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TECTONICS AND ALLUVIAL SEDIMENTATION OF THE UPPER OLIGOCENE VASQUEZ FORMATION, SOLEDAD BASIN, SOUTHERN CALIFORNIA

by

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ABSTRACT

The Upper Oligocene Vasquez Formation marks the earliest sedimentation in the Soledad basin, central Transverse Ranges, southern California. The Vasquez consists primarily of alluvial and fluvial sediments, and presently outcrops in three geographically restricted, fault-bounded sub-basins. The two southern sub-basins shared similar tectonic and depositional histories; the northernmost sub-basin appears to have had its own distinct evolution.

The Soledad basin originated as a predominately orthogonal rift during the latest Oligocene. Incipient subsidence was concentrated in the southern region of the basin, as debris-flow deposits accumulated on small, thick alluvial fans draining local source areas in the Vasquez Rocks sub-basin. Intense rifting, bimodal volcanism and rapid subsidence produced the half-graben geometry of this sub-basin, as a source area rose to the south/southeast across the active Soledad fault. Coeval displacements along the Vasquez Canyon and Pelona faults led to the asymmetric graben geometry of Texas Canyon sub-basin, as abundant detritus derived from an eastern/southeastern source interfingered with small, debris-flow-dominated fans along the Pelona fault margin. Periodic uplift along basin-margin faults produced thick, upward fining alluvial megacycles in both sub-basins.

Major tectonic uplift in the ancestral San Gabriel area led to drainage-system enlargement, increased water input into

the depositional system and deposition by hyperconcentrated flood flow in both sub-basins. Erosional dissection of the Mint Canyon ridge allowed physical interconnection of the two depocenters at this time.

Charlie Canyon sub-basin, the northernmost Vasquez depocenter, displays no clast suites or alluvial megacyclicity to suggest close relationships to the other two depocenters. A sequence of easterly derived braidplain sediments low in the section is overlain by a 1600m upward coarsening alluvial sequence. This sequence reflects probable inception of the San Francisquito fault, uplift of an ancestral Sierra Pelona source area and northward progradation of an alluvial-fan system.

Post-Oligocene clockwise rotation of the Soledad basin by up to 40 degrees is indicated by the paleomagnetic data of other workers. Restoration of the Soledad basin to its Oligocene orientation indicates that southeast-northwest extension caused primarily orthogonal rifting and heralded Vasquez deposition in small, rapidly subsiding basins. The sedimentary and tectonic history of the Soledad basin is consistent with a plate-tectonic model involving extension in the North American plate north of the unstable Mendocino triple junction.

INTRODUCTION

The Soledad basin is part of the central Transverse Ranges tectonic province, Los Angeles County, southern California (Bailey and Jahns, 1954). The Vasquez Formation is a thick alluvial sedimentary unit which outcrops in three geographically separate, fault-bounded zones or "sub-basins" within the Soledad basin (Fig. 1) (Muehlberger, 1958; Bohannon, 1976). From south to north, these sub-basins or depocenters have been designated Vasquez Rocks sub-basin, Texas Canyon sub-basin and Charlie Canyon sub-basin. (Jahns and Muehlberger, 1954; Muehlberger, 1958). In each sub-basin, the Vasquez Formation is either faulted against, or nonconformable upon, igneous and metamorphic basement rocks, which form prominent structural blocks between the three depocenters (Fig. 1). The San Andreas fault separates the Soledad basin from the Mojave block to the east; the San Gabriel fault defines the boundary between the Soledad and Ventura basins.

The Vasquez Formation provides a useful framework from which to evaluate Soledad basin evolution; it comprises both the oldest and thickest sequence of sediments in the basin (Fig. 2). A thick volcanic interval in the Vasquez Rocks sub-basin has yielded radiometric ages centering around 25-24 m.y. (Crowell, 1973; V. Frizzell, pers. comm., 1985); these volcanics occur low in the Vasquez stratigraphic sequence, and thus, provide control for the maximum age of Vasquez strata. A

Miocene (Arikareean) vertebrate assemblage from the nonmarine Tick Canyon Formation, which is separated from the Vasquez by a pronounced angular unconformity (Durham and others, 1954; Whistler, 1967; Woodburne, 1975; Ehlert, 1982). This radiometric and biostratigraphic control implies that Vasquez sedimentation occurred principally between 25 and 20 m.y.B.P., with a cumulative sedimentation rate of 1.38 m / 1000 years (Hendrix, 1986).

OBJECTIVES AND METHODS OF STUDY

There are three salient objectives to this study. The first is to synthesize sedimentary lithofacies and paleodispersal data in order to reconstruct depositional environments and Vasquez paleogeography (~~for example, Potter and Petti~~john, 1977; ~~Miall, 1984~~). Although both Muehlberger (1958) and Bohannon (1976) presented rudimentary environmental analyses of Vasquez sediments, there has been no previous comprehensive, actualistic evaluation of Vasquez depositional systems. The second objective is to discern tectonic style during Soledad basin evolution and Vasquez sedimentation, with particular attention to distinguishing orthogonal extension from oblique-slip tectonism. The final objective is to re-evaluate the sub-basin correlations proposed by Muehlberger (1958), in lieu of interpretations from the first two objectives. Modern concepts of alluvial sedimentation (for example, Heward, 1978b; Miall, 1978b, 1980, 1983) play an important role in interpreting Vasquez/Soledad basin depositional history and in addressing all three objectives.

Lithofacies analysis involved detailed measurement of stratigraphic sections; measured sections were correlated and compared along strike across sub-basins, where posible, to document lateral facies and/or thickness changes. Particular attention was paid to external bedding geometry, thickness and contacts, as well as to internal fabric, textures and structures. Maximum diameters of the largest clasts within 5m of the line of section were measured for all conglomeratic units.

Compositional clast counts of Vasquez conglomerates and breccias were performed using a one-hundred-point grid on the outcrop surface. Three counts (one-hundred clasts per count) were made at each stratigraphic locality (Hendrix, 1986). Reconnaissance study of regional Soledad basement lithologies preceded sedimentologic analyses to improve familiarity with Vasquez clasts. Sandstone samples were ~~collected~~, thin-sectioned and point-counted for comparison to clast-count data during provenance estimations. Samples were point-counted according to the methods described by Dickinson (1970), Ingersoll (1978) and Ingersoll and others (1984), utilizing 300 counts per slide.

Paleocurrents were measured in the field using a Brunton compass, with most measurements taken on cross strata and clast imbrications (Potter and Pettijohn, 1977). Paleoflow data were corrected for structural attitude (Ragan, 1973), and statistically analyzed utilizing circular statistical methods (Royse, 1970). Discussions of paleoflow directions or paleogeography throughout the text do not reflect palinspastic corrections for post-Oligocene clockwise rotations of this terrane (Luyendyk and others, 1980; Terres and others, 1981).

VASQUEZ ROCKS SUB-BASIN

The largest and southernmost of the three Vasquez depocenters, Vasquez Rocks sub-basin, features the Vasquez type section as defined by Sharp (1935) in Escondido Canyon. Other previous work in this sub-basin includes the mapping of Irwin (1950), Muehlberger (1958), Oakeshott (1958), and Bohannon (1976). The Soledad fault is the southern boundary of both this sub-basin and the Soledad basin proper, and is expressed as a high-angle structure dipping towards the Vasquez Rocks depocenter (Muehlberger, 1958) (Fig. 3). This fault brings Vasquez sediments against mid-Proterozoic anorthosite, gabbro, metapyroxenite and syenite of a large stratiform intrusion in the San Gabriel Mountains. Other local basement south of the fault includes rocks of the Lower Triassic Lowe intrusive series, featuring distinctive epidote- and hornblende-bearing granitic lithologies. Cretaceous granitic plutons, in turn, cut all older intrusive rocks of the San Gabriel/Soledad region; all above-named lithologies also outcrop north of the Soledad fault, along the eastern margin of the Vasquez Rocks sub-basin (Oakeshott, 1958; Silver, 1971; Ehlig, 1981).

The Vasquez has an aggregate thickness of 5500 m in this sub-basin, and is exposed as a southwest-dipping homocline. The sub-basin is cut by numerous left-lateral faults, which postdate initial Soledad fault activity (Fig. 3) (Muehlberger, 1958; Oakeshott, 1958); the most important of these left-lateral faults, in terms of sub-basin structural configuration, is the Green Ranch fault. This fault divides the sub-basin into two distinct blocks: the relatively undeformed Agua Dulce block, and the complexly folded and faulted Tick Canyon block (Fig. 3). The 5500m Vasquez section of this sub-basin is here subdivided into four key lithostratigraphic intervals: Basal Vasquez, Volcanic/Tick Canyon interval, Middle Vasquez and Upper Vasquez (Fig. 4).

Basal Vasquez

Three stratigraphic sections were measured within this interval across the sub-basin (Sections 1,3 and 8; Fig. 3). The Basal Vasquez varies considerably in thickness along strike, from 0 to 330 m, but in general, the interval is thicker towards the northwest. The breccias and conglomerates of this interval rest nonconformably on Lowe (Parker Mt.) granodiorite near the Soledad fault, but on syenites in the northern extent of the outcrop area.

In the lower portions of all three sections, the Basal Vasquez consists almost exclusively of poorly sorted breccia beds, some attaining thicknesses of 5 m. These breccias feature clay-rich textures and matrix-supported fabrics, with ubiquitous planar, unscoured lower bedding contacts. Maximum clast size exceeds 2m, and most clasts are highly angular. These breccias resemble high-yield-strength debris-flow deposits, where strength during transport was controlled primarily by cohesion provided by abundant matrix clay (Rodine and Johnson, 1976). Buoyancy, partly due to increased pore pressure in the clay matrix (Hampton, 1979), was probably the key clast-support mechanism during transport of the original debris flows (for example, Costa, 1984).

Upsection, the clay content of Basal Vasquez breccias decreases as matrix sand content concomitantly increases. Additionally, internal fabric becomes more clast-supported upsection; local clast imbrications and inversely graded bedding become more common (Fig. 5A). These sedimentologic features suggest lower primary yield strength during transport, where the frictional component of shear strength increases relative to the cohesive component (Rodine and Johnson, 1976). The principal clast-support mechanism for these upper Basal Vasquez deposits was probably dispersive pressure, enhanced by the high concentration of large clasts relative to matrix (for example, Fisher, 1971; Costa, 1984; Shultz, 1984). Development of clast imbrications in some beds implies local turbulent flow conditions and low flow viscosities, as opposed to highly viscous, laminar debris flows (Enos, 1977). Despite this upsection change of debris-flow character, there are few distinct lithofacies changes along strike, from southeast to northwest. The only salient change is the increase in thickness and number of interstratified pebbly sandstone beds towards the north; these beds reach a maximum thickness of 60 cm in section 8. Commonly, the lower contacts of such beds are gradational with underlying debris-flow deposits; additionally, there are few scour structures to suggest that these coarse sandstones are fluvially reworked debris-flow deposits. These finer-grained units are interpreted as deposits of "late-stage", turbulent debris-flow pulses, which followed the principal debris-flow slurry (for example, Costa, 1984).

Few reliable structures for paleocurrent measurements were observed in this interval, probably because original flow conditions inhibited development of such structures. Only eleven localities were found in the upper part of the interval where clast imbrications were obtainable (Fig. 6), yielding a northeasterly mean paleoflow.

Clast-count data (Hendrix, 1986) reflect high percentages of anorthosite, gabbro, syenite and Lowe granodiorite in breccias from sections 1 and 8. Near the Soledad fault, however, most clasts are compositionally identical to the Lowe granodiorite, upon which the breccias rest nonconformably. This section 3 clast assemblage implies that Lowe granodiorite was the only basement lithology exposed south of the Soledad fault during Basal Vasquez sedimentation.

Volcanic/Tick Canyon Interval

The Vasquez volcanics of the Agua Dulce block are exposed in a sequence which thins to the northwest from 1300 m near the Soledad fault to 850+ m near the Green Ranch fault (Fig. 3). The volcanics are compositionally bimodal, dominated by subalkaline basaltic andesites (Weigand, 1982). Texturally, these basaltic andesites vary from vesicular and amygdaloidal to densely microlitic (pilotaxitic). Plagioclase microlites (An_{30-70})

commonly exhibit calcite replacement and albitization in thin section. This suite becomes more dacitic eastward, within the extensive volcanic zone east of the Vasquez Rocks sub-basin (Fig. 3). The mafic volcanics are locally associated with felsic extrusives, including welded vitric rhyodacites and rhyolitic vitric-crystal air-fall tuffs.

Thick, laterally extensive lenses of coarse conglomerates and pebbly sandstones are interbedded with the Agua Dulce block volcanic deposits. Near the Soledad fault, most of these epiclastic sediments are texturally and structurally identical to low-yield-strength debris-flow deposits of the Basal Vasquez. Towards the northwest along strike, however, these interbedded sediments become finer-grained and more thinly bedded. Some of the finer-grained deposits are organized into upward fining and thinning cycles reaching 4.5 m in thickness. The paucity of bedform-migration structures, abundance of normally graded sandstone beds, and presence of massive, 15-30 cm-thick mudstones in these cycles suggest subaqueous deposition from suspension in areas created by volcanic ponding of fluvial drainages (for example, Ollier, 1967; Picard and High, 1981).

Due to the presence and composition of volcanics in the deposits of the Tick Canyon block, the Vasquez in this area is considered primarily time-equivalent to the Volcanic interval of the Agua Dulce block. The interpretation of subaqueous, ephemeral-lacustrine sedimentation may also be applied to much of the Vasquez section in the Tick Canyon block. The Vasquez in this area is organized into a thick basal breccia horizon overlain by three distinct volcanic/sedimentary couplets, each of which becomes thinner and finer-grained westward along strike (Hendrix, 1986) (Fig. 3, Sections 6 and 11).

The basal breccia horizon of the Tick Canyon block is best exposed in Tick Canyon itself, and is sedimentologically similar to the clay-rich, high-yield-strength debris-flow deposits of the lower Basal Vasquez. Clast counts from these breccias (Hendrix, 1986) reveal anorthosite, gabbro and syenite similar to clasts of the Basal Vasquez assemblages. These basal Tick Canyon block sediments, thus, are correlated to the Basal Vasquez interval (for example, Bohannon, 1976).

Ephemeral lacustrine sedimentation in the Tick Canyon area is best exemplified by a thick sequence of sediments above the second main volcanic horizon in this region. Ephemeral-lake/fan-delta sedimentation is indicated by several lines of evidence. First, there are two 2-3m-thick vitric-crystal-tuff marker beds within this sequence, both of which are relatively free of admixed epiclastic material above their basal contacts. The absence of erosional truncations or fluvial scour surfaces in these tuffs implies probable airfall origin and subsequet deposition from suspension in a standing body of water during periods of low epiclastic input. The second evidence for an ephemeral lacustrine environment centers around a suite of coarse-tail-graded sandstone and pebbly sandstone beds, stratigraphically between the tuff markers. These sandstones are pervasively calcite-cemented, with poikilotopic cement completely surrounding many grains in a fashion which implies eogenetic origin (see Schmidt and McDonald, 1979). The sandstones are organized into 4-to-5m-thick upward fining cycles, commonly capped by 10-40cm-thick, laminated or massive mudstone beds. The presence of thick mudstones and the normally graded structure of the sandstones imply suspension sedimentation, possibly as resedimented, subaqueous debris flows off the front of a prograding fan-delta system (for example, Larsen and Steel, 1978; Gloppen and Steel, 1981). The upward fining cyclicity is nested within larger upward coarsening and thickening cycles, some to 60 m thick. Such upward coarsening cyclicity has been described from other lacustrine fan-delta sequences (for example, Pollard and others, 1982), and probably represents sedimentary response to base-level fall (Gloppen and Steel, 1981) in the Tick Canyon depocenter. The third type of evidence for a lacustrine environment is the evaporitic, locally stromatolitic, argillaceous carbonates found upsection from the fan-delta sandstones. Internal drainage and concentration of bicarbonate ions are implied by these thin limestone beds (for example, Kendall, 1984). Finally, there are symmetrical, shoreline-facies ripple marks (Picard and High, 1981) in tuffaceous siltstones upsection from the fan-delta deposits (Fig. 5B). Westward, these ripple-marked silts pass gradationally into time-equivalent laminated to massive mudstones in Tick Canyon proper, possibly indicating deeper-water lacustrine sedimentation in this area.

The ephemeral-lacustrine/fan-delta sequence passes upsection gradationally into a suite of red, hematite-cemented sandstones organized into 2-3m-thick upward fining cycles. The sandstones, siltstones and pebble conglomerates of these cycles feature common trough, alpha and omikron cross strata resembling braided-fluvial transverse-bar/megaripple migration (Smith, 1970; Miall, 1977; Cant and Walker, 1978). These fluvial deposits signal a period when sedimentation rate outpaced subsidence rate, thus leading to infilling of the lacustrine depocenter and subsequent subaerial sedimentation.

