), however, the associated rocks in the two regions are very different.

The piedmontite-bearing rocks of San Gorgonio Pass contain many calciferous minerals, which may indicate a former local meta-sedimentary environment into which pegmatite was injected. Speculation as to the origin of these rocks, however, would demand more detailed field and microscope work; these occurrences are assuredly deserving of further study.

CACTUS(?) QUARTZ MONZONITE

Three masses of quartz monzonite, each sufficiently large to be separated in mapping from the transitional migmatitic gneisses, occur (1) in the foothills 4 miles northwest of Banning, (2) on Yucaipa Ridge between Pine Bench and Mill Creek, and (3) on the southwest slope of San Gorgonio Mountain, near the headwaters of Vivian Creek (pl. 1). Significantly, these three exposures of almost identical rock are separated by two of the largest faults of the region--the San Andreas and

Mill Creek faults.

Specimens from the three masses of quartz monzonite (Sgo-3, SGo-36, SGo-45) comprise 30 to 45 percent of microcline, 25 to 40 percent of altered albite-oligoclase, 25 to 30 percent of quartz, and 5 to 10 percent of green biotite. Muscovite and chlorite are sparse accessory minerals. The texture is equigranular with grain size averaging 2 mm.; sutured contacts between grains are common. The bouldery but broadly uniform slopes underlain by quartz monzonite stand in marked contrast to the angular, slide-covered slopes underlain by gneiss.

The quartz monzonite described above was included by Vaughan (1922, pp. 363-374) in his "heterogeneous plutonic rocks." Subsequent studies by Woodford and Harriss (1928, pp. 271-274) and by Guillou (1953, pp. 12-13) indicate that many of these plutonic rock types, only one of which appears to crop out in the area of plate 1, probably are variants of a single major intrusion--Vaughan's Cactus granite. The name recently has been modified by Guillou (1953, p. 12) to Cactus quartz monzonite. On the basis of these observed variant Cactus types, the quartz monzonite of the south part of the range is herein tentatively assigned to the Cactus quartz monzonite. These rocks, however, are uniformly finer grained than those at the type area near Cactus Flat, and further work may well modify this correlation. In fact, mapping by John J. W. Rogers in the Twentynine Palms area (in progress) suggests that the quartz monzonites of San Gorgonio Pass are more similar to the Palms granite than to the later White Tanks quartz monzonite (Miller, 1938); the White Tanks quartz monzonite, in turn, probably is correlative with the Cactus quartz monzonite (D. F. Hewett, oral communication).

Studies by Hewett and Glass (1953, p. 1049) of uranium-lead ratios of euxenite in pegmatite dikes in the Cactus quartz monzonite indicate a Middle Jurassic age (about 150 million years). The isotopic composition of the lead was not determined, however, so that the actual age is very probably somewhat less. These rocks might be a part of the Southern California batholith, which is Cretaceous in age.

DIKE ROCKS

Leucocratic dike rocks other than pegmatite crop out in scattered parts of the area. Dikes of quartz latite porphyry north of Burro Flat (SGo-9a) transect the foliation of the migmatitic gneiss, and comprise phenocrysts of andesine (65 percent) and quartz (35 percent) in a fine-grained groundmass of quartz (50 percent) and orthoclase(?) (50 percent). The origin of this rock is problematical. If the dikes were derived from the Cactus quartz monzonite, it is difficult to explain the pegmatite of apparently similar derivation which intimately permeates the gneiss; if the dikes represent still younger intrusives, their parent material is not recognized anywhere in this area.

CRYSTALLINE ROCKS OF THE SAN JACINTO MOUNTAINS

METAMORPHIC ROCKS

Scattered remnants of an old metamorphic series occur as inclusions and roof pendants in the intrusive rocks of the San Jacinto Mountains. According to Fraser (1931, p. 534), the principal metamorphic types are quartzo-feldspathic gneisses and schists, hornblende schist, phyllite, crystalline limestone, and quartzite. Recrystallized limestones are particularly well exposed on the outlying spurs of San Jacinto Peak 2 miles south of Whitewater (Tucker and Sampson, 1945, pp. 172-174). These rocks were included in the Palm Canyon complex by Miller (1944, pp. 21-25), who recovered from points near Cathedral City possible fossil material that suggests a Paleozoic age for the rocks.

Seemingly correlative rocks have been mapped west of the San Jacinto Mountains by Larsen (1948, pp. 16-18, pl. 1), who also assigns a Paleozoic age to them on the basis of supposedly Carboniferous fossils described by Webb (1939a). These rocks have been highly injected by igneous intrusives, and numerous layered gneisses and schists have been formed by lit-par-lit injection of igneous material. In this one respect, they are much like the migmatitic gneisses of San Gorgonio Mountain. All investigators agree, however, that the San Jacinto metamorphic rocks are largely of sedimentary origin.

INTRUSIVE ROCKS

Rocks of the Southern California batholith of Cretaceous age underlie most of the San Jacinto Mountains. This area has been studied in reconnaissance by Fraser (1931, pp. 525-533), Larsen (1948, pp. 67-69), and Miller (1944, pp. 52-59), and the following comments are based mainly on the observations of these investigators.

Coarse-grained, homogeneous, well-jointed rocks predominate in this area, and the steep, boulder-covered slopes stand in marked contrast to the more gentle and diverse slopes underlain by gneiss on the north side of the pass. The rocks have an average composition near that of a basic granodiorite. Light gray tonalite forms the hills for a few miles south of Banning, and it is bordered on the south by a coarse-grained granodiorite that also occurs in much of the Snow Creek drainage to the east. True granites are locally exposed south of Cabazon, as well as at other scattered localities. Tonalite underlies much of the southern part of the range. The gneissoid rock that forms the "flatirons" west of Palm Springs is a highly sheared and foliated granodiorite, whose relation to the more widespread plutonic rocks bordering it on the west has not been definitely established.

III. STRATIGRAPHY

INTRODUCTION

The sedimentary rocks of San Gorgonio Pass are of continental origin except for the Imperial formation, which represents northward incursion of marine waters into the Salton depression from the Gulf of California. All are of late Tertiary and Quaternary age. Correlation is complicated by Recent faulting and folding, interrupted exposures, scarcity of vertebrate fossils, and marked lateral variations and other stratigraphic complexities that reflect a history of simultaneous deposition and deformation. Indeed, only because of the distinctive marine Imperial formation is it possible to place the overlying and underlying continental strata at reasonably definite positions in the stratigraphic column.

Regional correlations with previously studied sedimentary rocks in areas east and west of San Gorgonio Pass are shown in figure 5. Table 2 is a summary of the stratigraphy within the pass.

COACHELLA FANGLOMERATE

General relations--The oldest sedimentary rock of the pass area, the Coachella fanglomerate, was named and first described by Vaughan (1922, p. 386). As pointed out by Bramkamp (1934a, p. 18), some of the rocks mapped by Vaughan as Coachella fanglomerate assuredly belong to younger units in the section, but the formational name is herein retained for the prominent cliff-forming beds exposed along the east wall of Whitewater Canyon near the trout farm (pl. 4, fig. 6).

Table 2. Sequence and character of the sedimentary rocks of San Gorgonio Pass

Formation	Map Symbol	Age	Max. Thickness (feet)	Lithology
Alluvium	Qal	Recent		Unconsolidated stream gravels and low stream terrace gravels.
- - - - UNCONFORMITY - - - - - - -				
Landslide deposits	Qls	Recent		
- - - - UNCONFORMITY - - - - - - -				
Undifferentiated terrace gravels	Qt	Quaternary		Terrace gravels and canyon-fill material of doubtful correlation.
- - - - UNCONFORMITY - - - - - - -				
Burnt Canyon breccia	Qbc	Quaternary	100±	Dissected landslide deposit.
- - - - UNCONFORMITY - - - - - - -				
Heights fanglomerate	Qh	Quaternary	500+	Tan to dark brown, ill-sorted conglomerate, mainly of dark clasts of gneissic rock.
- - - - UNCONFORMITY - - - - - - -				
Cabezon fanglomerate	Qc	Quaternary	1500+	Gray to tan ill-sorted conglomerate, rich in clasts of pegmatitic and granitic rocks.
- - - - UNCONFORMITY - - - - - - -				
Deformed gravels of Whitewater River	Qd	Quaternary(?)		Gray to tan, ill-sorted conglomerate, rich in clasts of pegmatitic and granitic rocks.
- - - - CONTACT NOT EXPOSED - - -				
San Timoteo(?) formation	Pst	Pliocene-Pleistocene	1800+	Tan to gray sandstone, siltstone, and conglomerate, rich in light-colored clasts of granitic rocks; interbedded fresh-water limestone.
- - - - CONTACT NOT EXPOSED - - -				
Painted Hill formation	Pp Ppc Ppb Ppd	Middle Pliocene(?)	3400+	Light gray sandstone and conglomerate, rich in clasts of granitic and volcanic rocks; Ppc, resistant conglomerate bed; Ppb, interlayered flows of olivine basalt and, Ppd, associated dikes.
- - - - - - - - - - - - - - - - -				
Imperial formation	Pi	Lower Pliocene(?)	300	Tan to yellow marine sandstone, siltstone, and shale; gypsiferous; fossiliferous.
- - - - - - - - - - - - - - - - -				
Hathaway formation				
Upper member	Phu	Lower Pliocene(?)	650	Gray, massive, ill-sorted conglomerate and breccia, rich in clasts of augen and flaser gneiss.
- - - - - - - - - - - - - - - -				
Lower member	Phl	Lower Pliocene(?)	1100+	Light gray sandstone, siltstone, conglomerate, and fresh-water limestone
- - - - CONTACT NOT EXPOSED - - -				
Coachella fanglomerate				
Upper member	Mcu Mcb Mcd Mcm	Upper Miocene(?)	3750+	Massive conglomerate, locally rich in clasts of basalt and dark green saussuritized gneiss; Mcb, interlayered flows of olivine basalt and, Mcd, associated dikes; Mcm, marker horizon containing distinctive clasts.
- - - - - - - - - - - - - - - -				
Lower member	Mcl	Upper Miocene(?)	850	Well-indurated massive conglomerate, locally rich in clasts of olivine basalt; basal breccia of gray schist fragments.

	San Timoteo badlands (Frick, 1921; Axelrod, 1950; English, 1953)	Western San Gorgonio Pass (this report)	Eastern San Gorgonio Pass (this report)	Indio and Mecca Hills (Dibblee, 1954)
Pleistocene	Bautista fm.	Heights fgl. Cabezon fgl.	Cabezon fgl. Deformed gravels of Whitewater River	Ocotillo cgl.
Upper Pliocene	San Timoteo fm.	San Timoteo(?) fm.		
Middle Pliocene	Mt. Eden fm.	Painted Hill fm.	Painted Hill fm.	Palm Spring fm. and Canebreak cgl.
Lower Pliocene		Imperial fm. Hathaway fm.	Imperial fm.	
Upper Miocene	Jackrabbit ss.		Coachella fgl.	Imperial fm. Mecca f.

Figure 5. Generalized correlation chart of sedimentary rocks of the San Gorgonio Pass region. All contacts are of doubtful age. Wavy lines indicate angular unconformities; solid lines indicate conformable contacts; dashed lines indicate contacts not exposed.

Coachella rocks crop out over an area of about 6 square miles north of Painted Hill and east of Whitewater River; no other rocks correlative with this unit are known.

Lithologic features and depositional environment--The Coachella fanglomerate shows marked lateral variations in composition, which reflect localized provenance. Probably the most typical section is exposed along an east-west line one-half mile south of the trout farm (section I-I', pl. 4). On the canyon wall here, east-dipping Coachella beds lie with depositional contact on the crystalline complex, and 1-1/2 miles to the east the formation is unconformably overlain by the Painted Hill formation. The total thickness of beds along this line is 4600 feet, and probably is near the maximum for the formation.

Near the trout farm, the basal beds consist of massive breccia of locally derived fragments of gray schist as much as 6 feet in diameter. This unit in some places appears so similar to the underlying shattered bedrock that the contact is difficult to recognize. The prominent banding in the cliff above the trout farm (fig. 6) is due primarily to differences in color of the sandy matrix, although the dark units contain more clasts of volcanic and dark metamorphic rocks than the light members, in which the clasts consist predominantly of gray schist. Within a few hundred feet upward in the Coachella section, clasts of olivine basalt become the principal constituent of the rock, and are responsible for the reddish-brown color of the cliffs along Whitewater Canyon. The rocks are so highly indurated that they commonly fracture across individual clasts. The clasts themselves show all degrees of rounding.

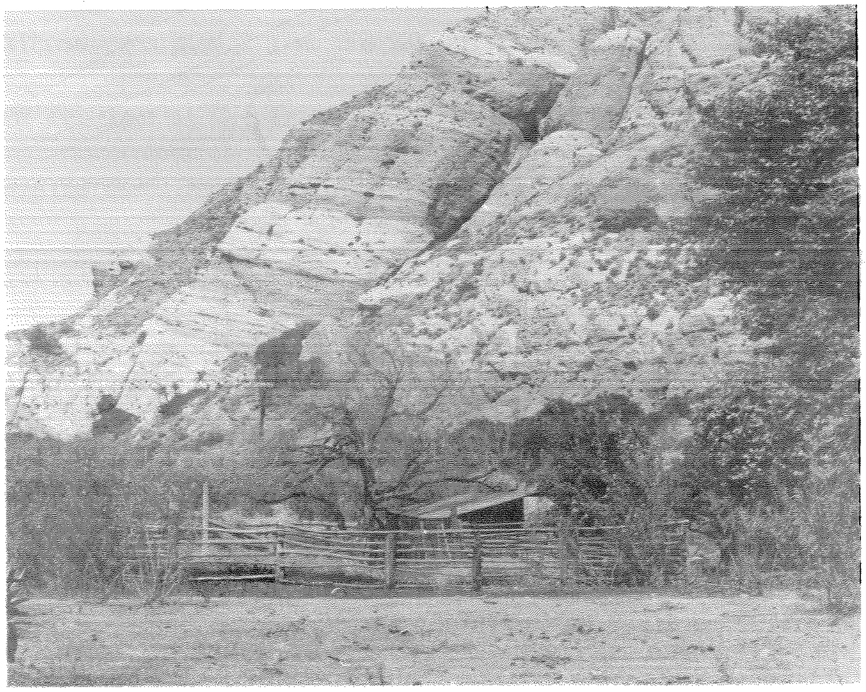
On the cliff east of the trout farm, a basalt flow is interlayered with Coachella beds 850 feet above the base of the section. This light gray to pale red-purple rock, in part a flow-breccia, contains sparse phenocrysts of olivine and labradorite(?), and consequently is here classed as a basalt even though the aphanitic groundmass may be somewhat more andesitic. The maximum thickness of this rock is about 50 feet, and it wedges out to the southeast; northward it is apparently correlative with the prominent flow on the north flank of the Rainbow anticline (pl. 1). This basalt flow separates the upper and lower members of the Coachella fanglomerate.

The varicolored flows exposed near the mouth of Mission Creek (pl. 1) probably were formed during the period of deposition of the Coachella beds; they are fine-grained to aphanitic basalts with phenocrysts of olivine and labradorite. A basalt dike of similar composition has been intruded along the fault between the crystalline complex and Coachella fanglomerate north of Painted Hill, but it is truncated by the Imperial formation. It must be immediately post-Coachella in age, or perhaps contemporaneous with uppermost Coachella beds that subsequently have been removed by erosion along the Coachella-Imperial unconformity. This dike is mapped together with the other Coachella basalts.

Northward from the trout farm in Whitewater Canyon,

Figure 6. Coachella fanglomerate at the trout farm in Whitewater Canyon. The rock is highly indurated and jointed. The banding is caused mainly by differences in color of the sandy matrix.

Figure 7. View looking north along the east flank of Painted Hill, showing the relationship between the sedimentary and crystalline rocks of this area. The rock units shown are the San Gorgonio igneous-metamorphic complex (SG), Coachella fanglomerate (Mc), Imperial formation (Pi), Painted Hill formation (Pp), and the resistant conglomerate bed (Ppc) within the Painted Hill formation. This area is shown on plate 4.




Ppc
Mc
Pi
Pp
Sc
Pi

successively younger Coachella beds rest with depositional contact on the crystalline complex, and the basalt flow that is 850 feet above the base of the section at the trout farm lies directly on the crystalline rocks opposite Red Dome (pl. 1). Still farther north, fanglomerate beds of the upper member are depositional on the crystalline rocks, and upper member beds also seem to be depositional on the crystalline rocks 2 miles south of the trout farm (pl. 4). These stratigraphic relations reflect major topographic relief at the time of Coachella deposition, and the presence of high-standing topography along the north edge of the Coachella depositional "trough" is further borne out by evidence of deposition from that direction.

Clasts of volcanic rock become less abundant toward the top of the upper member, and the beds become more light gray in color, owing to increased proportions of well-rounded granitic* and pegmatitic clasts. To the north, however, a dark green saussuritized gneiss, which forms the bedrock opposite Red Dome, locally has contributed debris to upper Coachella beds. Stringers of dark gray conglomerate, in which clasts of this gneiss are abundant, permit mapping of discontinuous marker horizons through the badlands north of Painted Hill, but they pinch out southeastward. Except for such beds, and for widely separated layers rich in clasts of volcanic rocks, the upper member of the Coachella fanglomerate is a uniform series of beds that become

*In this chapter, the term "granitic" is applied to rocks that range in composition from granodiorite to granite. Quartz monzonite predominates.

more unconsolidated upward in the section.

Age--No fossils have been found in the Coachella fanglomerate, but its unconformable position beneath the Imperial formation, together with its high degree of induration and well-developed jointing, suggest an age at least as old as late Miocene.

HATHAWAY FORMATION

General features--In the Lion Canyon area north of Cabazon (pl. 3, fig. 3) is exposed 1750 feet of highly deformed continental sandstones, siltstones, and conglomerates that were included in the Hathaway formation by Vaughan (1922, p. 377) and Bramkamp (1934a, p. 10). Vaughan also included in this formation similar sedimentary rocks north of Banning, but fossil evidence now suggests that these rocks are much younger than the beds in Lion Canyon, and they are herein assigned tentatively to the San Timoteo formation instead. The type section of the re-defined Hathaway formation is in the Main Branch of Lion Canyon, where the formation consists of two members.

Lower member--The lower member of the Hathaway formation consists of 1100 feet of tan to light gray arkosic sandstone with subordinate siltstone and lenticular beds of conglomerate. Delicate cross-bedding in the fine-grained beds indicates that much of the section is overturned (pl. 3). Clasts are mostly light-colored granitic rocks and flaser and augen gneisses; no fragments of volcanic rocks are present. In the matrix, brown biotite and blue-green hornblende predominate among the heavy minerals, which also include apatite, epidote, and sphene as accessories. The base of the section is not exposed.

