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BASIN ANALYSIS OF THE MIOCENE MINT CANYON FORMATION, SOUTHERN CALIFORNIA

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ABSTRACT

The nonmarine upper Miocene Mint Canyon Formation crops out in a broad westward plunging syncline within the Soledad basin, about 48 km north of Los Angeles, California, and is situated between the San Andreas and San Gabriel faults. The formation is comprised of fluvial and lacustrine deposits.

Clast counts and paleocurrent measurements indicate that the fluvial portions of the Mint Canyon Formation were deposited in a broad westward draining trough. Sediments along the flanks of the trough are of local derivation, but conglomerate along the axis of the trough is derived from volcanic terrane east of the San Andreas fault. Among the wide variety of volcanic clast types is a unique rapakivi-textured quartz-latite porphyry. A tertiary volcanic field, located about 240 km southeast of the Mint Canyon Formation east of the San Andreas fault, contains the same variety of volcanic rock types as those that occur as clasts in the Mint Canyon Formation, including the unique rapakivi-textured porphyry.

Conglomerate beds within the Caliente Formation of the Lockwood Valley-Dry Canyon area, located west of the San Gabriel fault and about 70 km north of the Mint Canyon Formation, contain the same clast types as those that occur in the Mint Canyon Formation, including the unique rapakivi-textured porphyry.

These data indicate that the Mint Canyon Formation is offset from the volcanic source area by about 240 km of right slip along the San Andreas fault and that the Caliente Formation is offset from the Mint Canyon Formation by about 70 km of right slip along the San Gabriel fault.

INTRODUCTION

The Mint Canyon Formation is a Miocene sedimentary unit of fluvial and lacustrine origin that crops out as a broad westward plunging syncline in the Soledad basin, approximately 48 km north of Los Angeles, California (Figure 1). The formation was named by Kew (1923) and has been described by Hershey (1902), Jahns (1939,1940) and Oakshott (1958).

The Mint Canyon Formation is situated in a structural block bounded by the San Andreas and San Gabriel faults and is truncated on the southwest by the San Gabriel fault (Figure 1). Basement rocks of the western San Gabriel Mountains border the formation on the southeast and Pelona Schist of Sierra Pelona borders portions of its northwestern margin. As mapped by Jahns (1940) and Oakshott (1958), the Mint Canyon Formation unconformably overlies the nonmarine Miocene Tick Canyon and lower Miocene Vasquez formations and is unconformably overlain by the marine Miocene Castaic Formation (Figure 1).

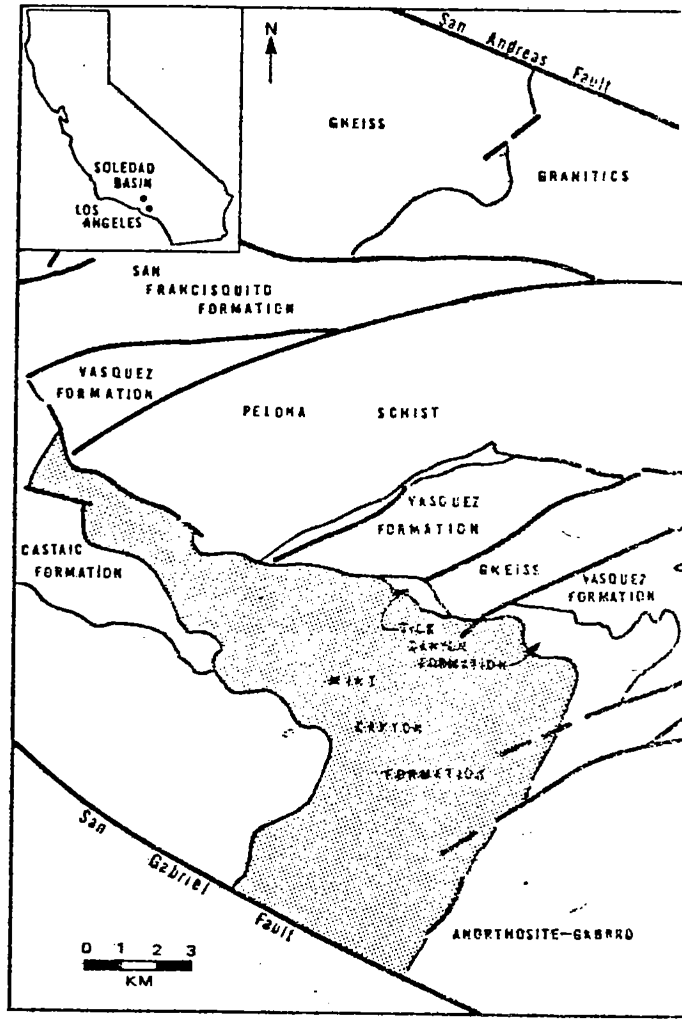

Figure 1. Sketch geologic map of the Soledad basin area.

The purpose of this study was to determine the depositional history of the Mint Canyon Formation and to reconstruct the paleogeography and paleogeology, especially as it relates to the San Andreas and San Gabriel faults. Over 130 clast counts were performed, more than 50 paleocurrent directions were measured, and source areas were identified for most of the rock types that occur as clasts in the Mint Canyon Formation. In addition, systematic detailed observations of the lithology, sedimentary structures and other features were made throughout the formation.

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Several reconnaissance trips were performed to areas within and near the Soledad basin and along the San Andreas and San Gabriel faults to identify potential clast source areas.

AGE OF THE MINT CANYON FORMATION

On the basis of a small vertebrate fauna, Kew (1923) assigned the Mint Canyon Formation to the upper Miocene. Stirton (1933) reviewed the Mint Canyon fauna, and using horse teeth, correlated the Mint Canyon Formation to the Ricardo Formation in the Mojave desert, and placed the Mint Canyon Formation in the lower Pliocene (Clarendonian).

Jahns (1939,1940) identified a late early or earliest medial Miocene vertebrate fauna (oreodont) from the basal part of the Mint Canyon Formation between Mint and Bouquet canyons (Figure 2). He concluded that there must be a significant time gap between the beds which yielded this fauna and beds higher up in the formation which yielded a late Miocene fauna. He, therefore, redefined the basal part of the formation as the Tick Canyon Formation and suggested that the two formations were separated by a slight angular unconformity. Jahns delineated the Tick Canyon Formation in two separate areas. The western area is located between Mint and Bouquet canyons, where the oreodont was found. The eastern area is located east of Mint Canyon (Figure 2). Jahns named the basal part of the Mint Canyon Formation the Tick Canyon Formation because of the "excellent exposures near an abandoned borax mine at the head of Tick Canyon". However, the type location is located between Mint and Bouquet canyons.

Durham, Jahns and Savage (1954) indicated that two distinct faunas occur in the Mint Canyon formation. Barstovian (late Miocene) fauna occur in the lower part of the formation and Clarendonian (early Pliocene) occur in the upper part of the formation.

STRATIGRAPHIC RELATIONSHIPS

Figure 1 shows the distribution and stratigraphic relationships of the Mint Canyon Formation as mapped by Jahns (1940), Jahns and Muehlberger (1954) and Oakshott (1958). On the northwest, the Mint Canyon Formation lies unconformably on Pelona Schist and gneiss. To the southeast, Mint Canyon beds lie unconformably on anorthositic and gabbroic rocks of the western San Gabriel Mountains. In most other places, the Mint Canyon Formation overlies the Tick Canyon Formation. Although the Mint Canyon Formation has been previously mapped as unconformably overlying the Tick Canyon Formation for reasons presented below, my work raises doubts concerning the validity of the Tick Canyon Formation as a stratigraphic unit separate from the Mint Canyon Formation. In addition, the regional relationship between the Mint Canyon Formation and overlying Miocene marine Castaic Formation has not been resolved in the published literature and is discussed below.

Relationship Between the Mint Canyon and Tick Canyon Formations

Jahns (1939,1940), described the type Tick Canyon Formation as resting unconformably on coarse conglomerate of the Vasquez Formation and consisting of about 200 m of red and reddish brown clay (in part lacustrine), siltstone and sandstone, with an irregular zone of cobble to boulder conglomerate at the base. He indicated that, although there is but one slight indication of angular discordance between these beds and overlying Mint Canyon beds, faunal differences indicate a disconformity. Jahns further concludes that the unconformable nature of the contact is evidenced by a general change in lithology, certain minor structural discrepancies, and by the irregular distribution of the Tick Canyon beds. He places the Mint-Tick contact at the base of a thick conglomerate zone rich in Pelona Schist debris. Oakshott (1958) mapped the boundary between the two formations in this area at the same location as Jahns (1940) (Figure 2).

My own work indicates that sediments stratigraphically above and below the contact of the type Tick Canyon Formation and the Mint Canyon Formation are similar in color and lithology, and contain abundant Pelona Schist fragments throughout. No evidence of an unconformity was observed. Relationships across the contact zone are gradational, with a progressive increase of Pelona Schist fragments higher in the section.

There may be a problem regarding the ages assigned to the type Tick Canyon Formation and the Vasquez Formation of Texas Canyon, which unconformably underlies the type Tick Canyon Formation. Bohannan (1975) considers the upper part of the Vasquez Formation in the Texas Canyon area to be approximately 22 m.y. old based on K-Ar radiometric ages obtained from volcanic rocks in the Vasquez Formation. Woodburne (1975) considers the oreodont Merychyus calamanthus, which Jahns (1939) identified from the Tick Canyon Formation, to be similar size and morphplogy to M. calamanthus collected from the Hector formation of the southwestern Cady Mountains. Woodburne (1974) radiometrically dated a tuff bed which occurs in the Hector formation 70 m stratigraphically above the fossil quarry at 21.0±5% m.y. (Arikareean land-mammal age).