Paleocurrent readings from braided-fluvial cross strata in the Tick Canyon block suggest northwesterly paleoflow (Fig. 6), which concurs with the general northwestward fining trends along strike and northwesterly distal lithofacies pattern seen through the Volcanic interval and Tick Canyon block sediments. Lowe granodiorite clasts dominate the upper horizons of this interval, yet minor gabbro and anorthosite are present lower in the interval within the Agua Dulce block.

Middle Vasquez

The 2600 m Middle Vasquez interval consists of four, well organized, upward fining and thinning alluvial megacycles, which can be traced laterally across the entire sub-basin. Each megacycle has been subdivided into a lower coarse sequence and upper fine sequence. Proximal to the Soledad fault, the megacycles have a mean thickness of 525 m, diminishing rapidly along strike to a mean thickness of 250 m per megacycle in the Vasquez Rocks County Park area to the northwest (Fig. 7), over a distance of less than 4 km.

Proximal to the Soledad fault, both the coarse and fine sequences of the megacycles are highly conglomeratic (Sections 4, 9 and 12, Fig. 3), with bedding units consistently thicker in coarse sequences. Additionally, these "proximal" coarse sequences are up to ~~100% thicker than~~ their fine counterparts. Coarse sequences are distinguished by 2m-to-5m-thick, clast-to-sandy-matrix-supported breccia beds with local clast imbrications, massive internal structure and commonly nonerosive basal contacts. In beds where erosionally scoured basal bedding contacts do exist, clast imbrications are better developed. Inversely graded basal zones are common, suggesting dispersive shear during transport (Fisher, 1971; Shultz, 1984). These breccias are low-yield-strength debris-flow deposits, where the frictional component of strength dominated clast support (Rodine and Johnson, 1976). The high clast concentrations and clast-supported fabric suggest inertial transport and low flow viscosities (Shultz, 1984). Some of these clast-supported breccias may be sieve deposits, especially the better-sorted beds; however, lack of good three-dimensional exposures precludes recognition of sieve lobe geometry (for example, Hooke, 1967; Bull, 1977; Gloppen and Steel, 1981).

Fine sequences proximal to the Soledad fault also feature coarse, low-yield-strength debris-flow deposits, but these are always more thinly bedded than in the coarse sequences. There are also numerous sandy conglomerates and pebbly sandstones interstratified with the debris-flow deposits, and these finer clastic beds are internally massive, generally non-erosional and horizontally bedded, with constant lateral thicknesses (i.e., 50-150 cm range). These latter deposits are interpreted as either sheetflow units or upper-plane-bed-flow deposits from rapidly waning currents in broad, shallow alluvial-fan channels (for example, Friend 1978; Tunbridge, 1981). Figure 5C illustrates an upward fining and thinning transition at outcrop scale.

As the megacycles are traced northwest across the sub-basin, distinct lithofacies changes occur within both coarse and fine sequences (sections 2 and 10, Fig. 3). The two types of sequences are of relatively equal thickness in the Vasquez Rocks County Park area. Coarse sequences feature low-yield-strength debris-flow deposits similar to those proximal to the Soledad fault, yet bed thicknesses in the mid-basin sequence rarely exceed 2 meters. Additionally, maximum clast size is less (rarely > 50 cm) and clast angularity noticeably diminshes in the mid-basin debris-flow beds; several of these individual units can be traced laterally up to 2 km to the southeast. Some coarse conglomerates feature basal scoured zones (Fig. 5D), which may reflect turbulent, channelized-streamflood conditions (Bull, 1977). There are several moderately well sorted, horizontally bedded, unchannelized, coarse pebbly sandstones and pebble conglomerates up to 1.5 m thick interstratified with these low-yield-strength debris-flow deposits. These beds commonly feature outsized clasts within a finer, pebbly matrix (Fig. 5E), and closely resemble pebbly sheetflow (Ballance, 1984) or "terminal-fan" sheetflow deposits (Friend, 1978). Gloppen and Steel (1981) cite large, outsized clasts as diagnostic of high-energy-sheetflow deposition, as flow competence decreases rapidly in an unchannelized mid-to-outer-fan environment.

The fine sequences in this "mid-basin" locality are characterized by an abundance of bedform-migration structures (cross stratification) (Fig. 5F) and by the presence of 4m-to-15m-thick upward fining cycles. Many of these cyclic sediments are reminiscent of longitudinal-bar, transverse-bar and bar-top-modification deposits of braided-fluvial systems (for exmple, Miall, 1978a; Bluck, 1979; Ramos and Sopena, 1983), and are likely the result of autocyclic channel-migration/avulsion processes (Heward, 1978b, Miall, 1980).

The four Middle Vasquez megacycles are too thick to have been generated by any autocyclic, steady-state alluvial process (for example, Miall, 1978b, 1980). The only geomorphic process which could have feasibly generated cyclicity of this scale is the back-filling of entrenched fanhead channels, avulsion, and wholescale migration of the locus of sedimentation on the fan surface (Hooke, 1968; Heward, 1978b). However, if this process had been responsible for the Vasquez megacycles, then two features should be evident: 1) megacycle fine sequences would represent periods of negligible sedimentation on inactive fan lobes, and would, therefore, not be as thick (Fig. 8); and 2) inactive fan lobes would have been sites of nondeposition and pedogenesis, yet there is a virtual absence of paleosols, rhizocretions or other alluvial pedogenic features (Hooke, 1972; Birkeland, 1974; Mack and Rasmussen, 1984). The basin-wide extent of these cycles also indicates allocyclic, tectonic control (Steel and Aashiem, 1978; Steel and Gloppen, 1980).

The Middle Vasquez upward fining megacycles are considered allocyclic, probably related to periodic tectonic events in the ancestral San Gabriel drainage basin and to uplift along the Soledad fault. Coarse sequences reflect large-scale fan progradation and migration of upper-fan debris-flow or channelized-streamflood facies over mid-to-outer-fan sheetflow and braided-fluvial deposits. Fine sequences reflect retrogradation of fan facies during periods of source area erosion and diminished faulting. Abbreviated fine sequences proximal to the Soledad fault probably reflect fanhead entrenchment between tectonic uplift pulses, where conditions existed for low sedimentation rate and erosion outside of entrenched channels (Miall, 1978b). Decreased bed thickness, clast size and clast angularity towards the northwest imply downfan trends and sediment dispersal in that direction (Miall,1970; Bull,, 1977; Steel and Aashiem, 1978). Paleoflow data from the Middle Vasquez interval (Fig. 6) support this model of northwestward sediment transport.

Clast-count data from the Middle Vasquez show a dominance of epidote-rich Lowe Granodiorite clasts, plus ancillary basaltic-andesite and dacite clasts within the two lower megacycles. Gabbro clasts increase in percentage upsection, and anorthosite appears within breccias of the 4th megacycle. Sandstone point counts support these data, with abundant Lowe-derived detrital epidote in all samples, plus minor lithic volcanic (Lv) grains. The volcanic detritus was probably derived from nearby volcanic sources created during the earlier extrusive episode (Hendrix, 1986).

Volcanism apparently continued during Middle Vasquez sedimentation. There are numerous vitric-crystal, ash-fall tuffs preserved in fine sequences, plus a 30m-thick diabase sill found at the top of the 3rd megacycle (Hendrix, 1986). These volcanogenic lithologies imply continued volcanism in Vasquez Rocks sub-basin subsequent to the main volcanic phase, and may imply time-equivalence between portions of the Middle Vasquez section and sediments of the Tick Canyon block.

Upper Vasquez

Field observations reveal a gradational, conformable contact between the uppermost Middle Vasquez and the conglomerates and breccias of the Upper Vasquez interval. Clast-count data indicate a gradual increase in gabbro and anorthosite in the Middle Vasquez 4th megacycle and Upper Vasquez sediments (Hendrix, 1986). There is no evidence of angular discordance between these two intervals; therefore, the assignment of Upper Vasquez sediments to either the Tick Canyon or Mint Canyon Formations (Oakeshott, 1958; Ehlert, 1982; Dibblee, 1984) is considered erroneous.

Most Upper Vasquez conglomerates contain subangular to subrounded gabbro, anorthosite and metapyroxenite clasts within sandy, clast-supported beds with a mean thickness of 1.75m. Subordinate Lowe Granodiorite clasts are found locally within this interval, but clast counts and sandstone P/F (plagioclase/total feldspar) ratios indicate the gradual exposure of a plagioclase-rich, anorthositic source terrane during the Middle/Upper Vasquez transition period.

Individual conglomerate beds are massive to normally graded, with inverse grading rarely observed. Clast imbrications are locally well developed, as are scoured basal bedding contacts. Some conglomerates pass vertically or laterally into coarse, pebbly cross-stratified sandstones. These latter features suggest turbulent, Newtonian flow conditions; however, massive clast fabrics, great bed thicknesses and lack of numerous bedform-migration structures imply that flow may not have been truly Newtonian (Costa, 1984; Shultz, 1984). A plot of bed thickness vs. maximum particle size reveals a correlation coefficient of 0.58, which is lower than those previously reported for conglomerates of true debris-flow origin, but higher than those from "classic" fluvial streamflood deposits (Bluck, 1967; Steel, 1974; Gloppen and Steel, 1981; Shultz, 1984) (Fig. 9). Most of the Upper Vasquez deposits, therefore, are interpreted as deposits of flows transitional between Newtonian flows and those which possess finite yield strength, termed "hyperconcentrated flood flows" (Smith, 1986). Clast fabrics of such deposits imply sediment/water ratios high enough to effectively dampen original flow turbulence (Costa, 1984).

The Upper Vasquez is an overall upward coarsening sequence exceeding 1200m in thickness. Paleoflow data from imbrications reveal a significant northward transport trend, as opposed to the more northwesterly trends of the Volcanic/Tick Canyon and Middle Vasquez intervals (Fig. 6).

TEXAS CANYON SUB-BASIN

The Vasquez in Texas Canyon sub-basin is exposed as a faulted, southwest-dipping homoclinal sequence bounded by the Vasquez Canyon fault along the southeast basin margin, and by the Pelona fault along the northwest margin (Fig. 10). Each of these high-angle faults dips towards the Texas Canyon depocenter (Remenyi, 1966). Mint Canyon Ridge is the structural block separating Texas Canyon and Vasquez Rocks sub-basins, and consists of Precambrian layered-to-porphyroblastic augen gneiss intruded by Cretaceous granitic rocks. Across the Pelona fault from the Vasquez outcrops, a distinctive block of Cretaceous quartz monzonite is thrust over the Pelona Schist along a narrow mylonite zone (Muehlberger, 1958). The Pelona Schist consists primarily of metasedimentary/metavolcanic quartz-mica-albite and actinolite-chlorite schists of latest Cretaceous to Paleocene age (Haxel and Dillon, 1978; Ehlig, 1981). Most of these basement lithologies are also exposed east of the Texas Canyon depocenter.

The Vasquez Formation in Texas Canyon consists of approximately 4000 m of conglomerates, breccias and subordinate sandstones. Four stratigraphic subdivisions are recognized: Lower, Middle, Upper and Uppermost Vasquez intervals (Fig. 11) (Hendrix, 1986).

Lower Vasquez

The Lower Vasquez is a 1600m-thick interval defined by four upward fining alluvial megacycles, ranging in thickness from 275m to 500m (sections 1,2,5,6,7 and 12; Fig. 10). As in the Middle Vasquez megacycles of Vasquez Rocks sub-basin, these megacycles are interpreted as allocyclic and tectonically generated (for example, Miall, 1980). Coarse sequences of these megacycles are up to 75% thicker than their associated fine sequences, and are characterized by massive, 1m-to-3m-thick breccia beds. Within the lowest megacycle, these breccias are clay-rich, and dominated by matrix-supported fabrics. Upsection, the breccias are pervasively sandier, exhibiting clast-supported fabric and inversely graded structure. Nonerosional basal contacts and random clast orientations are most common, yet local clast imbrications also occur. Sheetlike, poorly sorted pebbly sandstone beds to 40 cm in thickness are gradational and interstratified with many of these breccias. These coarse alluvial deposits resemble debris-flow deposits, probably of low yield strength due to low clay contents and viscosities (Rodine and Johnson, 1976; Hampton, 1979). Many of the interbedded sandstones are likely to have been waning-flood, late-stage debris-flow deposits.

Megacycle fine sequences feature 2m-to-6m-thick upward fining and thinning cycles containing massive to normally graded sandstone beds 20-150 cm thick. These cycles are commonly capped by thick, massive mudstone beds, yet contain few cross-stratified units. Thickness changes of sandstone beds along strike are negligible, where traceable, and the presence of parting lineations on sandstone bedding planes implies upper-plane-bed flow (for example, Picard and High, 1973). The absence of cross stratification implies high-energy (sheetflow?) transport (Miall, 1977) and rapidly waning flood conditions

(Tunbridge, 1981). Local scour structures are present, suggesting that flows were turbulent. Despite the paucity of "classic" braided-channel features, these upward fining cycles are probably autocyclic, related to flood-sedimentation events in a rapidly aggrading, mid-to-outer-fan environment (for example, Bull, 1977).

The megacyclic fine sequences are asymmetrically concentrated and better developed closer to the Pelona fault margin of the sub-basin. Southeastward along strike, the well developed allocyclic megacycles grade into coarse, matrix-supported breccias along the Vasquez Canyon fault (section 9, Fig. 10). Lithologically, these thick, poorly bedded breccias are dominated by gneissic lithologies similar to those of Mint Canyon Ridge. Along the Pelona fault, there are coarse, quartz-monzonite-rich breccias interfingering with the megacyclic sediments (section 8, Fig. 10).

Clast counts from the Lower Vasquez reveal that gneissic lithologies dominate the populations (Hendrix, 1986). Granitic clasts, lithologically similar to granites of Mint Canyon Ridge and the region southeast of Texas Canyon sub-basin (Figs. 3, 10), are also abundant. Numerous clasts of basaltic-andesite and dacite make up the most distinctive element of the Lower Vasquez assemblage; although Bohannon (1976) regarded these clasts as "exotic" (distal source), most are lithologically identical to the extrusive rocks of the eastern volcanic field of Vasquez Rocks sub-basin (Fig. 3). Sandstone point-count data reveal abundant metamorphic, volcanic and polycrystalline-quartz lithic grains in samples from this stratigraphic horizon

(Hendrix, 1986). Clast-imbrication paleocurrent data (Fig. 12) support the hypothesis of an eastern to slightly southeastern source for Lower Vasquez sediments.

The local gneissic breccias along Vasquez Canyon fault ostensibly were shed northward across this fault from an ancestral Mint Canyon Ridge gneissic positive area. However, most of the megacyclic Lower Vasquez sediments were apparently derived from a source region farther to the east/southeast of the Texas Canyon depocenter; these eastern-derived sediments interfinger with local quartz-monzonite breccias along the Pelona fault. The monzonitic breccias are poorly sorted, with highly disorganized to inversely graded clast fabrics; most of the beds range from 1m to 3m in thickness, and resemble low-yield-strength, clast-rich debris-flow deposits (for example, Shultz, 1984).

Middle Vasquez

The 250m-thick Middle Vasquez interval (Sec. 4, Fig. 10) consists of quartz-monzonite-rich breccias similar to those along the Pelona fault in the Lower Vasquez interval; however, these deposits extend across the sub-basin two-thirds of its width. Additionally, there are abundant, 1m-to-2m-thick sheetflow-facies sandstone beds interstratified with the breccias in the axial zone of the basin. Gneissic and volcanic clasts are admixed with monzonite detritus in this axial zone, as well, suggesting continual interfingering with the east-derived sediment. An overall fining of grain size in a direction away from the Pelona fault, coupled with planar cross-bed foresets, suggests sediment dispersal southward from a quartz-monzonite source across the Pelona fault (Fig. 12). No Pelona Schist detritus has been found in this interval; very likely, the monzonite terrane completely covered the ancestral Sierra Pelona positive element during Vasquez deposition. An overall upward coarsening trend in this thin interval attests to the origin of the Middle Vasquez deposits as a progradational alluvial-fan wedge (Heward, 1978b), which expanded as a result of local, intensified activity on the Pelona fault.

Upper Vasquez

Over 1500 meters of poorly exposed, clast-to-matrix-supported conglomerates and subordinate sandstones comprise the Upper Vasquez. Most conglomerates are horizontally stratified, nonchannelized, and similar in geometry and fabric to the hyperconcentrated-flood-flow deposits of the Upper Vasquez in Vasquez Rocks sub-basin. A plot of bed thickness versus maximum particle size (Fig. 13) yields a correlation coefficient of 0.61, a value transitional between coefficients for debris-flow deposits and fluvial conglomerates laid down by Newtonian, turbulent flows (Bluck, 1967; Gloppen and Steel, 1981).