One hundred feet north of the exposure of the Imperial formation in the West Branch of Lion Canyon (pl. 3), two vertical beds of white fresh-water limestone crop out plainly on the west wall of the canyon. Each is about one foot thick, and they are separated by one foot of green siltstone. The limestone is relatively pure and dense, shows algal structures (fragmentary and unidentifiable in thin section), and is transected by tubular structures apparently derived from reeds growing in shallow water. The localized and lenticular nature of the limestone, as well as the lack of calcareous material in adjacent rocks, suggest that it was deposited from hot-spring waters.

Upper member--Conformably overlying the lower member of the Hathaway formation is a 650-foot upper unit of massive conglomerate and breccia that is distinguished by a high proportion of boulders of flaser gneiss. Some of these are as much as 3 feet in diameter. Sparse fragments of dark gray silicified limestone also are present. This upper member of the Hathaway formation is best exposed on the south flank of the Lion anticline, where it is cut by the gorge of Lion Canyon (pl. 3). At the head of First Canyon, one-half mile to the northeast, this unit lies conformably beneath the Imperial formation. It is not exposed farther east.

On the west wall of the West Branch of Lion Canyon, conglomerates of the upper member extend across the crest of the Lion anticline, and evidently constitute what Vaughan (1922) and Bramkamp

(1934a, pl. I) mapped as the "Deep Canyon fanglomerate" of Quaternary age. On the walls of Deep Canyon, the upper member of the Hathaway formation apparently forms the core of the westward-plunging Lion anticline and is overlain by basalts and conglomerates of the Painted Hill formation. Conformable beneath the basalt flows of "B" Hill north of Banning (pl. 2) is a section of conglomerate that appears to be correlative with the upper member of the Hathaway formation, although it contains considerably less flaser gneiss than do the beds at Lion Canyon. Erosion has stripped away the Hathaway strata west of San Gorgonio Canyon.

Provenance--The clasts of flaser gneiss within the upper member of the Hathaway formation suggest local provenance, because crystalline rocks of this type are limited in present outcrop to the ground between the mouth of Cottonwood Canyon on the east and the general area of San Gorgonio Canyon on the west. Inasmuch as the upper member is underlain by a considerable thickness of relatively fine-grained deposits, it is unlikely that crystalline rocks just south of the Banning fault in this area could have contributed debris to the conglomerate and breccia of the upper member. Rocks of the San Jacinto Mountains, still farther south, do not include the characteristic flaser-gneiss types, although this area may have been the source of the sparse silicified limestone clasts. The possible post-lower Pliocene right lateral displacement on the Banning fault is thus probably limited to less than 5 miles, unless transport of material to form the upper member of the

Hathaway formation took place over distances of many miles.

Before definite conclusions can be reached concerning the provenance and possible fault offset of the lower Pliocene rocks of the pass area, stratigraphic evidence from the Indio Hills must be considered. In a brief visit to exposures of the Imperial formation in the northwestern Indio Hills, mylonitic-appearing clasts reminiscent of the San Gorgonio flaser gneisses were observed in the Palm Spring (?) formation (Dibblee, 1954) overlying the Imperial formation. The source of these clasts, together with the abundant fragments of siliceous limestone accompanying them, is an interesting problem undoubtedly related to the origin of the upper member of the Hathaway formation.

Depositional environment--The similarity in texture and lithology between the Hathaway formation and the overlying sedimentary beds of the pass area suggests that the same type of depositional environment prevailed throughout much of Pliocene and early Pleistocene time. Delicately bedded, fine-grained deposits interfinger with massive, bouldery beds as if they might have been laid down in a broad valley bordered by alluvial fans at the foot of steep mountain slopes. The sandstones and siltstones seem best visualized as having accumulated on an alluvial flood-plain with occasional shallow-water lacustrine and paludal sedimentation. The nearby San Jacinto Valley seems to be a modern example of a somewhat similar depositional environment.

A history of recurrent local deformation is indicated not only by angular unconformities within the section, but also by abrupt changes from fine- to coarse-grained deposits upward in the section. Furthermore, fresh-water limestone beds of probable hot-spring origin suggest that faults may have been continuously active. Such calcareous beds are found in the Hathaway formation, Painted Hill formation, Mt. Eden and San Timoteo formations (English, 1953, pp. 46, 54, 58), and in the Bautista beds (Fraser, 1931, p. 514).

Studies of plant fossils from the Mt. Eden formation by Axelrod (1937; 1950) yield a remarkably complete picture of the Pliocene ecology. These fossils suggest plant growth in a low-lying basin within 1000 feet of sea-level, characterized by a plains-savanna habitat, and surrounded by forested uplands. The climate was semi-arid, with 12 to 18 inches of annual rainfall distributed more evenly between summer and winter than today. The flora is of a distinct interior type, and hence the influence of Pliocene seas either on the east or west must have been small. Axelrod further states (1937, p. 134):

> The presence of vertebrates indicative of plains-grazing types in the Bautista beds suggests that conditions suited to such vegetation continued into the Pleistocene, and that the widespread development of chaparral which dominates the area today occurred subsequently.

Age--The conformable position of the Hathaway formation beneath the Imperial formation permits a tentative age assignment as early Pliocene. Inasmuch as the true age of the Imperial formation is questionable, the Hathaway formation must share in this uncertainty.

IMPERIAL FORMATION

General features--Marine beds in the San Gorgonio Pass area were first recognized by Vaughan (1922, pp. 375-376). He described them as the "Lion sandstone" of the Lion Canyon area, but he evidently overlooked the similar beds near Painted Hill. These northernmost exposures of the Imperial formation have been the subject of a thorough study by Bramkamp (1934a), but the results of this study have been published only in abstract form (Bramkamp, 1934b). Woodring (1932) briefly described these and other outcrops in the Salton trough, and numerous authors have studied the type Imperial section at Carrizo Mountain, 85 miles southeast of San Gorgonio Pass. A good bibliography of the more recent studies is given by Durham (1950, pp. 3, 23).

Lithologic features--East of Painted Hill, a thin stringer of Imperial formation, about one mile long, lies unconformably on both the Coachella fanglomerate and the much older crystalline complex (pl. 4, fig. 7). At this locality, the Coachella fanglomerate is faulted against the red hematitic schist of Painted Hill, and the Imperial beds truncate a series of alternating fault-bounded slices of schist and fanglomerate. Also truncated, at nearly 90 degrees, is a dike of olivine basalt that lies along one of the faults.

Imperial beds are overturned as much as 45 degrees where they lie on the crystalline complex east of Painted Hill (section G-G', pl. 4). Although minor faulting may confuse some of the relations along the contact, its depositional character is indicated by parallelism of bedding with the contact, by channeling of the "underlying" bedrock, and by a basal conglomerate of very locally derived fragments of hematitebearing schist and gneiss. The Imperial formation here comprises deep yellowish to brownish sandstone, siltstone, and shale, with a thickness ranging from 6 inches to 100 feet. Fossils locally are so abundant as to give the rock a coquina-like appearance. The section has been thoroughly studied, and is described in detail by Bramkamp (1934a, pp. 18-23, fig. 2). The contact with the overlying Painted Hill formation is arbitrarily placed above the uppermost marine bed, and the conformable and transitional nature of this contact is demonstrated by stringers of fossiliferous yellow siltstone that occur as much as 50 feet up in the otherwise continental-appearing gray conglomerates.

The Imperial beds become upright as traced northward along their strike, and dip 50 degrees east where they die out about one-half mile northeast of Painted Hill. This pinch-out evidently represents the limit of Imperial deposition, rather than an erosional truncation prior to deposition of the overlying Painted Hill formation, as is indicated by the increased coarseness of Imperial sandstone to the north and the continued evidence of complete conformability along the Imperial-Painted Hill contact.

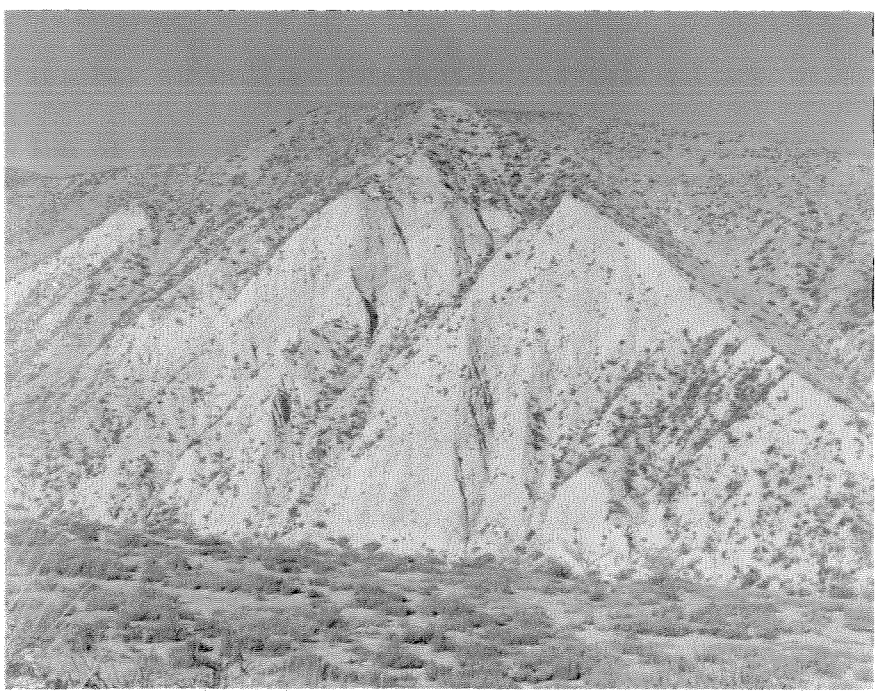
North of Cabazon, the Imperial formation crops out in two separate small exposures on the south flank of the overturned Lion anticline (pl. 3). The easternmost exposure forms the steep slopes below the Banning thrust at the head of First Canyon (fig. 8). About 300 feet of Imperial strata, mainly yellow siltstone, is exposed here, and represents the greatest known thickness of this formation in the pass area. Thin interbeds of gypsum are common. Details of the stratigraphy and fauna have been described by Bramkamp (1934a, pp. 11-14).

Although they are overturned, conformability of the Imperial strata with the beds of the "underlying" Hathaway formation is indicated by parallelism of bedding and by large-scale interfingering of yellow fossiliferous siltstone with the gray continental sandstone and conglomerate of the Hathaway formation. Fragments of Hathaway sandstone occur as clasts in the basal conglomerate of the Imperial formation. Conformability of the Imperial formation with the "overlying" Painted Hill formation is suggested by parallelism of bedding, although no actual interfingering of strata is evident at this locality.

One mile farther west, an incomplete section of the Imperial formation is exposed on the wall of the West Branch of Lion Canyon and on two ridges between here and Deep Canyon. These beds also appear to overlie the Hathaway formation on the south flank of the Lion anticline, but the exposures coincide with a fault zone, so that the stratigraphic relation to adjacent conglomerates is obscure. Still farther west, on the west wall of Deep Canyon, Imperial strata do not crop out along the presumed Hathaway-Painted Hill contact, and it seems likely that the Imperial formation pinches out between Lion and Deep Canyons. This conclusion is further supported by the coarseness of Imperial strata where last exposed. No exposures of Imperial formation occur farther west in San Gorgonio Pass, and it seems unlikely that Imperial seas ever extended much beyond the Cabazon area. Marine fossils have been

Figure 8. View looking east along the Banning fault at the head of First Canyon. The fault plane (center of photo) here dips 35 degrees north and separates crystalline rocks (upper left) from Imperial marine strata (lower right). This area is shown on plate 3.

Figure 9. Horizontal Heights fanglomerate (skyline) unconformably overlying north-dipping Cabezon fanglomerate at the mouth of Millard Canyon. The cliff is about 350 feet high. This area is shown on plate 3.



reported from oil wells drilled near Beaumont (R. T. Hill, 1930?), but none of these reports has been substantiated.

Depositional environment--The Imperial formation of San Gorgonio Pass was deposited in a littoral or shallow neritic environment, as is indicated by the fauna (Bramkamp, 1934a, p. 44; Durham, 1950, p. 24) and also by the wide variation in grain size and the concentrations of broken-up fossils. The waters evidently were of normal salinity, and represent a single incursion of the sea from the southeast. Variations in thickness and lithology of the basal Imperial beds east of Painted Hill suggest a rocky shoreline with moderate relief. Toward the west, beyond the margin of the shallow sea, conditions must have been much the same as during Hathaway time.

Oil possibilities--The presence of marine beds in San Gorgonio Pass has stimulated interest in possible oil production, but none of the ten or fifteen dry wells that have been drilled appears to have been located on a scientific basis. Indeed, most are in areas that probably are not underlain by the Imperial formation. Even where it is exposed at the east end of the pass, the limited thickness of the Imperial formation, together with its stratigraphic position between conglomerate units, seems to eliminate it as an encouraging oil prospect. Southeastward, however, there must be rapid thickening and associated facies changes; wells in the San Felipe Hills, 50 miles to the southeast, have penetrated 3000 feet of Imperial strata (Dibblee, 1954), and the regional geology suggests that suitable drilling structures may well exist beneath the alluvium of Coachella Valley. On the other hand, failure of recent deep tests by the Texas Company in the Imperial Valley area has dampened hopes for oil production from the Imperial formation, and no other significant marine beds are known in the Salton depression.

Age--There has been much disagreement among paleontologists concerning the age of the Imperial formation, inasmuch as the fauna is of tropical affinity and has little in common with the better-known Coast Range Tertiary faunas. Age estimates have ranged from "doubtfully Cretaceous" (T. W. Vaughan, 1900, p. 19) to late Pliocene (Hanna, 1926, p. 434). The most recent studies by Wilson (1948, pp. 1779-1780) and Durham (1950) suggest an early Pliocene age, mainly on the basis of careful re-examination of the fauna and correlation with Pliocene marine formations of Baja California. Durham (1950, table 9) recognizes that deposition of Imperial beds may have continued into middle Pliocene time, and that (p. 24), "the Colorado Desert area has had at least intermittent marine incursions from the beginning of Imperial time into the Recent." Bramkamp (1934a, p. 51) tentatively correlates marine beds of the San Gorgonio Pass area with the basal Imperial beds of the type section at Carrizo Mountain, and the Imperial formation is therefore considered to be of early Pliocene(?) age in this report.

PAINTED HILL FORMATION

General features--The name Painted Hill formation (a new name) is herein applied to the continental beds that conformably overlie

The Imperial formation east of Painted Hill. Bramkamp (1934a, p. 15) termed this unit the "Indio formation" because its stratigraphic position is similar to that of the "Indio formation" in the Indio Hills (Buwalda and Stanton, 1930). As pointed out by Woodring (1932, p. 10), however, the name "Indio formation" is preoccupied, and Dibblee (1954) recently has included in the Palm Spring formation those beds of the Indio Hills that are immediately post-Imperial in age. As yet there is no assurance that the post-Imperial rocks at Painted Hill and those in the Indio Hills actually are parts of the same formational unit.

Lithologic features--Along a line extending eastward from the top of Painted Hill (section G-G', pl. 4), the Painted Hill formation comprises 3400 feet of pale brown to light gray conglomerate and conglomeratic sandstone with sub-rounded to well-rounded clasts as much as two feet in diameter. Fragments of basalt constitute 50 percent of the clasts near the bottom of the section, but give way upward to increased proportions of clasts of gray gneiss, pegmatite, and granite. Light gray to white sandy matrix constitutes about 40 percent of the rock, except for sparse light brown sandstone beds like those that are well exposed on the top of the first ridge east of Painted Hill. The rock generally is poorly consolidated, but two resistant, ridge-making conglomerate beds are present in the interval between 300 and 500 feet above the base of the section (fig. 7). These units, unfortunately, are not sufficiently continuous to permit division of the formation into members.

North of the point where Imperial beds pinch out, the Painted

Hill formation lies directly on the Coachella fanglomerate with marked angular unconformity. Both units are relatively unconsolidated in this area, and much of the material in the Painted Hill formation appears to have been derived from the Coachella fanglomerate. The two formations thus are similar in general appearance, and the contact between them cannot be placed accurately; instead it is located on the basis of changes in dip along the unconformity (pl. 4). The Painted Hill beds disappear beneath younger fanglomerates 2-1/2 miles north of Painted Hill; southward, the formation is cut off by the Banning fault.

The Painted Hill formation also conformably overlies the Imperial formation northeast of Cabazon (pl. 3), but the geologic structure in this area is so complex that correlation of the various continental formations is somewhat speculative. The Painted Hill formation contains the well-rounded clasts of volcanic and granitic rocks that are typical of exposures in the type area, but includes a greater proportion of light gray sandstone. In addition, several thin beds of fresh-water limestone are similar to those in the lower member of the Hathaway formation. Higher in the section is a pink arkosic sandstone that forms the distinctive fluted cliffs one-half mile up the West Branch of Lion Canyon, and this unit probably is correlative with the conglomeratic sandstone exposed on the divide between Second and Third Canyons. It is unlike anything near Painted Hill, and hence is placed in the Painted Hill formation with some degree of doubt.

Flows of basalt are interlayered with beds of the Painted Hill formation in the area between Deep Canyon and Banning Canyon and at Devil's Garden Ranch northeast of Whitewater. Only one flow is present on the south flank of the Lion anticline, whereas two flows are exposed on the north flank of this fold just west of Deep Canyon, and three flows crop out west of Hathaway Canyon on "B" Hill. West of Lion Canyon, where the Imperial formation pinches out, the contact between the Hathaway and Painted Hill formations is arbitrarily placed at the base of the lowermost basalt flow.

A representative sample of basalt from Deep Canyon is a grayish-red amygdaloidal olivine basalt, subophitic in texture, and comprising augite, calcic labradorite laths averaging 0.5 mm. long, and olivine phenocrysts altered to iddingsite. Feeder dikes, presumably contributory to these flows, occupy fault zones in "B" Hill, and the basalt is identical in composition with that in Deep Canyon, but is darker gray, coarser grained, and shows well-developed ophitic texture. Basalt, possibly representing one or more dikes, is exposed on several spurs between Banning and Millard Canyons. These rocks are included in the Painted Hill formation, although their structural relation to the adjacent foothills is obscure.

The coarse conglomeratic rocks at the top of "B" Hill likewise are included in the Painted Hill formation because of their composition and stratigraphic position above the basalt flows, but it is possible that they are in part remnants of Quaternary fanglomerate. Rounded boulders of granitic rocks as much as 6 feet in diameter are present here. Painted Hill beds undoubtedly extended farther west at one time, but faulting and subsequent erosion have removed all traces of these rocks west of San Gorgonio Canyon, except for possibly equivalent rocks in the San Timoteo-Mt. Eden series.

Provenance and structural implications--The high proportion of well-rounded clasts of granitic rocks in the Painted Hill formation suggests that much of the source area lay beyond the area of predominantly metamorphic rocks that now contributes detritus to streams on the north side of San Gorgonio Pass. A large area of granitic rocks is exposed north of the Mission Creek and Mill Creek faults, and the streams that deposited the Painted Hill formation probably had their headwaters in this area (as does Whitewater River now) and flowed southward across a metamorphic terrane of subdued topographic expression. Subsequent uplift of this block of predominantly metamorphic rocks between the Banning and Mission Creek faults has given rise to the coarser and more angular fragments of metamorphic rock that make up a large portion of the late Quaternary fanglomerates and Recent alluvium.