If the above age assignments are correct, deformation and erosion of the uppermost beds of the Vasquez Formation and deposition of the type Tick Canyon Formation occurred over an unusually short interval of time.

The lithologic relationships between the type Tick Canyon Formation and Mint Canyon Formation, and age relationships between the Tick Canyon and Vasquez formations, as described above, suggest that age affinities assigned to vertebrate fauna of the type Tick Canyon Formation should be reappraised, or that one or more of the radiometric dates may be in error.

Based on the occurrence of similar rock types, Jahns and Muehlberger (1954) remapped the lowermost part of the Mint Canyon Formation east of Mint Canyon as the Tick Canyon Formation (Figure 2). They redefined the basal part of the Mint Canyon Formation as a moderately resistant light-gray to tan conglomerate horizon, which crops out 1.6 km south of Davenport Road between Mint and Tick canyons. My work shows that clasts within this basal conglomerate consist dominantly of light-colored pebbles and cobbles of fine-grained flow-banded and porphyritic volcanic rocks not of local origin, including a unique rapakivi-textured porphyry. The clasts are generally sub-rounded. The underlying Tick Canyon Formation has a darker color consisting of greenish gray, green, gray and brown conglomerate interstratified with thick sequences of reddish gray, gray and red mudstone and sandstone. Clasts within the Tick

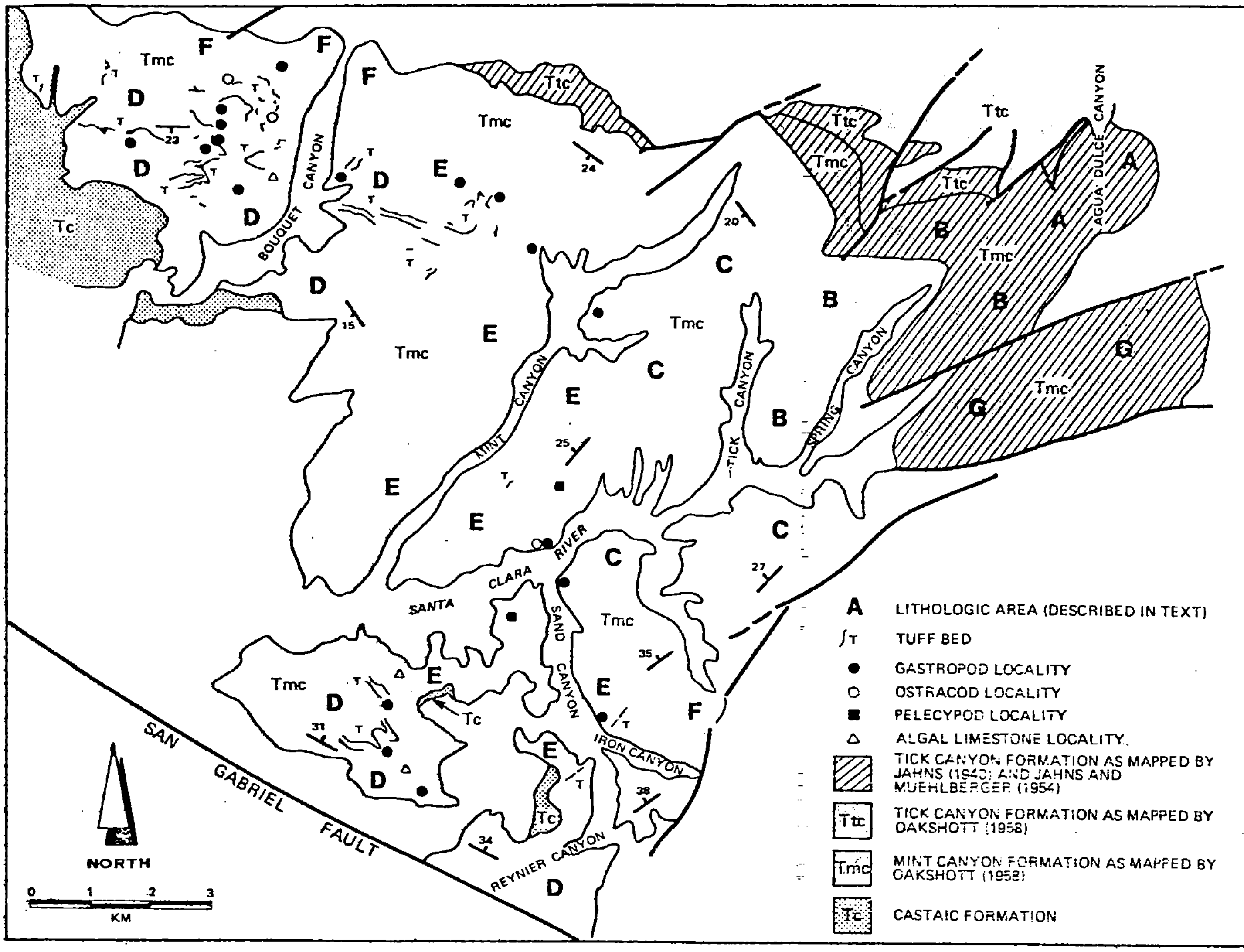

Figure 2. Sketch map of the Mint Canyon Formation showing lithologic areas described in text, fossil localities and tuff beds.

Canyon Formation include abundant dark-purple, brownish gray, reddish gray and green fine-grained volcanic rock types similar to volcanic rocks of the Vasquez Formation, but also contain quartz-bearing volcanic clasts, including a few scattered rapakivi -textured clasts, like those that occur in the Mint Canyon Formation.

The most important difference between the Mint Canyon Formation and underlying Tick Canyon Formation defined by Jahns and Muehlberger (1954) at this location is the abundance of clay and silt in the matrix of the beds. The Mint Canyon Formation consists of well washed conglomerate and sandstone relatively free of clay and silt, whereas the underlying Tick Canyon Formation contains appreciable amounts of silt and clay.

Between Spring and Tick canyons (Figure 2), Jahns and Muehlberger (1954) mapped the contact as trending east-west. The basal conglomerate of the Mint Canyon Formation is absent or not exposed in this area, but strata on either side of the contact zone are concordant and similar.

Further east, the contact trends north-south approximately along the axis of Spring Canyon. My observations indicate that light-colored conglomerates, relatively free of finer silty fractions, crop out for a considerable distance on both sides of the contact zone. Bedding attitudes are concordant on both sides of the contact zone.

To the east of Mint Canyon, Oakshott (1958) mapped the Mint-Tick contact at a horizon stratigraphically below the contact mapped by Jahns and Muehlberger (1954) (Figure 2). Oakshott assigned much of the Tick Canyon Formation as mapped by Jahns and Muehlberger to the Mint Canyon Formation and defined a fairly massive greenish gray conglomerate, overlying a reddish gray mudstone sequence, as the base of the Mint Canyon Formation.

Thus, there is a lack of agreement concerning the location and nature of the contact between the Mint Canyon and Tick Canyon formations in the published literature.

My own work indicates that the mapped contacts between the Mint Canyon and Tick Canyon formations are not based on any observable or mappable lithologic or structural discontinuities.

Relationship Between the Mint Canyon and Castaic Formations

The Castaic Formation was named by Crowell (1954) for some 2,100 m of shale with interbedded sandstone and minor beds of pebble conglomerate exposed in lower Castaic Canyon, several kilometers northwest of the Mint Canyon Formation. The Castaic Formation was separated from the Modelo Formation of the Ventura basin on the basis of lithologic differences and is restricted to the areas northwest of the San Gabriel fault. The Castaic Formation overlies the Mint Canyon Formation in the Sand Canyon area south of the Santa Clara River and in the Bouquet Canyon area (Figure 2).

The relationship between the Mint Canyon and Castaic Formations was subject to controversey prior to 1940. Eaton (1939), in citing miscellaneous determinations by B.L. Clark and U.S. Grant, considered the Modelo Formation (now called Castaic) of late Miocene age (Neroly). Stirton (1938), based on the occurrence of the fossil Hipparion, considered the upper part of the Mint Canyon Formation to be lower Pliocene. Jahns (1940) clearly demonstrated that this superposition of apparently older strata on younger strata was due to a discrepancy between the North American vertebrate time scale and the Pacific Coast marine invertebrate time scale rather than to improper identification of the fossils or structural relationships. A study of the vertebrate fauna of the Mint Canyon Formation and contact relationships between the two formations led Jahns (1940), and Jahns and Muehlberger (1954) to conclude that the Castaic Formation unconformably overlies and is clearly younger than the Mint Canyon Formation.

In the Sand Canyon area (Figure 2), The Castaic Formation is about 120 m thick and overlies the Mint Canyon Formation with definite angular discordance. At least portions of the Castaic Formation at this location consist of beach deposits,as shown by the presence of beach pebbles (Dr. Perry Ehlig, personal communication, 1982). The Castaic Formation in this area bears a strong resemblence to the Modelo Formation (Oakshott, 1958; Morrison, 1964).

My own work indicates that in the vicinity of Bouquet Canyon (Figure 2), the two formations are concordant and it is difficult to establish a precise contact between them. Previous workers (Jahns and Muehlberger, 1954) have placed the contact at the base of a sequence of cliff-forming conglomerate beds; however, I observed no change in clast types in conglomerate beds above and below the contact, and there are sandstone and mudstone beds above the contact which closely resemble those of the Mint Canyon Formation below the contact. The first occurrence of marine fossils is more than 30 m above the contact and no identifiable beach deposits are present; thus, the contact cannot be identified by an abrupt change from nonmarine to marine sedimentation and appears conformable.

