SAN ANDREAS FAULT IN SOUTHERN CALIFORNIA

A guide to San Andreas fault from Mexico to Carrizo Plain

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A guide to San Andreas Fault from Mexico to Carrizo Plain

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Plate 1 of first printing is obsolete, see Geologic Data Map No. 1 for pertinent fault data.

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OFFSET OF THE UPPER MIOCENE CALIENTE AND MINT CANYON FORMATIONS ALONG THE SAN GABRIEL AND SAN ANDREAS FAULTS

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ABSTRACT

A unique rapakivi-textured quartz latite porphyry and quartz monzonite porphyry occur in a Tertiary volcanic complex in the northern Chocolate Mountains northeast of the San Andreas fault. Identical porphyries occur as clasts in both the Miocene Mint Canyon Formation of Soledad Basin southwest of the San Andreas fault and the Miocene Caliente Formation of the Lockwood Valley - Quatal Canyon area west of the San Gabriel fault.

Deposition of the Mint Canyon Formation occurred within a broad westward draining trough which crossed the San Andreas fault near Soledad Pass. Conglomerate along the trough axis consists mainly of volcanic clasts, derived from the Chocolate Mountain volcanic complex, which include a small percentage of the unique quartz latite porphyry. Clasts in the northern and southern margins of the formation consist predominantly of locally derived basement rock types. Conglomerates of the Caliente Formation contain the same clast assemblage as occurs in the Mint Canyon Formation.

The Mint Canyon Formation is offset from the rapakivi source area by about 150 miles of right slip along the San Andreas fault and the Caliente formation is offset from the Mint Canyon Formation by about 35-40 miles of right slip along the San Gabriel fault, giving a total displacement of 185-190 miles along this part of the San Andreas system. This displacement is the same as that shown by pre-Cenozoic basement rocks. Since the youngest parts of the offset formations are about 12 my. old, the maximum age of this part of the San Andreas fault system is no greater than 12 my.

INTRODUCTION

The Mint Canyon Formation, described by Jahns (1940) and Oakeshott (1958), crops out in the Soledad Basin, 30 miles north of Los Angeles, and is situated between the San Gabriel and San Andreas faults, being truncated on the southwest by the San Gabriel fault. The Caliente Formation is widely exposed to the west of the San Andreas fault in the region southwest of Bakersfield. The part of the Caliente Formation referred to here, described by Carman (1964), crops out in the Lockwood Valley - Quatal Canyon area, directly west of the juncture of the San Gabriel and San Andreas faults. The Caliente Formation of the Caliente Range and Cuyama Valley area is described by Hill and others (1958). Both formations are of fluvial and lacustrine origin and contain vertebrate faunas spanning Medial Miocene to early Pliocene time (Jahns, 1940; James, 1963). Carman (1964, p. 42-43) concluded that the lower fluvial parts of the two formations were deposited in the same westward flowing drainage system and later off-set along the San Gabriel fault by about 20 miles of right slip, as was also postulated elsewhere by Crowell (1952). This conclusion was based on the similarity of clasts in conglomerate within the two formations, including anorthosite clasts, whose only known source is in the western San Gabriel Mountains, and volcanic clasts, foreign to both areas and assumed to be from the general area of the present Mojave Desert.

Among the volcanic clasts which occur in the Mint Canyon and Caliente formations is a unique rapakive-textured quartz latite porphyry. The identical rock occurs in place within the northern Chocolate Mountains on the east side of the San Andreas fault near the Salton Sea (Ehlig

