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The pliocene alluvial gravels in the southeastern Santa Clara Valley, California

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THE PLIOCENE ALLUVIAL GRAVELS IN THE SOUTHEASTERN SANTA CLARA VALLEY, CALIFORNIA

A Thesis
Presented to
The Faculty of the Department of Geology
San Jose State University

In Partial Fulfillment
of the Requirements for the Degree of
Master of Science

By Martin Alan Wills
December, 1995

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ABSTRACT

THE PLIOCENE ALLUVIAL GRAVELS IN THE SOUTHEASTERN SANTA CLARA VALLEY, CALIFORNIA

By Martin A. Wills

Pliocene sedimentary rocks in the southeastern Santa Clara Valley record late Tertiary basin formation and filling related to uplift of the nearby Coast Ranges. Nonmarine conglomerate, sandstone, and minor lacustrine rocks are here divided into the Scheller (oldest), Silver Creek, and Packwood gravels. Clasts in the two older units were derived mostly from Coast Range Ophiolite, Franciscan Complex, Claremont Formation, and Great Valley Group sources east of the Calaveras fault in the central Diablo Range. Clasts in the youngest unit were derived from Great Valley Group sources east of the Calaveras fault but west of the earlier sources. The predominantly clast-supported conglomerate and oxidized fine-grained rocks suggest that these units were deposited in braided streams. Inferred provenance and sparse paleocurrent data suggest that these streams flowed northwest into the northern Santa Clara Valley. The gravel units in the southeast Santa Clara Valley are deformed, suggesting that the tectonic activity responsible for uplifting the sources continued well after the rocks were deposited.

ACKNOWLEDGEMENTS

I would like to thank God for his inspiration. Additionally, I would like to acknowledge the people, without whose help this project would not have been possible: David Andersen for suggesting this topic and for his help in the field and advice on sedimentology; David L. Jones for his invaluable knowledge of the Franciscan geology in California and for his assistance in the field; the United States Geological Survey, Menlo Park, especially E.E. Brabb, B.L. Murchey, J.K. Nakata, and C. Meyers for the wealth of information they made available to the author and for their tireless effort to promote this project; Richard Sedlock for his support and direction; Cal Stevens for his help with the manuscript; and Rendy Keaten for her X-ray analysis of lacustrine sediments. Additionally, I would like to thank R. Lindquist and United Technologies Chemical Company (UTC) for allowing the author access to their property. I would like to thank M.A.W., C.P.W., F.B., and Vanessa, for believing that this project was attainable.

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INTRODUCTION

The late Cenozoic was a time of tectonic activity in the California Coast Ranges. Passage of the Mendocino triple junction, and the change from subduction to a transform boundary, divided an older forearc basin into smaller basins with diverse histories (Nilsen and Clarke, 1989; Sedlock, 1995). Coarse clastic deposits bordering the southeastern slopes of the Santa Clara Valley (Fig. 1) record the evolution of sedimentary environments within the basin and provide information about the uplift history and the sources of the sediment that filled it. The southern Santa Clara Valley west of the Diablo Range contains the rocks that form the basis for this study.

Upper Cenozoic fluvial rocks in the southeastern Santa Clara Valley have been studied since the early 1930's but not subdivided by most workers (Tolman, 1934; Crittenden, 1951; Dibblee, 1972a-b, 1973a-d). The purpose of this study is to characterize the differences between distinct gravel units in the study area and to evaluate correlations of these rocks with similar lithologic units to the north and west. These data are used to interpret the provenance, depositional environment, and orogenic events that produced the gravel units in the southeastern Santa Clara Valley. These data should assist future workers focusing on the sedimentary and tectonic history of the Santa Clara Valley and the relationship of this evolution to the geologic history of California.