The Imperial and Painted Hill beds north of the Banning fault are strikingly similar to those south of the fault, and it might be argued that these units were once contiguous and have since been laterally offset 7 miles along the Banning fault. The Imperial formation, however, lies on crystalline rocks north of the fault and on Hathaway beds south of the fault, so that former contiguity of the outcrops would make it difficult to explain the transitional Hathaway-Imperial contact. Probably the outcrops south of the Banning fault reflect slightly more basinward deposition than those near Painted Hill, and inasmuch as the present center of the basin lies to the east of Painted Hill, a right lateral displacement of still greater than 7 miles must be regarded as a possibility. The local basinward direction at the time of Painted Hill deposition, however, is not known, and may just as well have been south as east. No definitive statement concerning fault displacement can be founded on evidence based on the present relative positions of Imperial and Painted Hill strata north and south of the Banning fault, except that post-lower Pliocene displacement of over a few tens of miles is out of the question.

Painted Hill beds north and south of the Banning fault contain sparse but distinctive fragments of piedmontite-bearing gneiss and ilmenite-bearing pegmatite, which in all probability were derived from the Stubby Canyon-Whitewater area. Clasts of these rocks as much as 7 inches in diameter occur in Painted Hill beds at the head of Second Canyon. It is difficult to estimate the amount of strike-slip displacement on the Banning fault that is indicated by this evidence, but post-lower Pliocene movement of more than 10 miles is improbable. No post-lower Pliocene displacement is necessitated.

Age--The Painted Hill beds lie conformably upon the Imperial formation, and hence are probably of early or middle Pliocene age. Camel remains, undiagnostic as to specific epoch, were found in Painted Hill beds in the first canyon east of Deep Canyon, but no other fossils are known to have been recovered from this formation.

SAN TIMOTEO(?) FORMATION

General features--The San Timoteo formation was named and first described by Frick (1921), who recovered a large vertebrate fauna of late Pliocene age from the San Timoteo badlands west of Beaumont (fig. 1). Inasmuch as all of the fossil localities lie at or near the base of the section, Eckis (1934, p. 51) and English (1953, p. 66) suggest that deposition of the formation probably continued into Pleistocene time. The entire unit is herein considered to be Pliocene-Pleistocene in age. English (1953, p. 65) reports a thickness of 2600 feet for the San Timoteo formation, whereas Shuler (1953, p. 18), who mapped a somewhat larger area, reports a thickness of 4100 feet.

In the vicinity of Eden Hot Springs, San Timoteo beds overlie the middle Pliocene Mt. Eden formation, which has been described by Frick (1921; 1933), Fraser (1931), and Axelrod (1937; 1950). Recent work by Shuler (1953, p. 32) indicates a conformable contact between these two units, although the faunal break and the natural lithologic break evidently do not coincide. Still older rocks, perhaps of Miocene age, are reported by English (1953, pp. 33-36) to lie unconformably beneath the Mt. Eden formation.

Correlation and age--The correlation of the San Timoteo formation with the sedimentary rocks beneath the Heights fanglomerate north of Banning is based on two somewhat inconclusive lines of evidence:

(1) Near Kehl Ranch, 4 miles northwest of Beaumont, the

Banning fault brings the crystalline complex into contact with sedimentary strata that are mapped by Shuler (1953, pl. I) as part of the upper member of the San Timoteo formation. These beds consist of light gray to tan terrestial sandstones and conglomerates that are rich in sub-rounded clasts of granitic rocks. Five miles east of this point, where they are next exposed north of Banning and near the head of Brinton Canyon (pl. 2), the sedimentary rocks south of the fault appear to be identical with those at Kehl Ranch.

(2) Fragments of horse teeth were found in sandstone beds on the west wall of School Canyon north of Banning (pl. 2). Dr. John F. Lance of the University of Arizona states (personal communication) that the material definitely represents the genus Equus, and hence is no older than Blancan. It probably is Pleistocene in age. Correlation with the uppermost beds of the San Timoteo formation is therefore not unreasonable. There is also a possibility, however, of a correlation with the Pleistocene Bautista beds of San Jacinto Valley, described by Frick (1921, pp. 289-311) and Fraser (1931, pp. 514-516).

Additional fossil material and further interpretive work are needed before a definite assignment of age and formation can be given to these rocks north of Banning. Vaughan (1922, p. 376) included these rocks in the Pliocene Hathaway formation, but the Hathaway formation is herein restricted to the pre-Imperial rocks of the Lion Canyon area. Were it not for the apparent difference in age, one would be tempted to correlate the rocks from these two areas, as did the writer prior to the interpretation of the fossil evidence (Allen, 1954). The rocks have striking similarities in lithology, structural position, and general appearance.

Lithologic features--Exposed in School Canyon are 1800 feet of north-dipping San Timoteo(?) beds, and assuredly correlative with these are the nearby strata exposed in Brinton Canyon and on the south flank of "B" Hill (pl. 2). The rock in School Canyon comprises tan to gray arkosic sandstone and siltstone interbedded with conglomerate containing sub-rounded clasts of granitic, pegmatitic, and minor metamorphic rocks. In contrast to the Painted Hill formation, clasts of volcanic rock are rare, although they occur farther west in this area and have been reported from San Timoteo beds west of Beaumont (English, 1953, p. 58). Blue-green hornblende predominates among the heavy minerals, which also include brown biotite, apatite, epidote, and sphene as common accessories. The proportion of fine-grained material increases downward in the section, and gray to green siltstone predominates at the mouth of School Canyon.

A well drilled in 1953 one mile west of the mouth of Brinton Canyon penetrated 1100 feet of relatively flat-lying sandstone and conglomerate underlain by a 1000-foot section that consists predominantly of siltstone. All of these strata presumably are parts of the San Timoteo(?) formation. Several thin beds of fresh-water limestone crop out within the San Timoteo(?) formation at the upper ends of School and Brinton Canyons; these beds appear to be identical with those in the lower member of the Hathaway formation in Lion Canyon.

Between the Banning fault and the northernmost San Timoteo(?) exposures in School Canyon is a south-dipping section of gray conglomerate and sandstone that is well exposed along the west bank of San Gorgonio Canyon. These beds are unlike the San Timoteo(?) beds of School Canyon in their lack of siltstone units, their greater content of clasts of metamorphic rocks, and the presence in them of a greater proportion of fragments of basalt. They are, nevertheless, included in the San Timoteo(?) formation in the absence of evidence for a different correlation. It is not certain that these beds are right-side-up, but, together with the north-dipping beds of School Canyon, they seem to form a faulted syncline beneath the Quaternary gravels of Banning Bench (section A-A', pl. 2).

As followed eastward, the San Timoteo(?) formation becomes somewhat coarser and richer in pegmatite clasts. It thus seems likely that the uppermost San Timoteo(?) beds are correlative with the Cabezon fanglomerate, although exposures are lacking in the critical area between Hathaway and Millard Canyons. The eastward coarsening suggests deposition of the San Timoteo(?) beds from the east and northeast. As in the case of the Painted Hill formation, many of the clasts of granite may have been derived from areas north of the Mission Creek fault, but a likely source for the abundant pegmatite clasts can be found in the present area of Kitching Peak, north of Lion and Stubby Canyons (pl. 1).

On the south flank of "B" Hill, the San Timoteo(?) beds contain sparse fragments of piedmontite-bearing gneiss that are as much as 3 inches in diameter, together with gray-green epidote schist and ilmenite-bearing pegmatite. There can be little doubt that these distinctive clasts were derived from the eastern end of the range near Stubby and Whitewater Canyons, a distance of 8 to 12 miles from their present positions. Whereas transport of such material over distances of 12 miles is reasonable, the relatively high concentration of these clasts at "B" Hill may be difficult to explain in terms of a source area that far away. Post-San Timoteo(?) right lateral displacement on the Banning fault provides the most reasonable (but not the only) explanation for the present position of these distinctive clasts. To assume that the rocks have been displaced the full 8 to 12 miles is not necessary, however, because much larger clasts of piedmontite-bearing gneiss occur in the Cabezon fanglomerate near Lion Canyon, which is 5-1/2 miles closer than "B" Hill to the presumed source area. If the Cabezon and San Timoteo(?) beds are truly correlative, a post-San Timoteo(?) displacement of about 5 miles would best explain the present distribution of the distinctive clasts. Displacement of greater magnitude is a possibility, but a reasonable argument also could be made for little or no displacement, inasmuch as these distinctive clasts are not widespread at other horizons in the San Timoteo(?) formation.

DEFORMED GRAVELS OF WHITEWATER RIVER

Along the east flank of the San Bernardino Mountains, Whitewater River and Mission Creek are dissecting a thick series of gravels whose structure, as compared to that of the older sedimentary rocks, suggests a Quaternary age. A marked angular unconformity within the section is well exposed one mile northeast of Red Dome and near Kitchen Ranch (pl. 1), and is sufficiently continuous in this area to serve as a means of distinction between two formations in the otherwise uniform-appearing gravels. The tilted beds beneath the unconformity are herein termed the deformed gravels of Whitewater River, whereas the relatively undeformed beds above the unconformity appear to be continuous with the Cabezon fanglomerate farther south. The most widespread exposures of the deformed gravels are between Red Dome and the Mission Creek fault (pl. 1), where the formation consists of gray to light tan sandstone and conglomerate with well-rounded clasts of granitic rocks that are as much as 2 feet in diameter.

Numerous outcrops of gravel are well exposed on the steep banks of Whitewater River where it is re-excavating its old channel south of Red Dome. Although stratigraphic relations here are not so clear cut as those farther north, the gravels again appear to consist of two mappable units. Two miles south of the trout farm, where a broad terrace extends out from the east bank of Whitewater Canyon (pl. 4), relatively undeformed gravels overlie steeply tilted gravels that are faulted against the crystalline complex along the Whitewater fault.

Northward one-half mile along this same fault, the deformed gravels dip progressively less steeply, and are faulted against the Coachella fanglomerate. They are overlain here concordantly by gravels that are depositional on the Coachella fanglomerate beyond the fault, and the horizon above which the gravels are no longer broken by the Whitewater fault is mapped as the contact between the Cabezon fanglomerate and the deformed gravels despite the local absence of an angular unconformity between the two units. Evidently deformation has been contemporaneous with deposition in this area (as it certainly must be now), and any formational division necessitates some degree of oversimplification.

Near the junction of the North and South Forks of Whitewater River (pl. 1), a wedge of sedimentary rock within the Mission Creek fault zone tentatively is assigned to the deformed gravels because of its structural position similar to the deformed gravels along the fault to the east. The rock here, however, is unlike that to the east in that it contains a large proportion of well-rounded clasts of basalt. Assignment to the Coachella fanglomerate is an alternative possibility.

The deformed gravels of Whitewater River have not been recognized south of the Banning fault, although it is probable that the lower part of the Cabezon fanglomerate here includes beds contemporaneous with the deformed gravels.

CABEZON FANGLOMERATE

General features--Vaughan (1922, p. 387) included in the Cabezon* fanglomerate numerous bodies of dissected gravels that are exposed between San Gorgonio Pass and the Mojave Desert. All presumably are of Quaternary age. The type area apparently is in the foothills north of Cabazon, and the formational name is therefore retained for the extensive body of fanglomerate that appears to be continuous from Millard Canyon eastward to Whitewater, and thence northward around the flank of the range. More than 1000 feet of Cabezon beds crops out at Whitewater Hill, and the base of the section is not exposed. Whether or not basal Cabezon beds are exposed anywhere south of the Banning fault is problematical; the angular unconformity on the west wall of Stubby Canyon (pl. 3) is tentatively regarded as the contact between the Cabezon and Painted Hill formations, although it may be merely a local unconformity within the Cabezon section.

Lithologic and structural features--Along the north side of San Gorgonio Pass east of Millard Canyon, Cabezon fanglomerate forms most of the rugged foothills in front of the main mountain scarp. Between the crystalline complex and the Cabezon beds is a wedge of Tertiary sedimentary rocks that has been thrust over the fanglomerate, although the similarity of the Cabezon and Painted Hill beds makes the

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*Although the post office name is now spelled Cabazon, the former spelling of Cabezon was used by Vaughan, and is retained herein for the formational name.

contact difficult to recognize in places. Deformation contemporaneous with Quaternary deposition is indicated not only by the coarse and heterogeneous lithology of the Cabezon fanglomerate, but also by structural relationships east of Stubby Canyon, where Cabezon fanglomerate is exposed beneath a thrust plate of crystalline rocks that in turn is overlain by still younger deformed Cabezon beds (section F-F', pl. 3).

In the eastern part of the area, rocks north of the Banning fault are correlated with the Cabezon fanglomerate on the basis of similar composition, texture, and degree of deformation. In addition, a deformed layer of red soil, semi-conformable with the underlying Cabezon beds and therefore considered to be a part of the formation, can be traced from Beacon Hill northward to the mouth of Mission Creek. In upper Whitewater Canyon, Cabezon gravels lie in the old river channel and in the adjacent areas of formerly gentle topography; these rocks are discussed more thoroughly in the section on geomorphology.

On the east side of the mouth of Millard Canyon, north-dipping Cabezon fanglomerate is well exposed beneath horizontal Heights fanglomerate (fig. 9). Here, Cabezon beds contain nearly equal numbers of clasts of pegmatite and metamorphic rock in a grayish-brown sandy matrix. Eastward, clasts of pegmatite become proportionally fewer, and their place is taken by fragments of granitic, basaltic, and light colored metamorphic rocks. At Beacon Hill (pl. 1), the fanglomerate consists of 70 percent clasts of gray gneiss, 20 percent clasts of pegmatite, and 10 percent clasts of basalt. Clasts of granitic rock form most of the fanglomerate at the mouth of Mission Creek and at Raywood Flat.

Provenance--The lithology of the Cabezon fanglomerate suggests local derivation from streams not unlike those of today; indeed, much of the fanglomerate north of the Banning fault lies within the valley of the present Whitewater River and must have been deposited by the "ancestral" Whitewater River prior to re-excavation of the valley. As in the case of the Painted Hill formation, many clasts of granitic rock were derived from sources north of the Mission Creek fault. The abundant clasts of pegmatite in the Millard and Lion Canyon exposures probably were derived from the large area of pegmatite bodies near Kitching Peak, although present stream gravels in this area are much richer in dark clasts of metamorphic rocks than is the Cabezon fanglomerate.

Interbedded with the Cabezon fanglomerate at Beacon Hill is a 30-foot-thick lens of light gray limestone breccia in a section otherwise completely devoid of calcareous clasts. This breccia contains fragments of coarsely crystalline limestone as much as 4 feet in diameter in a calcareous matrix; 70 percent of the clasts are of limestone. Although deposition of the Cabezon beds seems to have been from the north and west, the absence of other limestone clasts from the formation in these directions suggests that this one layer had a different origin. Most likely, it was derived from one of the numerous areas of limestone in the San Jacinto block, and was laid down, perhaps as a debris flow, in the Cabezon fanglomerate. At the present time, several lenses of limestone within the San Jacinto crystalline complex crop out only 1-1/2 miles south of Beacon Hill (Logan, 1947, p. 271). It is interesting to note that the limestone breccia of Beacon Hill is the only sedimentary rock on the north side of San Gorgonio Pass that appears to contain a significant amount of material derived from the San Jacinto block.

Age--A Quaternary age for the Cabezon fanglomerate is suggested by its lack of intense deformation as compared to that of the late Tertiary rocks, and by its probable correlation (based on lithologic evidence) with the uppermost San Timoteo(?) beds to the west.

HEIGHTS FANGLOMERATE

North of Banning and Beaumont is an extensive area of deeply dissected but relatively undeformed gravels, named the Heights fanglomerate by Vaughan (1922, p. 392). Its Quaternary age is indicated by its unconformable position above the Cabezon fanglomerate, and this relationship is well illustrated at the mouth of Millard Canyon (fig. 9). The best exposures of Heights fanglomerate are on the west wall of San Gorgonio Canyon, where it is evident that the rock surface underlying the fanglomerate is one of considerable relief. The maximum thickness here is greater than 240 feet.

The Heights fanglomerate is distinctive, as compared with the other Quaternary fanglomerates, in its content of clasts of predominantly metamorphic rocks; extremely weathered boulders of gray migmatitic gneiss compose most of the rock. These clasts are so thoroughly decomposed that boulders are cleanly truncated by erosion on stream banks. Distinctive fragments of greenschist in the exposures north of Banning indicate very local provenance in the mountain area across the San Andreas fault to the north. Post-Heights lateral movements on the San Andreas fault probably have displaced these gravels no more than one mile relative to the source area.

That the broad surface of Banning Bench is a degradational feature and not the uppermost limit of deposition of the Heights fanglomerate is indicated by still higher surfaces cut on this fanglomerate at the extreme north and south ends of the bench, as well as by the presence of dissected Heights gravels above the level of Banning Bench near the mouth of Smith Creek. On these benches and terraces, which are discussed in greater detail in the section on geomorphology, it is difficult to distinguish between the planated Heights fanglomerate and the thin veneer of younger terrace gravels (primarily reworked Heights material) that presumably must overlie the fanglomerate. Inasmuch as the terraces are concordant with the bedding in the fanglomerate, and the composition of the fanglomerate and terrace gravels apparently is identical, it was not feasible to map the units separately in the field. The Heights fanglomerate of plates 1, 2, and 3 therefore includes some younger terrace gravels.

BURNT CANYON BRECCIA

Burro Flat is an area of grassy, rolling hills which is anomalous in the otherwise rugged and brush-covered country of the pass area. Gardner (1949) recognized the distinctive nature of this area, and thought that it was caused by underlying coarse stream gravels (his "Burnt Canyon formation") derived from Burnt Canyon at a time when it flowed out through the present gorge of Hathaway Creek. An origin as a landslide mass seems more likely, as is indicated by:

(1) angularity, freshness, and lack of sorting of the clasts;

(2) absence of matrix material;

(3) steep bordering scarps and bulbous outline of the rock mass;

(4) longitudinal "streaks" of coarser rock fragments on the surface of the slide;

(5) lack of surficial soil, with a consequent grass (rather than brush) cover.

The landslide mass rests partly on the crystalline complex and partly on the flat surface of the Heights fanglomerate, and therefore must be younger than the fanglomerate. Recent movements on the San Andreas fault have left prominent scarps in the Burnt Canyon breccia (fig. 10), and the scarps evidently have survived better in this porous material than in the weathered crystalline rock of adjacent areas. The wide, flat, debris-covered floors of Wood Canyon and its tributary, Burnt Canyon (pl. 1), suggest that much of the slide material had its source in the rugged scarp at the head of these canyons. The crystalline rock types here and in the other small canyons north of the slide are identical with those found as fragments in the Burnt Canyon breccia.

ALLUVIUM

Extensive alluvial fans, the gravels of which are similar to the older dissected fanglomerates, are being built on the floor of San Gorgonio Pass, and the heads of these fans extend up many of the wider stream canyons. Gravels of low stream terraces, which have been discussed in detail by Russell (1932), are grouped together with the Recent alluvium.