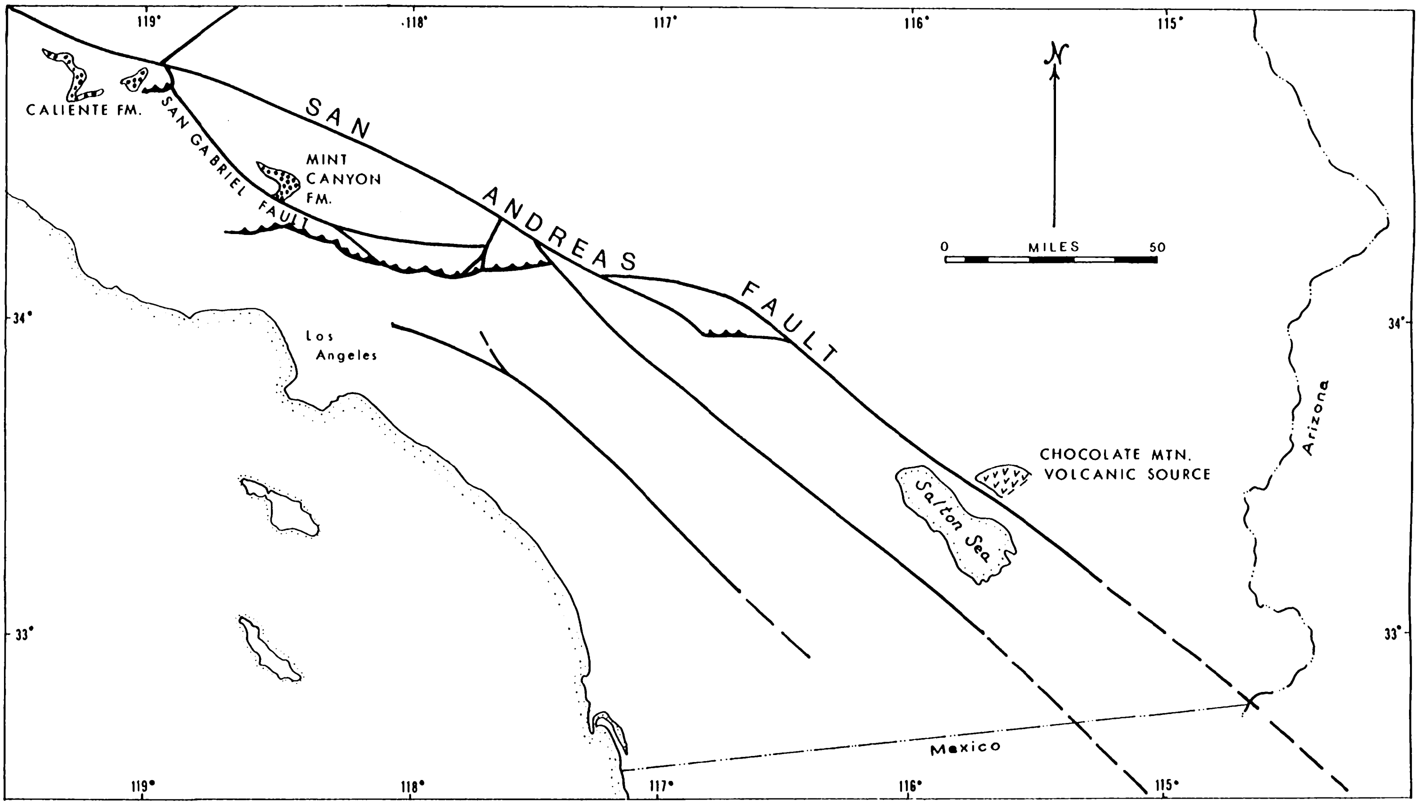
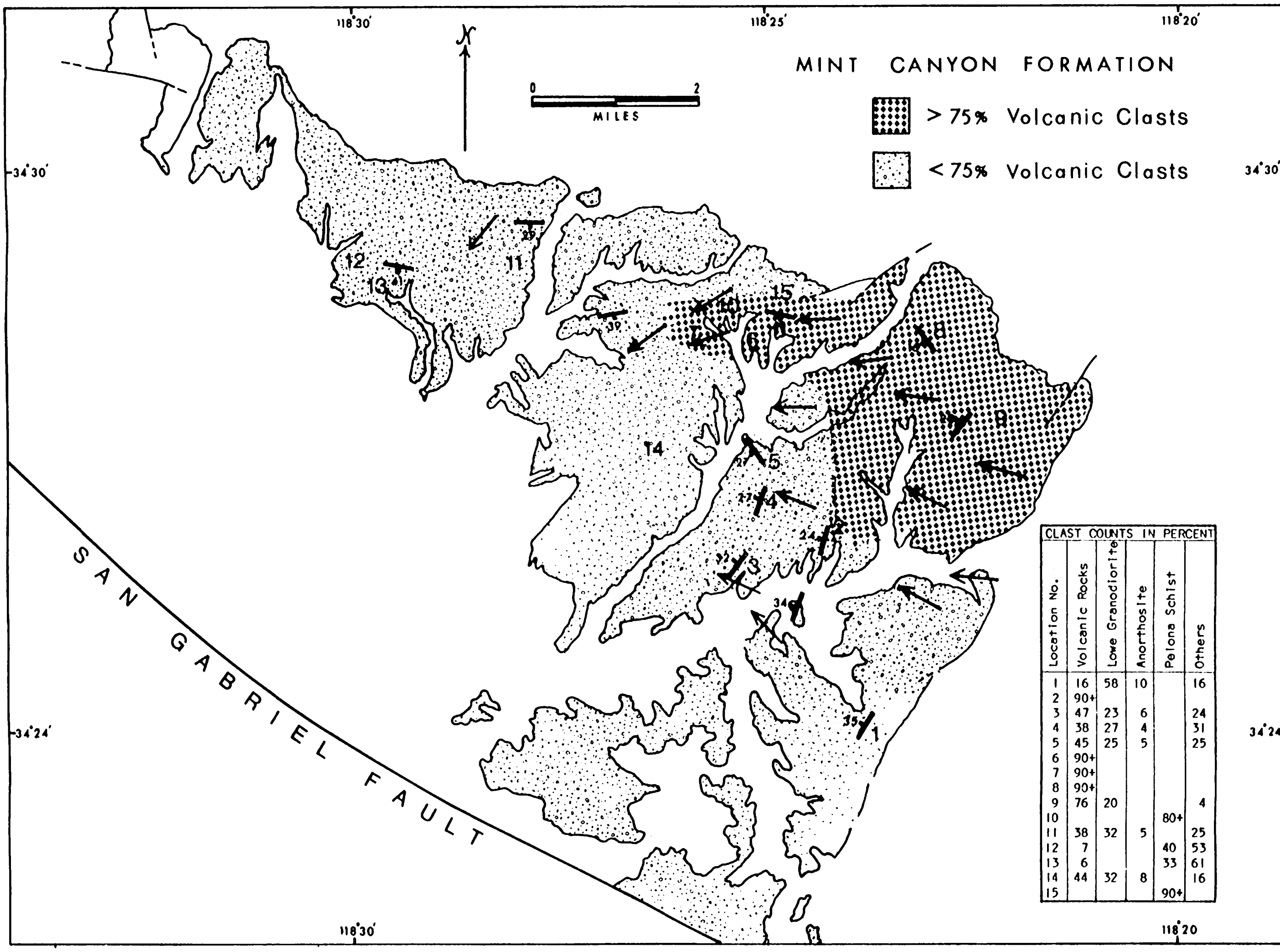