Paleocurrent data from clast imbrications indicate a northerly paleoflow (Fig. 12), similar to the Upper Vasquez of Vasquez Rocks sub-basin. Subrounded to well rounded gabbro and anorthosite clasts of probable San Gabriel provenance are present in the conglomerates of this interval, admixed with gneissic, granitic and volcanic clasts (Hendrix, 1986).

Uppermost Vasquez

This 700m-thick interval, although possessing similar clast populations to those of the Upper Vasquez interval, is stratigraphically distinct due to the presence of autocyclic, upward fining braided-fluvial sequences. These fluvial deposits are composed predominantly of sandstones and sandy conglomerates, yet they pass gradationally into hyperconcentrated-flood-flow deposits southeastward along strike, and interfinger with quartz-monzonite-rich debris-flow deposits along the Pelona fault. There is abundant evidence of longitudinal and transverse-bar accretion surfaces in the Uppermost Vasquez fluvial deposits (for example, Bluck, 1979; Ramos and Sopena, 1983); several upward fining cycles are capped by mudstones and thin, concordant evaporitic carbonate beds. Paleocurrent data from imbrications suggest a return to westward paleoflow during deposition of the braided fluvial autocycles, as sediment was shed longitudinally down the basin axis (Fig. 12).

PALEOGEOGRAPHIC SYNTHESIS: VASQUEZ ROCKS AND TEXAS CANYON

The Vasquez Rocks and Texas Canyon depocenters shared similar tectonic and sedimentary histories, as indicated by suggested stratigraphic correlations (Fig. 14). Incipient subsidence generated an irregular depocenter in the Vasquez Rocks sub-basin. The dominance of debris-flow lithofacies in the Basal Vasquez suggests deposition on small, steep alluvial fans (for example, Hooke, 1968; Steel and Aashiem, 1978). The absence of distinct lithofacies changes northward (away from the Soledad fault) and the presence of dramatic differences in clast compositions along strike in the Basal Vasquez suggest sedimentation on small fans draining many local basement sources, rather than a single fan system prograding from a southern source. Clast imbrications suggest that the anorthosite/gabbro source may have existed within the basin; this source may have been uplifted along an incipient Soledad fault zone (Hendrix, 1986). Southward backstepping of this fault may have occurred, as extension in the sub-basin progressed (for example, Crowell, 1974; Steel and Wilson, 1975); this source was likely buried by subsequent volcanic and sedimentary deposits. The dominance of Lowe granodiorite clasts in the Basal Vasquez proximal to the Soledad fault implies that a local granodiorite source existed, probably southeast across the fault, where Lowe granodiorite is presently exposed (Fig. 3).

The Volcanic/Tick Canyon interval represents: 1) sedimentation during the principal rifting/basin-widening phase of Soledad basin evolution; 2) establishment of the Soledad fault as the major structure controlling sedimentation in the Vasquez Rocks sub-basin, with the elevation of a major Lowe granodiorite source south of the fault zone in the ancestral San Gabriel highland; 3) incipient development of a fan system with a downfan-to-the-northwest geometry, with northwest diversion of most epiclastic material by volcanic flows; and 4) development of the half-graben geometry which prevailed in Vasquez Rocks sub-basin during the remainder of Vasquez deposition (Fig. 15).

No strata correlative to the Basal Vasquez or Volcanic/Tick Canyon interval have been recognized in Texas Canyon sub-basin, probably because rifting initiated and was most intense, in the southern region of the Soledad basin. The absence of the volcanics in Texas Canyon also supports this contention, as does the thinning-to-the-northwest pattern of the volcanics in Vasquez Rocks sub-basin.

The asymmetry of alluvial lithofacies in the Middle Vasquez of Vasquez Rocks and Lower Vasquez of Texas Canyon implies half-graben and asymmetric-graben geometries, respectively, for these sub-basins. The presence of local, debris-flow-dominated fan deposits along the Pelona fault suggests that the steepest margin of Texas Canyon sub-basin was the northwest margin (for example, Hooke, 1972; Steel and Aashiem, 1978) (Fig. 15), where steep, relatively small, quartz-monzonite-rich fans interfingered with gneissic, granitic and volcanic detritus derived from an eastern source area.

Four upward fining alluvial megacycles appear in both Vasquez Rocks and Texas Canyon sub-basins, generated by fan-system progradation in response to four regional episodes of tectonic activity in Soledad basin, followed by retrogradation. Although clast petrology, sandstone compositions and paleocurrent data imply separate source areas and lack of physical interconnection between the two depocenters, the allocyclic megacycles provide a means of establishing time-equivalence and correlation between the stratigraphic sections of these two sub-basins (Fig. 14). The ancestral Mint Canyon Ridge provided a barrier between the two sub-basins, yet the absence of gneissic detritus in Vasquez Rocks sub-basin implies that drainages off the ridge were asymmetric towards Texas Canyon. The presence of Vasquez volcanic clasts in the Lower Vasquez of Texas Canyon implies that rifting and extrusive igneous activity had occurred in Vasquez Rocks sub-basin prior to Texas Canyon deposition, thereby strengthening the above-mentioned correlation.

The abundance of sheetflow deposits in the megacyclic fine sequences of both sub-basins implies rapid vertical aggradation and basin subsidence (Friend, 1978). Additionally, the rapid thickness and lithofacies changes and high sedimentation rates imply that the Vasquez fans were small and thick; such fan geometry was a logical artifact of the narrow, tectonically confined nature of the sub-basins (for example, Hooke, 1968; Bull, 1977). Major tectonic uplift of the Soledad basin terrane and enlargement of the ancestral San Gabriel drainage system commenced during the beginning of Upper Vasquez sedimentation in both sub-basins. The uplift generated the upward coarsening of the Upper Vasquez intervals, while enlargement of the drainage basins led to increased water discharge into the depocenters (for example, Schumm, 1981) and lower sediment/water ratios of individual depositional events, thus contributing to the deposition of hyperconcentrated flood flows rather than true debris flows. It is likely that this increased water discharge was not related to regional paleoclimatic changes, since independent data do not indicate such a latest Oligocene/earliest Miocene climatic event (Savin and others, 1975; Ingle and others, 1976).

Time-equivalence of the Upper Vasquez in both sub-basins is supported by: 1) similar sedimentologic character of deposits (hyperconcentrated-flood-flow lithofacies); 2) presence of San Gabriel anorthosite and gabbro clasts in Texas Canyon conglomerates, implying physical interconnection of the two depocenters; and 3) northward paleoflow data from anorthosite/gabbro-bearing conglomerates in both sub-basins. During the tectonic uplift and reorganization phase, the ancestral Mint Canyon Ridge was probably dissected (Fig. 16), allowing passage of detritus from Vasquez Rocks sub-basin to Texas Canyon sub-basin. However, the eastern source region continued to supply abundant gneissic and granitic debris, longitudinally dispersed along the axis of the Texas Canyon sub-basin. Additionally, erosional remnants of Mint Canyon Ridge gneisses projected above the expanding Upper Vasquez fan system, since local gneiss breccias appear along the Vasquez Canyon fault margin at this time-stratigraphic horizon.

CHARLIE CANYON SUB-BASIN

The Vasquez Formation attains a thickness of 2400 meters within the Charlie Canyon sub-basin (Fig. 17), within a west-southwest-plunging syncline (Fig. 18). The San Francisquito fault dips at a high angle towards Charlie Canyon sub-basin (Sams, 1964; Konigsberg, 1967), and separates Vasquez sediments from the Pelona Schist along the southern margin (Fig. 18). The northern margin of the sub-basin is defined by the Bee Canyon thrust, which brings Cretaceous-Paleocene submarine-fan deposits of the San Francisquito Formation structurally above the Vasquez

(Kooser, 1982). In accordance with the proposal of Bohannon (1976), the Vasquez of Charlie Canyon sub-basin is subdivided into three intervals: Lower, Middle and Upper Vasquez (Fig. 17).

Lower Vasquez

This 800m-thick interval is exposed in the eastern and northernmost regions of the sub-basin (Sections 1,3,4,5,6,10 and 11, Fig. 18). The lower section is defined by 3m-to-5m-thick upward fining and thinning cycles of autocyclic braided-fluvial character (for example, Miall, 1980). Discontinuous, lenticular beds of massive-to-planar-cross-stratified pebble conglomerates at the bases of these fluvial cycles pass upsection into sheetlike, coarse to fine-grained, moderately well sorted sandstones suggestive of longitudinal-bar, sandflat or transverse-bar deposits (Miall, 1977; 1978a; Cant and Walker, 1978). Pebbles from these lower cycles are ubiquitously well rounded, and dominated by a chert-metarhyolite-granite clast suite (Hendrix, 1986); clasts of San Francisquito Formation arkose are subordinately present.

The lower braided-fluvial zone passes gradationally upsection into a sequence of thinly laminated, massive or ripple-marked mudstones and fine sandstones. Coarse-sandstone beds, to 25 cm thick, locally punctuate the section, as do concordant gypsum horizons locally interstratified within the mudstones. These gypsum horizons increase in thickness and number westward along strike, concomitant with an increase in thickness and number of mudstone beds. Paleoflow data, primarily from asymmetric ripple marks on bedding planes, suggest westward transport (Fig.

19).

Middle and Upper Vasquez

The remaining 1600 meters of Middle and Upper Vasquez define an upward coarsening, prograding-fan sequence (Sections 2,7,8,9,and 12, Fig. 18). This sequence appears to grade both vertically and laterally into the mudstones of the Lower Vasquez, and is defined at its base by horizontally bedded, moderately well sorted coarse sandstones similar to "terminal-fan" sheetflow deposits (for example, Friend, 1978; Tunbridge, 1981). This sheetflow lithofacies is succeeded upsection by pebbly, highly channelized and lenticular sandstones of probable high-energy, braided-midfan environments (Fig. 20A) (Bull, 1977); the channelized-midfan deposits are overlain by coarse, massive to horizontally bedded conglomerates with well imbricated clasts (Fig. 20B). These latter deposits closely resemble the hyperconcentrated-flood-flow deposits (Smith, 1986) described from the other two sub-basins. The remainder of the Vasquez section consists of poorly sorted breccias and conglomerates, which coarsen and become highly matrix-supported upsection (Fig. 17); many of these breccias display bedding and fabric characteristics of debris-flow deposits (Miall, 1978a; Shultz, 1984).

Clast counts display important vertical trends within this upward coarsening sequence. Whereas the distal-to-midfan conglomerates of the Middle Vasquez interval are dominated by San Francisquito Formation arkose clasts, these gradually diminish upsection, concomitant with increasing quartz-diorite and quartz-monzonite clasts (Hendrix, 1986). Sandstones from the Middle

Vasquez feature argillaceous sedimentary grains of probable San Francisquito provenance, whereas Upper Vasquez sands are dominated by plagioclase, quartz and potassic feldspars of plutonic origin (Hendrix, 1986).

Paleocurrents from numerous clast imbrications reveal a significant northerly paleoflow trend, from across the San Francisquito fault in the vicinity of the present Sierra Pelona ridge (Fig. 19). However, as noted in previous studies (Konigsberg, 1967; Bohannon, 1976), no Pelona Schist clasts appear in the Vasquez sediments of Charlie Canyon sub-basin.

Paleogeographic Synthesis

The Lower Vasquez accumulated on a broad floodplain, and was derived from a relatively distant eastern source. Although Bohannon (1976) considered the San Francisquito fault to have been active during Lower Vasquez sedimentation, there are no rapid thickness, coarseness or lithofacies changes close to the fault. The gradual westward fining and lithofacies changes, relatively good sorting of sandstones, and good rounding of clasts suggest that these sediments accumulated on a broad alluvial braidplain (e.g., Rust and Koster, 1984) with a distant source. Additionally, many of the Lower Vasquez clasts bear no similarity to local basement lithologies, implying possible distant or "exotic" sources.

If the San Francisquito fault was not active during

Lower Vasquez sedimentation, it certainly became active at the onset of Middle Vasquez deposition. A thick alluvial-fan system prograded northward from a source terrane uplifted across the fault (Fig. 21); this system buried the Lower Vasquez braidplain sediments as it prograded. As initially proposed by Konigsberg (1967), the absence of Pelona Schist debris in the Vasquez implies that the schist had a tectonic cover of quartz diorite and monzonite, overlain by San Francisquito sedimentary deposits. As the allochthon was eroded, it produced an "inverted stratigraphy" of clasts in the Vasquez conglomerates in the adjacent sub-basins; the presence of quartz-monzonite and San Francisquito arkose clasts in Texas Canyon sub-basin supports this hypothesis. The quartz monzonite exposed in the southwest corner of Charlie Canyon sub-basin (Fig. 18) is a remnant of this eroded allochthon.

The absence of ancestral San Gabriel basement clasts and distinct megacyclicity in the Vasquez sediments of Charlie Canyon sub-basin suggests no physical interconnection or depositional similarity between this depocenter and Vasquez Rocks or Texas Canyon sub-basins, other than the nonmarine nature of the sediments. Indeed, if the ancestral Sierra Pelona highland was the principal source area for much of the Vasquez detritus in Charlie Canyon, it seems logical that it prevented interconnection with Texas Canyon sub-basin to the southeast. Recent study of central Transverse Ranges basement structures (Powell, 1981) implies mid-Tertiary dextral offset along the San Francisquito fault; such displacements would have placed the original site of Charlie Canyon farther west relative to the other sub-basins. It is even possible that this strike-slip offset was coeval with uplift of the ancestral Sierra Pelona during Middle/Upper Vasquez deposition. Since extant age control for Vasquez sedimentation is poorest in Charlie Canyon sub-basin, chronostratigraphic correlation between what is called "Vasquez" in this sub-basin and the Vasquez of Vasquez Rocks and Texas Canyon sub-basins is unconstrained.

TECTONIC SYNTHESIS AND SOLEDAD BASIN EVOLUTION

The association of thick alluvial fills with bimodal volcanics is a hallmark of intracontinental rift tectonics (Martin and Piwnskii, 1972; Dickinson, 1976). Since this association exists in Vasquez Rocks sub-basin, and since Texas Canyon sub-basin apparently shared a tectonically similar history, it is likely that these two depocenters originated within a zone of crustal extension (see Muehlberger, 1958; Glazner and Loomis, 1984; Nilsen, 1984). It is tempting to envision the Soledad basin as structurally related to wrench tectonics similar to that which generated many other Cenozoic basins in southern and central California (Crowell, 1974; Blake and others, 1978). However, it is clear that much of this wrench tectonism accompanied evolution of the San Andreas transform system (Atwater, 1970). The San Gabriel and San Andreas faults originated no earlier than 14 m.y.B.P., long after Vasquez sedimentation (Crowell, 1975). Plate reconstructions for the eastern Pacific region (Pilger and Henyey, 1979; Powell, 1981; Engebretson, 1982; Glazner and Loomis, 1984) suggest that the northward migrating Mendocino triple junction and incipient San Andreas transform system lay to the south of the Soledad terrane during initial rifting of the basin (Fig. 22). The fact that the Soledad basin evolved inboard of a convergent margin may explain the subalkaline/calc-alkaline chemical affinities (Weigand, 1984) of the Vasquez volcanics.

If the San Andreas transform margin had not evolved in the Soledad region during Vasquez sedimentation, it is reasonable to assume that if the Soledad basin evolved as part of an evolving strike-slip or pull-apart system, then hypothetical strike-slip displacements cannot be related to San Andreas transform deformation. Distinguishing strike-slip or pull-apart basins from orthogonal rifts based solely on sedimentologic grounds can be difficult (Reading, 1980; Hempton, 1983). The most direct lines of evidence for characterizing strike-slip tectonics during sedimentation are: 1) lithologic mismatches between sediments and source areas, and 2) evidence of depocenter migration with time (Steel and Gloppen, 1980; Crowell, 1982; Hempton, 1983). Documentation of the latter includes recognition of stratigraphic younging in the direction of source terrane migration (Steel and Aashiem, 1978; Crowell, 1982), which cannot be accomplished with the Vasquez due to poor biostratigraphic control and lack of proper sediment/basement onlap exposures. However, the former condition apparently exists along the Soledad fault margin of Vasquez Rocks sub-basin, where anorthositic basement is faulted against Lowe Granodiorite-bearing breccias of the Middle Vasquez, producing apparent sinistral offset in map view. However, this anomaly is explained by the upsection increase of anorthosite clasts and sandstone P/F vlues in the Vasquez sediments (Hendrix, 1986), reflecting erosional unroofing of an anorthosite pendant from beneath a mantle of Lowe granodiorite. It is, therefore, not necessary to invoke strike-slip along Soledad fault to explain this contact relationship. Nowhere else adjacent to the Vasquez depocenters is there any evidence of sediment/source-lithology mismatch.