IV. GEOMORPHOLOGY AND GROUND-WATER

INTRODUCTION

In this chapter only those aspects of geomorphology and ground-water that pertain directly to the structural geology are considered. These include surfaces of low relief, alluvial fans, and location of springs. Other authors have discussed many of the remaining aspects.

The glacial geology of San Gorgonio Mountain has been described by Fairbanks and Carey (1910) and Vaughan (1922, pp. 335-336). None of the glacial moraines extends into the area of plate 1, but deposition of some of the Quaternary fanglomerates almost certainly must have coincided in time with glaciation of the high country. Soils of the pass area have been described by Dunn, et al. (1921). Wind is an exceptionally effective agent of erosion and transportation in San Gorgonio Pass, particularly south and east of Whitewater. Sand dunes of various types and well-known ventifact localities occur here. These and other aspects of eolian activity within the pass have been described in detail by Russell (1932, pp. 80-120). Above the floor of the pass, numerous small cliff-edge dunes occur at the tops of steep west-facing slopes at altitudes of as much as 8500 feet. No significant occurrences of ventifacts or wind-blown sand were observed within the late Tertiary and Quaternary sedimentary rocks.

SURFACES OF LOW RELIEF

General features--Within the hills along the north side of San Gorgonio Pass, the present regimen is one of re-excavation following a widespread burial of the former terrain by Quaternary alluvial fans. Present streams are incised into thick and extensive fanglomerate deposits which rest upon a surface of considerable relief cut across both the crystalline complex and Tertiary sedimentary rocks. Many of the deeply incised streams are plainly guided by former canyons that were cut into the older rocks prior to the period of gravel filling. This is particularly evident in lower Whitewater Canyon. Within the mountains, Quaternary gravels extend up to altitudes above 8000 feet, and surrounding these gravel-covered areas are surfaces of low relief and thick residual soils on the old crystalline rocks. Such areas of gentle relief are especially widespread farther north in the San Bernardino Mountains (Vaughan, 1922, pp. 321-334), and probably indicate a Recent history far different from that of adjacent mountain masses (Mendenhall, 1907).

Interruptions in the dissection of the Quaternary fanglomerates by streams draining the north side of the pass have led to development of numerous terraces and benches which give some clue to the structural history of the region. The principal surfaces at the west end of the pass are Beaumont plain, Banning Bench, and Pine Bench; at the east end of the pass are the Cabezon surface and Whitewater River terrace.

Beaumont plain--West of the area of plate 1, the Beaumont plain is being actively dissected by tributaries of San Timoteo and Potrero Creeks; these features have been described in detail by Russell (1932, pp. 72-73). The Beaumont plain probably is correlative with the widespread bench of the Yucaipa-Calimesa area and Redlands Heights. It increases in height above the present stream level in a downstream direction, and is not appreciably faulted or warped. The cause of rejuvenation is not known.

Banning Bench--A surface of erosion distinctly higher than the Beaumont plain truncates much of the foothills area between the floor of the pass and the steep mountain front several miles north (fig. 2). This surface is cut mainly on Heights fanglomerate and is capped by a thick layer of soil. It is best seen on Banning Bench (also known as Banning Heights and Barker Bench), Mile-high Bench (north of Beaumont), and along the Beaumont-Oak Glen highway. The easternmost exposures are near the mouth of Millard Canyon (fig. 9), although scattered remnants of gravel and areas of low relief within the mountains farther east may also be correlative with the Banning Bench surface. In the mountains to the north, well-defined terraces represent the Banning Bench surface in many of the main canyons.

That the surface of Banning Bench is a degradational feature and not the uppermost surface of Heights deposition is indicated by still higher surfaces on Heights fanglomerate at the north and south ends of the bench, as well as by greater thicknesses of Heights gravels near the mouth of Smith Creek. Likewise, the red soil-covered surface near upper Hathaway Creek, which probably is correlative with the Banning Bench surface, is surrounded by hills representing greater thicknesses of the same fanglomerate that underlies the surface itself.

Banning Bench shows little evidence of local deformation except for one Recent fault scarp just south of the ranger station. In addition, warping of beds along the south edge of the bench near Banning probably is ascribable to movements on a bordering fault. However, little other evidence of faulting is present along the southern margin of the benches. Their irregular boundaries suggest that the Banning Bench surface is not merely a faulted portion of the Beaumont plain, although further field work north of Beaumont would be necessary to prove this.

One significant feature of the Banning Bench surface is its upstream divergence from the present stream levels. At the mouth of San Gorgonio Canyon, the bench surface is about 160 feet above the stream, whereas 5 miles north (upstream) the difference in levels is 500 feet. Similar relations hold north of Beaumont, where the divergence has been attributed by Dennis and Melin (1942, p. 5) to regional southward tilting. On the other hand, streams in their constant effort to reduce gradient might be expected to leave remnants of former steeper channels and fans if the dissection were sufficiently rapid. Eckis (1928, pp. 237-243) has pointed out that such "fanhead trenches" are almost universal in Southern California, and are a result of normal continuous degradation rather than a direct result of tilting or faulting.

Certainly, normal reduction of the gradients of streams crossing Banning Bench has contributed in some degree to the upstream divergence of bench and stream levels. But several lines of evidence suggest that tilting also has taken place:

(1) It is unlikely that such an extensive, deeply weathered, soil-covered surface of low relief could have developed on slopes of 4^{o} to 5^{o}, which now characterize the upper parts of these benches.

(2) The sizes of clasts within the gravels on the surface of Banning Bench are not significantly different from those in nearby present stream channels. Fans of the pass area with slopes of 4^{o} to 5^{o} generally have much larger fragments, although this varies widely with rock type and drainage area.

(3) If upstream divergence of terrace and present stream levels is attributed solely to normal degradation, it is strange that the adjacent Beaumont plain should be incised by streams whose levels diverge from the plain in a downstream direction. It seems more likely that the Banning Bench surface, being older, simply shows more of the effects of tilting; furthermore, the amount of southward tilting may have increased toward the mountains.

Pine Bench--The highest fanglomerate deposits in the foothills north of Banning and Beaumont are those at Pine Bench. This small area, which is at an altitude of 5500 feet, is surrounded by steep scarps sloping down to the surface of Banning Bench below. Gravels similar to those at Pine Bench are exposed on at least one ridge farther west.

At both the extreme north and south ends of Banning Bench are small remnants of surfaces on Heights fanglomerate at altitudes intermediate between those of the Banning Bench and Pine Bench surfaces. The terrace remnant north of the San Andreas fault between San Gorgonio Canyon and Burro Flat is perhaps correlative with this intermediate level, although it also may be a remnant of the Banning Bench surface at Burro Flat that has been uplifted along the fault.

Cabezon surface--Heights fanglomerate, capped by a distinct undeformed layer of soil, overlies Cabezon fanglomerate at the mouth of Millard Canyon (fig. 9). Nine miles east, at the mouth of Whitewater Canyon, the Cabezon fanglomerate is itself capped by a reddish soil layer that is in general, though not in detail, conformable with the underlying fanglomerate. This surface is herein termed the Cabezon surface. Although it is somewhat similar in appearance to the Banning Bench surface, its greater age is indicated by its greater degree of dissection and marked deformation. At Beacon Hill, both the Cabezon beds and the soil that caps them show quaquaversal dips of as much as 30°, and the soil layer plunges beneath Recent alluvium around the periphery of the domical structure.

The Cabezon surface can be projected across Whitewater Canyon between Beacon and Whitewater Hills, but farther west the increased deformation of the Cabezon fanglomerate, together with its greater degree of dissection, precludes tracing of the surface in this direction. The Banning fault displaces the Cabezon surface near

Whitewater, and northeast of Painted Hill the gently eastward-dipping soil layer marking the Cabezon surface is being "submerged" beneath Recent alluvium.

At the mouth of Mission Creek, the Cabezon surface probably is an old fan surface, but it now dips 6^{o} southeast and plunges beneath Recent alluvium 2 miles southeast of Kitchen Ranch (pl. 1). This surface is transected by Mission Creek, and is incised by Whitewater River farther west near Red Dome. Mission Creek and Whitewater River at one time perhaps joined on this fan surface. Subsequent incision has superposed these two streams on rocks of differing hardness and structure, with a resulting divergence of stream paths. Local eastward tilting of this old fan surface is suggested by four lines of evidence:

(1) The clasts in the old fan are smaller than those associated with other nearby "active" fans that have slopes of 6^{o} (e.g. top of Snow Creek fan). Large fans of this slope, furthermore, are rare.

(2) The Cabezon surface intersects the Recent alluvium with an abrupt change in slope. None of Eckis' "fanhead trenches" (1938, pp. 237-243), which presumably are a result of normal degradation, is associated with such an abrupt change in slope.

(3) If the slope of the Cabezon surface is projected upstream (northwest), it clears the ridge tops for a distance of more than 6 miles. If all of this intervening material was removed after development of the fan, it is strange that the more easily erodable fan

deposits have not been completely dissected.

(4) A broad surface of low relief at altitudes ranging from 6500 to 8000 feet is associated with thick Cabezon(?) gravels at Raywood Flat. This area is presently undergoing spectacular dissection by Mill Creek and Whitewater River (figs. 11, 12). The presence of this surface and the underlying gravels is highly suggestive of either upwarping or faulting, inasmuch as the steep stream gradients between Raywood Flat and the borders of the range make explanation on other grounds difficult. Reconnaissance of the upper Whitewater River area suggests that no major Recent faulting is present in this river system; tentatively correlated terrace remnants can be followed for most of the distance between Whitewater and Raywood Flat. It is thus likely that Raywood Flat represents a broad upwarping of the San Bernardino Mountains in this area, perhaps along a north-south axis. Such arching would also help explain the San Jacinto Mountains and the present altitude of Pliocene marine beds in San Gorgonio Pass near Cabazon. Upwarping of a similar nature has been postulated from regional evidence by Sharp (1954). The eastward-tilted Cabezon surface at the mouth of Mission Creek may be the mountain-border equivalent of the Raywood Flat surface.

Whitewater River terrace--In removing the Cabezon fanglomerate that once filled its former channel, Whitewater River has cut a prominent terrace surface that can be followed discontinuously for 6 miles between the Banning fault and Catpaw Flats (pl. 1). All of these terrace remnants are rock-defended, thus explaining their survival in the rapidly deepening canyon. This terrace level probably correlates with similar-appearing surfaces still farther upstream, but limited field work and lack of adequate topographic data preclude definite correlation at this time. The terrace has not been recognized south of the Banning fault. Near Red Dome it can be distinguished from the Cabezon surface by (1) its inset geometric relation to the river gorge, (2) its slightly lower altitude, (3) the lesser degree of its surface dissection, and (4) its capping of relatively fine-grained gravels.

The Whitewater River terrace rises progressively higher above stream level in the upstream direction; near the trout farm the gradient of the stream is 2^{o}, as compared to the 3^{o} slope of the terrace. This divergence may be caused by southward tilting, although near the Banning fault, which is at the southern end of this terrace system, two lines of evidence suggest that local northward tilting is now taking place:

(1) "Dry Lake", a closed basin just west of the mouth of Stubby Canyon (pl. 1, fig. 3), probably owes its closure to northward tilting which has cut off the branch of Lion Canyon that formerly drained this area. No Recent fault scarps cross the basin, but the Banning fault is only one-half mile to the south.

(2) In connection with the earthquake investigation program of the U. S. Coast and Geodetic Survey in Southern California, a closely spaced first-order level network was established across the

Banning fault in Whitewater Canyon. This line was originally leveled in 1935 and was releveled in 1949. Although the 1949 observations still are subject to "adjustment", comparison of the figures suggests that if tilting is taking place at all, it is in a northward direction here. The maximum measured change in elevation was 6 millimeters, and there is surprisingly sporadic variation along the 6-mile line. The evidence for consistent northward tilting is only suggestive at best.

ALLUVIAL FANS

Alluvial fans derived from the San Bernardino Mountains cover the floor of San Gorgonio Pass, and cause the southward gradient across the pass to be greater than the eastward gradient "down" the pass (fig. 2). Vaughan (1922, pp. 340-342) and Russell (1932, pp. 32-34) both commented on the fact that these south-sloping alluvial fans completely dominate the fans that have been built out from the much steeper San Jacinto scarp on the south, so that San Gorgonio River washes against the south wall of the pass over almost its entire course in this area. Vaughan attributed this unequal fan development to the greater stream flow resulting from larger drainage areas on the north, assisted by possible raising of the San Gorgonio block by Recent faulting on the north side of the pass. Russell discounted the effect of differences in drainage area and amount of precipitation, and instead emphasized the contrast in rock types of the San Jacinto and San

Gorgonio blocks.

The writer favors two principal explanations for the predominance of fans derived from the north:

(1) Alluvial fans are built solely during floods, and comparison of precipitation figures for the two sides of the pass (table 1) indicates a greater "flood potential" of the streams that drain the San Gorgonio block. Greater flood runoff is also aided by the somewhat larger drainage area north of the pass. The writer cannot agree with Russell's statement (p. 33) that inasmuch as "alluvial fans are more characteristic of dry than of humid climates, it might well be argued that <u>lesser</u> precipitation values would favor fan growth."

(2) The difference in rock types of the two sides of the pass is a truly important factor. However, the writer again disagrees with Russell (p. 34) that a considerable part of this difference is caused by the thin strip of easily erodable Tertiary sedimentary rocks along the north side of the pass, a strip that furnishes "a very large amount of material for the active fans of today." The important point is, rather, that the San Gorgonio igneous-metamorphic complex is more easily eroded because of its heterogeneity and thoroughly fractured structure, in addition to the several great zones of crushed rock along major faults within it. The homogeneous rocks of the San Jacinto Mountains, on the other hand, tend to break off into such large boulders that only very exceptional floods can move great

quantities of such material. The granular material (grüss) resulting from disintegration of the boulders perhaps is carried off by minor annual floods, and hence does not accumulate close to the mountain to form a large fan. Although the mechanics of slope formation are not at all well understood, the steep "boulder-controlled" slopes of San Jacinto Peak may be more stable under existing climatic conditions than the gentler slopes across the pass to the north.

GROUND-WATER

As is typical of semi-arid regions, springs in San Gorgonio Pass delineate many structural features. Springs of this area have been divided into three groups, according to whether they are caused by (1) fault damming, (2) exposure of unconformities, or (3) canyon constriction.

Fault damming--Recent faults cutting alluvial-filled valleys tend to form barriers to ground-water because of (1) development of impervious gouge, (2) juxtaposition of alluvial deposits of differing permeability, or (3) raising of relatively impermeable "basement" rocks in the downstream block.

Much ground-water rises along the San Andreas fault, where it is tapped by local water companies. The most important springs of this type are at Camp Comfort (in San Gorgonio Canyon) and in Burro Flat at Thompson and Peat cienagas. There is little evidence that great quantities of water are carried by the crushed rock in the fault zone itself.

Recent displacements characterize the eastern end of the Gandy Ranch fault, and prominent springs thereon are (1) the Southern Pacific springs in lower Millard Canyon, (2) the Morongo Indian Reservation springs in lower Potrero Canyon, and (3) the springs near the forks of Hathaway Canyon. In the last area, southern termination of the Heights fanglomerate (also caused by faulting) may be an important factor contributory to the rising ground-water.

The western portion of the Banning fault does not appear to affect the distribution of ground-water, but the obvious cienaga in Whitewater Canyon testifies to Recent displacement in the fault's eastern portion. Still farther east in Coachella Valley, the Banning fault can be traced only by subtle changes in vegetation resulting from differences in ground-water levels on the two sides of the fault.

At the forks of Millard Canyon, 5 miles north of Cabazon, the Cabazon Water Company springs must be caused by faulting, although the break is not discernible far east and west of the canyon bottom.

Exposure of unconformities--The permeability and porosity of Quaternary fanglomerates in the pass area make them excellent aquifers, and the base of the fanglomerate deposits has been exposed by dissection in many areas, so that springs are common along this unconformity. The best examples are at the edge of Banning Bench, where water percolating southeastward forms springs at the Heights-San Timoteo(?) contact in School Canyon, Brinton Canyon, and two smaller canyons between these. Springs in Smith Creek, one mile above Highland Springs Resort, are on the contact between Heights fanglomerate and the crystalline complex. The sporadic record of success of wells drilled on Banning Bench, together with evidence that the rock floor beneath the Heights fanglomerate is one of considerable relief, suggests that ground-water here is guided by old stream channels in the buried topography.

In a situation similar to that at Banning Bench, springs occur in the South and East Forks of Whitewater River at the base of the dissected Cabezon(?) fanglomerate of Raywood Flat. Likewise, water rises at Perched Springs in Burro Flat at the base of the Burnt Canyon breccia, an aquifer that is even more permeable than the underlying Heights fanglomerate.

Canyon constriction--Lessening of the cross-sectional area of stream gravels through constriction of the canyon walls can force ground-water to the surface. Such constriction may be caused by differential rock types, old faulting, or stream superposition. Superposition probably is the explanation for the cienagas in San Gorgonio Canyon 5 miles north of Banning, and in Whitewater Canyon opposite the trout farm. Likewise, the springs one-half mile east of Kitchen Ranch apparently are caused by superposition of Mission Creek onto a ridge of relatively resistant Miocene(?) basalt.

V. GEOLOGIC STRUCTURE

SAN ANDREAS FAULT

Introduction--The San Andreas fault is a major tectonic feature of western North America. Seismic activity suggests that faulting related to this great zone of weakness extends for a distance of more than 700 miles from the Gulf of California to the Pacific Ocean north of San Francisco. Noble (1926, pp. 416-417) has distinguished between the San Andreas fault and the San Andreas fault zone; the fault itself ordinarily is defined as the linear trace of recent activity--the "master break"--within the much wider area characterized by the "branching and interlacing, roughly parallel fractures" that make up the fault zone. The fault zone attains widths of 6 miles in Central California, and the present study suggests that it becomes still wider in parts of Southern California. Detailed descriptions of fault features, together with summaries of the evolution of thought concerning this fault, have been contributed by Lawson, et al. (1908), Taliaferro (1943), Wallace (1949), Hill and Dibblee (1953), and Noble (1926, 1932, 1953, 1954).

From the type locality of the San Andreas fault at San Andreas Valley near San Francisco (Willis, 1938, p. 806), the fault forms an obvious and uninterrupted break for more than 350 miles southeast to the Cajon Pass area (fig. 1). Beyond this point the fault frays out into several great branches (Noble, 1932, p. 360), but the name San Andreas traditionally has been applied to the most nearly aligned and obvious prolongation--the fault that lies at the foot of the San Bernardino

Mountains and continues into San Gorgonio Pass. Within the pass area, however, various structural complications cast doubt on the continuity of the fault through this region. The more obvious of these anomalous features have been discussed in the introduction of this report.