LITHOLOGY OF THE MINT CANYON FORMATION

For this study, the Mint Canyon Formation has been divided into seven lithogically distinct areas (Figure 2). Because lithologic changes between areas are gradational and the boundaries are only approximately located, no boundary lines are shown. The bed-thickness classification used here is: laminated, less than 1 cm; very thin bedded, 1 to 10 cm; thin bedded, 10 to 50 cm; medium bedded, 50 to 150 cm; thick bedded, greater than 150 cm.

Area A

The Mint Canyon Formation in the Agua Dulce Canyon area (Figure 2) consists mostly of strongly cemented, massive, poorly sorted green gray cobble boulder conglomerate. Clasts consist mostly of dark colored volcanic rock types. The matrix contains appreciable amounts of silt and clay, imparting a dirty appearance to the rocks. Many of the clasts and matrix constituents have a thin coating of a green clay-like mineral that is also dispersed throughout the matrix at some locations. This mineral is probably celadonite which, according to Hendricks and Ross (1941), commonly forms in vesicular basalt under reducing conditions. The unconformably underlying Vasquez Formation contains basalt flows, from where the celadonite was probably derived.

These conglomerate are probably alluvial-fan deposits. The relatively high clay and silt contents suggest a nearby source area with minimal reworking of the sediments.

Area B

Area B (Figure 2) consists of alternating repetitive sequences of brown and green gray conglomerate, conglomeratic sandstone, sandstone and mudstone. The conglomerate and conglomeratic sandstone comprise approximately 55 to 65 percent of the exposures,with the remaining exposures consisting of mudstone with lesser amounts of sandstone.

The conglomerates are thick-bedded to massive, poorly to moderately sorted, and generally occur as lenses up to approximately 3 m thick and irregular channel deposits. Some of the lenses are fairly tabular and can be traced for several tens of meters, whereas others, especially in the southerly portion of the area, are irregular and lens out over short distances. The conglomeratic sandstone is thick to thin-bedded,with individual sequences ranging from about a meter to over 10 m thick. Clasts within the conglomeratic sandstone occur as lenses, concentrated channel deposits, and are also randomly dispersed. Clasts within the conglomerate and conglomeratic sandstone consist mostly of subangular to subround volcanic and plutonic pebbles and cobbles. The sandstones occur mostly within the mudstone as fine- and medium-grained laminated and thin-bedded sequences up to 2 m thick. The conglomerate, conglomeratic sandstone and sandstone contain appreciable amounts of silt and clay, and celadonite(?) is commonly present. The mudstone occurs as laminated and massive sequences up to 5 m thick that are commonly gradational with the sandstone. Some of the mudstone sequences have scoured or eroded upper surfaces where they are overlain by conglomeratic sandstone and conglomerate.

Based on criteria presented by Allen(1962, 1963, 1964, 1965, 1970), Vis her (1965), Bernard and Major (1963), Collison (1977) and Bull (1972), the sediments in area B are interpreted to be mostly of fluvial origin. Some of the irregular conglomerate lenses in the southerly portion of Area B are probably alluvial-fan deposits.

Area C

The sediments in Area C (Figure 2) essentially consist of the same general rock types as in area B. The main differences are that those in Area C are generally lighter colored, generally have more poorly developed bedding, have a higher proportion of conglomerate and conglomeratic sandstone (approximately 70 to 75 percent), individual conglomerate and conglomeratic sandstone sequences are not as laterally continuous, and the well defined alternating repetitive sequences are not as prominent. Also, the coarser sediments of Area C contain noticeably lesser amounts of silt and clay (they generally appear "cleaner"). Some of the conglomerate in Area C also appear to be better sorted than in Area B.

These sediments are also interpreted to be of fluvial origin. The relative lack of fines in the coarser fractions suggest that they are more "well washed" and probably had a more distant source than those in Area B. The sediments in Area C were probably deposited in an alluvial-wash environment. Paleocurrent measurements and clast source areas, discussed later, are consistent with this interpretation.

Area D

Sediments of the Mint Canyon Formation in Area D (Figure 2) consist mostly of brown, light-brown and red-brown laminated and thin-bedded mudstone and sandstone with relatively minor amounts of conglomeratic sandstone and conglomerate. White and blue-gray volcanic ash beds averaging about 2 m thick are also scattered throughout Area D (Figure 2).

The mudstone and sandstone commonly occur as laterally continuous sequences exceeding approximately 20 m thick. Fresh-water gastropods identified by Kew (1923) as Paludestrina imitator Pilsbury, ostracods, algal limestone, well preserved whole fossil leafs and carbonized wood fragments are fairly common within the area. Cross bedding occurs in some of the sandstone beds.

The conglomeratic sandstone and conglomerate occur mostly as isolated lenses and channel deposits and are commonly cross bedded.

Some of the tuff beds are composed of friable clean vitric ash, although in most places, the ash has been altered to a dull white rock. Some of the tuff bed contains variable amounts of sand and silt, and exhibit sedimentary structures such as cross bedding, ripple marks and graded bedding.

Most of the sediments in Area D are interpreted to be of lacustrine origin. This interpretation is supported by the predominance of thick laterally continuous sequences of laminated mudstone and sandstone, and the abundance of fresh-water gastropods, ostracods and algal limestone. In addition, Pardee and Bryan (1926) and Twenhofel (1932) indicate that the preservation of whole leaves suggests quiet-water (lacustrine) conditions.

The lack of evaporite deposits indicates that the lake probably had an outlet. In addition, Rezak (1957) suggests that concretionary algal limestone masses, as opposed to stromatolitic, are indicative of fresh-water conditions.

Several features suggest that the lake was shallow. Baker (1928) notes that fresh-water organisms such as gastropods tend to inhabit only shallow water. The distribution of the gastropods observed in the Mint Canyon Formation does not show a fossil-free center rimmed by fossiliferous near-shore bands. Instead, the distribution of the gastropods is random. Wallace (1940) suggests that the deepest part of the lake probably occurred near the thickest section of ash (west of Bouquet Canyon). Gastropods occur throughout this area. Also, the presence of conglomerate channels throughout the area is suggestive of shallow water conditions.

In summary, it appears that most of the sediments in Area D were deposited in a shallow fresh-water lake.

Area E

The sediments in Area E are interpreted to represent a zone of transition from a fluvial to a lacustrine environment. The boundaries of this zone are very approximate and are based partly on observed lithologic features and rock types, and partly on the projection of these features along strike in accordance with the general structure of the Mint Canyon Formation. Although in some areas the boundaries do not necessarily follow structural trends, this is attributed to lateral facies changes where fluvial and lacustrine sediments were being deposited concurrently. At many locations in Area E, fluvial and lacustrine sediments interfinger and occur in approximately equal amounts. Ostracods, fresh-water gastropods and small pelecypods occur in some of the mudstones in the area of Sand and Mint canyons (Figure 2). At these locations, the mudstones are overlain by conglomeratic sandstone and conglomerate. The pelecypods occur in a slightly yellow tan distinctive shaley mudstone that crops out in the Sand Canyon area on both sides of the Santa Clara River (Figure 2). The most obvious gradation from fluvial to lacustrine sediments occurs between Mint and Bouquet canyons where conglomerate and sandstone pass through a littoral zone and grade laterally into mudstone. The presence of a littoral zone is indicated by wave-generated "swash marks" defined by zig-zag patterned heavy-mineral concentrations within a tuff horizon. Small well defined deltaic structures occur immediately below the tuff bed. The deltaic structures were probably produced by a pond draining into the lake. The mudstones are identical to the lacustrine sediments that occur in Area D to the west, and the conglomerate and sandstone are the same as the fluvial sediments that occur in Area C to the east. At several locations in Area E, the fluvial conglomerates are clearly channeled into the lake sediments. In addition, at the same location, two tuff beds rapidly decrease in thickness over a distance of about 300 m from greater than 2 m thick to less than 2 cm. All of these features strongly suggest a littoral zone.

South of the Santa Clara River, the transition zone is not as clearly defined except for the previously mentioned occurrence of pelecypods in a bed overlain by conglomerate. Morrison (1958) reports that at the southern end of Sand Canyon in the Reynier-Iron canyons area (Figure 2), the Mint Canyon Formation consists of about 35 percent conglomerate and sandstone. He further indicates that although fresh-water gastropods occur in the mudstone, the sediments are typically coarse grained and are not typically lacustrine. This description is suggestive of a transition or gradational zone between fluvial and lacustrine sediments. My own observations indicate that a thick sequence of mudstone typical of the lacustrine sediments that occur in Area D grade laterally (easterly) across Sand Canyon into conglomerate and sandstone typical of the fluvial sediments that occur in area C. In addition, a white tuff bed like those previously described crops out just north of Reynier Canyon (Figure 2), thins to the northeast, and appears to lens out in the vicinity of Iron Canyon.

In summary, it appears that the sediments in Area E represent a transition or gradational zone where fluvial sediments were being deposited near and within the margins of a lake.

Area F

Sediments of the Mint Canyon Formation in Area F (Figure 2) consist mostly of coarse locally derived conglomerate and breccia. The conglomerates are red brown, brown and gray, and are generally poorly sorted and massive. The matrix of the conglomerates consists mostly of angular and subangular sand-size fragments of quartz, feldspar and lithic fragments admixed with variable amounts of clay and silt. The clasts range from angular to subround and consist mostly of cobbles and boulders. The breccias are generally the same except they commonly contain more silt and clay than the conglomerate and are generally coarser. Schist breccias are especially common where the Mint Canyon Formation overlies Pelona Schist.