Figure 1.
Index map showing location of Mint Canyon Formation, Caliente Formation and Chocolate Mountain source terrane.

and Ehlert, 1972). Adjoining basement terrane in the Orocopia Mountains contains anorthosite, syenite, augen gneiss and Lowe Granodiorite identical in petrology, history and age to that of the Soledad Basin and western San Gabriel Mountains (Crowell and Walker, 1962; Silver, 1971). Other volcanic rocks strikingly similar to those found in both the Caliente and Mint Canyon Formations also occur in the northern Chocolate Mountains and are significantly different from other assemblages observed in volcanic terranes within the Mojave Desert. This, in combination with other findings summarized below, indicates Lockwood Valley and the Soledad Basin were located to the west of the northern Chocolate Mountains, near the present position of the Salton Sea, during Miocene deposition of the Caliente and Mint Canyon Formations.

DEPOSITIONAL ENVIRONMENT OF MINT CANYON FORMATION

The Mint Canyon Formation crops out in a broad southwestward plunging syncline within the central and southwestern Soledad Basin (Fig. 2). In most places it overlies a small and variable thickness of the Tick Canyon Formation which contains a late early Miocene vertebrate fauna significantly older than that found in the main body of the Mint Canyon Formation (Jahns, 1940, p. 169). The unconformity at the base of the combined Mint Canyon and Tick Canyon Formations transects a mosaic of west to southwest trending faults which were active both during and after deposition of the Oligocene - lower Miocene Vasquez Formation. Coarse locally derived conglomerate within the Tick Canyon Formation appears to fill canyons in a pre-existing topog-



Location No.	Volcanic Rocks	Lowe Granodiorite	Anorthosite	Pelona Schist	Others
1	16	58	10		16
2	90+				
3	47	23	6		24
4	38	27	4		31
5	45	25	5		25
6	90+				
7	90+				
8	90+				
9	76	20			4
10				80+	
11	38	32	5		25
12	7			40	53
13	6			33	61
14	44	32	8		16
15				90+	

Figure 2.
Map of the Mint Canyon Formation showing paleocurrent directions and clast type distribution.

raphy of moderate relief. The upper part of the formation includes much reddish sandstone and siltstone, perhaps reflecting the development of a broad valley of low relief. Jahns, (1940, p. 162) considers the contact between the Mint Canyon and Tick Canyon Formations as an unconformity; however, in the eastern part of the area the contact appears gradational. Here the transition is marked by a change from largely locally derived sediments to conglomerate and conglomeratic sandstone containing abundant exotic volcanic clasts. Thus, the onset of Mint Canyon deposition reflects an expansion of the area draining into the Soledad Basin.

The Mint Canyon Formation has an exposed thickness of about 6,000 feet along the axis of the Soledad Basin. Here it consists almost entirely of sandstone and conglomerate of fluvial origin. Strata exposed to the south and west are in large part of lacustrine origin. In the vicinity of Bouquet Canyon the exposed thickness is about 4,000 feet (Jahns, 1940, p. 162). Further northwest between San Francisquito and Elizabeth Lake Canyons, the Mint Canyon Formation is overlapped by the slightly younger marine Castaic Formation.