Trace of the fault through San Gorgonio Pass--The steep front of the San Bernardino Mountains clearly defines the trace of the San Andreas fault from Cajon Pass to Pine Bench, on the north side of San Gorgonio Pass (figs. 1, 2, 13); from here southeastward into Burro Flat (fig. 10) the fault is marked by numerous north-facing scarplets, springs, sag ponds, and exposed zones of greenish pulverized rock. In the interval between Pine Bench and Burro Flat, however, the Recent scarps show a systematic change in trend of more than 30 degrees in a distance of less than 6 miles, and were the fault to continue southeastward from Burro Flat with the same trend as indicated by the easternmost scarps, it would cross San Gorgonio Pass and extend very nearly through the top of San Jacinto Peak. That the fault does not continue in this direction is indicated not only by the absence of physiographic evidence of faulting, but also by the continuity of rock types in the San Jacinto block. Southeast of Burro Flat, the fault therefore must (1) turn abruptly eastward, or (2) be offset by another fault, or (3) continue in a trend different from that indicated by the Recent scarps, or (4) dive beneath a thrust plate, or (5) die out.

The southeasternmost scarps of the San Andreas fault at Burro Flat are only two miles north of the trace of the east-trending

Figure 10. View looking southeast along the San Andreas fault at Burro Flat. Note the springs and Recent scarps along the fault. The light-colored hills in the middle distance are composed of Burnt Canyon breccia, a landslide deposit. San Jacinto Peak is on the horizon.

Figure 11. View looking north across the lip of Whitewater Jump-off. The trees at the upper left are on a widespread surface of low relief mantled by Cabezon(?) fanglomerate, which is here resting on crushed crystalline rocks (lower right) of the Mill Creek fault zone. Figure 12 is a vertical air photograph of this same area.

Banning fault, and yet the over-all continuity of the Banning fault indicates that it is not offset by a fault of major displacement. For the San Andreas fault to turn abruptly and join the Banning fault would require a change in trend of more than 45 degrees in this 2-mile interval; such seems out of the question. Furthermore, the Banning fault, despite its over-all continuity, is broken in three places by minor faults that trend parallel to the San Andreas fault at Burro Flat (pls. 2, 3). Whereas none of these small faults is directly in line with the southeasternmost scarps at Burro Flat, they do indicate that San Andreas-type strain, however small, continues its southeasterly trend and does not veer suddenly eastward.

Offset of the San Andreas fault by another fault is precluded by the absence of either the offset portion of the fault or evidence of a fault capable of such offsetting movement. The Banning fault, for example, is offset by faults of San Andreas trend, rather than vice versa.

Previous workers (Lawson et al., 1908; Vaughan, 1922) have linked the trace of the San Andreas fault as a smooth curve between Pine Bench and Whitewater, and in doing so they either have discounted or have not observed the trend of the Recent scarps in Burro Flat. Admittedly, there is a possibility that the Recent scarps do not follow the major fault line, and minor irregular divergences of scarps within the fault zone are known to be characteristic features of the San Andreas fault elsewhere (Wallace, 1949, p. 804; Hill and Dibblee, 1953, p. 445). The changes in trend of scarps in the Burro Flat area, however, are neither irregular nor minor. Further proof that the main fault does not continue in a more easterly direction from Burro Flat is given by the following two lines of evidence:

(1) Inasmuch as the topographic "groove", or rift, seems to be even more characteristic of the San Andreas fault than Recent scarps (Wallace, 1949, p. 408), at least some longitudinal valleys should mark the fault trace. Except for the locally trough-shaped valley of the West Branch of Millard Canyon, such rift topography is decidedly absent from the area through which the fault presumably would pass. The suggestion by Fairbanks (in Lawson, 1908, p. 45) that the lack of rift topography in this area is caused by Recent uplift and dissection of the range does not seem tenable. The very existence of rift valleys along the San Andreas fault in Southern California is caused primarily by erosion of the pulverized rocks from within the fault zone (Wallace, 1944, p. 66; Crowell, 1952, p. 22), and increased erosional efficacy should accentuate, not conceal, the rift topography. What more extreme example of rift topography could be cited than the nearby valley of Mill Creek, which has been incised along the trace of the Mill Creek fault?

(2) Although the crystalline rocks in the area between Burro Flat and Whitewater are extremely shattered and contorted, presumably owing to their proximity to the Banning fault, no evidence of a throughgoing break north of the Banning fault is present within these rocks. It is true that no specific horizons can be followed completely

across this zone from Cottonwood Canyon west, but the rock types nevertheless are similar. Furthermore, there is no one aligned discontinuity in attitudes of foliation; there is no throughgoing zone of pulverized rock; and springs are absent from the canyons that would be crossed by the hypothetical fault.

Inasmuch as the Banning fault (pls. 1, 3) is a flat thrust in much of the area in which continuity of the San Andreas fault is questioned, it might be argued that the San Andreas fault merely is concealed beneath this thrust plate. However, most of the change in trend of Recent scarps along the San Andreas fault takes place west of the point where the fault presumably would dive beneath the thrust plate, so that this hypothesis still must explain the markedly non-linear trend of the fault in the pass. Furthermore, there is good evidence that the Banning fault gradually steepens at the west end of the thrust zone, and does not trend north to "overlap" the San Andreas fault.

A related hypothesis proposes that the thrusting in the Millard Canyon-Whitewater area represents Recent deformation of the San Andreas fault plane itself, so that at depth the thrust steepens and becomes part of a continuous, planar, northwest-trending fracture. Large strike-slip displacement presumably could have taken place on the San Andreas fault before it was thus deformed to its present complex near-surface configuration. This hypothesis, however, does not explain the observed westward continuity of the thrust zone with the Banning fault rather than the San Andreas fault. If there has been large pre-thrusting lateral movement, it seems likely that it has taken place on the Banning fault, rather than on the San Andreas fault.

There appears to be only one remaining alternative: the so-called San Andreas fault is dying out in the vicinity of Burro Flat. This conclusion, of course, implies that displacement on the fault in this area has not been large.

Displacement--The various lines of evidence pertaining to the displacement on the San Andreas fault are:

(1) Lateral stream offsets along the fault are absent in this area. At least the deeply intrenched canyon of San Gorgonio River should show some evidence of offset if there had been appreciable Recent strike-slip movement along the fault.

(2) Recent scarps in this area consistently indicate upward movement of the south block, although not more than 50 feet of such movement is necessitated by any of the scarps.

(3) The zone of crushed rock in the fault zone is less impressive than that along the Banning fault, as is also the contortion of adjacent foliated rocks. Furthermore, the multiplicity of fault slices characteristic of the fault zone to the northwest (e.g. Noble, 1953) does not appear in this area.

(4) The steep mountain front north of the fault indicates a Quaternary or late Tertiary vertical component of movement amounting to several thousand feet, with the north side relatively raised. If, on the other hand, it is argued that the scarp is caused by lateral

displacement juxtaposing rock masses of different heights, slicing apart of the San Bernardino and San Gabriel ranges is the only reasonable offset that could account for such a scarp. Recent studies that have compared the crystalline rock types in both ranges, however, suggest that the south face of the San Bernardino Mountains is not merely the offset equivalent of the north face of the San Gabriel Mountains (K. Hsu, personal communication). Vertical displacement along the fault zone is the most reasonable explanation for the mountain front.

(5) All crystalline rocks within the area of plate 1 and north of the Banning fault are of the same family--the San Gorgonio igneous-metamorphic complex. The extent of similar rock types in adjacent areas is not completely known, but it seems highly unlikely that post-Mesozoic lateral displacements of hundreds of miles could have taken place on any faults north of the Banning fault, including the San Andreas fault. The rocks on opposite sides of these breaks are too similar in their migmatitic structural features, remnants of amphibolite, intrusion by quartz monzonite, and high content of titanium minerals. On the other hand, it cannot be denied that this evidence is suggestive rather than definitive. Somewhat similar rock types occur in the Little San Bernardino Mountains and other nearby ranges, and the possibility of a few tens of miles of movement cannot be excluded solely on the basis of comparison of crystalline rock types.

(6) Distinctive clasts of greenschist in the Heights fanglomerate of Banning Bench must have been derived from the greenschist exposures in San Gorgonio Canyon north of the San Andreas fault (pl. 1); there is no other possible source area in this region. The present location of this fanglomerate relative to the source area indicates that less than one mile of post-Heights lateral displacement has taken place along the San Andreas fault here. The Heights fanglomerate is probably of late Pleistocene age.

(7) The greenschist of San Gorgonio Canyon is cut off on the south by the fault, but movements no greater than several thousand feet seem to be necessary to explain its presence here (pp. 29-30). Chlorite-hornblende-quartz-albite rocks that are transitional between the greenschist and the surrounding amphibolitic gneisses crop out north of the fault near Burro Flat and south of the fault near Oak Glen. Whether these exposures represent an actual offset is speculative; these rocks (together with the greenschist itself) may owe their distinctive characteristics to the high shear stress and to hydrothermal activity along the fault (p. 30).

(8) Five miles west of Pine Bench a distinctive sedimentary rock crops out over an area of several square miles in a block between the San Andreas and Mill Creek faults. It is particularly well exposed along the highway in the gorge at the mouth of Mill Creek, and has been named the Potato sandstone by Vaughan (1922, pp. 374-375). It is of unknown age, but its much higher degree of

induration and sorting as compared with the late Tertiary rocks south of the San Andreas fault suggests that the Potato sandstone is at least as old as Miocene.

Of particular tectonic significance is the fact that near its base the Potato sandstone contains numerous fragments of schist that is almost identical with rocks described by Hill (1939) from the Pelona schist of the San Gabriel Mountains. Several investigators have postulated that these clasts therefore provide evidence of a ± 30 mile post-Potato lateral displacement on the San Andreas fault. Such a displacement must be regarded as a possibility, but there also are other possibilities for the provenance of these clasts: (a) Pelona schist underlies the Crafton Hills just south of the San Andreas fault and opposite the Potato sandstone locality (Hill, 1939, p. 98). Although rocks in the Crafton Hills appear to be of a somewhat different facies from that of the Potato clasts, the Crafton Hills area cannot be discounted as a possible source, particularly when it is considered that the fault boundaries of the Potato sandstone block imply large post-Potato vertical adjustments in this area. (b) All of the crystalline rocks exposed south of the San Andreas fault between the Potato sandstone locality and the San Gabriel Mountains are Pelona schist types (Hill, 1939, p. 98). These rocks are now largely buried by alluvium, but possibly an area in this region could have contributed clasts of schist to the Potato sandstone. (c) The presence of greenschists in San Gorgonio Canyon suggests that other

Pelona-type rocks once may have existed north of the San Andreas fault in this region.

(9) An almost continuous zone of east-trending pegmatite dikes extends across the projected trace of the fault south of Burro Flat (pl. 1). Likewise, Recent scarps of the Gandy Ranch fault continue unbroken across this same area.

(10) Where the Banning fault is broken by faults of San Andreas trend, the maximum lateral component of displacement is 2000 feet.

Summary--The Recent displacements on the San Andreas fault in San Gorgonio Pass probably have been largely vertical with less than one mile of strike-slip component. Earlier lateral displacements also may have been small, although the possibility of horizontal movements totaling a few tens of miles must be recognized. In view of the evidence for 20 to 30 miles of lateral displacement along the San Andreas fault on the north side of the San Gabriel Mountains (Noble, 1926; Noble, 1954), it is questionable whether the San Andreas fault of San Gorgonio Pass truly deserves the parent name; other faults, previously considered branches, may have absorbed most of the lateral strain.

BANNING FAULT

General features--The Banning fault, the major structural feature on the north side of San Gorgonio Pass, brings Cenozoic sedimentary rocks into contact with the much older crystalline complex throughout the 25-mile interval between Whitewater and Yucaipa Valley, and it probably extends still farther west to the San Jacinto fault zone. Vaughan (1922) mapped this fault only as far west as San Gorgonio River, whereas R. T. Hill (1928, p. 142) recognized its much greater westerly extent and gave it the name Banning fault.

West of Cabazon the Banning fault neither displaces Quaternary gravels nor appears to affect the distribution of ground-water, and these features perhaps explain the lack of attention it has received in this area. Eastward in Coachella Valley, where it usually has been called the San Andreas fault, Recent scarps permit easy recognition of the Banning fault at least as far as Biskra Palms in the Indio Hills, near which point it is joined by the Mission Creek fault (fig. 1). The type locality is here designated as the area in which the fault crosses San Gorgonio River north of Banning. The most extensive exposures, however, occur between Millard and Cottonwood Canyons (pl. 3), where they show far greater structural complexity than those near Banning.

Western segment--The westernmost exposure of the Banning fault is in the foothills between Beaumont and Yucaipa, where the light-colored crushed rock in the fault zone forms a prominent fault-line scarp. The fault is known locally as the White Hill fault (Dennis and Melin, 1942), but its continuity with the Banning fault 4 miles farther east is demonstrated not only by similar trend and alignment, but also by corresponding rock types and structural features that lie adjacent to the fault in the two areas. The fault is particularly well exposed near the north end of Singleton Road, where it is a steep reverse fault that dips 70° to 80° north (Shuler, 1953, p. 59).

Westward, the fault is concealed by the unbroken alluvium and Quaternary gravels of Yucaipa Valley and Redlands Heights, but prolongation of the fault into the Redlands area and still farther west to the San Jacinto fault zone is strongly suggested. Crystalline rocks are exposed in Crystal Springs Canyon, 3 miles southeast of Redlands, but Pliocene-Pleistocene San Timoteo beds crop out beneath Quaternary gravels less than one mile south of this point. These beds dip 20° to 30° north, and well data indicate thicknesses of at least 2000 feet, so that fault contact with the crystalline rocks seems almost certain. Recent work by Arnett (1949), English (1953), and Sprotte (1949), indicating as much as 11 miles of post-Pliocene right-hand lateral displacement on the San Jacinto fault, leads to speculation that the Banning fault might be the offset equivalent of one of the prominent east-west faults of the San Gabriel Mountains.

Middle segment--The Heights fanglomerate, of Quaternary age, has not been displaced by the Banning fault on the bench north of Banning, but the fault is exposed in the rocks beneath the fanglomerate in Brinton Canyon and on the east side of the bench at the switchback in Banning Canyon Road (pl. 2). Metamorphic rocks are here in contact with San Timoteo(?) beds, and the difference in thickness of the overlying fanglomerate north and south of the break suggests that a fault scarp existed here at the time of fanglomerate deposition. The relatively straight course of the fault in this area is indicative of steep dip of the fault plane. In the first canyon west of Potrero Canyon the fault is displaced out to the front of the foothills, and from here east to Millard Canyon it is covered by an uninterrupted expanse of alluvium.

Two main breaks mark the trace of the Banning fault between Millard and Stubby Canyons (pl. 3). In general, crystalline rocks have been thrust over Tertiary sedimentary rocks along the northern break, and the Tertiary rocks are in turn faulted against Quaternary Cabezon fanglomerate along the southern break. The similarity in rock types across the southern branch suggests that most of the movement on the Banning fault has taken place on the northern break. The plane of the northern break, which is well exposed in most of the canyons that cross it, shows a general flattening eastward and locally becomes horizontal in the region of Stubby Canyon. The attitudes of the southern branch are similar to those of the northern branch, but the dips are steeper.

Abrupt variations in the attitude of the fault plane, which even dips south at the head of Second Canyon, suggest that it locally has been folded. However, origin as a high angle reverse fault or a thrust fault, rather than as a vertical fault that was subsequently folded, is indicated by: (1) truncation at a low angle of one of the earliest thrust planes by younger sedimentary beds on the east wall of Stubby Canyon, (2) seismic evidence that thrusting is continuing in this area today (Dehlinger, 1952), and (3) displacement of horizontal Heights fanglomerate at the head of the West Branch of Lion Canyon along a thrust fault that dips 38° north. The total offset of the Quaternary beds at this last locality is not discernible, but it probably is small; that the Recent faulting is of reverse and not normal type is indicated by the low angle of break in this relatively unconsolidated material (Hubbert, 1951, pp. 362-363). Although a normal fault displaces both Recent alluvium and one of the older thrusts at the mouth of Stubby Canyon, this faulting appears to be a local adjustment that is not typical of the mountain front as a whole.

On the east wall of the mouth of Stubby Canyon, exposures indicate that recurrent thrust faulting has taken place during deposition of the Cabezon fanglomerate (section E-E', pl. 3). From here eastward to Cottonwood Canyon are several thrusts, some entirely within crystalline rocks and others evidently buried beneath the alluvium in front of the foothills (pl. 3). Near the mouth of Seventh Canyon, one of the thrusts has overridden a breccia derived from rocks of the upper plate, so that the position of the contact is obscure. In this area, the northernmost thrust is the most recent, inasmuch as it appears to truncate the older shallower thrusts. On the other hand, in Second and Third Canyons, the southernmost fault is most recent, and is marked by remnants of scarps in the Recent alluvium.

It might be argued that the thrusts between Millard and Cottonwood Canyons are merely subsidiary to a major vertical fault of similar trend and of possible strike-slip nature. Such subsidiary thrusts along the San Andreas fault have been described by Noble (1932), Crowell (1950, 1952), Wallace (1949), and others. That the thrusts along the Banning fault are, nonetheless, part of the main fault system and not merely subsidiary features is indicated by (1) continuity, at least westward, of the thrusts with the steeper portion of the Banning fault, (2) seismic evidence that thrusting is the predominant method of strain release in this critical area (Dehlinger, 1952), and (3) lack of Recent scarps indicative of major vertical faulting south of the thrust zone. The lack of evidence for the presence of a throughgoing fault in the crystalline rocks north of the thrust zone has been discussed above in connection with the San Andreas fault.

Eastern segment--East of Cottonwood Canyon a sudden change in topographic expression is associated with the faulting. Not only is there no evidence of thrusting, but the fault trace is marked by a longitudinal valley suggestive of rift topography. Where next exposed, one mile west of Whitewater River, the fault plane dips 65^{o} north and appears to be a single break. Furthermore, throughgoing Recent scarps, the topography of which is indicative of relatively steep dip of the fault plane, commence not far east of Cottonwood Canyon. These same scarps do not appear to extend westward into the thrust zone between Cottonwood and Stubby Canyons, however, and it thus seems that the Banning fault changes from a flat thrust to a high-angle reverse fault within a distance of less than 3 miles. This sudden change is discussed farther on, in the section on mechanics of the Banning-San Andreas fault system.

East of Whitewater River, topographic expression of the Banning fault suggests near-verticality. From Painted Hill eastward into Coachella Valley, the fault is marked by subtle changes in vegetation that reflect differences in ground-water levels on the two sides of the fault. Although it is a nearly east-west break at Whitewater, the Banning fault curves southward and is trending 120° (east-southeast) where it enters the Indio Hills 15 miles to the southeast. This is the same trend as that of the San Andreas fault in the Transverse Ranges northwest of San Gorgonio Pass.

Displacement--The various lines of evidence pertaining to the displacement on the Banning fault are:

(1) The length and continuity of the fault trace suggest that it is a major tectonic feature of Southern California, and possibly one of large displacement.