High sedimentation rates have been used to characterize pull-apart basins (Miall, 1978b); however, rapid sediment accumulation can also occur in orthogonally rifted alluvial basins (Schwab, 1976; Hempton, 1983). A subordinate, but possibly significant, characteristic of sedimentation in alluvial depocenters adjacent to active strike-slip faults is the development of stacked, upward coarsening megacycles (several hundreds of meters in thickness) (Steel and Gloppen, 1980; Hempton, 1983). Such upward coarsening cyclicity results from periodic rapid horizontal offsets of alluvial depocenter and source terrane along the strike-slip fault, followed by gradual progradation of the fan system in response to vertical displacements associated with the horizontal offset. The asymmetric stratigraphic transition from coarse alluvium to distal, finer-grained alluvium or lacustrine sediments would be an expected consequence of relatively rapid strike-slip offsets of basin and source area. Such upward coarsening megacycles appear in several ancient alluvial basins of proposed strike-slip origin, including the Violin Breccia of Ridge basin (M. Link, pers. comm., 1985), the post-Hercynian basins of Spain (Heward, 1978a,b) and the Devonian Hornelen basin of Norway (Steel and Aashiem, 1978). In Vasquez Rocks and Texas Canyon sub-basins, however, the four alluvial megacycles are upward fining; nowhere is there evidence of stacked, upward coarsening cyclicity. Although the model linking tectonic style and alluvial megacyclic sedimentation is tenuous due to the paucity of published case histories, there are ancient examples of upward fining alluvial allocycles in basins where evidence of strike-slip deformation cannot be found (Steel and Wilson, 1975; Mack and Rasmussen, 1984). We feel that this criterion could prove potentially useful for delineating ancient strike-slip basins, once a sufficient database on large-scale, cyclic alluvial sedimentation is accumulated.

An important codicil for the use of megacylicity in deducing tectonic style relates to basin/source paleoclimate and to the recurrence interval of marginal fault displacements. If paleoclimate is too humid or recurrence interval too long, the alluvial system may have time to reestablish equilibrium, resulting in upward fining intervals above each upward coarsening megacycle, thus obscuring tectonic control of megacyclicity. The evaporitic sulfates and carbonates and abundance of debris-flow deposits prior to drainage-basin reorganization suggest a semiarid paleoclimate (e.g., Bull, 1977; Schumm, 1981; Kendall, 1984). The high sedimentation rates calculated for the Vasquez suggest dynamic tectonism, rapid subsidence and frequent fault displacements (e.g., Reading, 1980); therefore, megacyclicity probably reflects tectonic style.

Sedimentologic data do not provide evidence for strike-slip tectonism during Vasquez sedimentation. Additionally, the thick volcanic sequence low in the Vasquez Rocks section seems to favor early magmatic activity and high geothermal gradient, possibly in an active rift zone. Although magmatism can also be associated with pull-apart basins, such volcanism is generally a later-stage evolutionary event rather than an early process in the basin's history (Mann and others, 1983).

The kinematics of Soledad orthogonal rifting may be related to upper-lithosphere brittle failure in the North American plate, as the continental margin was uplifted above the buoyant, young, subducting Farallon plate (Nilsen, 1984), and/or as the unstable Mendocino triple junction evolved (Ingersoll, 1982). Ingersoll's (1982) model predicts northwest-southeast extension in the North American plate north of the migrating triple junction, which concurs with the pre-rotational stress requirements for Soledad basin rifting. The "subducted Mendocino fracture zone" model of Glazner and Loomis (1984) does not explain Soledad basin formation once the 45-degree Miocene clockwise rotations of this terrane are palinspastically corrected (Luyendyk and others, 1980; Terres and others, 1981). However, wholescale uplift and drainage system enlargement during Upper Vasquez sedimentation may well be explained by the Glazner/Loomis model, as the terrane south of the Vasquez depocenters was tectonically uplifted during fracture-zone passage at the Oligo-Miocene boundary. Miocene clockwise rotations occurred later within the evolving San Andreas transform system.

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REFERENCES CITED

Atwater, T., 1970, Implications of plate tectonics for the Cenozoic tectonic evolution of western North America: Geological Society of America Bulletin, v. 81, p. 3513-3536.

Bailey, T.L. and Jahns, R.H., 1954, Geology of the Transverse Range Province, Southern California: California Division of Mines and Geology Bulletin 170, p. 83-106.

Ballance, P.F., 1984, Sheetflow-dominated gravel fans of the non-marine Middle Cenozoic Simmler Formation, Central California: Sedimentary Geology, v. 38, p. 337-359.

Birkeland, P., 1974, Pedology, weathering and geomorphological research: Oxford University Press, London, 307 p.

Blake, M.C., Campbell, R.H., Dibblee, T.W. Jr., Howell, D.G., Nilsen, T.H., Normark, W.R., Vedder, J.C. and Silver, E.A., 1978, Neogene basin formation in relation to plate tectonic evolution of the San Andreas fault system, California: American Association of Petroleum Geologists Bulletin, v. 62, p. 344-372.

Bluck, B.J., 1967, Deposition of some Upper Old Red Sandstone conglomerates in the Clyde area: A study in the significance of bedding: Scottish Journal of Geology, v. 3, p. 139 - 167.

FIGURE CAPTIONS

Figure 1 - Generalized geologic map of Soledad basin area, depicting adjacent lithologic units: gn = Precambrian gneisses; an and ga = Precambrian anorthosite and gabbro; gd = Triassic Lowe granodiorite series; gr = Cretaceous granitic to quartz-monzonitic plutonics; ps = Pelona Schist; sf = San Francisquito Formation. Vasquez Formation stippled: 1 = Vasquez Rocks sub-basin; 1a = eastern volcanic field; 2 = Texas Canyon sub-basin; 3 = Charlie Canyon sub-basin.

Figure 2 - Composite Soledad basin stratigraphic section

Figure 3 - General geologic map of Vasquez Rocks sub-basin, depicting measured section locations, stratigraphic intervals, local basement lithologies, key faults and geographic features. Basal Vasquez stippled. Ttc = Tick Canyon Fm.

Figure 4 - Generalized stratigraphic section for Vasquez Rocks sub-basin; vectors reflect paleocurrents at select horizons; lithofacies and clast suites listed.

Figure 5 - Alluvial lithofacies, Vasquez Rocks sub-basin: A) Inversely graded, clast-supported debris-flow deposit, Basal Vasquez: pencil along bedding plane (stippled) is 10 cm long. B) Symmetrical ripple marks

in tuffaceous sandstone, ephemeral lacustrine shoreli lithofacies, Tick Canyon block. C) Proximal low-yield-strength debris-flow deposits, top of coarse sequence, 3rd megacycle, Middle Vasquez. D) Channelized cobble conglomerate, megacycle coarse sequence, Middle Vasquez; E) Pebbly sheetflow bed with outsized clast, megacycle coarse sequence, Middle Vasquez midfan deposits. F) Grouped trough cross stratification (T) above mudstone ripups (R), braided-midfan lithofacies of megacycle fine sequences, Middle Vasquez.

Figure 6 - Paleocurrent rose diagrams for all stratigraphic intervals of Vasquez Rocks sub-basin; circled values indicate total number of localities at which measurements were collected; standard deviation of samples also given.

Figure 7 - Lateral (northwest) thickness and lithofacies changes, Middle Vasquez, Vasquez Rocks sub-basin.

Figure 8 - View north across Vasquez Rocks sub-basin, illustrating three 250m-thick allocyclic megacycles of Middle Vasquez interval.

Figure 9 - Bed thickness vs. maximum particle size plot for 40 hyperconcentrated-flood-flow beds, Upper Vasquez, Vasquez Rocks sub-basin; correlation coefficient shown.

Figure 10 - General geologic map of Texas Canyon sub-

basin, depicting stratigraphic intervals, mesured section locations, key faults, and local basement lithologies. Ttc = Tick Canyon Fm.; Tmc = Mint Canyon Fm.

Figure 11 - Composite stratigraphic section for Vasquez Formation in Texas Canyon sub-basin; four key stratigraphic horizons depicted. Details as for Fig. 5.

Figure 12 - Paleocurrent data from Texas Canyon sub-basin; details as for Figure 7.

Figure 13 - Bed thickness vs. maximum particle size plots, Upper Vasquez hyperconcentrated-flood-flow conglomerates, Texas Canyon sub-basin.

Figure 14 - Stratigraphic correlation between Vasquez sections of Vasquez Rocks and Texas Canyon sub-basins.

Figure 15 - Paleogeographic block diagram illustrating Vasquez sedimentation during deposition of Middle Vasquez in Vasquez Rocks sub-basin, and Lower Vasquez in Texas Canyon sub-basin; lithofacies are: A1 = high-yield-strength debris-flow; A2 = low-yield strength debris-flow; B = braided-fluvial/midfan; C = sheetflow; E1 = ephemeral lacustrine; E2 = lacustrine fan-delta.

Figure 16 - Paleogeographic block diagram illustrating Upper Vasquez sedimentation, Vasquez Rocks and Texas Canyon sub-basins; lithofacies are as for Figure 15, plus D = hyperconcentrated-flood-flow.

Figure 17 - Composite stratigraphic section for Vasquez Formation in Charlie Canyon sub-basin. Details as for Figure 4.

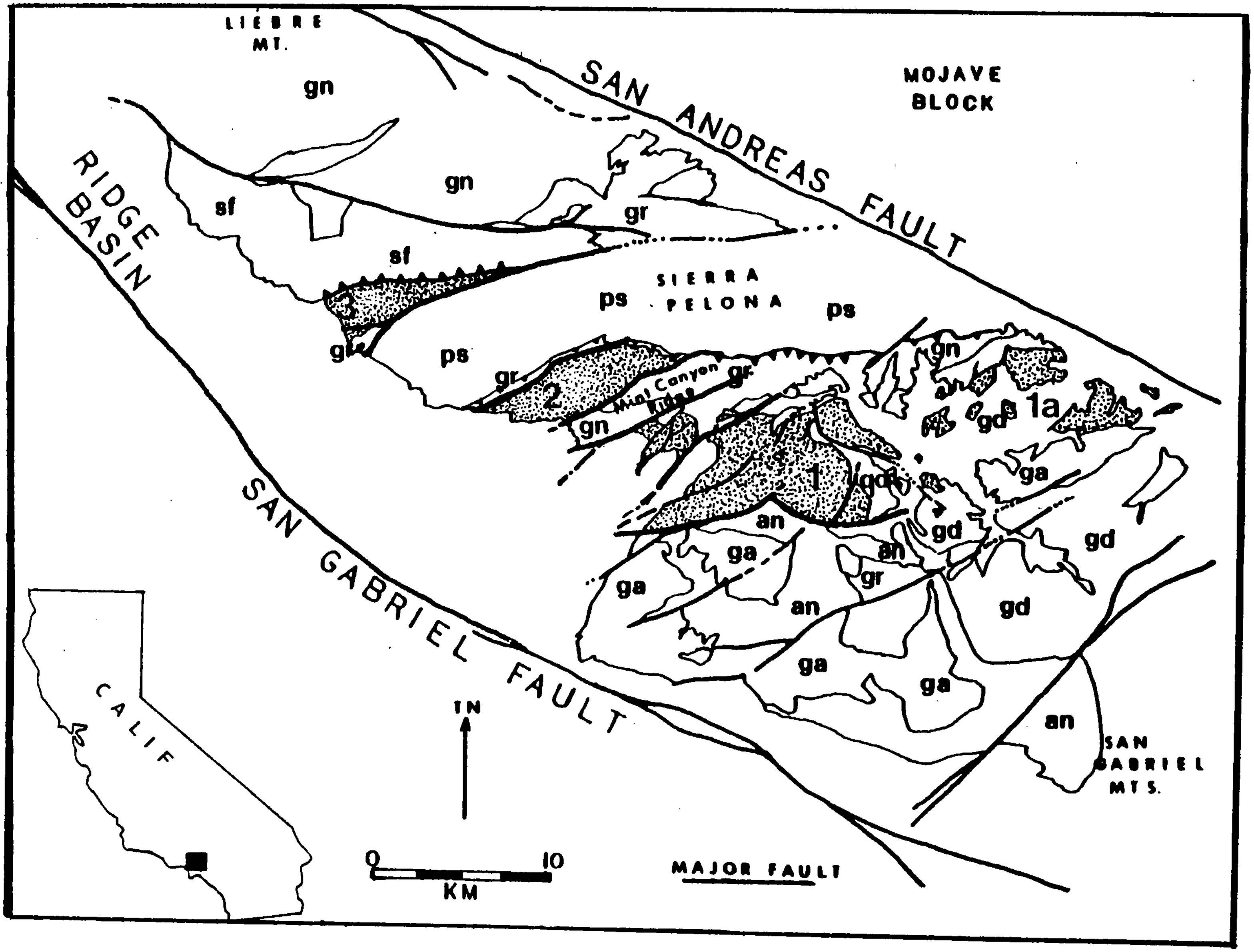
Figure 18 - General geologic map of Charlie Canyon sub-basin; details as for Figures 3 and 10.

Figure 19 - Paleocurrent data from Charlie Canyon sub-basin; details as for Figure 6.

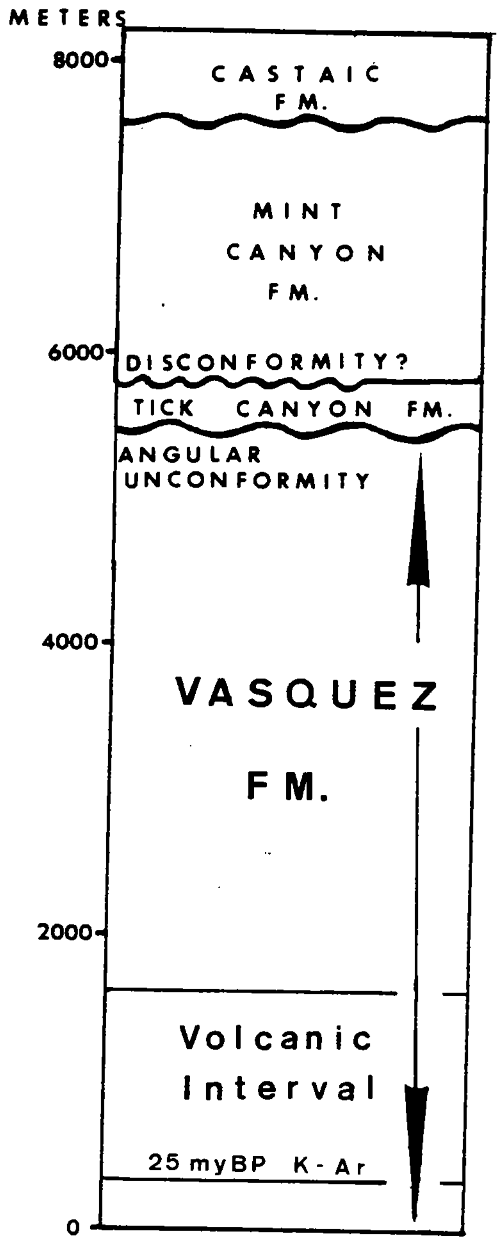
Figure 20 - Alluvial lithofacies, Charlie Canyon sub-basin: A) Channelized-midfan lithofacies, Middle Vasquez; B) Well imbricated clasts in hyperconcentrated-flood-flow lithofacies, Upper Vasquez

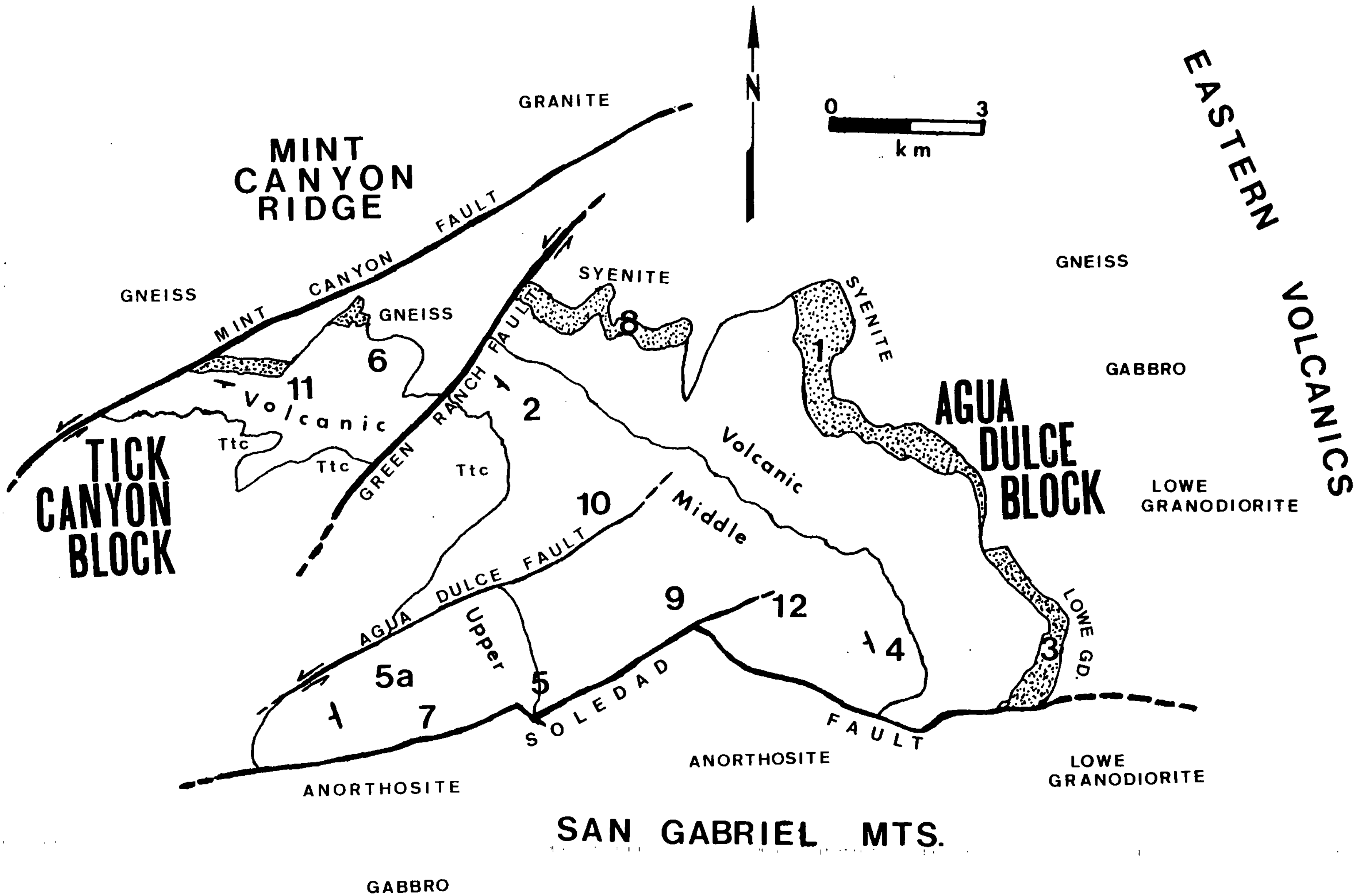
Figure 21 - Paleogeographic block diagram, Charlie Canyon sub-basin; lithofacies as for Figures 15 and 16, except for F = braided floodplain.