The northwestward thinning of the Mint Canyon Formation is partly the result of erosion prior to deposition of the Castaic Formation but also reflects original thinning toward the northern margin of the basin in which the Mint Canyon Formation was deposited. Paleocurrent measurements obtained within the fluvial part of the Mint Canyon Formation indicate current flow was essentially from east to west (see Fig. 2). The majority of the paleocurrent measurements were taken from scour and fill channels along with imbricate pebbles and cobbles.

Clast counts were made at numerous locations within the Mint Canyon Formation. A few representative ones are shown in Fig. 2. Clasts in the northern and southern margins of the formation consist predominantly of locally derived basement rock types, while clasts in the central part are dominantly of volcanic origin. The area shown in heavy pattern contains greater than 75 percent volcanic clasts, and much of this area contains over 90 percent volcanic clasts imbedded in a volcaniclastic matrix. The volcanic clasts are as much as 3 feet in diameter and are angular to subrounded. Although a small fraction of the Mint Canyon clasts appear to have come from the nearby Vasquez volcanics, most are foreign to the area and must have been derived from east of the San Andreas fault.

Included among the wide variety of volcanic clast types is a unique rapakivi-textured quartz latite porphyry; this rarely exceeds 5 percent of the total clasts.

We interpret the volcanic conglomerate to have been deposited along the axis of a broad alluvial wash. A modern analogy might be Salton Wash between the Orocopia and Chocolate Mountains.

The source areas of locally derived conglomerates place constraints on where the alluvial wash crossed the San Andreas fault. South of the volcanic conglomerate Lowe Granodiorite is the dominant clast type. The biotite-bearing facies of Lowe Granodiorite is particularly abundant. The occurrence of biotite-bearing Lowe Granodiorite basement is restricted to the northwestern San Gabriel Mountains just east of Soledad Pass. The main alluvial wash could not have crossed the San Andreas much further east than the present position of Soledad Pass. Anorthosite clasts are also common in the southern area but are generally only a fourth to a fifth as abundant as Lowe Granodiorite. This suggests that the anorthosite terrane of the western San Gabriel Mountains was either largely buried beneath an alluvial cover or was an area of very low relief. Volcanic clasts occur in the southern area but are much less abundant than in the central region and include a high proportion of volcanic types derived from the Vasquez Formation. Vasquez volcanics cap basement rocks in the Soledad Pass area today and probably capped basement rocks in a part of the western San Gabriel Mountains during the Miocene.

Clasts along the northern margin of the Mint Canyon Formation are generally small and consist of rock types exposed a short distance to the north and northeast. Clasts from the syenite and blue-quartz granite exposed along the west side of Soledad Pass occur scattered among volcanic clasts in the northeastern part of the volcanic conglomerate. West of Mint Canyon, clasts of Pelona Schist are abundant near the base of the formation and locally form beds of monolithologic breccia. Pelona Schist underlies Sierra Pelona to the north of the Soledad Basin and the base of the Mint Canyon Formation rests directly upon Pelona Schist between Bouquet and San Francisquito Canyon. West of Bouquet Canyon there are abundant clasts of brown sandstone and reworked pebbles and cobbles from the Paleocene Francisquito Formation which crops out west of Sierra Pelona. Thus, the distribution of locally derived clasts requires the alluvial wash to have crossed the San Andreas fault in the general vicinity of Soledad Pass.

Lake deposits consisting of interbedded sandstone, siltstone and claystone dominate the northwestern and southern exposures of the Mint Canyon Formation. The tracing of mappable beds indicates most of the lake deposits are stratigraphically higher than the volcanic conglomerate. Their occurrence close to the base of the formation in the northwestern and southern exposures is attributed to onlapping of strata onto the basin margin following deposition of the volcanic conglomerate along the axis of the basin.

CALIENTE FORMATION

The Caliente Formation crops out almost continuously in a northwest-southeast direction from Lockwood Valley to the central part of the Caliente Range, a distance of about 50 miles. Near the southern edge of Lockwood Valley it laps out against basement rocks and is overlain by the Lockwood Clay (Carman, 1964, p. 38). In the Caliente Range and to the south of Cuyama Valley it grades westward into the marine Branch Canyon Formation (Hill and others, 1958, p. 2991). Thus, the Caliente Formation was deposited as a piedmont alluvial fan on a north-northwest trending coastal plain. Regional drainage must have been essentially from east to west.