Area G

Area G (Figure 2) consists mostly of purple gray coarse conglomerate abundant in purplish anorthosite clasts, some exceeding 3 m in diameter. The conglomerate rests on the Vasquez Formation. Lack of exposures prohibits any conclusions pertaining to the structural relationship between the conglomerate and the Vasquez Formation. My own observations indicate that west of Agua Dulce Canyon, the anorthosite-rich conglomerate grades into pale-red-gray cobble conglomerate and conglomeratic sandstone relatively devoid of anorthosite detritus, but rather consisting of locally derived granitic and metamorphic rock types. These conglomerate and conglomeratic sandstone contain more silt and clay and are more poorly sorted than the sediments that crop out in area B to the north.

THICKNESS

Jahns (1940) indicates that the Mint Canyon Formation is 1,230 m thick when measured from the top of the underlying Tick Canyon Formation west of Mint Canyon to the base of the Modelo (now called Castaic) Formation in Bouquet Canyon. Jahns and Muehlberger (1954) show a maximum thickness of 1,372 m for the Mint Canyon Formation.

My study indicates that the maximum exposed thickness is approximately 1,800 m along the axis of Soledad basin where the formation consists almost entirely of fluvial sediments. The exposed thickness of lacustrine sediments to the west is about 1,000 m. According to Winterer and Durham (1962), a well was drilled west of Bouquet Canyon through more than 2,134 m of Mint Canyon Formation shale and mudstone without reaching its base. Logs of the well provided to me by Dr. John C. Crowell of the University of California at Santa Barbara show that fresh water gastropods were encountered near the bottom of the well. This indicates that west of Bouquet Canyon the Mint Canyon Formation exceeds 2,000 m thick. When combined with the exposed thickness of fluvial sediments measured along the axis of Soledad basin the total thickness exceeds 3,800 m.

CORRELATION OF STRATA

An initial goal of this study was to trace stratigraphic horizons within the Mint Canyon Formation across the Soledad basin. This would facilitate correlation of strata from one area to the next and might help resolve the question of whether the exposed lacustrine sediments north and south of the Santa Clara River were deposited in one or two basins. Unfortunately, distinctive marker horizons that could be traced across the entire basin were not observed.

Wallace (1940) briefly discussed the issue of whether one or two basins existed, but did not draw any definite conclusions. Jahns and Muehlberger (1954) indicate that at least two lake basins were present. My own work suggests the presence of one basin. Although the tuff beds that crop out north and south of the Santa Clara River provide local marker beds, they are not distinctive enough to determine whether those south of the Santa Clara River are the same horizons as those north of the River. However, as previously described, a distinctive yellow tan pelecypod-bearing horizon crops out on both sides of the Santa Clara River. This suggests that a single body of water spanned across the present location of the Santa Clara River. In addition, paleocurrent directions, discussed in the next section, do not support the concept of two separate lake basins.

PALEOCURRENTS

Paleocurrent data were collected from both the fluvial and lacustrine facies of the Mint Canyon Formation. Current directions are shown in figure 3.

Most paleocurrent measurements were obtained from scour-and-fill channels and cross bedding. The trends of scour-and-fill channels were obtained in areas of bold outcrops, where differential erosion of sandstone and mudstone has caused the bottoms of conglomerate beds to be exposed as overhangs, yielding three-dimensional exposures of channels. The direction of current flow was obtained from imbrication of clasts. The scatter produced by braiding of stream channels back and forth across the main direction of sediment transport was reduced by making several paleocurrent measurements at a single location, where possible, and averaging the results. Paleocurrent measurements obtained from the lacustrine portions of the Mint Canyon Formation were collected from rare fluvial channels and cross bedding.

Field measurements of paleocurrent directions have not been corrected for fold plunge or tilt around fold axis. The data were obtained from beds which have low dips (less than 30 degrees); thus, such corrections would be small (less than 3 degrees) and would have no significant effect upon the interpretation of data.

The paleocurrent data clearly establish that sediment transport was generally from east to west. This is consistent with the distribution of clast types (discussed in the next section) and their exposed source areas, and the observed interrelationship between fluvial and lacustrine beds. Figure 4 is a current-direction rose diagram summarizing the data.

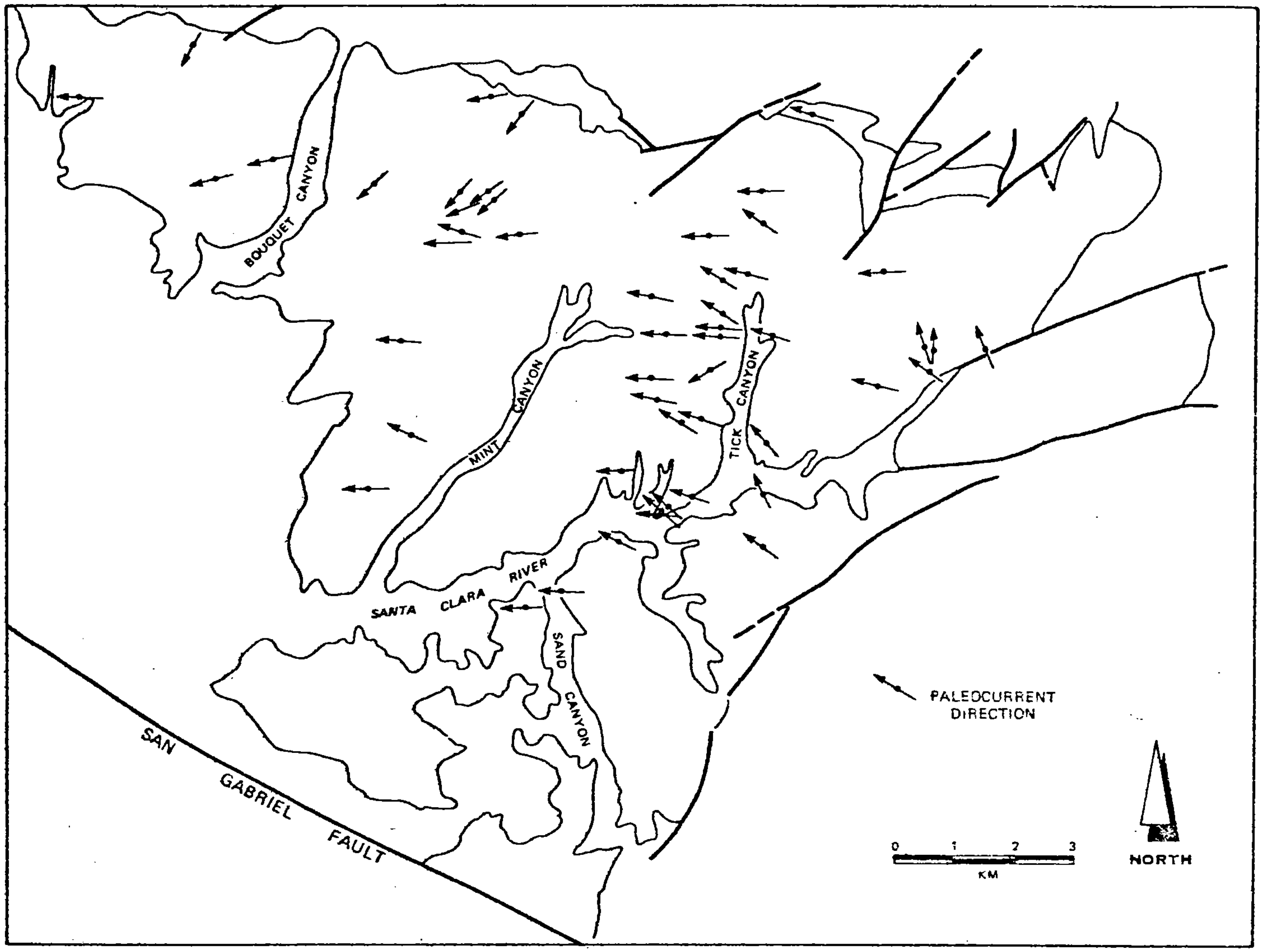

Figure 3. Sketch map showing plotted paleocurrent measurements.

DISTRIBUTION AND ORIGIN OF CLAST TYPES

Numerous clast counts were made throughout the Mint Canyon Formation in order to determine the distribution and major source areas of the clasts. The size of clasts counted ranges from pebbles to boulders. Whenever feasible, a minimum of 100 clasts were counted at each location. Clasts are divided into three general rock types: volcanic, basement and sedimentary. Figure 5 shows clast-count locations.

The volcanic clasts range in composition from rhyolite to basalt, and include abundant intermediate flow-rock varieties ranging from porphyritic pyroxene andesite, hornblende andesite and dacite, biotite-and-hornblende-bearing dacite and quartz latite, and biotite rhyolite. Colors include various shades of red, gray, yellowish white, green and purple. The volcanic clasts are as much as 1 m in diameter and are generally angular to sub-round. Included among the volcanic rock types is a unique, easily distinguishable rapakivi-textured quartz-latite porphyry. Three varieties of the rapakivi-textured clasts, including a red variety, are present. Some hard, dense sub-round metavolcanic clasts are also present. Many of them are fractured. Cobbles consisting of fractured metavolcanic clasts embedded in a sandstone matrix also occur as clasts in the Mint Canyon Formation.