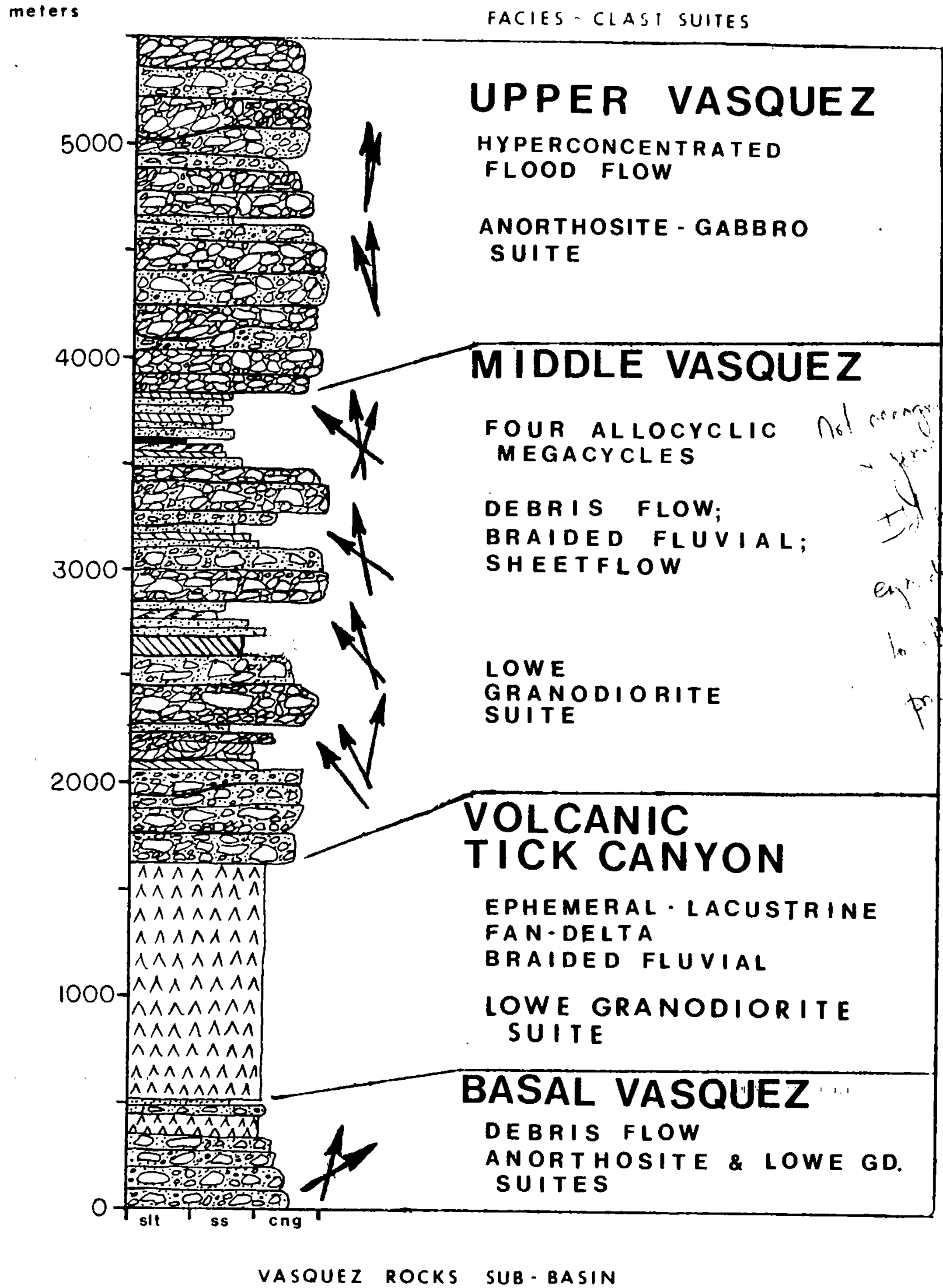
Figure 22 - Plate-tectonic setting of North American continental margin during rifting of Soledad basin 24-25 m.y.B.P.: PAC = Pacific plate, NA = North American plate, FAR = Farallon plate, MTJ = Mendocino triple junction, ISAS = incipient San Andreas transform system (after Powell, 1981; Glazner and Loomis, 1984).

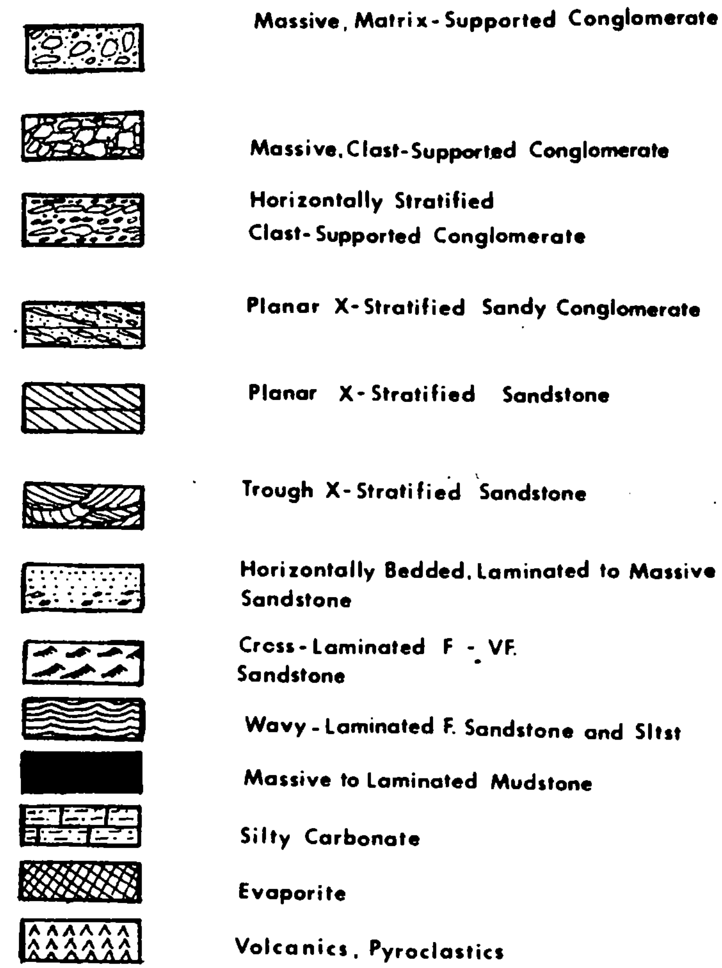


LIEBRE MT.
MOJAVE BLOCK
SAN ANDREAS FAULT
RIDGE BASIN
SIERRA PELONA
Mint Canyon Ridge
SAN GABRIEL FAULT
SAN GABRIEL MTS.
CALIF
TN
0
10
KM
MAJOR FAULT
gn
sf
gr
ps
ga
an
gd
1
1a
2


METERS
8000
CASTAIC FM.
MINT CANYON FM.
6000
DISCONFORMITY?
TICK CANYON FM.
ANGULAR UNCONFORMITY
4000
VASQUEZ FM.
2000
Volcanic Interval
25 myBP K-Ar
0


MINT CANYON RIDGE
GRANITE
N
0 3 km
EASTERN VOLCANICS
GNEISS
MINT CANYON FAULT
GNEISS
GNEISS
SYENITE
SYENITE
GABBRO
6
11
8
1
2
Volcanic
Ttc
Ttc
Ttc
GREEN RANCH FAULT
TICK CANYON BLOCK
AGUA DULCE BLOCK
Volcanic
LOWE GRANODIORITE
10
Middle
AGUA DULCE FAULT
9
12
Upper
4
3
LOWE GD.
5a
5
7
SOLEDAD FAULT
ANORTHOSITE
ANORTHOSITE
LOWE GRANODIORITE
SAN GABRIEL MTS.
GABBRO





[illegible]

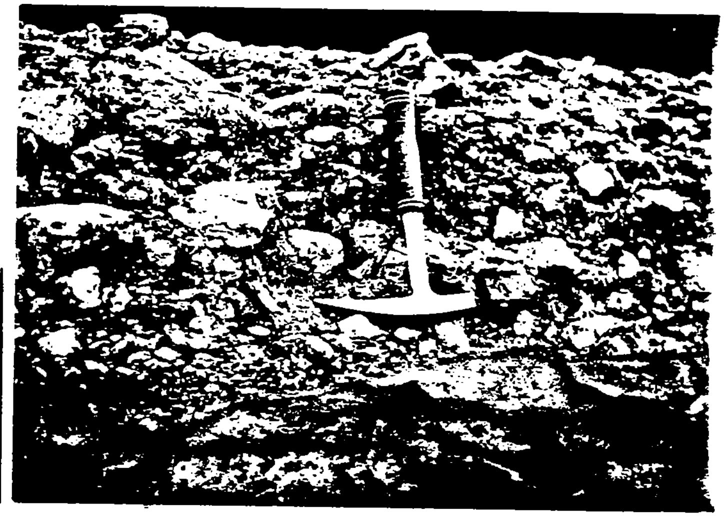
Not [illegible] [illegible]

This figure is generalized to the point [illegible] all lithofacies into a genre. Individual [illegible] are hundreds of feet thick!

A

B

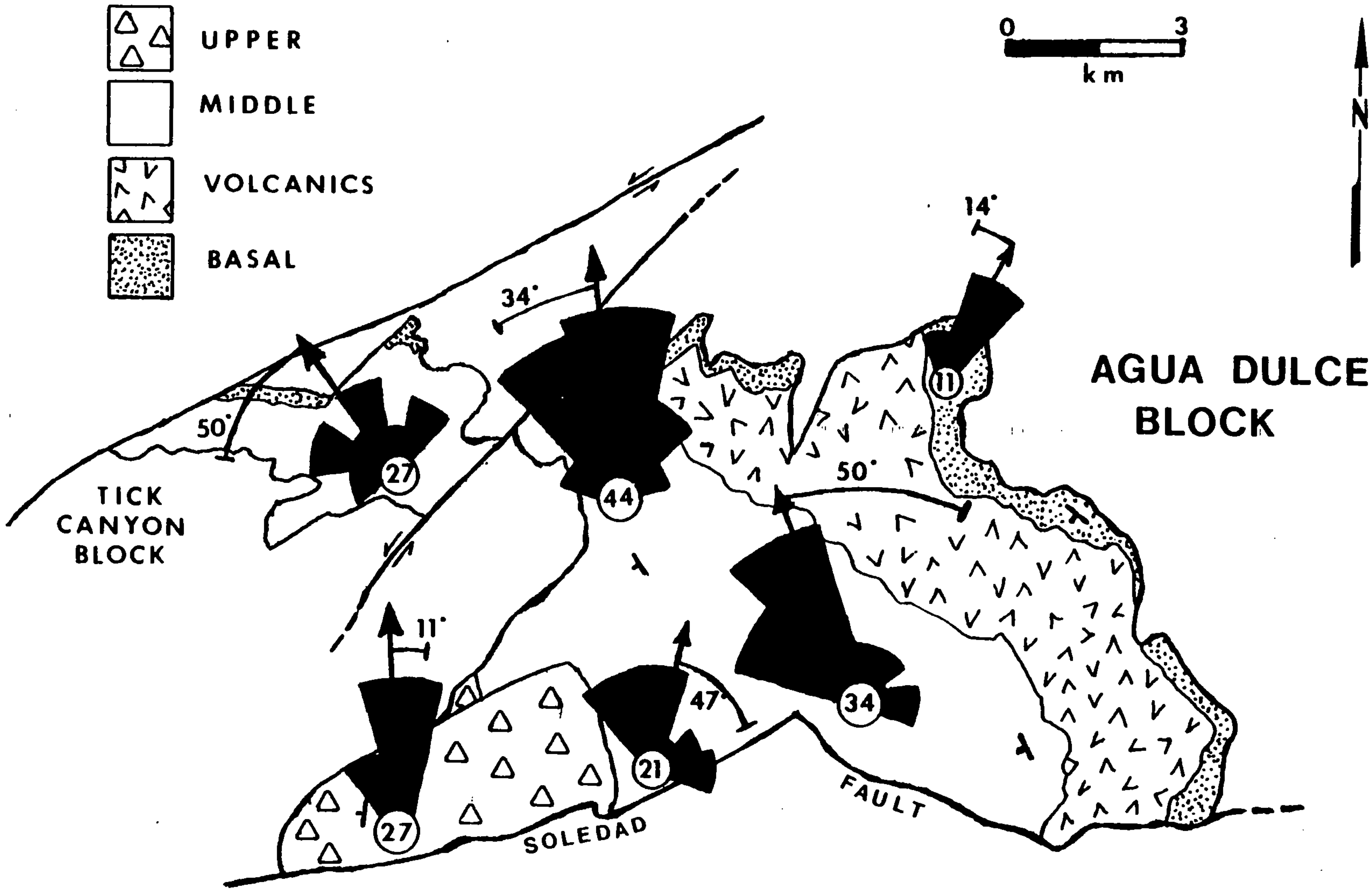
C



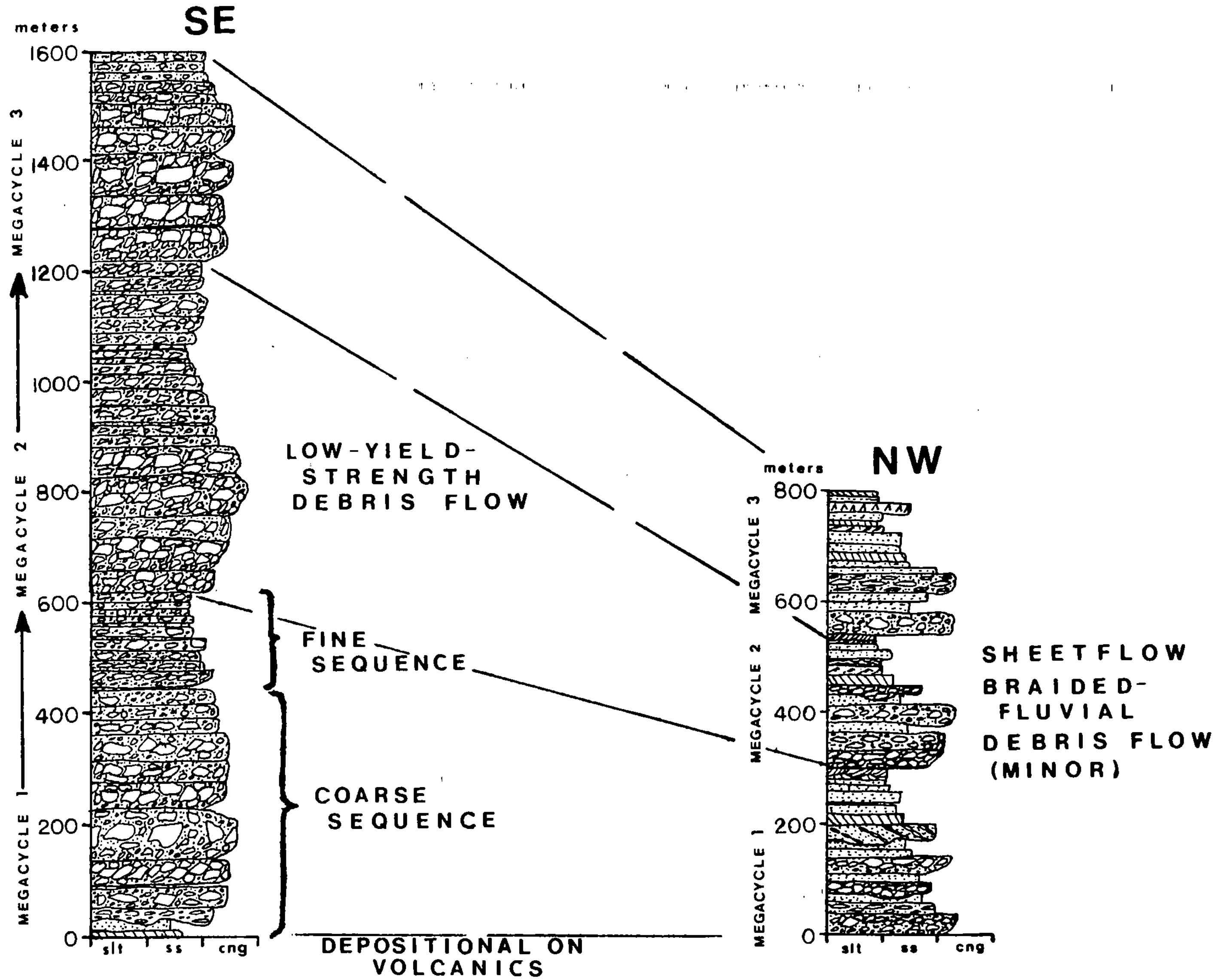
D

E

F



UPPER
MIDDLE
VOLCANICS
BASAL
0
3
km
N
AGUA DULCE
BLOCK
TICK
CANYON
BLOCK
14°
34°
50°
50°
11°
47°
11
27
44
27
21
34
SOLEDAD
FAULT