(2) Throughout the pass area, the fault is characterized by a zone of crushed rock more impressive than similar zones along the nearby San Andreas fault. This zone, distinctive for its light green color, reaches thicknesses of several thousand feet.

(3) No Tertiary rocks crop out west of Whitewater and north of the Banning fault, yet a well drilled in 1926 less than one mile south of the probable trace of the fault in Yucaipa Valley bottomed at 5358 feet in Tertiary(?) sedimentary rocks (Oakeshott, et al., 1952, p. 32). Similarly, a well drilled in 1953 midway between Banning and Beaumont penetrated 2100 feet of Pliocene-Pleistocene(?) beds without striking the crystalline complex.

(4) Cabezon fanglomerate has been faulted against the

crystalline complex near Whitewater, and indicates Recent relative upward movement of the north block of at least 800 feet. Drag of Cabezon beds on the east wall of Whitewater Canyon also indicates upward movement of the north block.

(5) The very existence of San Gorgonio Pass suggests large vertical displacements on the Banning fault. It is noteworthy that both the pass and the fault are east-west features, in contrast to the northwest trend of the San Andreas and San Jacinto fault systems.

(6) Stream offsets indicative of Recent lateral displacement are absent along the trace of the Banning fault in San Gorgonio Pass. Although most of the streams draining the north side of the pass debouch onto alluvial fans and therefore might not be expected to show lateral offsets, the intrenched canyon of Whitewater River certainly should be displaced if this type of Recent movement had been large.

(7) Pebbles derived from the Painted Hill formation have been dragged eastward along the thrust fault between the heads of Second and Third Canyons, and suggest that the thrusting here has had an oblique or right-hand strike-slip component.

(8) Drag of Tertiary beds south of Painted Hill suggests that some right-hand strike-slip movement took place on the Banning fault.

(9) Flaser-gneiss clasts of probable local origin within the lower member of the Hathaway formation (pp. 49-50) suggest that

there has been less than five miles of lateral displacement on the northern (major) branch of the Banning fault since early Pliocene time. Further mapping of the regional geology is needed, however, before this evidence can be evaluated with confidence.

(10) The occurrence of piedmontite-bearing clasts within the Painted Hill formation (p. 63) indicates less than 10 miles of lateral displacement since Early or Middle Pliocene time, and no displacement is necessitated.

(11) The occurrence of piedmontite-bearing clasts within the San Timoteo(?) formation near Banning (p. 68) is most reasonably explained by approximately 5 miles of post-San Timoteo(?) right-hand strike-slip displacement on the Banning fault, although logical arguments could be made either for still greater lateral displacement or for none at all.

(12) The crystalline rocks north and south of the Banning fault, underlying San Gorgonio and San Jacinto Peaks respectively, appear to be of different types. Whereas this discontinuity might be explained in terms of large pre-Pliocene lateral displacement on the Banning fault, there is no known locality where the "fit" across this east-west shear zone would have been any better than it is now. Nor does vertical displacement alone seem adequately to explain the difference in rock types. Rather than the discontinuity of rock types being <u>caused</u> by displacement on the fault, it also is possible that the Banning fault is here <u>because</u> of, and associated with, the

natural boundary between two geologic units.

The Transverse Ranges reflect a deep-seated crustal shear zone of considerable extent (Menard, 1953). If this zone is pre-Cretaceous in age, the northern limit of the San Jacinto intrusive rocks may have been determined by this transverse shear zone, instead of the intrusive rocks having been cut off by the fault in post-Cretaceous time. This problem is one of major regional significance, and insufficient evidence is now at hand to permit a final answer.

Summary--The Banning fault is a major east-west tectonic feature of Southern California, and forms the southern limit of the Transverse Ranges in the area of San Gorgonio Pass. Reverse-fault component of movements of many thousands of feet have taken place in Quaternary time, although Recent (post-Heights) displacement is restricted to that portion of the fault that lies east of Millard Canyon. There is little evidence of Recent strike-slip movement in the San Gorgonio Pass area, and post-lower Pliocene lateral displacement probably is no greater than 10 miles. The geographic positions of clasts in the San Timoteo(?) formation are most easily explained by a post-San Timoteo(?), pre-Heights right lateral displacement of about 5 miles. Pre-early Pliocene lateral displacement on the Banning fault may have been great but is not demanded by evidence in this area.

MISSION CREEK FAULT

Nomenclature and previous work--The Mission Creek fault was named and first described by Vaughan (1922, pp. 401-403) on the basis of exposures near the mouth of Mission Creek. Partly because of inadequate topographic maps, it has been wrongly assumed that this fault is continuous with the prominent fault that is marked by the straight canyons of Mill Creek and a part of the North Fork of Whitewater River. The present study, however, indicates that the Mission Creek fault extends west from the mouth of Mission Creek along the South Fork of Whitewater River, and thence veers southward to join the San Andreas fault in San Gorgonio Canyon north of Banning (pl. 1). The western part of this redefined Mission Creek fault corresponds to the Raywood fault of R. T. Hill (1928, pp. 147, 162). The more northerly fault marked by the course of Mill Creek is herein renamed the Mill Creek fault.

Features of the fault trace--In the 4-mile interval between the San Andreas fault and Raywood Flat, the trace of the Mission Creek fault is marked by the straight canyons of San Gorgonio River and the tributary that joins the main canyon at Power House No. 1 (pl. 1). Beneath the unbroken Cabezon(?) fanglomerate of Raywood Flat, this fault is joined by at least two other faults of more northwesterly trend. The entire zone is well exposed still farther east in the gorge of the South Fork of Whitewater River, where the exposed width of the pulverized zone is greater than one-quarter mile; the fault zone here dips 45° north.

The course of the South Fork of the Whitewater River is, in general, determined by the Mission Creek fault for a distance of 5 miles east from Raywood Flat. It is interesting to note, however, that the present gorge, which is incised into an old and broader valley, lies generally south of the trace of the fault. Numerous remnants of terraces that are mantled with Cabezon(?) fanglomerate overlie the fault trace north of the present stream. It is possible that southward tilting has displaced the rejuvenated stream course to a position somewhat south of the former valley axis. Similar asymmetric terrace survival is evident in the canyons of Mill Creek and San Gorgonio River.

The Mission Creek fault zone is well exposed one mile northeast of the junction of the North and South Forks of Whitewater River (pl. 1). Here the zone of crushed rock is 1000 feet thick and dips 50° to 60° north. Sedimentary rocks, tentatively assigned to the deformed gravels of Whitewater River, form the northernmost fault wedge; the remaining rocks comprise dark-colored crushed amphibolite, and Miocene(?) basalt intruded and subsequently crushed along the fault zone. Similar basalt is exposed in the fault zone one mile farther west on the bank of Whitewater River.

The deformed gravels of Whitewater River butt against crystalline rocks along the Mission Creek fault in the eastern part of the map area. The fault dips 62° north at the easternmost exposure 0.7 mile northeast of Kitchen Ranch. The prominent scarp along the fault north and west of Kitchen Ranch probably is in large part a fault-line scarp, inasmuch as a surface of low relief that truncates the crystalline rocks north of the fault seemingly is correlative with the dissected Cabezon surface at nearly the same altitude on the south. Furthermore, unbroken Cabezon fanglomerate seems to cover the fault trace on the large hill west of the mouth of Mission Creek, and remnants of undeformed Cabezon fanglomerate are preserved on the lip of the scarp 0.8 mile northeast of Kitchen Ranch.

Southeast of Kitchen Ranch, beyond the area mapped in this study, the Mission Creek fault curves gradually southward and is marked by Recent scarps from Desert Hot Springs to its junction with the Banning fault in the Indio Hills near Biskra Palms (Dibblee, 1954)(fig. 1). This region has been the center of considerable seismic activity, and the records of a 1948 earthquake of magnitude 6.6-6.7, centered southeast of Desert Hot Springs (Richter, 1949), still are under study. The main shock, together with most of the numerous aftershocks, occurred north of the surface trace of the Mission Creek fault. Their distribution suggests that the north dip characteristic of the fault plane in the San Bernardino Mountains continues to the southeast.

Displacement--Lines of evidence bearing on the displacement of the Mission Creek fault are:

(1) The covering of unbroken Cabezon(?) fanglomerate at Raywood Flat indicates the absence of Recent movement here. Alluvial scarps near Desert Hot Springs (fig. 1), however, testify to increased Recent activity toward the east.

(2) The nature and distribution of crystalline rock types on opposite sides of the fault seem to preclude post-Jurassic movements amounting to hundreds of miles, but are compatible with displacements of a few tens of miles (p. 100).

(3) The zone of crushed rock along this fault is fully as impressive as any in the San Gorgonio Pass area. This is compatible with large displacement, but does not demand it.

(4) Deformed gravels of Whitewater River that are faulted against crystalline rocks near the mouth of Mission Creek indicate relative upward movement of the north block in Quaternary time.

(5) The relatively shallow dip of the fault zone in the Raywood Flat area is not suggestive of contemporary strike-slip movement (Anderson, 1951, p. 15), nor is the abutment of this fault into the San Andreas fault. Earlier movements, on the other hand, may have been of different direction. It is possible that this east-west segment of the Mission Creek fault is related to the northwest-trending segment farther southeast in the same way that the San Andreas fault is related to the Banning fault. The geometry of this relation is discussed farther on, in connection with the mechanics of the Banning-San Andreas fault system.

Age--Basalt flows are interlayered with the upper Miocene(?) Coachella fanglomerate near the Mission Creek fault. These flows increase in number and thickness toward the fault, and the basalt evidently was extruded along the fault zone. Crushed basalt dikes are present within the fault zone near Whitewater River. Thus the Mission Creek fault must have existed as a throughgoing break in late Miocene(?) time.

PINTO MOUNTAIN(?) FAULT

Nomenclature and previous work--Along the north side of the Little San Bernardino and Pinto Mountains (fig. 1), east of the area mapped in this study, is a prominent east-west lineament that probably marks a major fault. This break first was recognized by R. T. Hill (1928, p. 146), who named it the Pinto Mountain fault and suggested that it extends eastward as far as New Mexico. Although this suggestion certainly is untenable, Hill's identification of the fault in the Pinto Mountain area seems valid. Later investigators have termed this same fault the Pinto fault (Miller, 1938, p. 419), the Warrens Well fault (Hill and Dibblee, 1953, p. 453), and the Base Line fault (California Dept. Public Works, Water Resources Div., 1953; Hewett, 1954), but R. T. Hill's original name of Pinto Mountain fault is used herein.

Features of the fault trace--As followed westward from its presumed type locality in the Twentynine Palms area (figs. 1, 14), the Pinto Mountain fault veers southward and probably enters Morongo Valley at the summit of the highway grade between Morongo and Yucca Valleys. Lack of geologic mapping in this critical area raises some question as to use of the name farther west, but field reconnaissance and study of air photographs strongly suggest continuity of this fault along the northwest side of Morongo Valley into Big Morongo Canyon (fig. 14). Most previous maps represent the fault as turning more abruptly southward and following the southeast side of Morongo Valley to join the Mission Creek fault at a high angle near Kitchen Ranch.

Near the mouth of Big Morongo Canyon, the Pinto Mountain(?) fault is marked by prominent scarps and springs, and ground-water is dammed by the fault where the canyon turns abruptly north 2 miles from its mouth. Within the area of plate 1, the fault is marked primarily by aligned stream courses caused by erosion in the crushed rocks along the fault trace. In addition, the greenish crushed rocks themselves are exposed near the points where the fault is crossed by Mission Creek and the North Fork of Whitewater River. The fault zone shows slight copper mineralization at scattered localities.

Near the junction of the North and South forks of Whitewater River, the Pinto Mountain(?) fault merges with the Mission Creek fault at a low angle. The much greater thickness of crushed rock along the Mission Creek fault, both east and west of the junction, might indicate that the Pinto Mountain(?) fault is a branch of the Mission Creek fault, rather than vice versa. Nowhere is the attitude of the Pinto Mountain(?) fault plane discernible, although the relatively straight course across rugged topography suggests a steep dip.

Displacement--Several pertinent but inconclusive lines of evidence concerning displacement on the Pinto Mountain(?) fault are:

(1) Within the map area, Recent movements have been minor; ground-water is not affected by the fault in either Mission Creek or Whitewater River. Immediately east of the map area, however, where the fault veers gradually northward (fig. 14), Recent scarps testify to relative upward movement of the south block.

(2) The crystalline rocks north of the Pinto Mountain(?) fault are chiefly plutonic types, in contrast to the predominantly metamorphic rocks to the south. This is particularly true east of the map area, and suggests over-all upward movement of the north block. The rocks are of the same migmatitic type, however, which may preclude displacements of hundreds of miles (p. 100).

(3) Along the north side of the Little San Bernardino Mountains, the backworn scarp suggests relative uplift of the south block. In general, Recent scarps are absent here.

(4) There is no direct evidence of lateral displacement along the fault. Lateral slip, on the other hand, is made plausible by the evidence of varying vertical component of movement, together with the exceptionally smooth trend of the fault trace.

Tectonic significance--Too little is yet known about the displacements on the Pinto Mountain(?) and associated faults to permit speculation about the mechanics of the fracture system. It is noteworthy that the fault pattern has a remarkable resemblance to the Garlock-San Andreas system, as has been pointed out by Hill and Dibblee (1953, p. 453), and conclusions concerning that better-known system may prove applicable to the Pinto Mountain-Mission Creek-San Andreas fault system as well. Both systems are associated with major changes in trend of the San Andreas fault.

Of particular regional tectonic significance is the fact that the eastern part of the Pinto Mountain fault marks the southward termination of the northwest-trending faults of the Mojave Desert (fig. 1). As was intimated by R. T. Hill (1928), this east-west lineament, together with at least two similar fault lines south of it, may represent a continuation of Transverse Range structure eastward from the San Gabriel and San Bernardino ranges. This zone now appears to be undergoing breaking-up by northwest-trending faults of the San Andreas system, and the entire east-west zone possibly has been offset somewhat by movements on these younger faults (fig. 1).

MILL CREEK FAULT

Nomenclature and previous work--The name Mill Creek fault is applied herein to the prominent fault that determines the courses of Mill Creek and the east-west segment of the North Fork of Whitewater River (pl. 1; figs. 13, 14). The name originally was used by R. T. Hill (1928, pp. 162-163), who applied it to the break that previously had been described by Vaughan (1922, pp. 401-403) as the Mission Creek fault. The present study indicates that both investigators were mistaken in their conception of a single fracture linking Mill Creek with the mouth of Mission Creek.

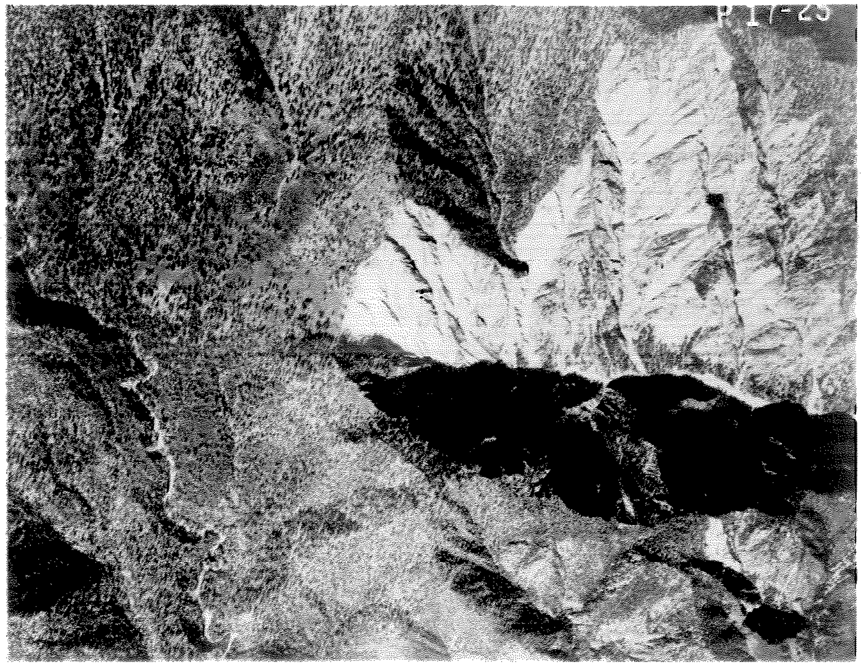
Features of the fault trace--Near the mouth of Waterman Canyon north of San Bernardino, the Mill Creek fault diverges from the San Andreas fault at a low angle, and its trace is marked by Recent scarps as far east as City Creek (figs. 1, 13). A reconnaissance map of this area is shown by Eckis (1934, pl. C). Physiographic features testify to continuity of the fault to Mill Creek, where it forms the northern boundary of the Potato sandstone fault block. For 10 miles farther east the straight, incised valley of Mill Creek is determined by the fault, and rapid erosion of the main canyon has left the valleys of Falls, Vivian, and High Creeks hanging 1000 feet above the floor of the main canyon. A cross-section of the fault zone is well exposed at the head of Mill Creek, 3 miles east of Fallsvale, where the zone of greenish and purplish crushed rock is several hundred feet thick and dips 60° south.

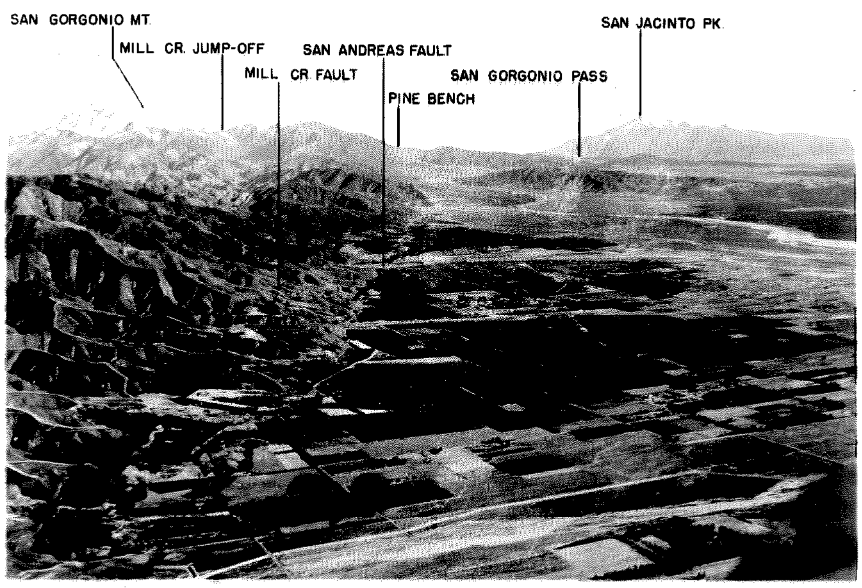
Rapidly progressing excavation by the headwaters of Mill Creek and a tributary of Whitewater River has carved giant "amphitheaters" into the relatively flat and gravel-covered area north of Raywood Flat. These spectacular features locally have been termed "jump-offs" because of the great topographic contrast at their lips (figs. 11, 12, 14).