Basement rock types include Lowe Granodiorite, anorthosite, Pelona Schist, syenite and blue quartz syenite, quartzo-feldspathic gneiss, diorite and gabbro. All of these rocks crop out locally. The Lowe Granodiorite, anorthosite, syenite and Pelona Schist are distinctive rock types which are easily identified. The Lowe Granodiorite is a light-brown or tan-colored rock commonly characterized by large pink potassium-feldspar crystals. Four facies of Lowe Granodiorite occur in the Mint Canyon Formation. These are biotite-potassium-feldspar, garnet-potassium-feldspar-hornblende, potassium-feldspar-hornblende and hornblende facies. Sub-round boulders of Lowe Granodiorite are common. Anorthosite clasts are generally blue-gray to purplish-gray and commonly consist of sub-round pebbles and cobbles. The syenite clasts consist mainly of dark-colored alkali feldspar and clasts of fine-grained biotite which replaces original mafic minerals. Some syenite clasts contain small amounts of blue to violet quartz, and with increasing quartz content, grade into alkali

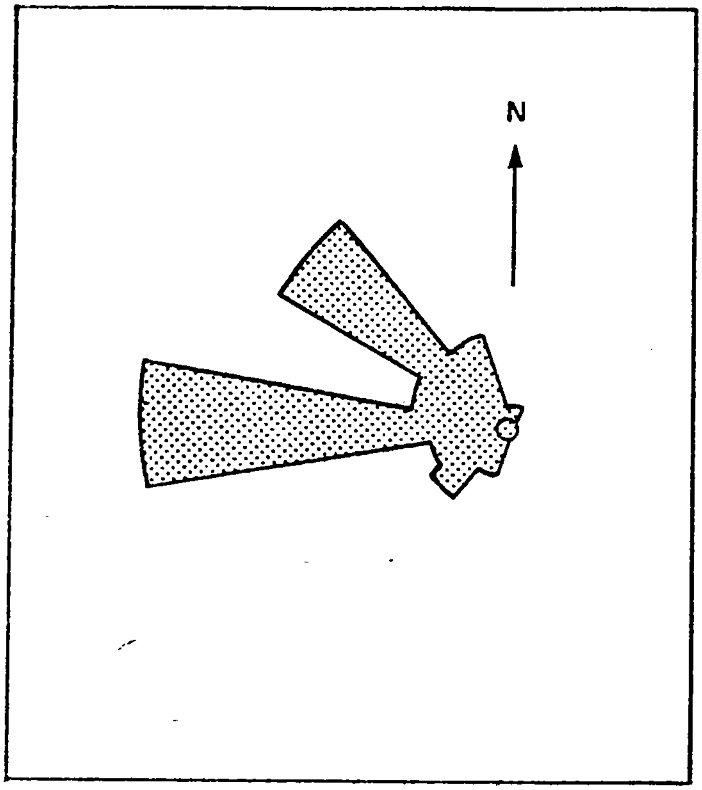

Figure 4. Paleocurrent rose diagram derived from paleocurrent directions shown in figure 3.

granite. Pelona Schist clasts are generally tabular to rarely blocky and range from green to various shades of gray.

Sedimentary clasts consist of well indurated medium-to dark-brown sandstone, are commonly subround to round, and rarely exceed 35 cm in diameter.

Figure 5 shows the concentration and distribution of some of the clast types in the Mint Canyon Formation. Volcanic clasts, including the unique rapakivi-textured quartz-latite porphyry, are most abundant in the central portions of the formation. The metavolcanic clasts occur mostly along the northern margin of the Mint Canyon Formation, usually in association with sandstone clasts. Clasts of basement rock types occur scattered throughout most of the Mint Canyon Formation but are dominant in the northern and southern margins. Those along the northern margin are generally small and consist mostly of Pelona Schist along with granitic and gneissic rock types. Clasts of syenite and blue-quartz granite occur scattered among volcanic clasts in the northeastern part of the volcanic conglomerate. Basement clasts along the southern margin include Lowe Granodiorite, anorthosite, gneiss and syenite, with Lowe Granodiorite being the dominant clast type.

Observations made within the Tick Canyon Formation west of Mint Canyon (Figure 2) indicate that Pelona Schist detritus in the basal conglomerate includes cobbles and boulders of cataclastic rock types which progressively decrease up-section with an increase of non-cataclastic Pelona Schist fragments. Ehlig (1958) indicates that metamorphism of the Pelona Schist proceeded synchronously with displacement along an overlying thrust fault (Vincent thrust fault). The thrust fault is defined by a wide zone of mylonitic and cataclastic rocks. The presence of these cataclastic rocks in the basal Tick Canyon Formation probably represents the initial "unroofing" of Sierra Pelona as the upper thrust plate was eroded off.

Figure 6 is a histogram showing relative percentages of various clast types within the Mint Canyon Formation.

Source Terranes

The only local source for the Lowe Granodiorite clasts occurs in the San Gabriel Mountains (Figure 7). Lowe Granodiorite is exposed over an area of approximately 160 square km in the central and northwestern San Gabriel Mountains. All four facies of the Lowe that have been recognized as clasts in the Mint Canyon Formation occur in the San Gabriel mountains (Figure 7).

Paleocurrent data and the distribution of anorthosite clasts in the Mint Canyon Formation (Figures 4 and 5) indicate that the source for the clasts is the anorthosite terrane of the western San Gabriel Mountains. Although Anorthosite clasts are fairly common in the southern portion of the Mint Canyon Formation, they are not nearly as abundant as Lowe Granodiorite. This suggests that the anorthosite terrane was largely buried or was an area of low relief. The relatively greater abundance of anorthosite in the upper or younger portions of the Mint Canyon Formation to the west (Figure 5) may reflect the eventual unroofing or uplift of the anorthosite terrane during late Mint Canyon time.

The clasts of syenite and blue-quartz syenite which are scattered among volcanic clasts in the northeastern part of the volcanic conglomerate were probably derived from syenite and blue-quartz granite terrane exposed east of the Mint Canyon Formation near the San Andreas fault (Figure 7).

The metavolcanic clasts which occur along the northern margin of the Mint Canyon Formation are identical to clasts in the Paleocene San Francisquito Formation north of the Mint Canyon Formation (Figure 7). The cobbles of metavolcanic clasts embedded in a sandstone matrix appear to be the same as conglomerate and sandstone in the San Francisquito Formation. Therefore, they are assumed to be locally derived from the San Francisquito Formation.

The clasts of Pelona Schist abundant along the northern margin of the Mint Canyon Formation were apparently derived from Sierra Pelona directly north of Soledad Basin. Sierra Pelona is underlain by Pelona Schist and the base of the Mint Canyon Formation rests directly upon Pelona Schist west of Bouquet Canyon (Figure 2).

Although some of the Mint Canyon volcanic clasts appear to have come from the nearby Vasquez Formation, most are unlike clasts and flows that occur in the Vasquez Formation and have no known local source. These considerations strongly suggest that many of the volcanic clasts in the Mint Canyon Formation were derived from east of the San Andreas fault, including the unique rapakivi-textured quartz-latite porphyry.

A mid-Tertiary volcanic terrane containing the same types of hypabyssal and extrusive volcanic