Conglomerate beds within the Caliente Formation of the Lockwood Valley-Quatal Canyon area contain clast types strikingly similar to those found in conglomerates of the lower part of the Mint Canyon Formation. Clasts are generally smaller and more rounded than in the Mint Canyon Formation, but the suite of clast types is the same. In most places 50-75 percent of the clasts are of volcanic origin. Included among the volcanic clast types is the unique rapakivi-textured porphyry. Lowe Granodiorite comprises 10-20 percent of the clasts within the southeastern part of the area and is present in lesser amounts within the northwestern part of the area. Anorthosite is widespread but probably does not exceed 10 percent of the clasts at any location. Clasts of Pelona Schist are common throughout the area and are locally abundant in Quatal Canyon. Other clast types include syenite and blue-quartz granite, brown sandstone - probably reworked from the Paleocene Francisquito Formation, and common types of granitic rock.

GEOLOGY OF THE CHOCOLATE MOUNTAIN SOURCE TERRANE

A mid-tertiary volcanic terrane containing the same hypabyssal and extrusive volcanic rock types as those that occur as clasts in the Mint Canyon Formation, including the rapakivi-textured porphyry, is located 150 miles southeast of the Mint Canyon Formation in the northern Chocolate Mountains, east of the San Andreas fault. Rapakivi-textured rocks occur at several locations within the range but the unique rapakivi-textured quartz latite porphyry found as clasts in the Mint Canyon and Caliente Formations is limited to the northern Chocolate Mountains. A pluton of several square miles consisting of rapakivi-textured quartz monzonite porphyry occurs along the western margin of the range southeast of Salton Wash. The pluton is cut by a myriad of steeply inclined northwest-trending dikes varying from rhyolite to andesite in composition. Northeast of the pluton rapakivi-textured dikes intrude older crystalline rocks. These dikes are probably offshoots of the pluton. The dikes are commonly ten to twenty feet thick, steeply inclined, and north to northwest trending. Red colored rapakivi-textured extrusive rocks have not been found in place but occur in alluvial terraces along the northern edge of the Chocolate Mountains.

Other types of volcanic rocks in this area include andesitic to rhyolitic dikes in part related to small plutons and intermediate to silicic flows, domes, and ignimbrites that crop out primarily in the eastern part of the range. During the Miocene, the volcanic cover was probably much more extensive than today.

DESCRIPTION OF RAPAKIVI TEXTURED ROCKS

The unique rapakivi-textured rocks which occur in outcrop within the northern Chocolate Mountains and as clasts in the Caliente and Mint Canyon Formations are characterized by numerous phenocrysts of conspicuously mantled feldspar. The rocks fall into three groups: (1) light-colored quartz monzonite porphyry typical of the pluton in the northwesternmost Chocolate Mountains; (2) quartz latite porphyry with light-colored feldspar phenocrysts in a dark gray fine-grained to aphanitic groundmass typical of the dike rocks, and (3) red quartz latite porphyry of probable extrusive origin.

The most distinctive type is the dike rock in which feldspar phenocrysts constitute about a third of the rock and form stout single crystals and nearly equant glomeroporphyritic masses. The phenocrysts are generally 5 to 10 mm wide with some attaining 20 mm. The pinkish potash feldspar phenocrysts are typically mantled by a white rim of oligoclase about 1 mm wide with a few crystals containing andesine cores. Composite phenocrysts contain potash feldspar and plagioclase phenocrysts snowballed together and surrounded by a mantle of oligoclase. Some plagioclase phenocrysts contain abundant inclusions of biotite and show a complex growth history of zoning and resorption. In some of the rocks plagioclase is mantled by potash feldspar. Clots of fine-grained plagioclase, biotite, and hornblende are dispersed through most rocks. Some clots are partially rimmed by oligoclase. The dikes also contain small phenocrysts of quartz, biotite and hornblende. The matrix is composed of very fine-grained quartz, feldspar and biotite. Granophyric and myrmekitic intergrowths are common. Reddish brown allanite is a minor accessory. Chemical analyses of six samples of this type of rock are shown in Table 1 (analyses CH-1, CH-2, MT-1, MT-2, CA-1 and CA-2). Dike rocks containing sparse phenocrysts also occur but are less abundant than the type described above. One sample from each area has been chemically analyzed (CH-3, MT-3, CA-3).

The rapakivi-textured quartz monzonite porphyry is similar to the dike rocks described above except for a coarser grained matrix. Feldspar phenocrysts are the same size as in the dike rocks, generally constitute 10 to 20 percent of the rock. Biotite is oxidized to hematite. Some specimens contain small irregularly shaped gas cavities. The single chemical analysis of this type of rock (MT-5 in Table 1) indicates less SiO_2 and more Al_2O_3 than in the other rocks analyzed. This appears to be due to kaolinization of feldspar in the matrix.

OTHER VOLCANIC ROCKS

In addition to rapakivi-textured rocks, exotic clasts within the Caliente and Mint Canyon Formation include minor olivine basalt and mafic andesite, abundant intermediate flow-rock varieties ranging from porphyritic pyroxene andesite to hornblende dacite, abundant flow-banded dacite to rhyolite, and biotite-sanidine rhyolite. All of these rock types occur in the Chocolate Mountains. Some are present as hypabyssal intrusions within the range and the others occur in lava flows, domes and pyroclastic deposits along the northeastern flank of the range.