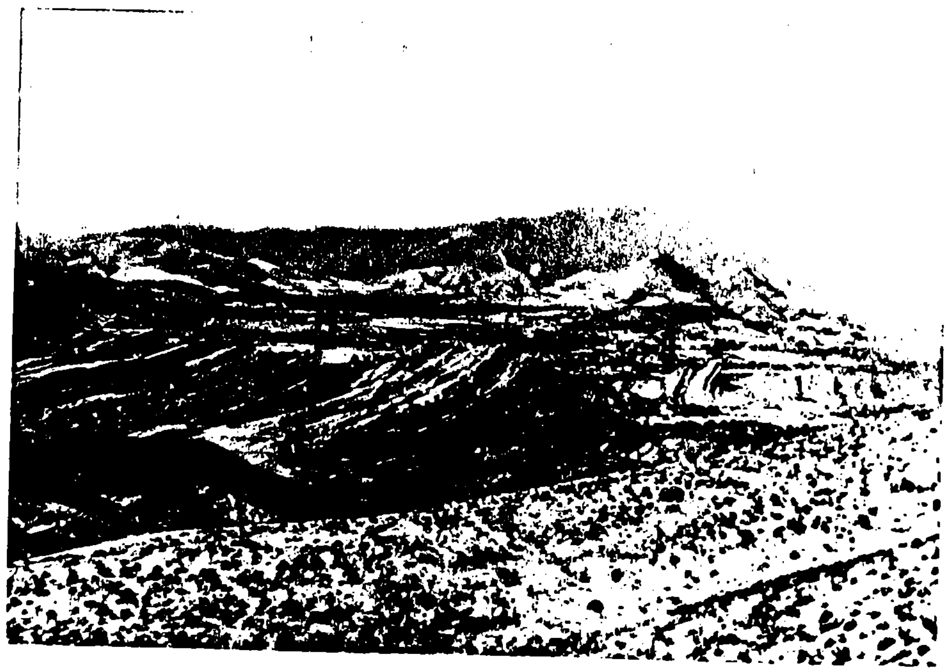


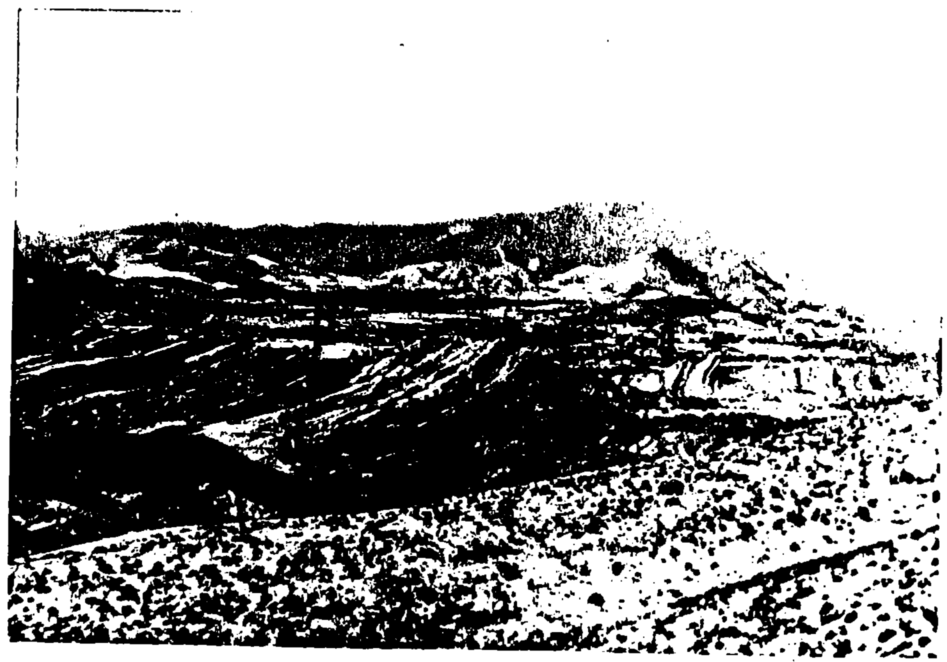
MIDDLE VASQUEZ - PROXIMAL BASIN POSITION (CYCLIC)

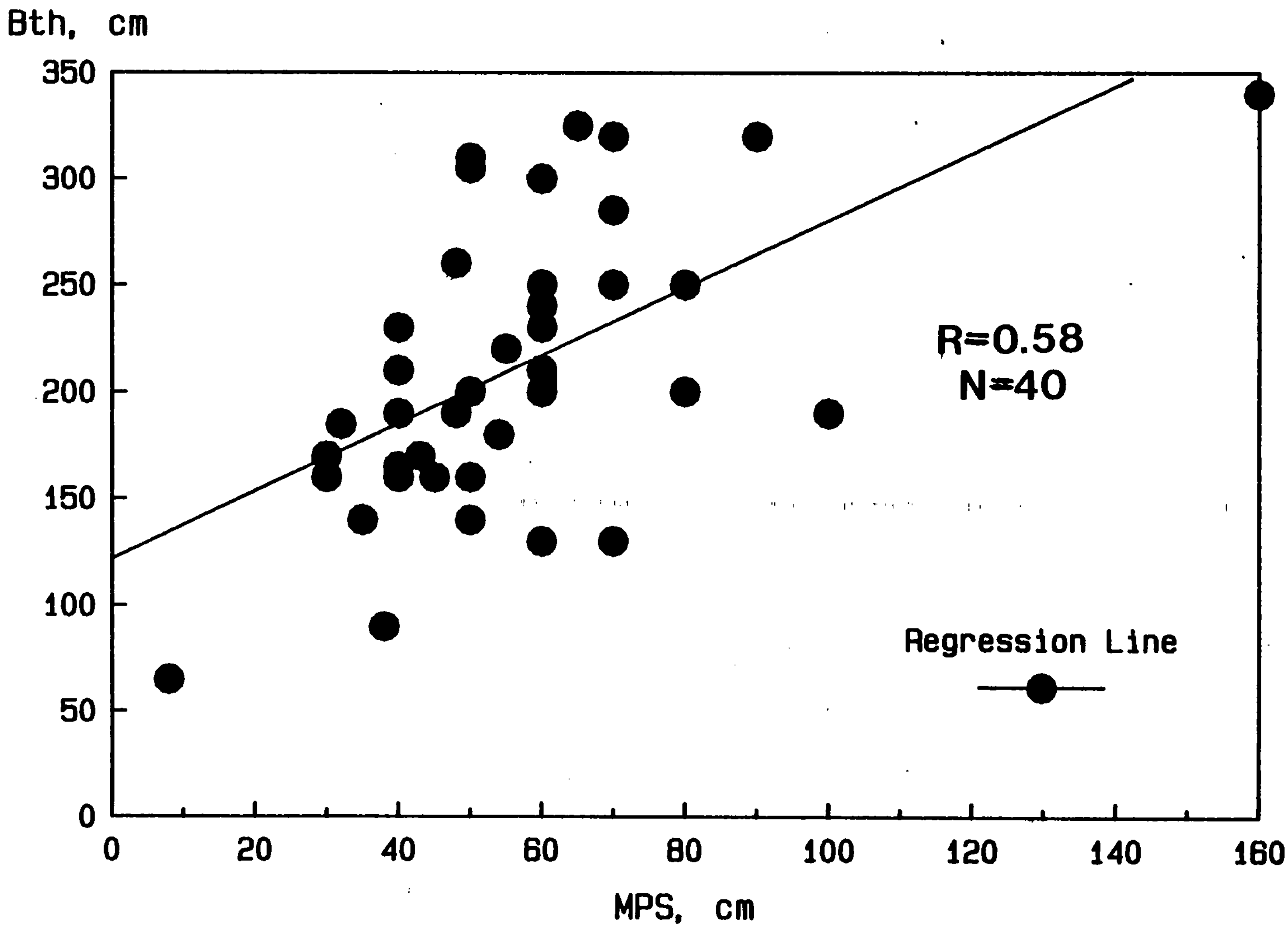
SECTIONS 4; 9; 12

LOWER MIDDLE VASQUEZ (CYCLIC) MID BASIN-DISTAL

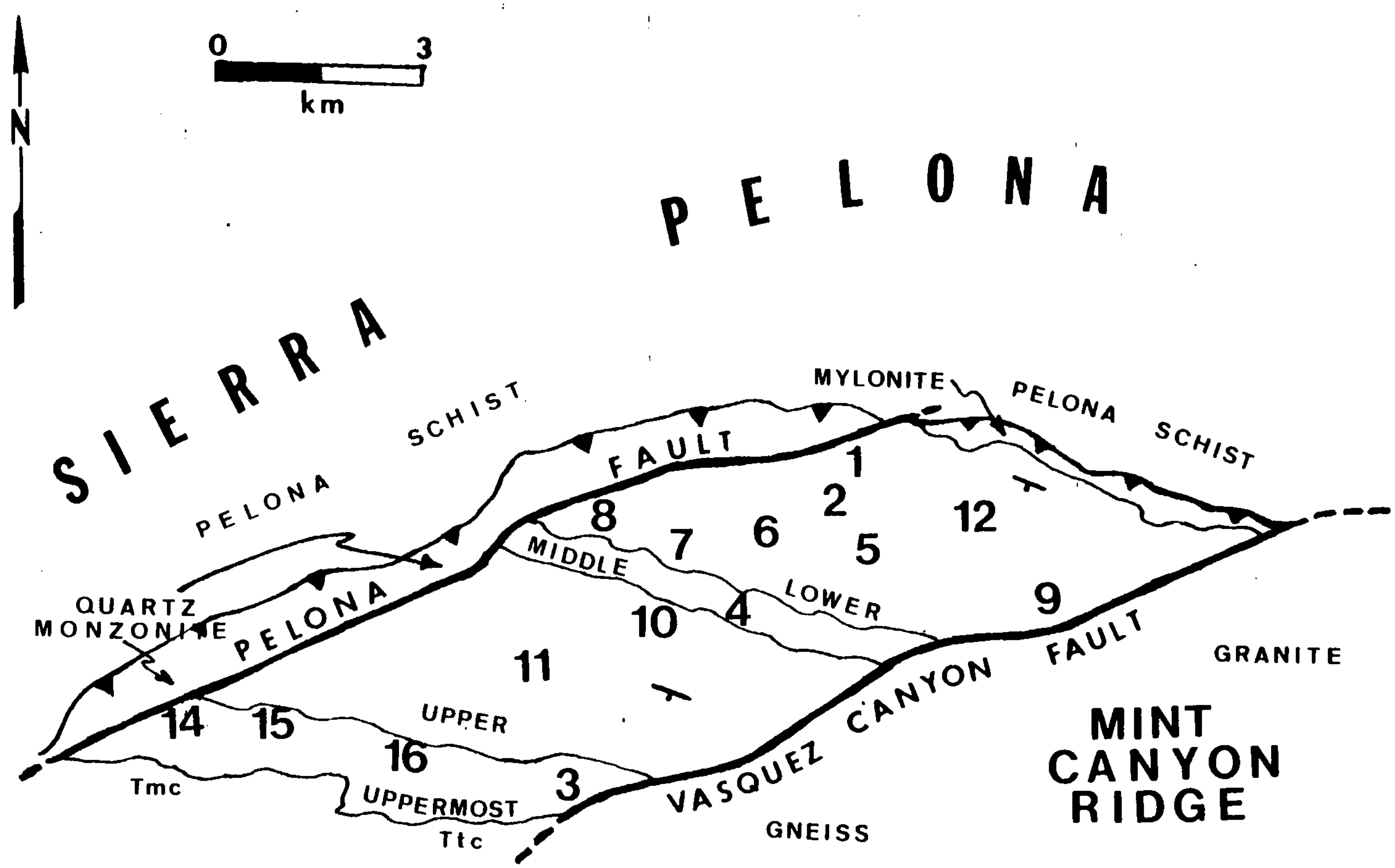
SECTION 2 - VASQUEZ ROCKS



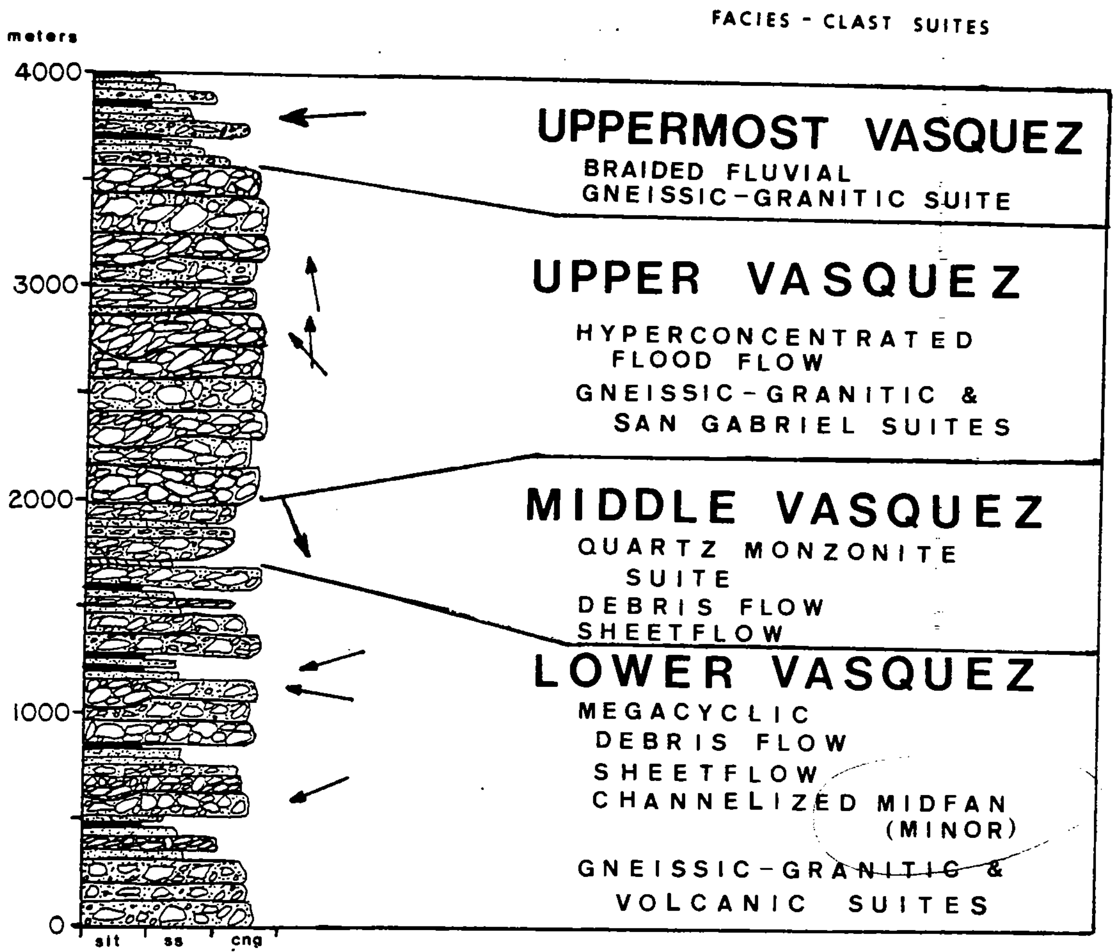




Bth, cm
350
300
250
200
150
100
50
0
0
20
40
60
80
100
120
140
160
MPS, cm
R=0.58
N=40
Regression Line