The east-west segment of the canyon of the North Fork of Whitewater River is analogous to the valley of Mill Creek; rapid erosion of the main canyon has caused development of spectacular falls where it is joined by Hell-for-sure Creek and the headwaters of the North Fork itself. During normal stream flow, practically all the water contributory to the North Fork comes over the falls from the high country to the north; during floods, most of the water must come down the normally much drier canyon from Whitewater Jump-off (pl. 1). Whitewater River evidently derives its name from the milky appearance of streams excavating the pulverized rocks of the Jump-off area and the South Fork.

Figure 12. Vertical aerial photograph of Whitewater Jump-off. North is toward the top of the page.

Figure 13. View looking southeast along the San Andreas and Mill Creek faults from over San Bernardino. Waterman Canyon wash is in the foreground. Photo by Fairchild Aerial Surveys.




SAN GORGONIO MT.
MILL CR. JUMP-OFF
SAN ANDREAS FAULT
MILL CR. FAULT
SAN GORGONIO PASS
PINE BENCH
SAN JACINTO PK.

Near the junction of Hell-for-sure Canyon and the North Fork of Whitewater River, the Mill Creek fault appears to fray-out and end. It is possible, though not likely, that the fault extends eastward to the Pinto fault and has been offset by it. If so, this easternmost segment of the Mill Creek fault is not characterized by the thick zone of greenish crushed rock typical of exposures father west.

Displacement--Lines of evidence bearing on the displacement of the Mill Creek fault are:

(1) Well-developed slickensides on two fault planes within the zone of crushed rock at Mill Creek Jump-off indicate pure strike-slip movement on one plane and pure dip-slip movement on the other. The time relations of the two displacements are not determinable.

(2) Cabezon(?) fanglomerate at Whitewater Jump-off is displaced by a fault that dips 75° north and has a throw of about 15 feet. Either normal or strike-slip faulting is responsible. It is not known whether the dip of this particular plane is indicative of the attitude of the fault zone as a whole.

(3) The consistently greater height of the San Bernardino Mountains north of the Mill Creek fault suggests over-all relative uplift of the north block. Similar evidence is afforded by the northward termination of the Potato sandstone against the fault 5 miles west of the map area.

(4) If this fault truly dies out to the east, strike-slip

Figure 14. View looking east from near the top of San Gorgonio Mountain. Mill Creek Jump-off and the trace of the Mill Creek fault are shown at the lower right. Photo by Fairchild Aerial Surveys.


San Gorgonio Mtn, 11485
Twentynine Palms
Pinto Mtn Fault
Big Morongo Cr.
Morongo Valley
Whitewater Canyon
Mission Creek Fault

movement must not have exceeded a very few miles.

(5) Comparison of crystalline rock types on opposite sides of the fault seems to preclude displacement of hundreds of miles, but would permit displacements of a few tens of miles (p. 100).

OTHER FAULTS

Cox Ranch fault--The Cox Ranch fault, named for the Cottonwood Canyon Ranch of Jim Cox, extends for at least 5 miles between Kitching Peak and Whitewater Hill (pl. 1). It is evidenced by the alignment of numerous cols and by a marked discontinuity in the otherwise uniform foliation of the metamorphic rocks. The amount of movement on the fault is unknown, but the presence of identical rock types on opposite sides of the break suggests that the displacement has not been large. Evidence of Recent movement is lacking. The fault may continue westward from the col just south of Kitching Peak, but its trace there is not known; eastward it appears to butt into the Banning fault north of Whitewater Hill.

Gandy Ranch fault--The Gandy Ranch fault extends northwest from the mouth of Millard Canyon for at least 8 miles, and very nearly bisects the angle between the Banning and San Andreas faults (pl. 1). The type area is here designated as the Gandy Ranch between Hathaway and San Gorgonio Canyons, where the fault is well marked by longitudinal valleys resulting from erosion in the zone of crushed rock. Heights fanglomerate on the nearby ridges has not been displaced by the fault, and it appears that the springs on the trace of the fault in San Gorgonio

Canyon are caused by constriction of the canyon, rather than by Recent fault movement. Farther east, however, prominent alluvial scarps and ground-water damming testify to Recent displacement on the Gandy Ranch fault.

Drag in beds of Heights fanglomerate between Hathaway and Potrero Canyons indicates relative upward displacement on the south block, whereas the scarps in both Potrero and Millard Canyons indicate most recent uplift of the north side. Absence of a very wide crushed zone, and the presence of similar rock types north and south of the fault, suggest that total displacement has not been large. East of Millard Canyon, the Gandy Ranch fault appears to merge with the Banning fault; its westerly extent beyond the map area is not known, but study of air photographs reveals no obvious trace of the fault in this direction.

Whitewater fault--A relatively minor but continuous fault separates crystalline rocks, Coachella fanglomerate, and Quaternary gravels along the east wall of lower Whitewater Canyon (pl. 4). This break, herein termed the Whitewater fault, butts into the Banning fault at a high angle on the south; 2-1/2 miles north of this point the fault intersects the canyon floor, and still farther north it is concealed by Recent stream gravels. Aligned basalt exposures on both sides of the canyon at Red Dome suggest that, if the fault continues this far north, the displacement is small.

The east side of the Whitewater fault has been raised relative to the west side. It is generally a reverse fault, although the dip of the fault plane shallows northward so that locally it becomes a thrust. Just north of the Banning fault, the rock bench underlying the deformed gravels of Whitewater River(?) has been offset 150 feet by the Whitewater fault, and there is no evidence that the displacement increases farther north. Several branch faults, one a shallow thrust dipping west and truncated by Cabezon fanglomerate, complicate the structural relationships midway between Whitewater and the trout farm. Still farther north, the fault breaks old fanglomerates but is overlain by unbroken younger gravels; the lowermost unfaulted horizon is arbitrarily designated as the contact between the Cabezon fanglomerate and the deformed gravels of Whitewater River.

A major north-south fault underlying the gravels of Whitewater Canyon was postulated by Vaughan (1922, p. 403), presumably for the purpose of explaining the straightness of the canyon. For the same reason, Vaughan also postulated a fault in Stubby Canyon linking the Mission Creek and "San Andreas" (Banning) faults. It now appears, however, that the uniform and well-developed foliation in the metamorphic rocks, rather than faulting, has determined the courses of Stubby, Cottonwood, and Whitewater Canyons.

FOLDING

Pliocene sedimentary rocks on the floor of San Gorgonio Pass show intense folding, whereas the early Quaternary rocks are only gently folded, and the youngest dissected Quaternary fanglomerates are virtually undeformed. Near the Banning fault, fold axes trend east and reflect north-south compression. The most intense folds are in the areas of low-angle thrusting, and these folds probably are large-scale drag features resulting directly from vertical movements on the Banning fault. There is no evidence that thrusting has developed as an end stage of folding.

The anomalous radial drainage pattern of Beacon Hill, together with the quaquaversal dips of both the underlying fanglomerate and the semi-conformable capping of weathered material, indicates that folding probably is taking place here at the present time. Similar but less obvious deformation undoubtedly is progressing at many other places in the area, but exposures are too few to permit generalizations concerning the stress pattern.

MECHANICS OF THE BANNING-SAN ANDREAS FAULT SYSTEM

It has been established that right-hand strike-slip displacement has taken place on faults both northwest and southeast of San Gorgonio Pass, not only on the basis of geodetic observations (Meade, 1948; Whitten, 1948), but also from study of the earthquake displacements of 1857 in Tejon Pass (Lawson, et al., 1908; Wood, 1954) and 1940 in Imperial Valley (Buwalda and Richter, 1941). It seems likely that some component of this strike-slip strain continues into San Gorgonio Pass along the San Andreas fault from the northwest and along the Banning fault from the southeast. What, then, is the structural significance of an east-west thrust fault within San Gorgonio Pass itself?

A possible answer to the seemingly anomalous fault pattern of the pass is found in the structural analysis elucidated by Anderson (1951, pp. 7-21). Utilizing Mohr's theory of failure, Anderson relates normal, thrust, and "wrench" (strike-slip) faults to the three possible orientations of the maximum and minimum principal stresses, assuming one of the principal stresses to be vertical. An important assumption of Mohr's theory is that the intermediate principal stress has no effect upon the condition of yielding, and, although this has been shown to be invalid in some cases, Mohr's theory probably is the best available for application to the brittle crustal rocks of the earth (Nadai, 1950, pp. 224, 230).

Of particular interest is the situation in which the intermediate and maximum principal stresses are nearly equal. If, for example, the intermediate stress should locally exceed the maximum stress, and hence should become the new maximum stress itself, a completely different type of faulting would result <u>despite the fact that the over-all stress system had changed but slightly</u>. Anderson (1951, p. 20) uses this type of analysis to demonstrate the possible close relationship of thrust and strike-slip faulting, and the fault pattern of San Gorgonio Pass may well be an example of such a situation. Assuming the maximum principal stress to be in a generally north-south direction, with the minimum stress oriented east-west, strike-slip faulting of the San Andreas type would result when the stress differential became sufficiently large (fig. 15). If, now, the east-west least stress were very close in magnitude to the vertical stress, a slight local increase in the east-west compression could cause a sudden change in this area from northwest-trending strike-slip faulting to thrusting along east-west faults. Dehlinger (1952, p. 172) postulates such a situation in San Gorgonio Pass from seismic evidence alone.

The above argument assumes perfect homogeneity, but it may be that recently established lines of faulting in San Gorgonio Pass are controlled as much by previously existing zones of weakness as by variations in the regional stress pattern. It seems likely that northwest-trending faults are relatively recent features transecting a zone of much older east-west structures, and that within the pass the recent movement has been "deflected" along the older east-west Banning fault. The limiting of Recent activity to the eastern portion of the Banning fault tends to support this hypothesis. Furthermore, an old, deep-seated, east-west shear zone, well defined by cataclastic metamorphism of the crystalline complex, is known to exist in the foothills of the north side of the pass, and this sheared rock is far weaker than the rocks of the main mountain masses on the two sides of the pass. This line of reasoning does not in any way supplant the approach using Mohr's theory; in fact, it provides a reasonable mechanism for the proposed local stress variation in the pass area. It was noted that a slight increase in east-west compression might lead to thrust faulting; the same effect would be produced by a decrease of strength in the east-west direction, and this zone of weakness is exactly what is observed in the field.

In summary, recent movements on both the Banning and San Andreas faults probably are caused by an over-all stress system

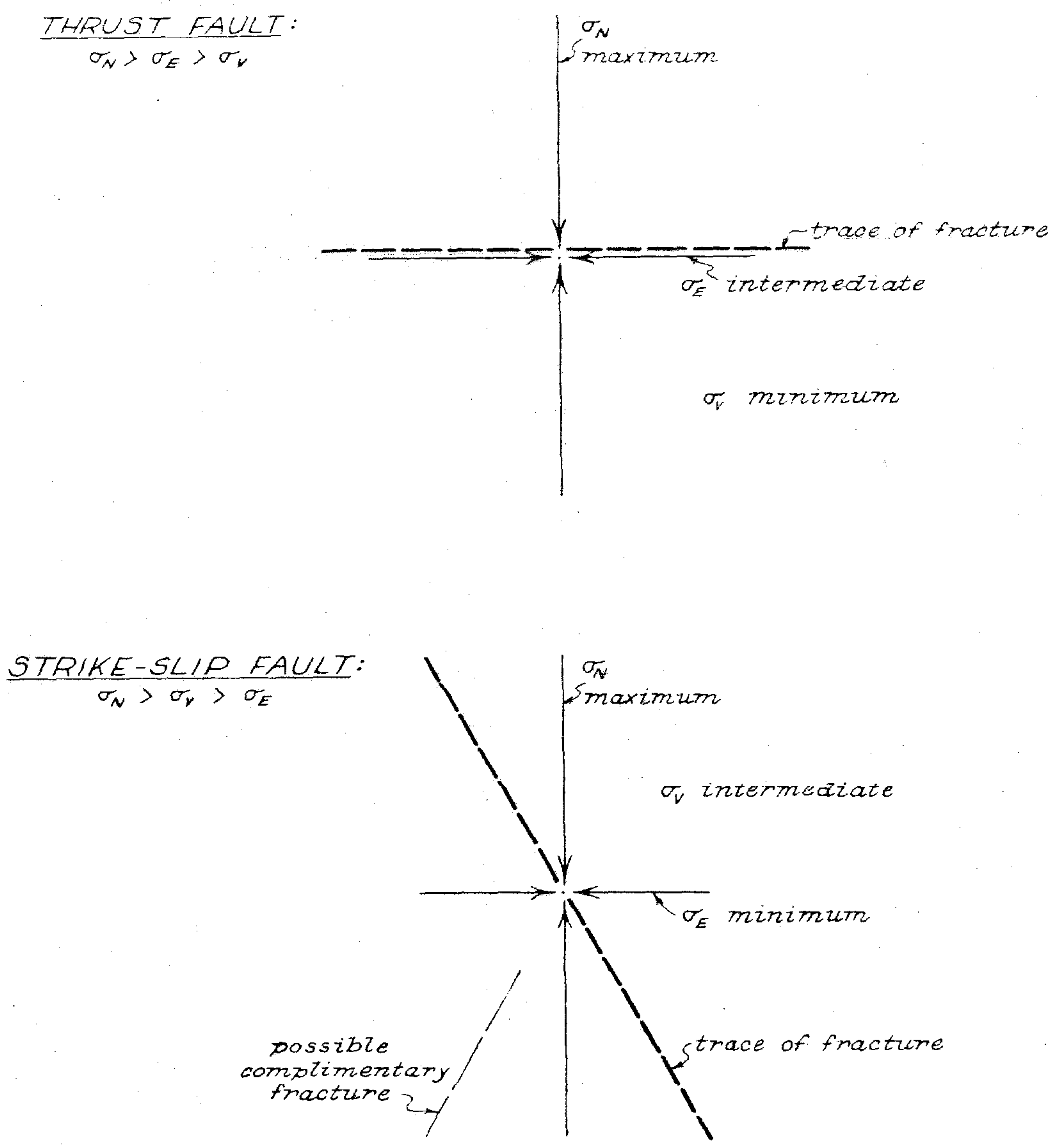


Figure 15. Plan view of principal stress relationships necessary to cause thrust and strike-slip faulting. Note that if the east-west and vertical stresses (σ_E and σ_V) are nearly equal, a very slight relative change in these stresses could cause a reversion from strike-slip to thrust faulting or *vice versa*.

involving a general north-south maximum stress and with the east-west least principal stress only slightly less than the vertical stress. In the vicinity of the pass, an older east-west line of weakness causes the east-west stress effectively to become the intermediate stress, and east-west thrust faulting predominates over strike-slip faulting in this one local area. Elsewhere along the San Andreas fault, where it cuts across all previous structures, the east-west principal stress either is much less than the vertical stress, or the structures in the old adjoining rocks are of insufficient continuity or weakness to modify the regional stress pattern.

THE PROBLEM OF LARGE LATERAL DISPLACEMENT

Hill and Dibblee (1953) recently have suggested that right lateral displacement along the San Andreas fault zone perhaps has totaled 65 miles since upper Miocene time, 225 miles since Eocene time, and 350+ miles since Jurassic time. Are such large lateral displacements compatible with structural relations within San Gorgonio Pass?

In connection with the problem of displacement on the San Andreas fault (p. 100), it has been noted that post-Jurassic displacements of hundreds of miles on any of the faults north of the Banning fault seem to be precluded by the nature and distribution of crystalline rock types on opposite sides of these faults. This evidence, however, does not rule out the possibility of lateral displacements amounting to several tens of miles.

Even lateral movements of a few tens of miles are difficult to reconcile with the complex surface geometry of faults within the pass area (pl. 1): the San Andreas fault appears to butt into the Banning fault and die out; the Mission Creek fault does not form a smooth curve with the San Andreas fault; and the Mill Creek fault probably dies out eastward. On the other hand, increasing evidence of ± 30 miles of late Tertiary lateral displacement along the San Andreas fault 50 miles northwest of San Gorgonio Pass (Noble, 1954) demands an explanation of how this strain has been transmitted farther southeast. Three possible views are:

(1) Much of the lateral strain along the San Andreas fault has been relieved by fraying-out into major branches, at least four of which diverge northward from the fault between Cajon Pass and San Gorgonio Pass. Southward, the San Jacinto fault (fig. 1) may have absorbed much of the regional strain; it is straighter, more continuous, and shows greater seismic activity than any faults of the San Gorgonio Pass area. Indeed, the general fraying-out of the San Andreas fault system in Southern California may be a good reason in itself for believing that the lateral strain thereby has been, and is being, dissipated.

(2) During periods of pre-Quaternary displacement in the pass area, the surface geometry of faults probably was different from that existing at the present time, so that, for instance, the Mission Creek fault then may have been aligned with the San Andreas fault to

absorb more easily the lateral strain.

(3) Lateral strain has been relieved to some degree by thrusting on east-west faults in the pass area, as has been discussed in connection with the mechanics of the Banning-San Andreas fault system.

The Banning fault is different from other faults in the pass area, in that it is a throughgoing fracture that separates very different crystalline rock types. Although Recent movements on this fault have been small, and post-San Timoteo(?) lateral displacement probably has been no greater than 5 miles, pre-Pliocene displacements may have been large. However, no evidence in this area demands large pre-Pliocene displacement.

In view of the increasing evidence of complexity of strike-slip faulting in southeastern California, the writer feels that the entire zone between the Elsinore fault and the eastern side of the Salton depression should be termed the San Andreas fault zone. We have, as yet, no evidence that any one particular fault within this 50 mile-wide zone truly deserves the parent name.

ORIGIN OF SAN GORGONIO PASS

There can be little doubt that faulting is the ultimate cause of the feature known as San Gorgonio Pass. But fundamental questions remain: to what degree is the present configuration of the pass caused by erosion in the fault zone rather than by actual fault movement, and why should such a deep gash occur between two of the highest mountains in Southern California?

The Banning fault is the logical northern boundary of the pass. Not only is its east-west trend parallel to the pass (fig. 3), but large post-Pliocene vertical movements on this fault can be deduced on the basis of independent stratigraphic evidence. Recent movements on the San Andreas fault have widened the pass at its western end, but the northwest trend of this fault eliminates it as a major break responsible for the pass itself, as has been pointed out previously by R. T. Hill (1928, p. 160) and Russell (1932, pp. 66-69). The slopes of San Jacinto Peak form the south wall of the pass (fig. 2), but, except for this precipitous scarp itself, there is no surficial evidence of Recent faulting south of the Banning fault. Furthermore, at the western extremity of the pass southeast of Beaumont, it can be demonstrated that no major east-west faults cut Pliocene-Pleistocene beds in the area south of the Banning fault. These beds are here depositional on the San Jacinto crystalline rocks (Fraser, 1931, p. 513). One might argue, therefore, that the pass is caused primarily by erosion in a wide zone of crushed rock, and is not the direct result of movements along bounding faults.