DISCUSSION

Rapakivi-textured clasts in the Mint Canyon and Caliente Formations are so unique and so similar to rocks in the northern Chocolate Mountains as to leave no doubt that the Chocolate Mountains are their source. These rocks are unique due to a combination of coexisting features including abundance, size and shape of feldspar phenocrysts; the presence of mantled feldspars; other textural features and variations in textures, and the presence of allanite as a minor accessory. The suite of volcanic clasts in which the rapakivi-textured rocks occur matches volcanic rocks within the Chocolate Mountains but is different from assemblages found in other volcanic terranes in southern California.

TABLE 1. CHEMICAL ANALYSES OF RAPAKIVI TEXTURED ROCKS

	CH-1	CH-2	CH-3	CH-4	CH-5	MT-1	MT-2	MT-3	MT-4	MT-5	CA-1	CA-2	CA-3
							(wt %)						
SiO_2	69.29	67.11	69.87	71.08	75.28	70.05	69.22	69.19	68.42	68.01	71.87	70.43	72.25
Al_2O_3	14.65	15.76	14.94	15.30	13.66	14.36	14.54	15.88	15.49	17.51	14.55	14.58	13.89
Fe_2O_3	3.71	4.35	3.09	1.95	0.11	3.45	3.13	2.97	3.94	2.80	2.20	2.88	2.68
MgO	0.58	0.65	0.89	0.37	0.11	0.59	0.47	0.77	0.50	0.37	0.41	0.47	0.49
CaO	1.06	1.31	1.52	1.04	0.63	1.19	1.18	1.50	1.02	1.33	1.02	0.89	1.01
Na_2O	4.16	4.18	4.24	4.04	4.05	4.12	4.27	4.30	3.98	3.87	4.01	3.91	3.83
K_2O	4.23	4.05	3.23	4.42	4.61	4.26	4.31	3.92	4.12	3.74	4.25	4.18	4.42
TiO_2	0.51	0.51	0.50	0.42	0.37	0.51	0.50	0.51	0.48	0.52	0.49	0.51	0.47
P_2O_5	0.10	0.14	0.09	0.12	0.11	0.10	0.10	0.13	0.11	0.11	0.13	0.09	0.11
MnO	0.08	0.09	0.08	0.05	0.05	0.08	0.06	0.08	0.05	0.05	0.05	0.06	0.05
							(ppm)						
Rb	170	130	119	170	184	161	164	114	178	125	184	172	190
Sr	159	119	160	160	144	120	143	221	119	241	195	91	119