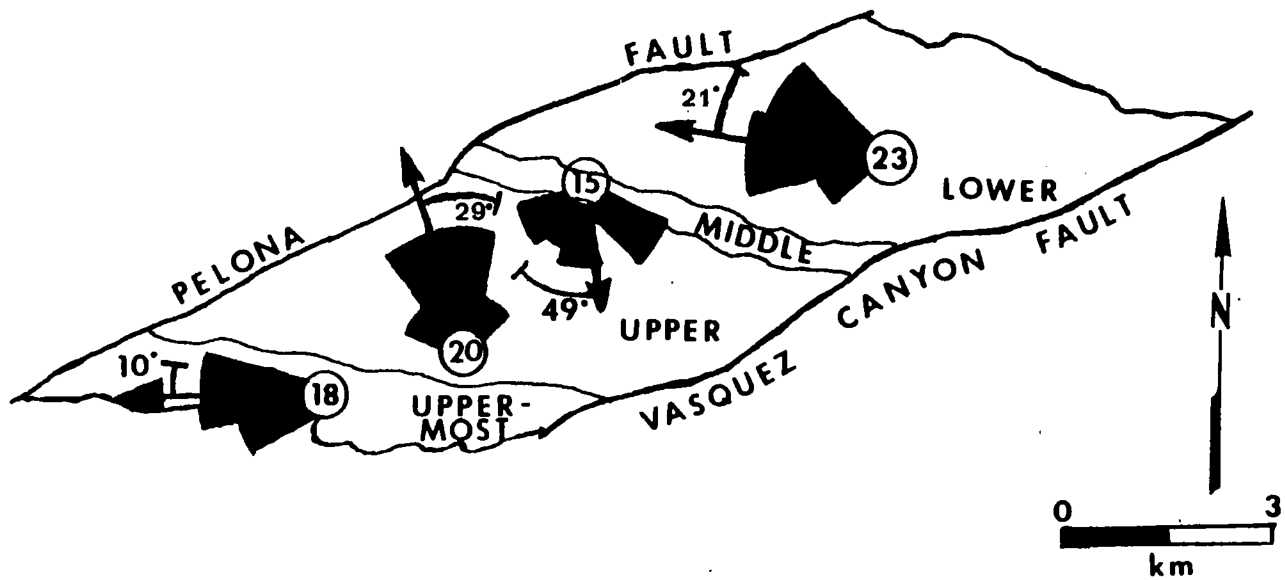


0
3
km
N
SIERRA PELONA
PELONA SCHIST
MYLONITE
PELONA SCHIST
FAULT
PELONA
QUARTZ MONZONITE
PELONA
MIDDLE
LOWER
UPPER
UPPERMOST
Tmc
Ttc
VASQUEZ CANYON FAULT
GRANITE
GNEISS
MINT CANYON RIDGE
1
2
3
4
5
6
7
8
9
10
11
12
14
15
16

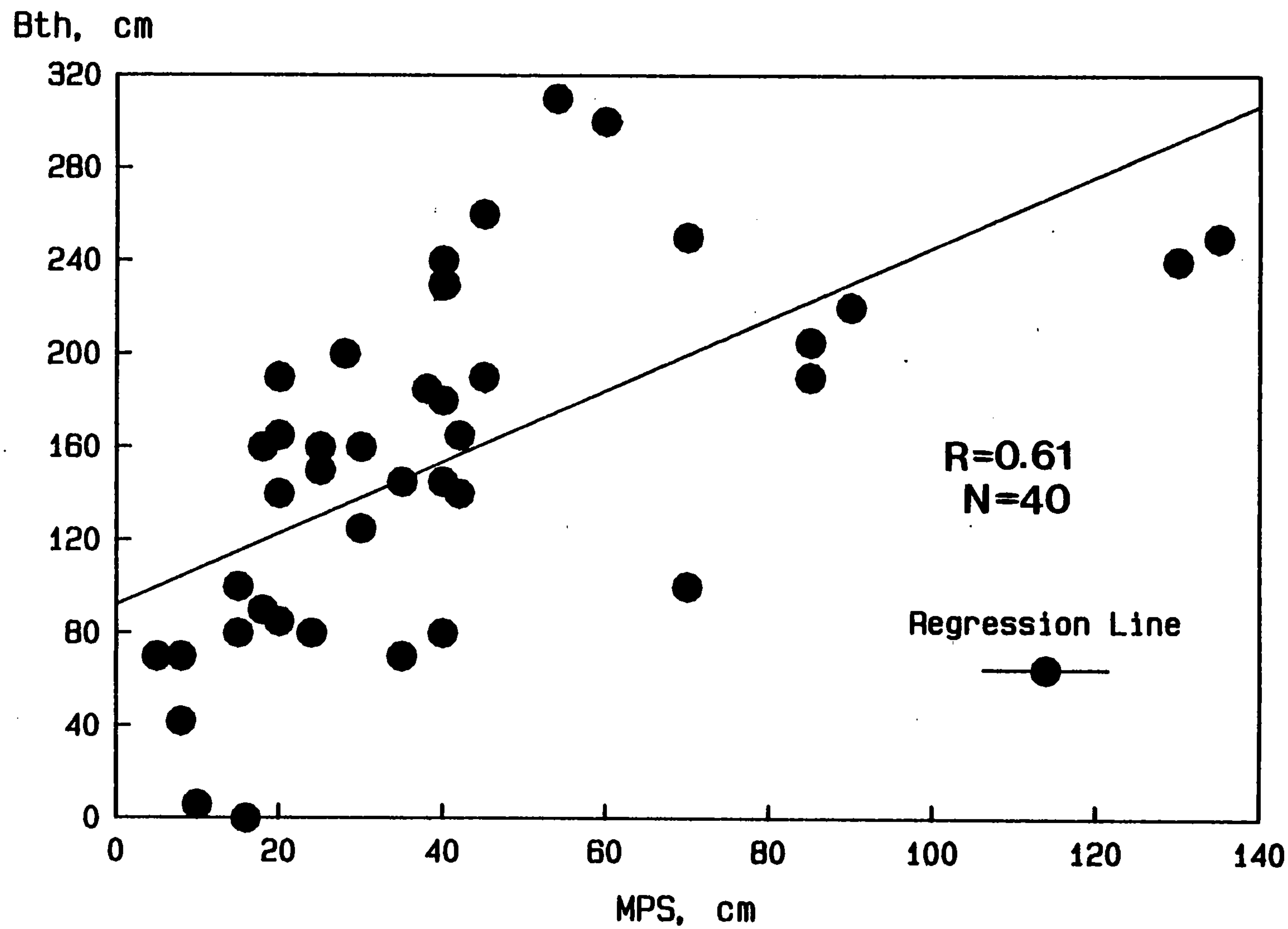


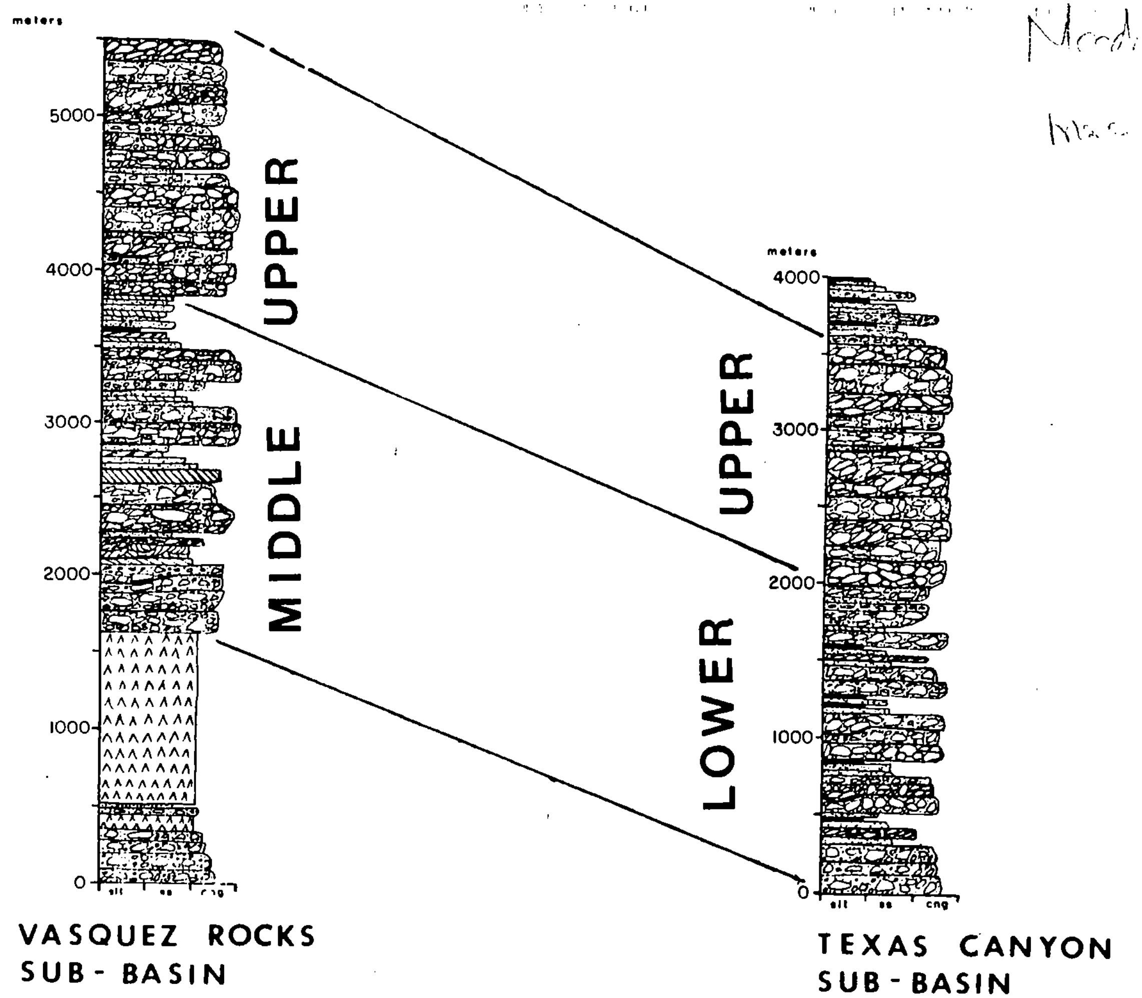
FACIES - CLAST SUITES
meters
4000
3000
2000
1000
0
slt
ss
cng
UPPERMOST VASQUEZ
BRAIDED FLUVIAL
GNEISSIC-GRANITIC SUITE
UPPER VASQUEZ
HYPERCONCENTRATED FLOOD FLOW
GNEISSIC-GRANITIC & SAN GABRIEL SUITES
MIDDLE VASQUEZ
QUARTZ MONZONITE SUITE
DEBRIS FLOW
SHEETFLOW
LOWER VASQUEZ
MEGACYCLIC
DEBRIS FLOW
SHEETFLOW
CHANNELIZED MIDFAN (MINOR)
GNEISSIC-GRANITIC &
VOLCANIC SUITES

Fig. 11



FAULT
21°
23
LOWER
15
29°
MIDDLE
PELONA
49°
UPPER
20
CANYON
FAULT
10°
18
UPPER-
MOST
VASQUEZ
N
0
3
km


Bth, cm
320
280
240
200
160
120
80
40
0
0
20
40
60
80
100
120
140
MPS, cm
R=0.61
N=40
Regression Line

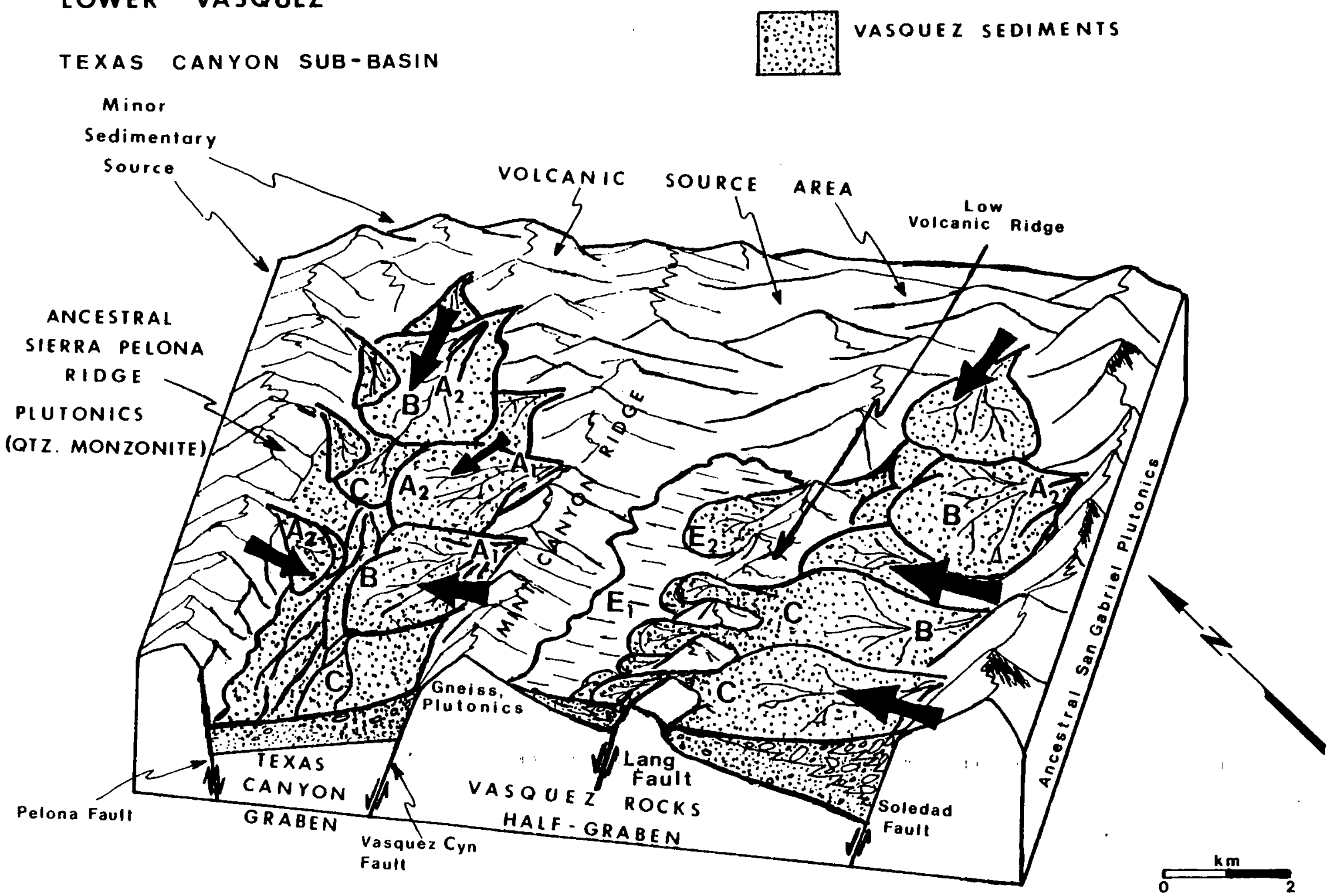

meters
5000
4000
3000
2000
1000
0
UPPER
MIDDLE
VASQUEZ ROCKS
SUB - BASIN
meters
4000
3000
2000
1000
0
UPPER
LOWER
TEXAS CANYON
SUB - BASIN