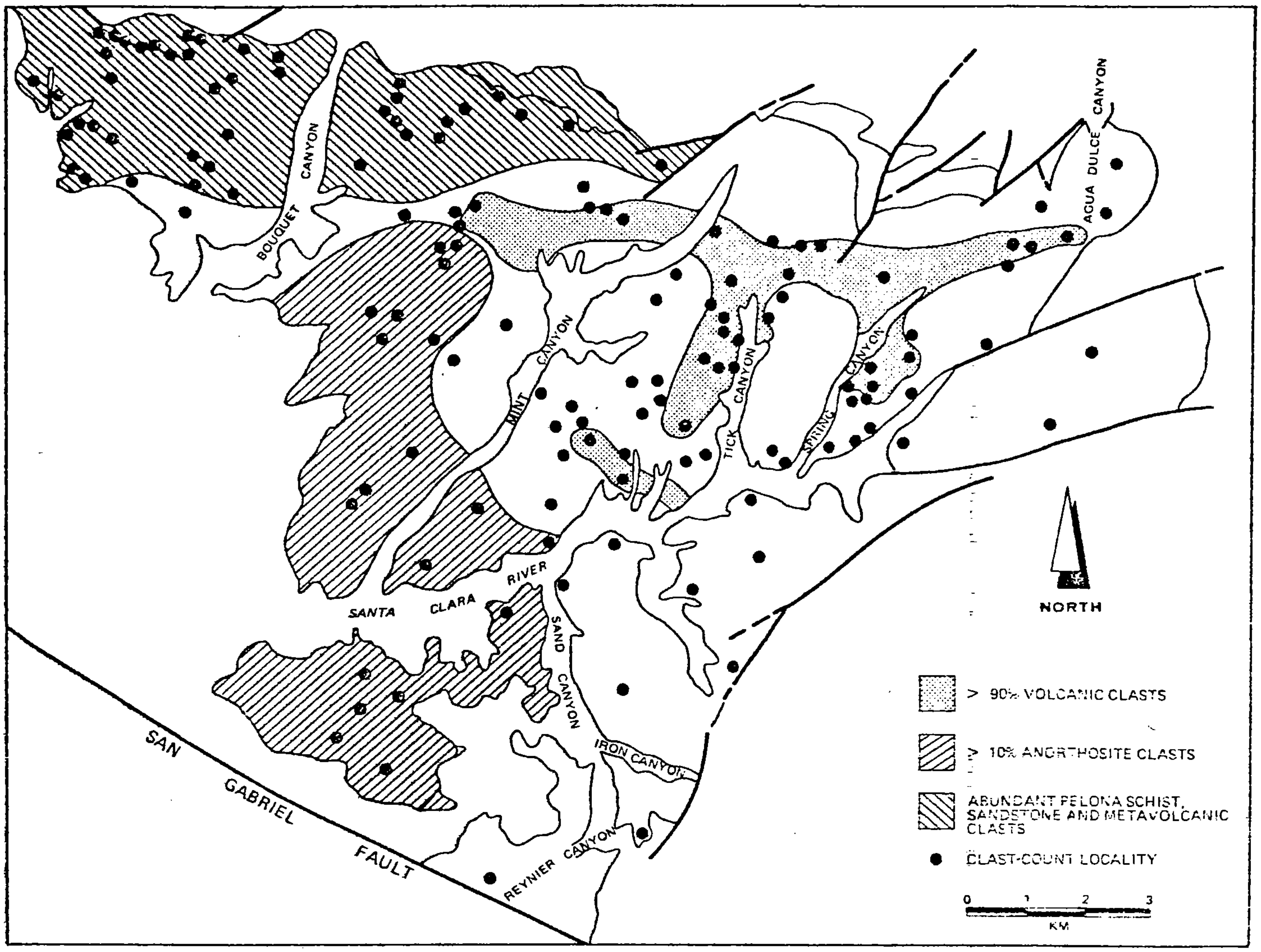

Figure 5. Sketch map showing clast-count localities and distribution of some clast types in the Mint Canyon Formation.

rocks as those that occur as clasts in the Mint Canyon Formation, including the rapakivi-textured quartz-latite porphyry, is located east of the San Andreas fault in the northern Chocolate Mountains about 240 km southeast of the Mint Canyon Formation (Figure 10).

The following description of the rapakivi-textured rocks is summarized from information previously published (Ehlig and Ehlert, 1972; Ehlig, Ehlert and Crowe, 1975).

Description of Rapakivi-Textured Rocks

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

The most distinctive type is a 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. 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 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 throughout most rocks. Some clots are partially rimmed by oligoclase. Reddish brown allanite is a minor accessory.

The features described above are common to both the rapakivi-textured rocks that occur in the Chocolate Mountains and the rapakivi-textured clasts in the Mint Canyon Formation, and leaves little doubt that the source of the rapakivi-textured clasts in the Mint Canyon Formation is the Chocolate Mountains.

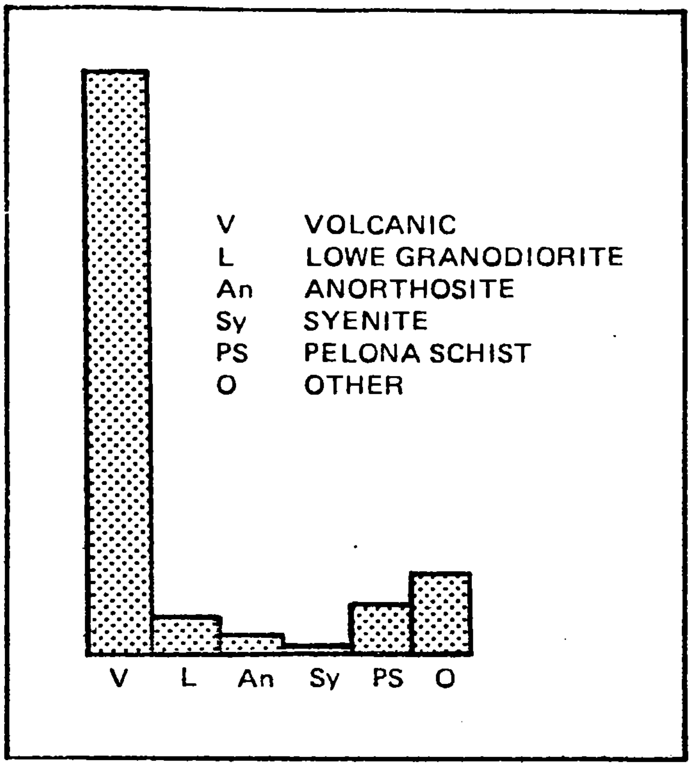

Figure 6. Histogram showing relative percentages of clast types in the Mint Canyon Formation.

CALIENTE FORMATION

Conglomerate beds of the nonmarine Caliente Formation of the Lockwood Valley-Dry Canyon area (Figure 8) contain clast types strikingly similar to those found in conglomerates of the Mint Canyon Formation. In these areas, the Caliente Formation consists mainly of conglomerate, sandstone and mudstone. To the west, it grades into the marine Branch Canyon Formation.

Carman (1964) divided the Caliente Formation of the Lockwood Valley area (Figure 8) into three members consisting of a basal conglomerate (member 1), a lenticular lacustrine facies (member 2), and a conglomerate-sandstone-siltstone sequence (member 3). Carman indicated that member 1 contains anorthosite and volcanic clasts, with no local source, identical to those in the Mint Canyon Formation, and concluded that the fluvial portions of the two formations were deposited in the same drainage system and later offset along the San Gabriel fault by about 32 km of right slip, in accord with offsets on the San Gabriel fault previously postulated by Crowell (1952).

Carman (1964) indicated that member 3 (which unconformably overlies member 1) contains very few anorthosite and volcanic clasts relative to member 1, and contains a much greater proportion of locally derived clasts, suggesting that the Lockwood Valley area was cut off from the source of volcanic and anorthosite clasts sometime during deposition of the Caliente Formation, and that thereafter, the major source of clasts was local crystalline rocks.

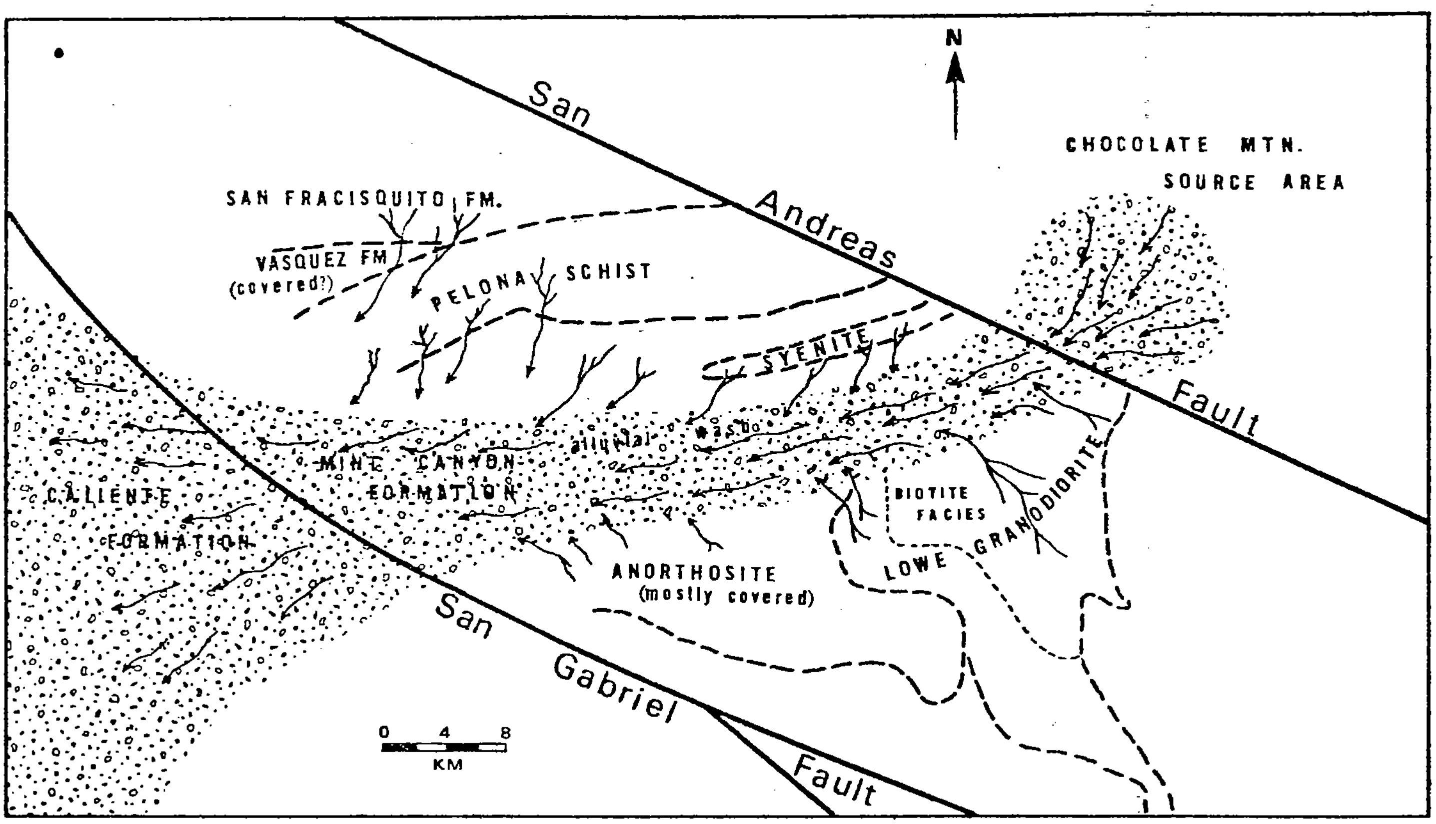

Figure 7. Clast source areas and postulated drainage pattern during deposition of the lower part of the Mint Canyon and Caliente formations before movement began along the San Gabriel and San Andreas faults.