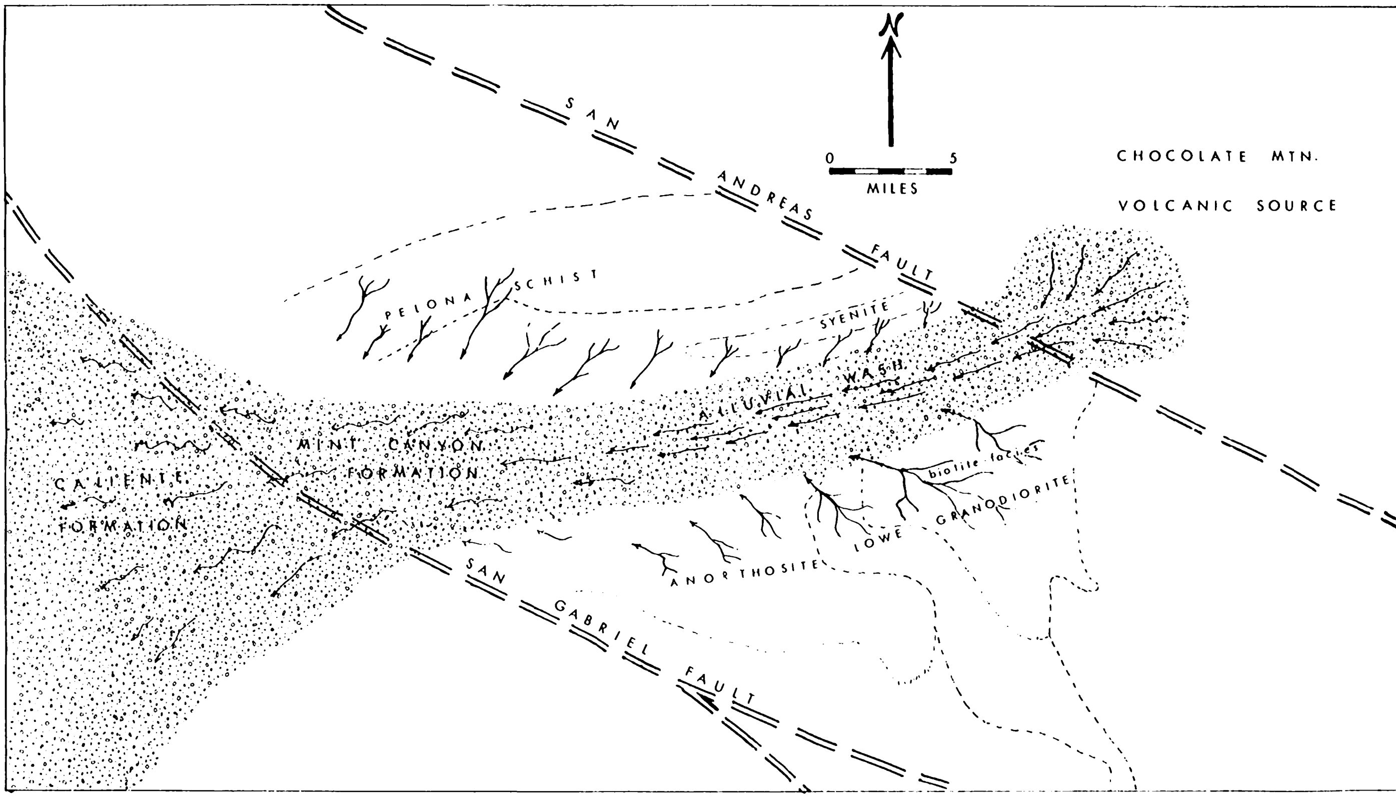


Figure 3.
Postulated drainage pattern during deposition of lower part of Mint Canyon and Caliente Formation before movement began along San Andreas and San Gabriel faults.

The Mint Canyon Formation must have been deposited in close proximity to the Chocolate Mountains as inferred from the angularity of volcanic clasts and the absence of clasts from source areas other than the Chocolate Mountains and the region around Soledad Basin. Paleocurrent data and the distribution of locally derived clasts, particularly Lowe Granodiorite, indicate the Mint Canyon Formation was deposited in a westward draining trough which crossed the San Andreas fault in the vicinity of Soledad Pass. A minumum offset reconstruction would place Soledad Pass approximately opposite the mouth of Salton Wash during deposition of the Mint Canyon Formation and would require about 150 miles of right slip along the San Andreas fault since deposition of the Mint Canyon Formation.

The Caliente Formation of the Lockwood Valley - Quatal Canyon area has the same clast assemblage as the Mint Canyon Formation, including clasts derived from pre-Miocene rocks on both sides of the Soledad Basin and volcanic clasts from the Chocolate Mountains. Since the two formations are the same age and contain the same clast suite, they must have been deposited in the same trough and subsequently have been separated by right slip along the San Gabriel fault. A reasonable reconstruction indicates 35 to 40 miles of offset.

The above offsets are the same as those derived from correlation of basement rocks across the San Gabriel and San Andreas faults (Crowell, this vol.) and thus indicate faulting commenced after deposition of at least the lower half of the Mint Canyon Formation and most of the

Caliente Formation. Carman (1964, p. 42-43) notes that the upper part of the Caliente Formation is of local origin and may have been deposited after the San Gabriel fault began to move. The extensive lake deposits within the upper half of the Mint Canyon Formation were probably formed after the Caliente Formation was cut off from the Soledad Basin. The lower part of the Mint Canyon Formation contains a Barstovian fauna and the upper part contains a Clarendonian fauna (Durham and others, 1954, p. 66-67). The Caliente has about the same age range (James, 1963). Correlations by Turner (1970, p. 112) place the Barstovian - Clarendonian boundary at 12 to 13 my. This is a maximum age for the San Gabriel fault and is probably close to its true age since marine rocks of Mohnian age are offset only about 20 miles (Crowell, 1952). Turner (1970) believes the Mohnian stage occurred about 10 to 12 my. ago. The southern part of the San Andreas fault is probably younger than the San Gabriel fault but how much younger is unknown.

The offsets described above indicate a total displacement of 185-190 miles of right slip along the southern half of the San Andreas fault system within the past 12 my.