LOWER MIDDLE VASQUEZ

VASQUEZ ROCKS SUB-BASIN

LOWER VASQUEZ

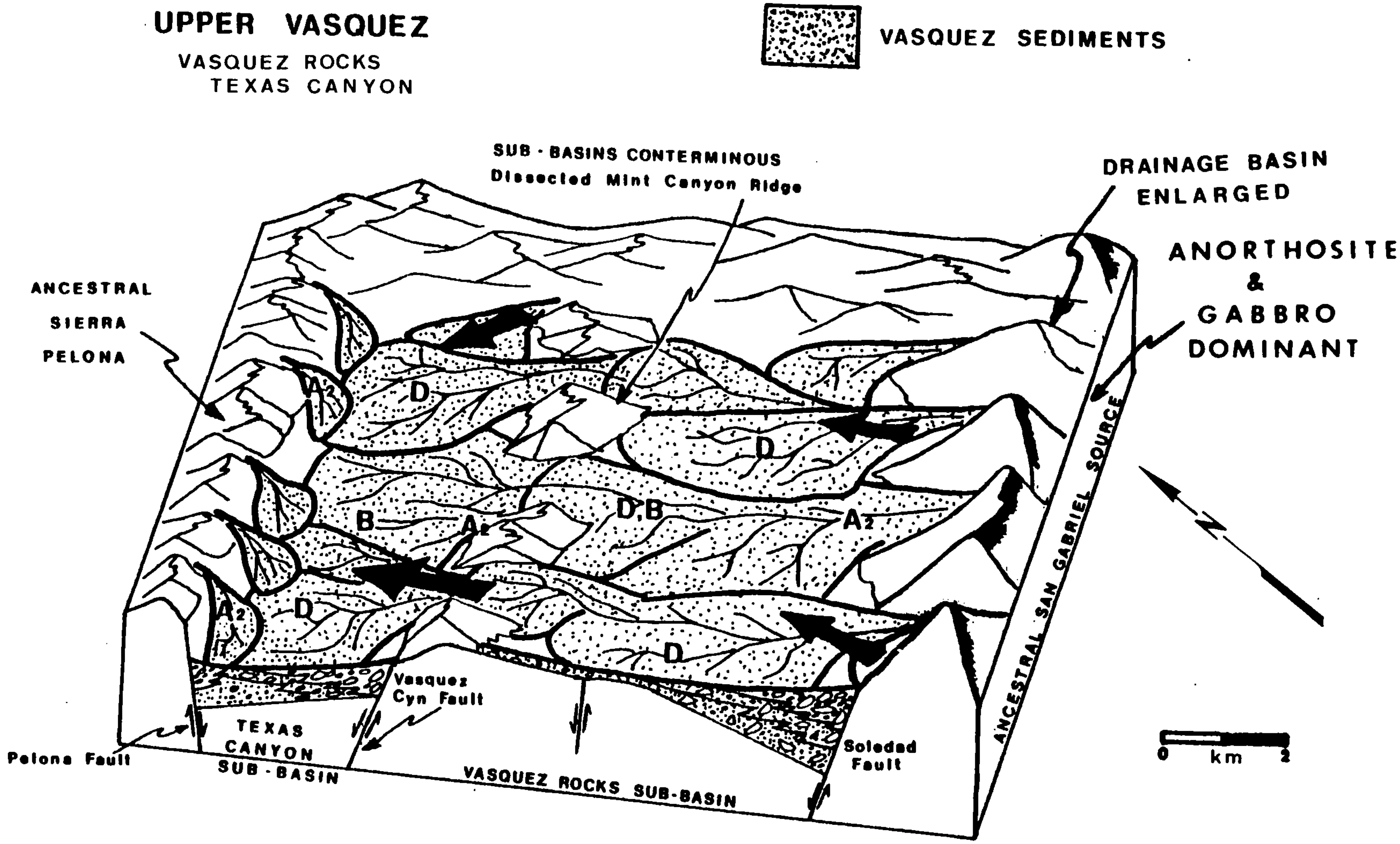
TEXAS CANYON SUB-BASIN

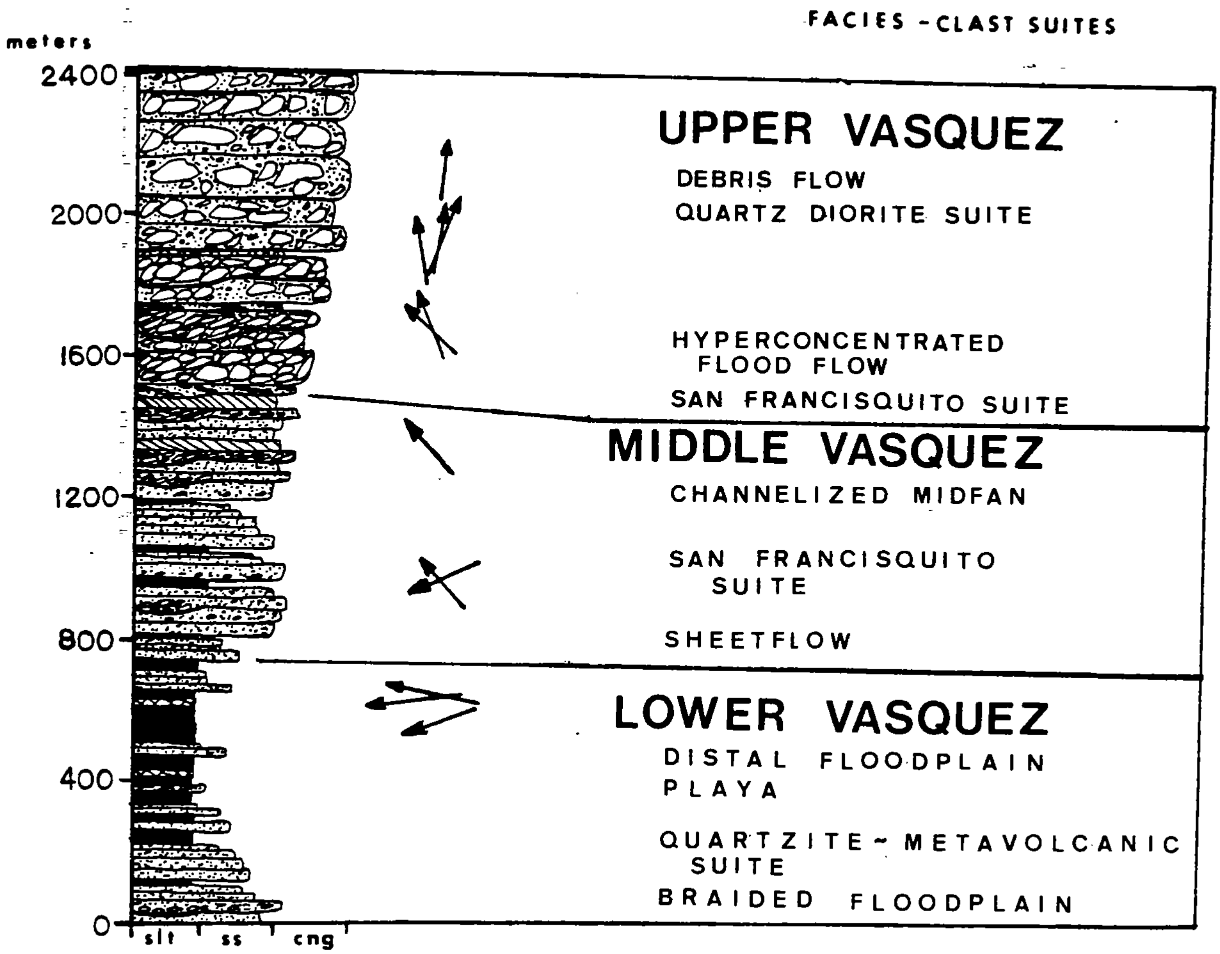


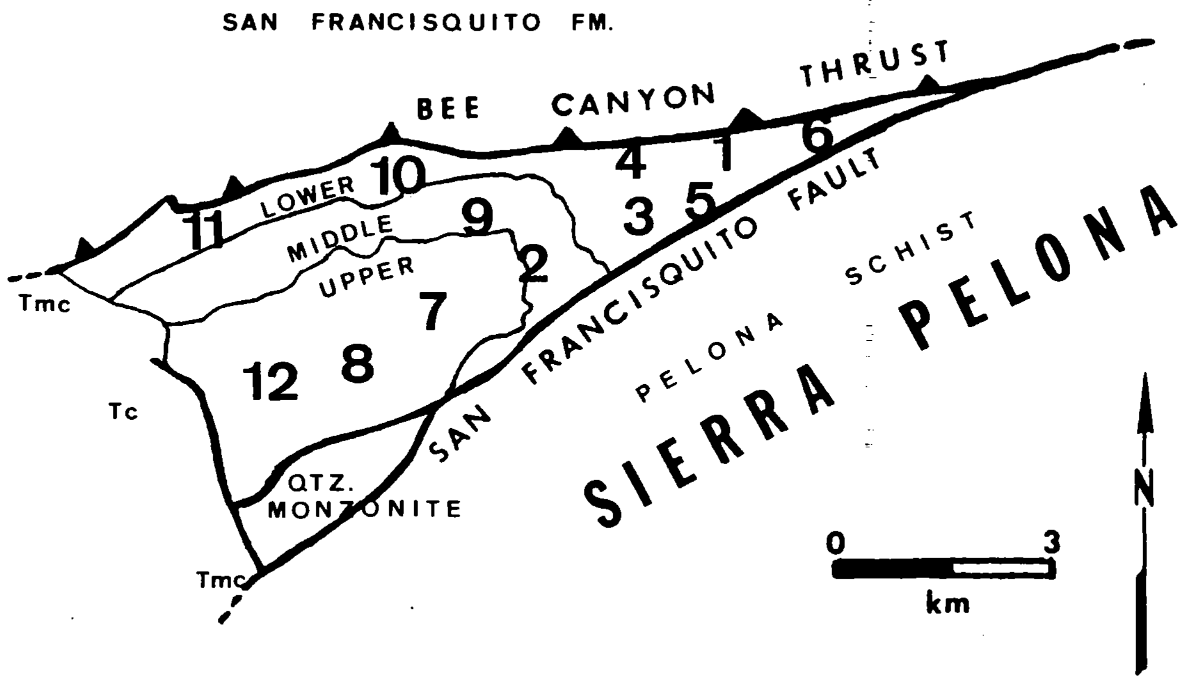
UPPER VASQUEZ

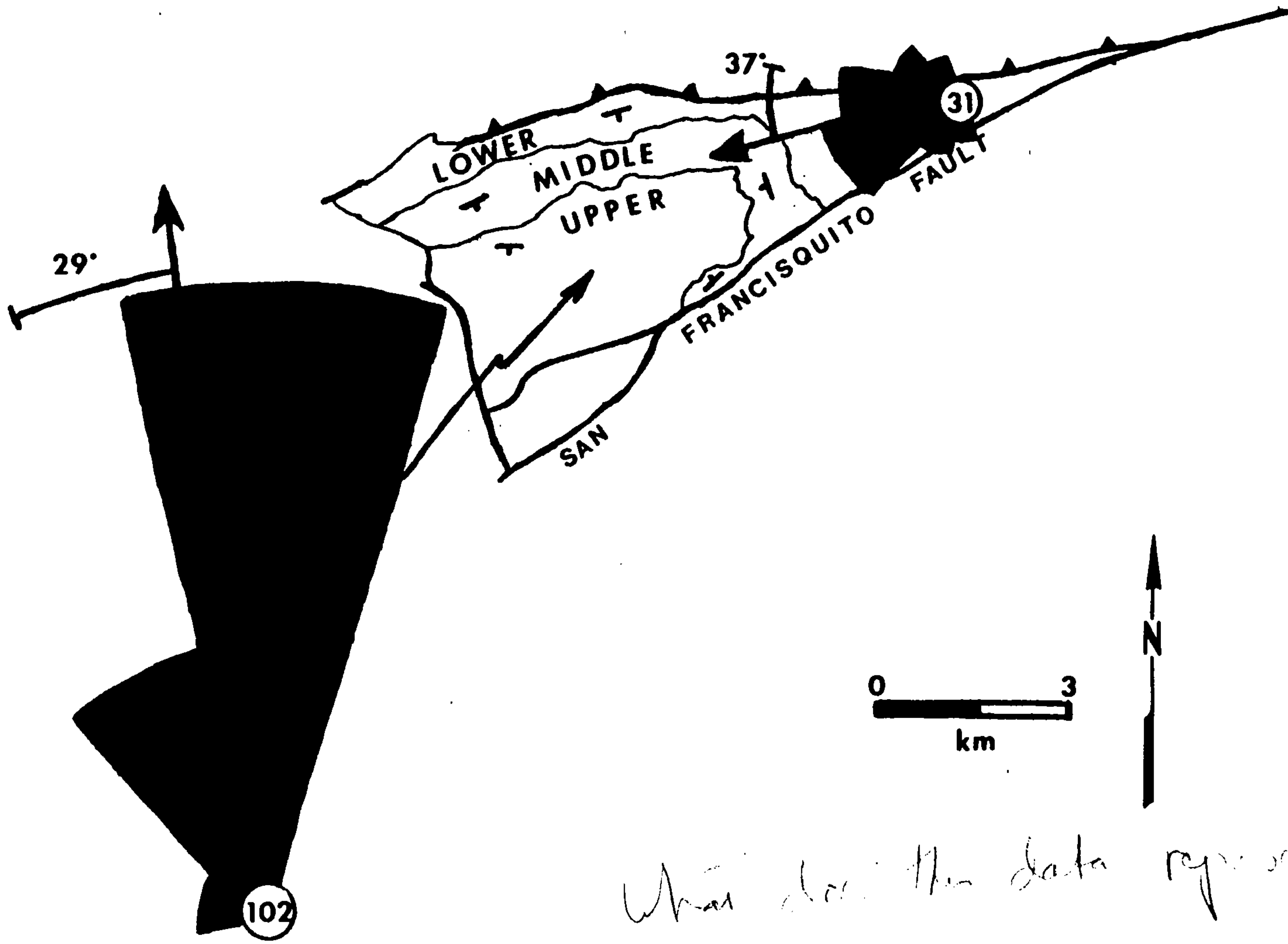
VASQUEZ ROCKS
TEXAS CANYON

VASQUEZ SEDIMENTS

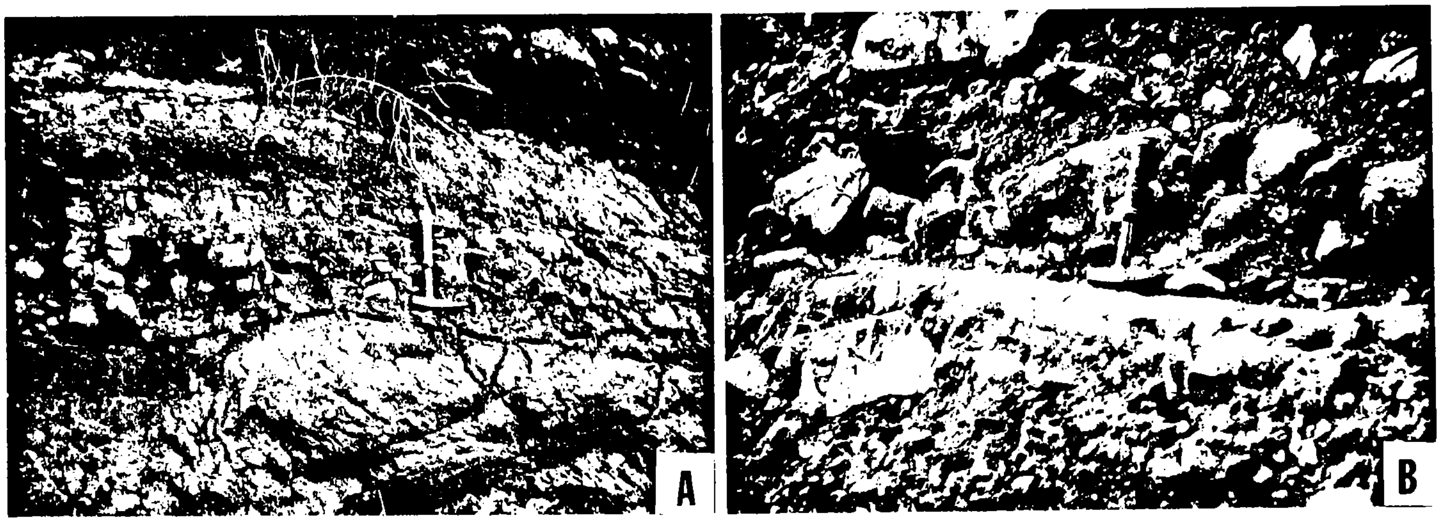



FACIES - CLAST SUITES
meters
2400
2000
1600
1200
800
400
0
slt
ss
cng
UPPER VASQUEZ
DEBRIS FLOW
QUARTZ DIORITE SUITE
HYPERCONCENTRATED FLOOD FLOW
SAN FRANCISQUITO SUITE
MIDDLE VASQUEZ
CHANNELIZED MIDFAN
SAN FRANCISQUITO SUITE
SHEETFLOW
LOWER VASQUEZ
DISTAL FLOODPLAIN
PLAYA
QUARTZITE ~ METAVOLCANIC SUITE
BRAIDED FLOODPLAIN


SAN FRANCISQUITO FM.
BEE CANYON THRUST
LOWER
MIDDLE
UPPER
Tmc
Tc
Tmc
QTZ. MONZONITE
SAN FRANCISQUITO FAULT
PELONA SCHIST
SIERRA PELONA
1
2
3
4
5
6
7
8
9
10
11
12
0
3
km
N



What does the data represent?


A
B