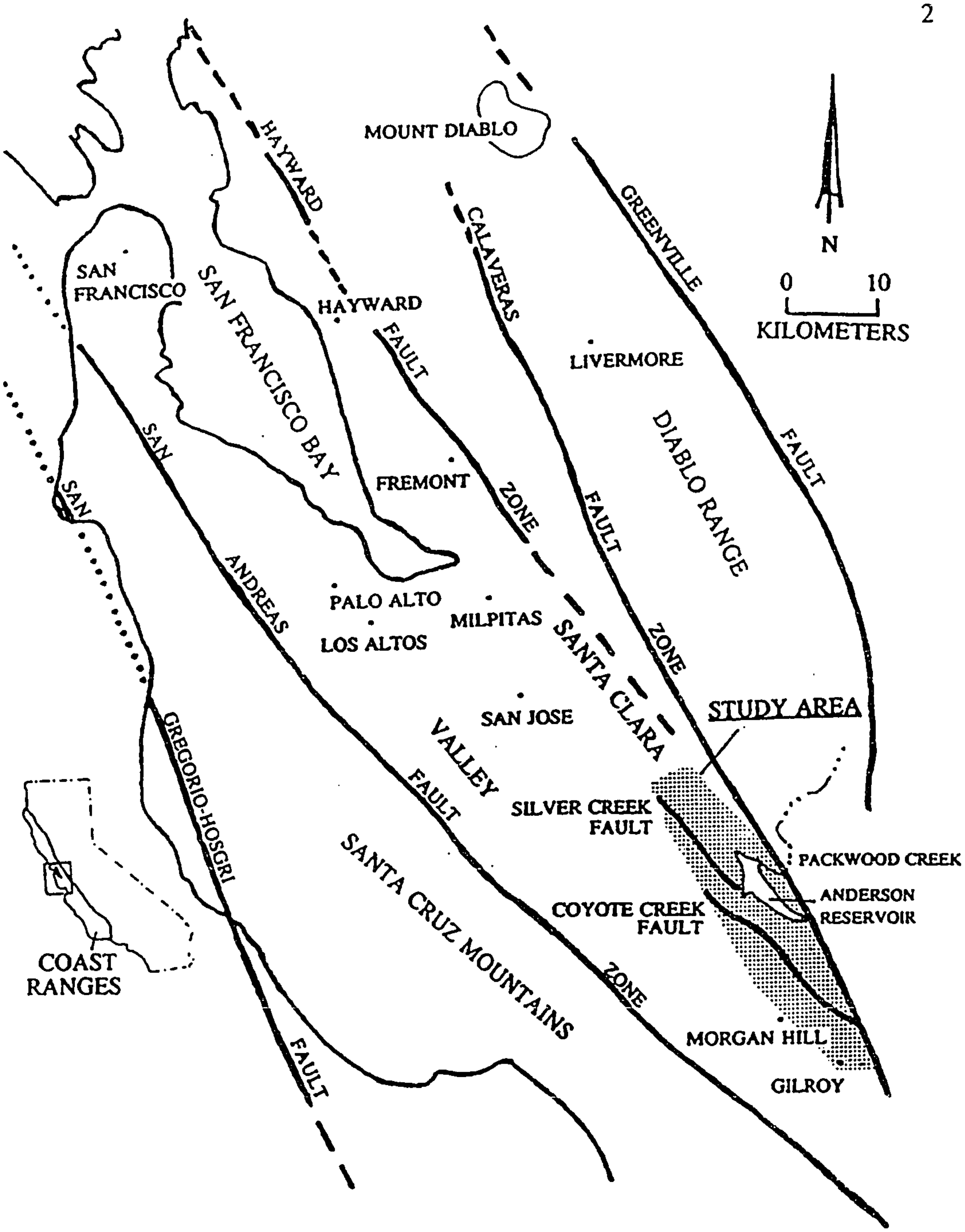


Figure 1. Map of San Francisco Bay area with location of study area (modified from Aydin, 1982).

REGIONAL GEOLOGY

Coast Range Physiography

West-central California consists of many separate ranges and valleys that are interpreted to have been produced by a complex system of dextral strike-slip faults and reverse or thrust faults related to the transform margin along the North American-Pacific plate boundary (Sedlock, 1995). The ranges east and west of the southern Santa Clara Valley are bounded by thrust faults. Associated strike-slip faults are the Calaveras and Hayward fault zones, both with modern records of seismicity (Aydin, 1982; Page, 1982; Lienkaemper and others, 1991; Galehouse, 1992). The Silver Creek and Coyote Creek faults (Fig. 1) are Cenozoic imbricate thrusts representative of contractional orogenesis (Graymer and DeVito, 1993; Jones and others, 1994).