ACKNOWLEDGMENTS

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SECTION 5

Field Trip Guide

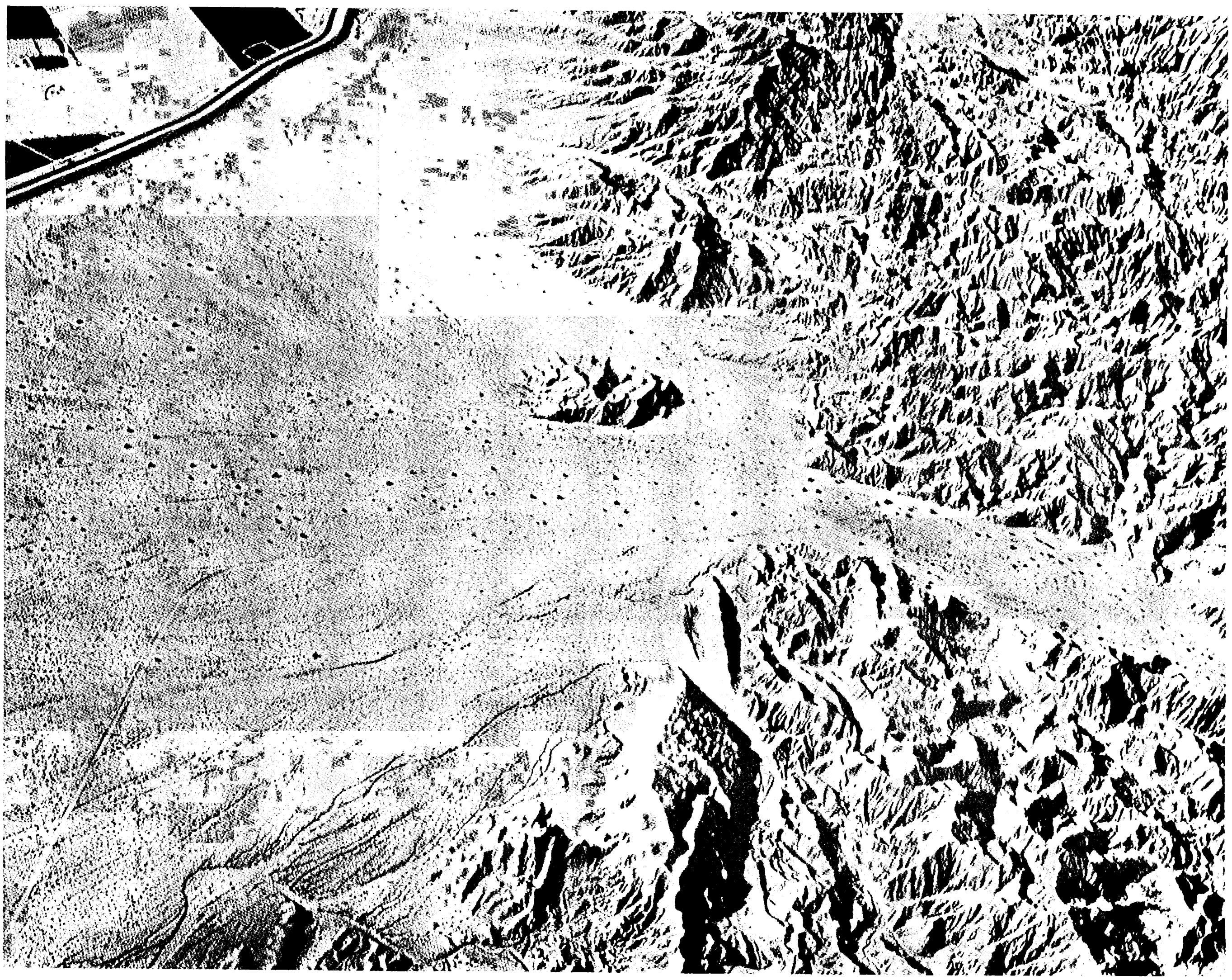

Photo 9. Mouth of Painted Canyon, Mecca Hills, looking northwest. Skeleton Canyon, in foreground immediately to right of the darkly shadowed hills, contains the trace of San Andreas fault.
J. S. Shelton Photograph No. 6818, 24 Nov. 1974, 6500 ft. elevation.

[Continue west on Soledad Canyon Rd. for another 10 miles. Pass under freeway (State 14) then turn right 0.4 mi. further onto Shadow Pines Blvd. Go 0.7 mi. to end and then 1 block west to Abelia Rd.; turn right and continue north 0.4 mi. to side road on right leading into Tick Canyon Wash. Park along wash.]

Tick Canyon Stop

The area is underlain by westward-dipping sandstone and conglomerate of the upper Miocene Mint Canyon Formation. Notice that most of the clasts in the conglomerate are of volcanic origin. A few of the clasts contain abundant phenocrysts of mantled feldspar (rapakivi texture). These clasts are derived from dikes near the northern end of the Chocolate Mountains. The other volcanic clasts are also characteristic of volcanic rocks exposed in the Chocolate Mountains (see Ehlig and others, this vol.). Also, note channelling and clast imbrication indicating sediment transport from east to west.

[Return to Soledad Canyon Rd. and go 2 miles west to Sand Canyon Rd.; turn right and go 0.9 mi. north.]