It is difficult, on the other hand, to explain the presence of fine-grained Pliocene marine beds in the very deepest and most rugged part of the pass if a predominantly erosional origin is postulated. These beds were deposited at sea level under conditions of somewhat lower topographic relief than exists today, and therefore they must be preserved in a relatively depressed fault block. Even should one postulate large lateral displacement on the Banning fault in post-Imperial time, this provides no more satisfactory solution of their present position. The present maximum elevation of 2500 feet of these marine beds reflects post-lower Pliocene uplift, perhaps by gentle arching along a north-south axis through the mountain peaks in a manner suggested by Sharp (1954). But still greater uplift along the bounding faults must have taken place in the adjacent crystalline rocks.

There seems to be no escape from the fact that another major break parallel to the Banning fault must underlie the alluvium at the base of the San Jacinto scarp near Cabazon. The northernmost spurs of San Jacinto Peak extend to within 2 miles of the Banning fault in this area, so that the down-faulted block between the two breaks is remarkably narrow in terms of its length. This hypothetical southern fault must die out westward, because no such break is present southeast of Beaumont. Inasmuch as the relief of the San Jacinto scarp gradually changes from 8500 to less than 300 feet in this same 20-mile interval, such a hinge-type displacement on the fault is reasonable.

The many dissected benches and terraces on both sides of San Gorgonio Pass testify to the removal of great amounts of material in Recent time, and upwarping of the pass area probably has caused removal of material from the floor of the pass itself. All of the foothills and remnants of fanglomerate certainly are not outlined by Recent faults, and the Banning fault-line scarp west of Millard Canyon owes its present relief to erosion. Nevertheless, considering the marine beds and other fine-grained deposits south of the Banning fault, it is difficult to see how erosion could be the primary cause of the present physiography of the pass. San Gorgonio Pass appears to be of composite origin, with faulting on the north and south predominant in its physiographic development.

The Banning fault is a reverse fault, and it therefore is likely that its hypothetical analogue across the pass to the south also is a reverse fault. Thus San Gorgonio Pass probably is a graben bounded by reverse faults, somewhat analogous to Willis's "ramp valley" (1928, p. 493) except that it is not clear whether the faults flatten with depth as visualized by Willis. Although this type of structure ordinarily has been considered unusual or "questionable" (Billings, 1942, p. 201), other Southern California examples of valleys bordered by reverse or thrust faults are known in the western Ventura basin (Reed and Hollister, 1936, pp. 101-104). Russell (1932, pp. 68-69) also tentatively postulated that San Gorgonio Pass is a dropped block bordered by thrust or reverse faults, although it is interesting that the one fault exposure at the mouth of Stubby Canyon from which Russell drew this conclusion is herein interpreted as a normal fault.

That such a deep gash as San Gorgonio Pass should separate two of the highest mountain peaks of Southern California is remarkable. But rather than visualizing the pass as a down-faulted block transecting a formerly continuous high mountain range, it is more reasonable that the mountains have reached their present heights because of faulting in the pass, as is indicated by the presence of fine-grained marine beds within the pass and by structural and stratigraphic evidence along the Banning fault. The mechanics of the Banning-San Andreas fault system suggest that reverse and thrust faulting in the pass area are caused by local "deflection" of San Andreas-type strain along an older east-west line of weakness. Thus, local conversion of strike-slip strain into vertical displacements on the bounding faults of San Gorgonio Pass is a reasonable explanation of both the pass itself and the unusually high peaks adjacent to it.

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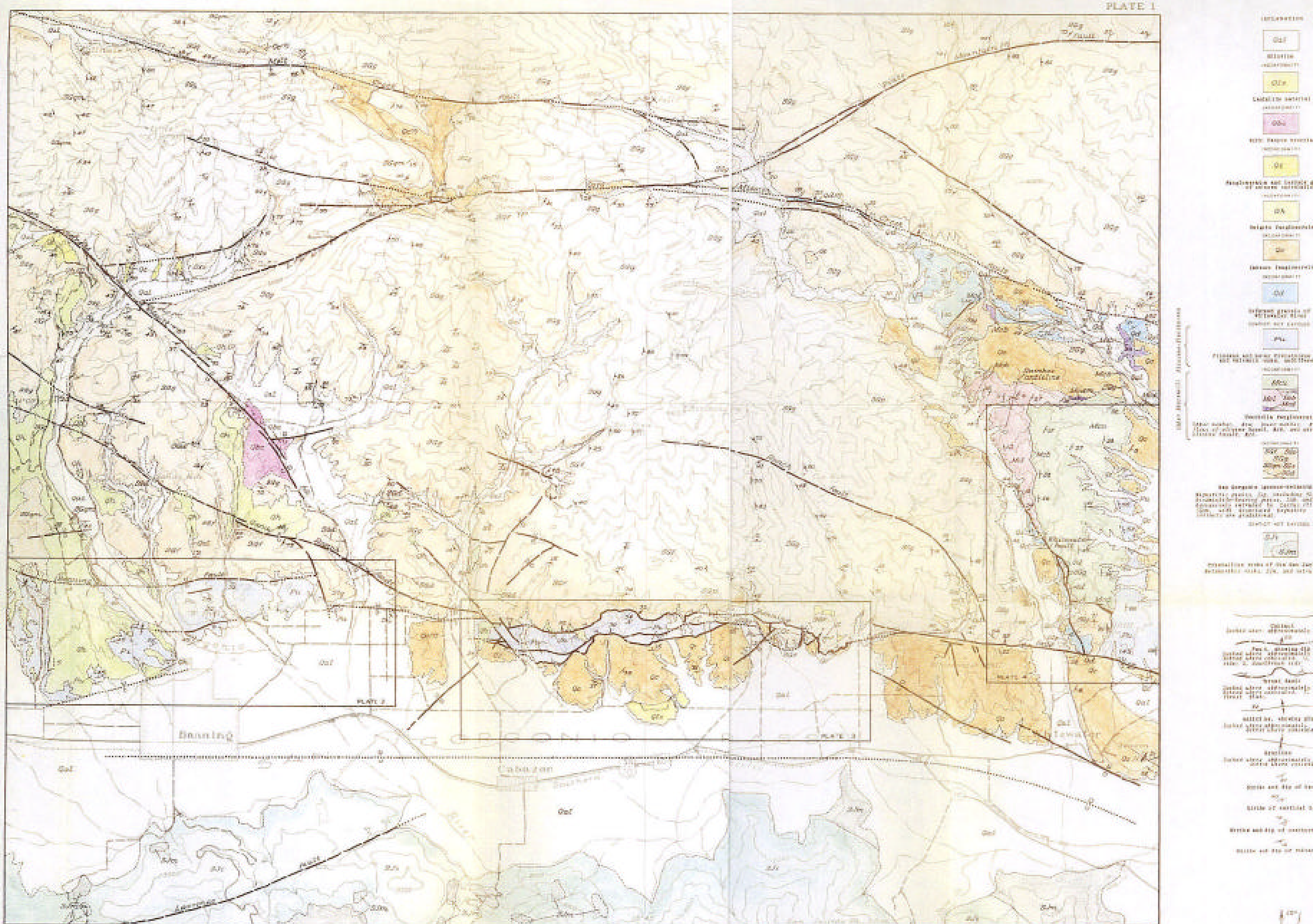


Base map south of 34°00' modified from Corps of Engineers, U. S. Army, 1943-1944
Base map north of 34°00' from air photographs; topography adapted from U. S. Geological Survey, 1903. Accuracy: poor.

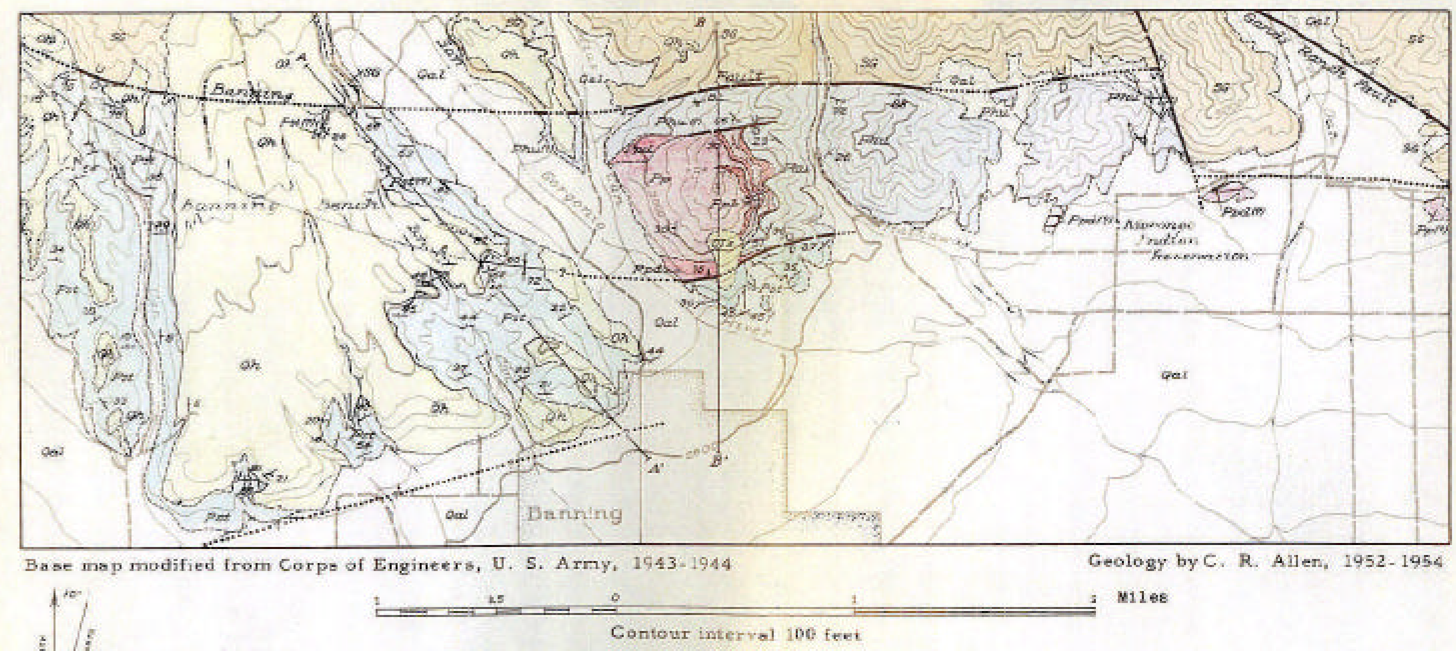
Geology north of San Gorgonio Pass by C. R. Allen, 1952-1954
Geology south of San Gorgonio Pass adapted from J. H. Fraser (1931)

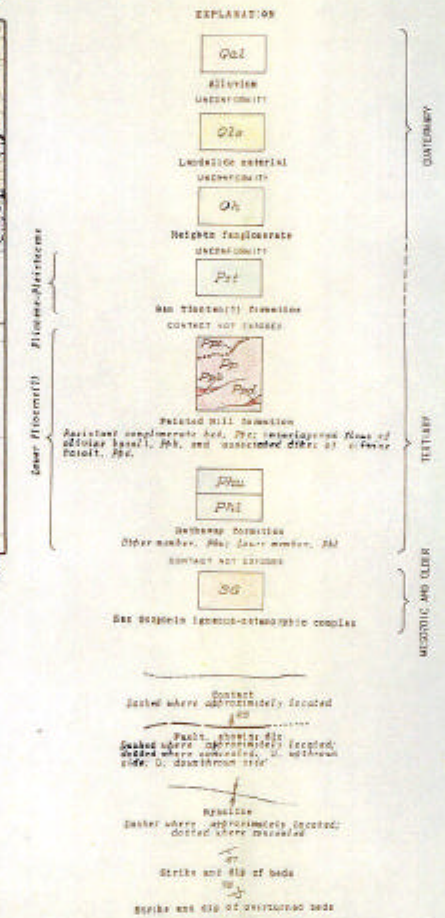
Miles

Contour interval 500 feet

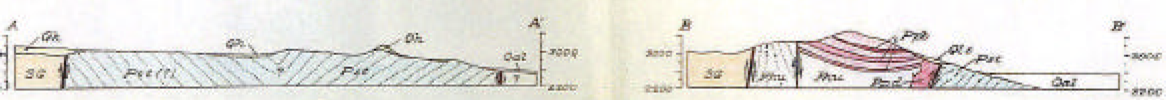
RECONNAISSANCE GEOLOGIC MAP OF THE SAN GORGONIO PASS AREA, SOUTHERN CALIFORNIA

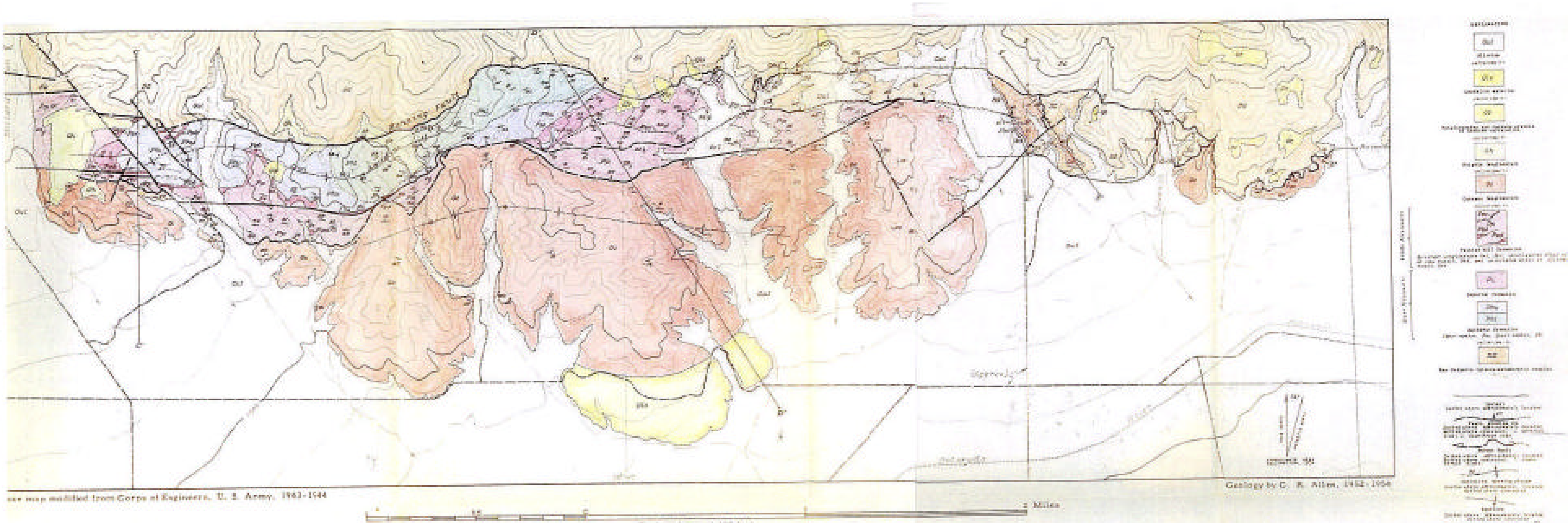
PLATE 2





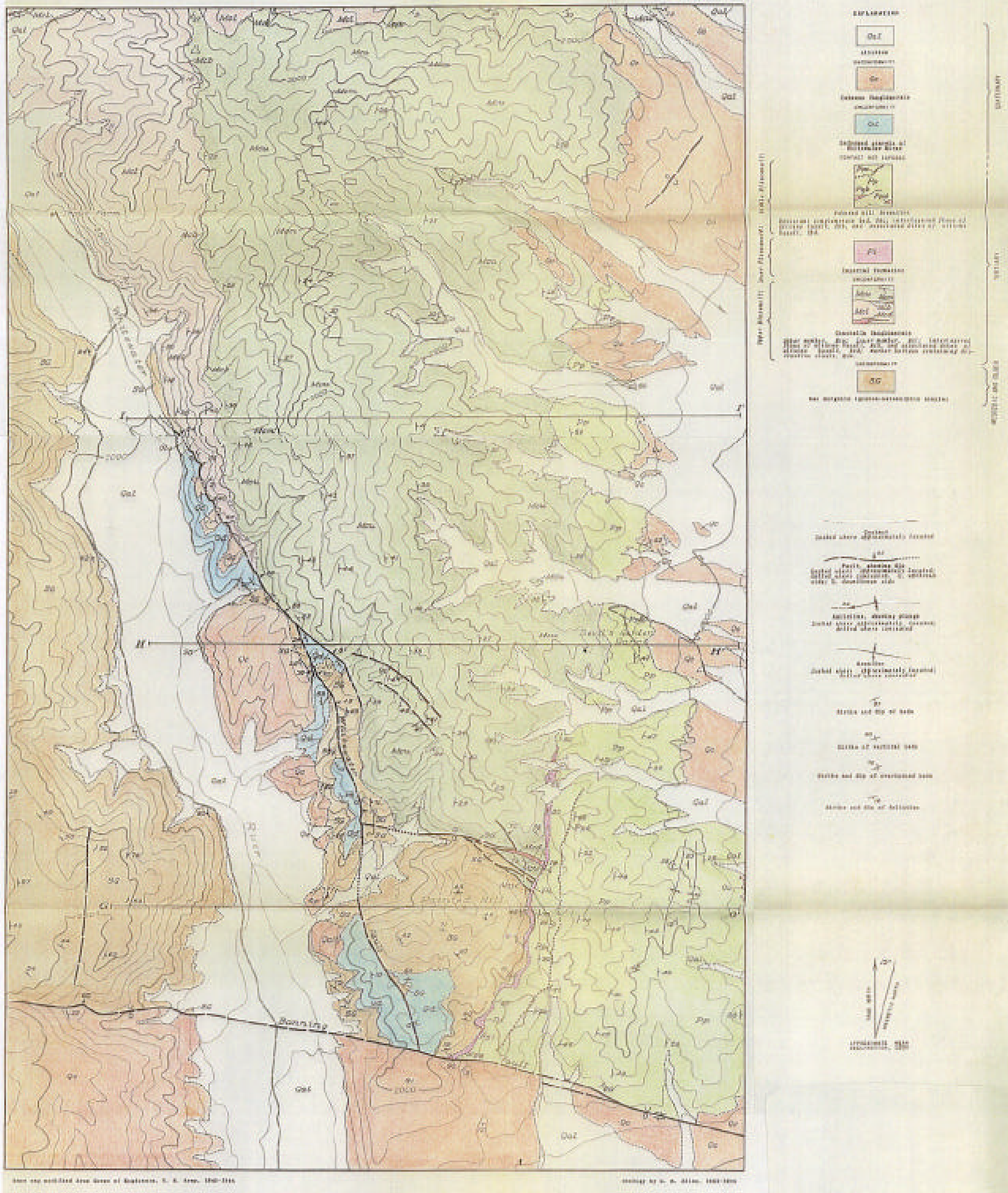
GEOLOGIC MAP AND STRUCTURE SECTIONS OF THE FOOTHILLS NORTH OF BANNING





GEOLOGIC MAP AND STRUCTURE SECTIONS OF THE FOOTHILLS BETWEEN MILLARD AND COTTONWOOD CANYONS

PLATE 4



Contour interval 100 feet

GEOLOGIC MAP AND STRUCTURE SECTIONS OF THE PAINTED HILL AREA