Geologic Units

The ranges around the Santa Clara Valley contain different mixtures of bedrock and surficial materials of Mesozoic and Cenozoic age (Fig. 2). The Santa Cruz Mountains consist of Jurassic to Quaternary rocks including Coast Range Ophiolite, plutonic rocks intruding older metamorphic rocks, Franciscan Complex, Great Valley Group, and various Cenozoic marine and nonmarine sedimentary rocks. The Diablo Range is composed of Coast Range Ophiolite, Franciscan Complex, Great Valley Group, and marine and nonmarine sedimentary rocks of Cenozoic age (Wagner and others, 1990).

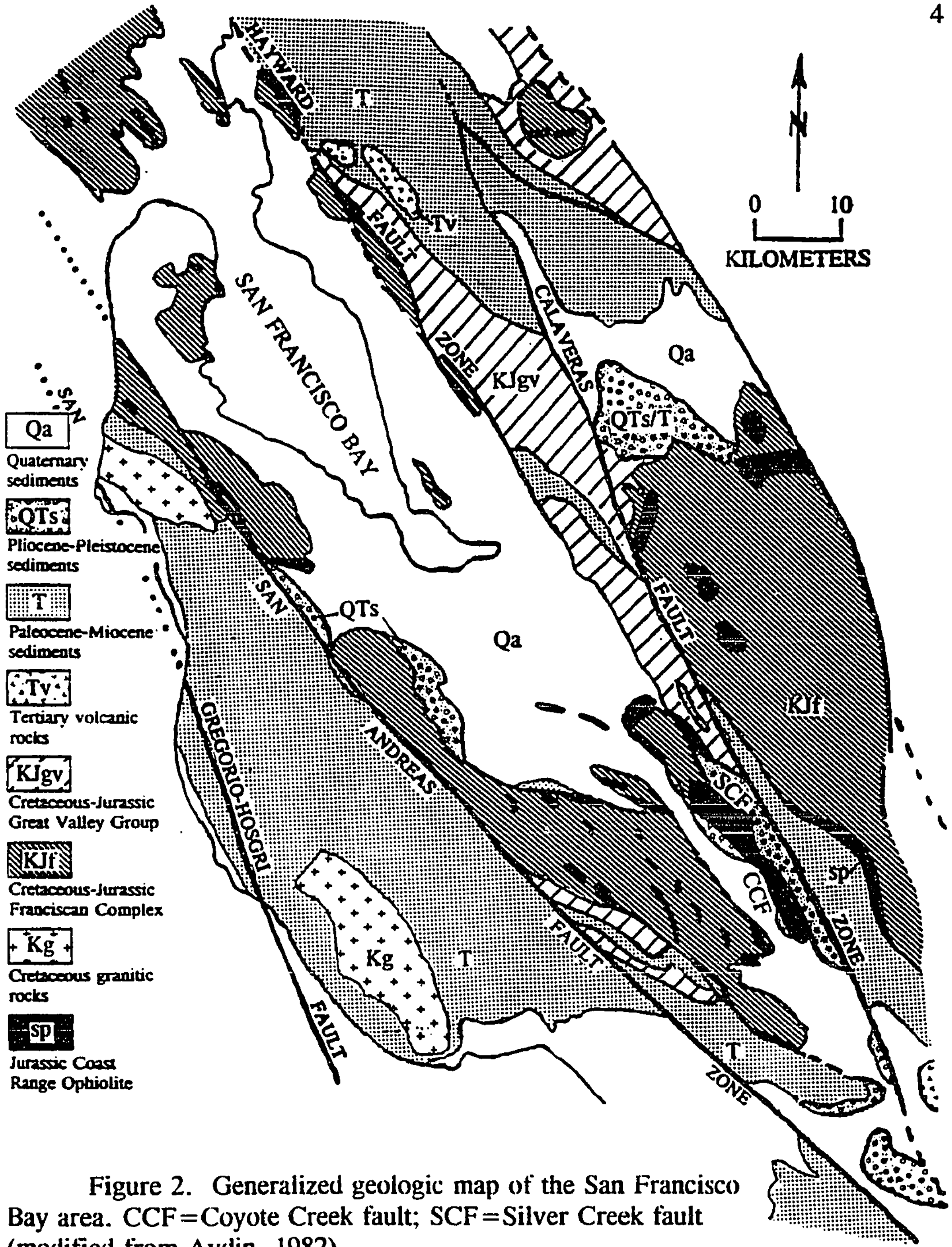


Figure 2. Generalized geologic map of the San Francisco Bay area. CCF=Coyote Creek fault; SCF=Silver Creek fault (modified from Aydin, 1982).

Mesozoic Rocks

Mesozoic rocks in and around the Santa Clara Valley include the Coast Range Ophiolite, Franciscan Complex, and the Great Valley Group. Six tectonostratigraphic terranes (Fig. 3) have been differentiated within the Franciscan Complex; these are in fault contact with the Coast Range Ophiolite, Great Valley Group, and Salinian block in the San Francisco Bay region (Blake and others, 1984). The Franciscan terranes include subduction or collision complexes, fragments of ocean floor or ocean islands, and graywacke-rich terranes of uncertain origin (Blake and others, 1984).

Coast Range Ophiolite. The Coast Range Ophiolite is composed mostly of serpentinite and silica carbonate rock (Graymer, 1995) with lesser amounts of greenstone and radiolarian chert (Blake and others, 1984). This ophiolite represents oceanic crust and/or island arc basement of Middle Jurassic age (Blake and others, 1984). Outcrops of the Coast Range Ophiolite are present on both the east and west sides of the Santa Clara Valley with locally extensive outcrops in the southeastern portion of the valley (Fig. 2).

Franciscan Complex. Franciscan Complex rocks are exposed in the ranges on the east and west sides of the Santa Clara Valley (Fig. 3). The rocks consist of a disrupted and deformed mosaic of graywacke, olive-green siltstone and shale, radiolarian chert, conglomerate, and various metamorphic rocks, including greenstone,