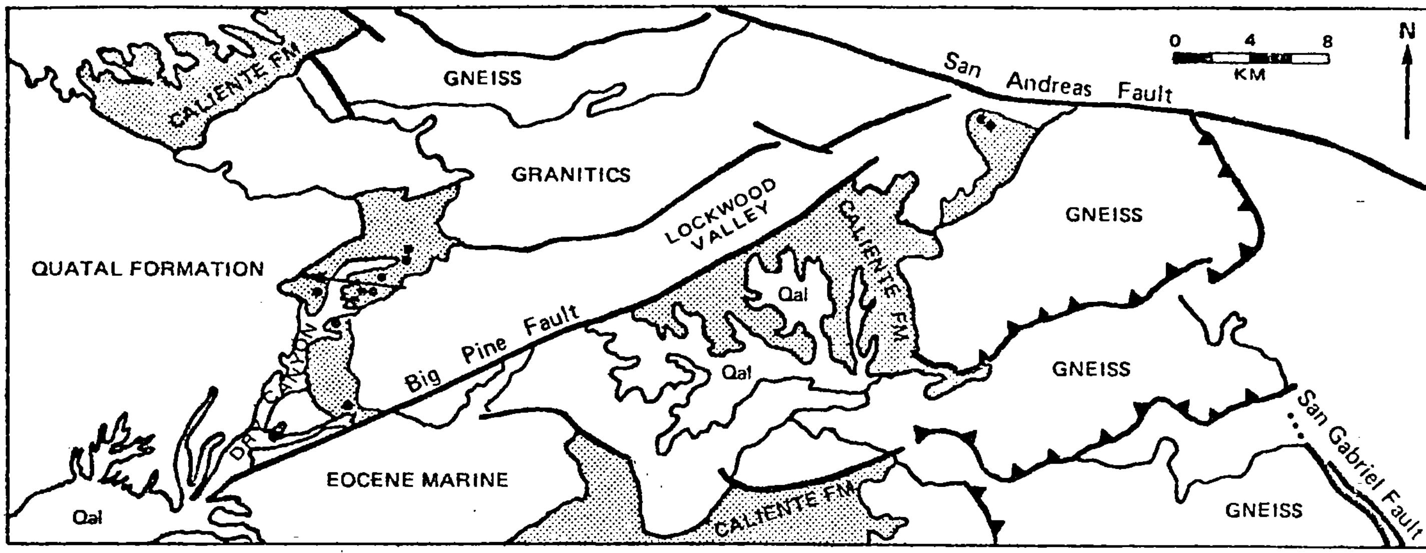

Figure 8. Sketch map of the Lockwood Valley-Dry Canyon area showing the location of clast counts and paleocurrent measurement in the Caliente Formation. Dots represent clast-count locations.

He correlated these events with the start of lateral movement on the San Gabriel fault, as suggested by Crowell (1952).

My own observations and clast counts performed in the Caliente Formation of the Lockwood Valley and Dry Canyon area show that the suite of clasts is remarkably the same as the Mint Canyon Formation. Included in the Caliente Formation are clasts of the unique rapakivi-textured porphyry and Lowe Granodiorite. Figure 8 shows the location of the clast counts and a paleocurrent direction measured in the Caliente Formation. Although Carman (1964) recognized the occurrence of anorthosite clasts in the Caliente Formation and postulated their source to be the San Gabriel Mountains, he made no mention of the Lowe Granodiorite or rapakivi-textured porphyry and apparently was not familiar with these clast types. Figure 9 is a histogram derived from the clast counts performed in the Caliente Formation. Note the remarkable similarity to the histogram for the Mint Canyon Formation (Figure 6).

No vertebrate fossils have been found in the Caliente Formation of the Lockwood Valley area. However, based on discussions with D.E. Savage, Carman (1964) indicated that the beds of the Caliente Formation in the Dry Canyon area range in age from Hemingfordian through Barstovian (lower to medial Miocene), roughly the same age span as the lower (fluvial) portion of the Mint Canyon Formation.

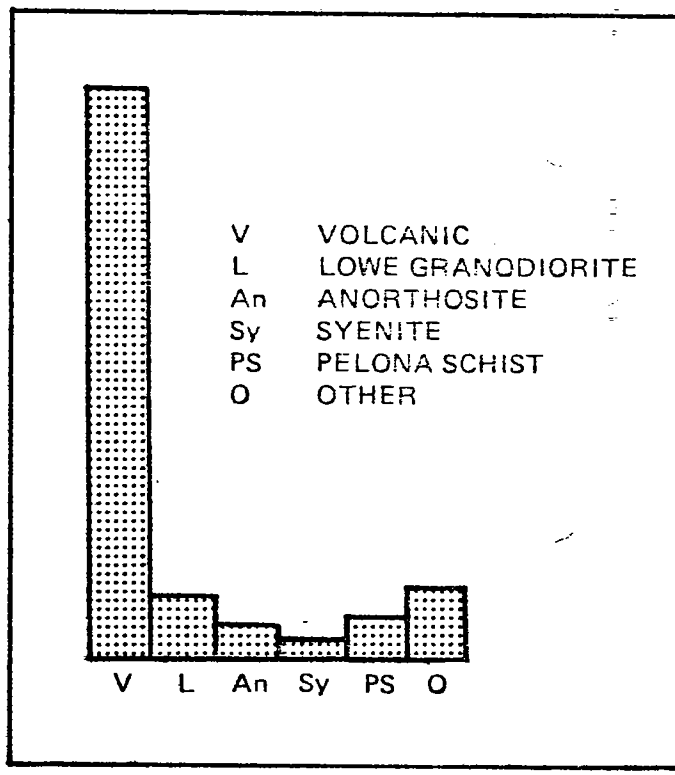

Figure 9. Histogram showing relative percentages of clast types in the Caliente Formation. Note the similarity in relative percentages to the Mint Canyon Formation (see figure 6).

DISCUSSION

Paleocurrent directions, distribution of clast types and lithologic characteristics of the Mint Canyon and Caliente formations indicate the lower (older) portions of the formations were deposited in the same westward flowing drainage system, and sometime between medial and late Miocene, the Caliente Formation was cut off from its foreign clast source because of movement on the San Gabriel fault.

The Caliente and Mint Canyon formations must have been deposited in close proximity to the Chocolate Mountains (Figure 10), as inferred from the presence of the rapakivi-textured clasts, their angularity, and the absence of clasts from source areas other than the Chocolate Mountains and the region around Soledad Basin. A minimum-offset reconstruction would require about 240 km of right slip on the San Andreas fault and 70 km of right slip on the San Gabriel fault since deposition of the lower (older) portions of the Mint Canyon and

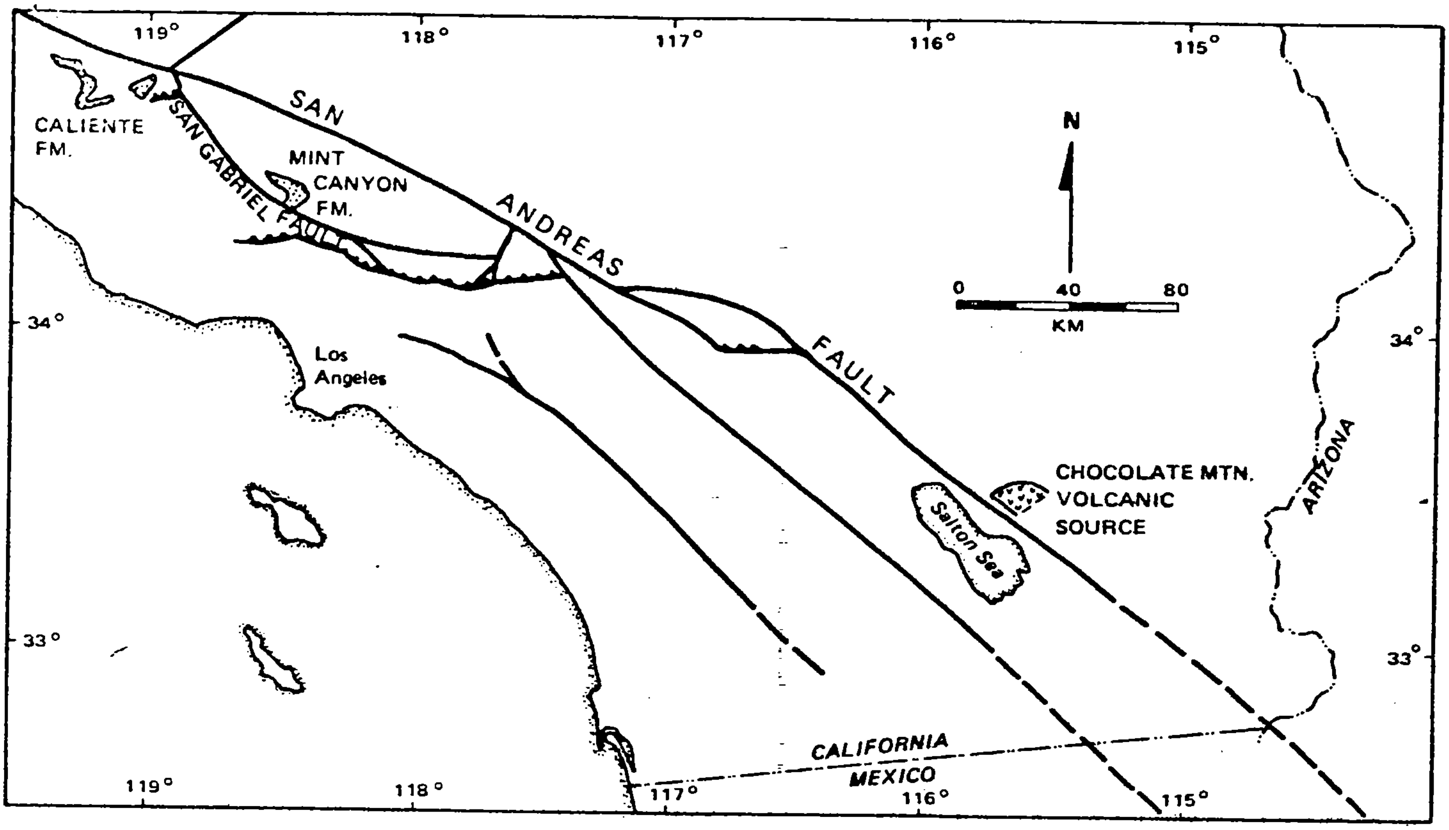

Figure 10. Sketch map showing location of the Mint Canyon and Caliente formations and Chocolate Mountain source area.

Caliente formations. The offsets are approximately the same as for the complex of basement rock types that occur in the areas and thus must represent maximum displacement values (Crowell, 1975). These data, when considered with the results of previous work performed on the San Gabriel fault by Crowell (1952,1975), can reveal much on the timing of displacement on the San Gabriel fault and can provide insight into the mechanisms involved in the origin of the Mint Canyon Formation lake basin.

Displacement History of the San Gabriel Fault

Crowell (1952) was the first to point out the probability of large-scale lateral displacement on the San Gabriel fault by correlating late Miocene (Mohnian) anorthosite-bearing coarse clastic sediments southwest of the San Gabriel fault to a source area northeast of the fault in the western San Gabriel Mountains (Figure 11 C and D), requiring 25 to 40 km of right slip on the San Gabriel fault since late Miocene time. The restricted clast composition of these sediments and consideration of appropriate source areas indicate that the 25 to 40 km is probably a maximum displacement for these sediments. Inasmuch as the medial Miocene Caliente Formation is displaced about 70 km right laterally, about 30 to 40 km of right-lateral displacement must have occurred prior to deposition of the upper Miocene anorthosite-bearing conglomerate and prior to the formation of the Mint Canyon Formation lake basin (Figure 11 A through D).

Bohannan (1975) has suggested that anorthosite- and Lowe Granodiorite-bearing breccias of the late Oligocene-early Miocene Sespe Formation in Canton Canyon have been offset from the western San Gabriel Mountains by about 60 km of right slip on the San Gabriel fault (Figure 10 A through D). As pointed out by Crowell (1975), this indicates that the San Gabriel fault may have been active during early Miocene time.

In the following section, the data in hand will be used to develop a possible tectonic model explaining the origin of the Mint Canyon lake basin.

Origin of The Mint Canyon Formation Lake Basin

During late Miocene time, crustal deformation resulted in the formation of the Mint Canyon lake basin in which more than 2,100 m of lacustrine sediments accumulated. It is suggested here that the lake basin formed in response to movement on the San Gabriel fault and may have had a tectonic origin similar to the Ridge Basin, located northeast of the San Gabriel fault just north of the Mint Canyon Formation. What we know of the geologic history of the Soledad basin and Ridge Basin areas indicates that the Mint Canyon Formation was probably deposited in the same general tectonic environment as the Ridge Basin sediments to the north. Both areas are located within the crustal block bounded by the San Gabriel and San Andreas faults, both areas lie immediately northeast of the San Gabriel fault and both areas received relatively thick accumulations of sediments when the San Gabriel fault was known to be active.

Crowell (1974,1975) has shown that the sediments of Ridge Basin accumulated in a depression that involved a continuously laterally moving "hole" along the northeast side of the San Gabriel fault. The question of whether the Mint Canyon lacustrine sediments formed in more than one basin becomes

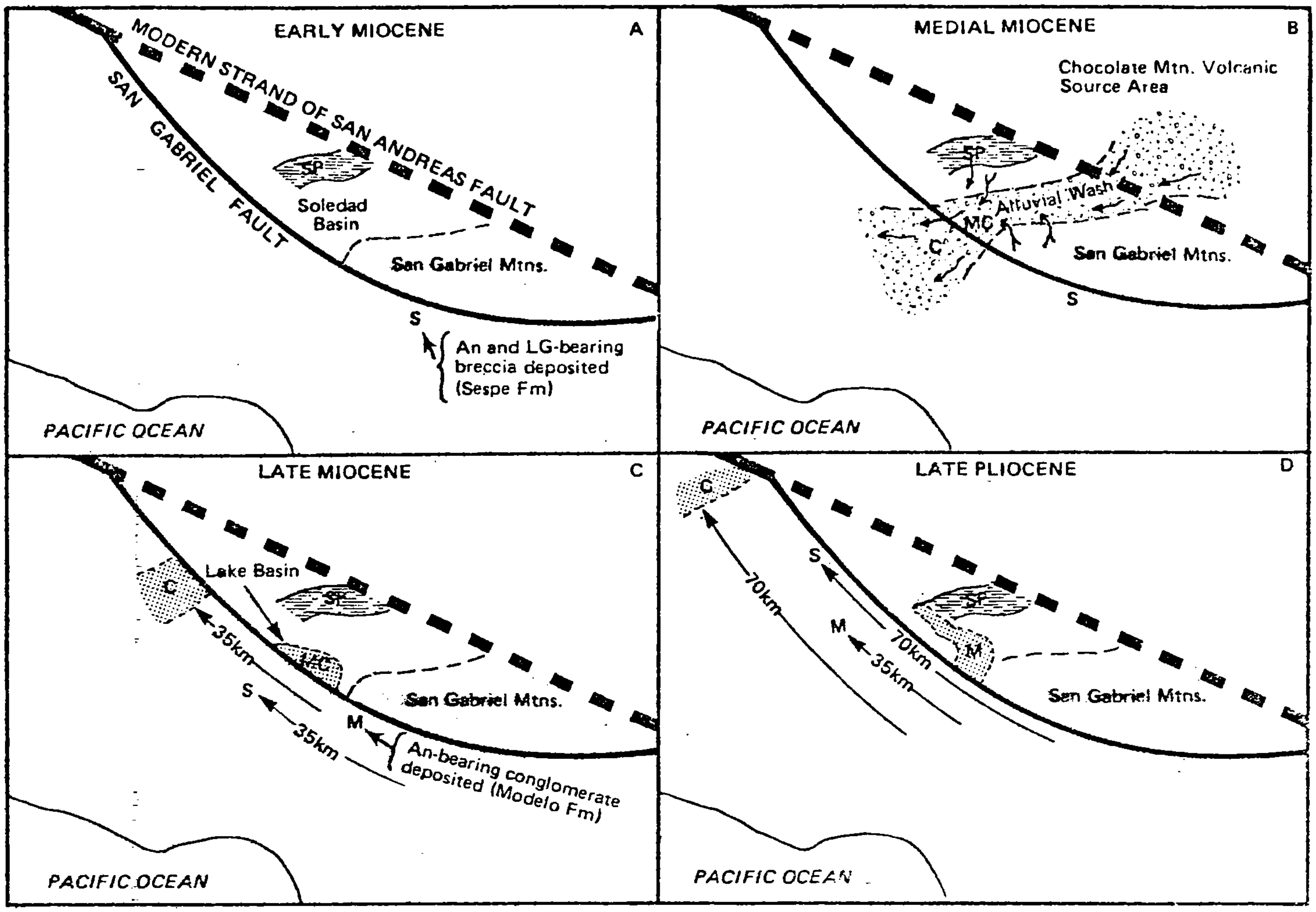

Figure 11. Sequence of paleogeographic diagrams depicting the movement history of the San Gabriel fault based on correlation of upper Tertiary sediments. MC=Mint Canyon Formation, C=Caliente Formation, SP=Sierra Pelona, M=Modelo Formation, S=Sespe Formation.

important in that the multiple-basin model would not fit the moving-"hole" concept as well as a single-basin model. As previously discussed, my work indicates the presence of a single lake basin. Whatever the exact tectonic environment may have been, it seems certain the origin of the Mint Canyon lake basin was certainly somehow related to movement on the San Gabriel fault.

Paleogeography

The paleogeographic picture that evolves from the above considerations would have the anorthosite- and Lowe Granodiorite-bearing Sespe breccia of Canton Canyon (Bohannan, 1975) being deposited southwest of the San Gabriel fault from a source area in the western San Gabriel Mountains during latest Oligocene or early Miocene time (Figure 11 A). During medial Miocene time, the lower (older) fluvial portion of the Mint Canyon and Caliente formations were being deposited in the same westward flowing drainage system (Figure 11 B). The San Gabriel fault then began to move right-laterally, and by late Miocene time, had displaced the Sespe breccia and Caliente Formation 35 km northward (Figure 11 C). At the same time, the Mint Canyon Formation lake basin formed. Also, anorthosite-bearing Modelo Formation conglomerates were being deposited southwest of the San Gabriel fault from a source in the San Gabriel Mountains (Figure 11 C). Right-lateral movement continued on the San Gabriel Fault, and by late Pliocene time, the Caliente Formation and Sespe breccia had been displaced an additional 35 km for a cumulative right-lateral offset of 70 km, and the Modelo anorthosite-bearing conglomerate was displaced 35 km from its original site of deposition (Figure 11 D). This cumulative offset is approximately the same as those derived from correlation of basement rocks across the San Gabriel fault, as indicated by Crowell (1975).

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