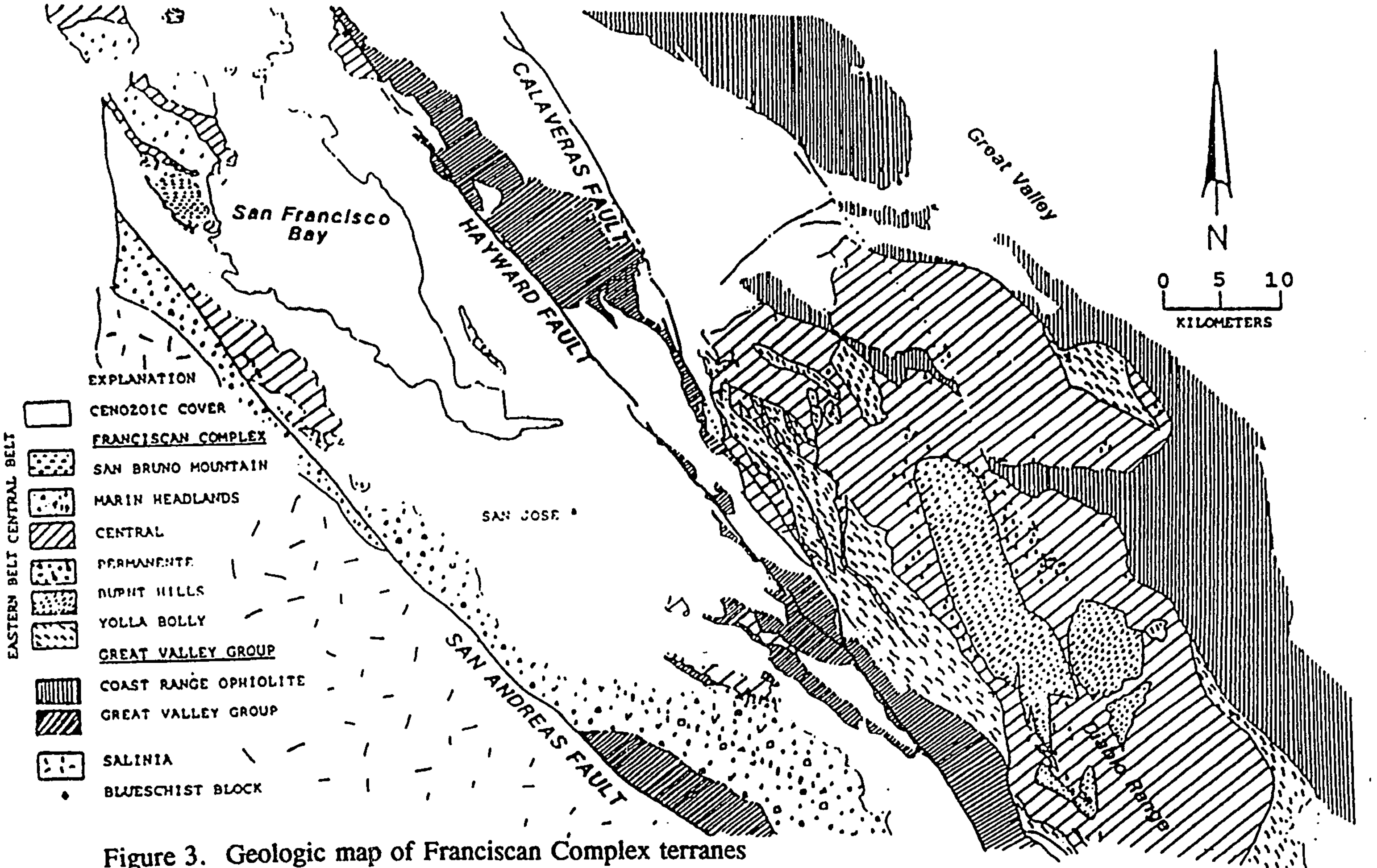


Figure 3. Geologic map of Franciscan Complex terranes and related rocks (modified from Blake and others, 1984).

metagraywacke, metachert, glaucophane schist and actinolite schist (Aydin and Page, 1984; Graymer, 1995). Outcrops of greenstone are limited to small, isolated bodies along the eastern margin of the Santa Clara Valley, whereas they are widespread on the west (Wagner and others, 1990). Franciscan graywackes are distinctive in that they possess foliation, quartz veins and muscovite, and they lack biotite (David L. Jones, personal communication, 1994).

Great Valley Group. The Great Valley Group consists chiefly of turbiditic marine conglomerate, arkosic sandstone, graywacke sandstone, dark-gray siltstone, and shale. These rocks are distinguished from Franciscan rocks by the absence of stratal disruption, foliation, and melanges (Blake and others, 1984). Great Valley Group graywackes are distinguished from Franciscan graywackes by the presence of biotite and the general absence of quartz veins and muscovite (David L. Jones, personal communication, 1994). The Great Valley rocks also contain more abundant fossils than the Franciscan rocks (Graymer, 1995). Great Valley Group rocks crop out on both the east and west sides of the Santa Clara Valley, but they are most abundant on the east (Fig. 2).

A particularly important unit within the Great Valley Group is the Oakland Conglomerate, named by Crittenden (1951). He reported that it commonly consists of distinctive, rounded, pebble- to boulder-sized clasts, including black chert and siliceous porphyritic volcanic rocks, in a matrix of coarse sand. There also are outcrops of Cretaceous conglomerate on the western side of the Santa Clara Valley in the Santa Cruz Mountains near and south of Loma Prieta (Vanderhurst, 1981), but these conglomerates are not as extensive as the Oakland Conglomerate exposed in the Diablo Range (Vanderhurst, 1981). The most abundant conglomerate outcrops are in the Diablo Range east and northeast of Silver Creek Valley along the eastern side of the Santa Clara Valley (Crittenden, 1951; Dibblee, 1972a-b, 1973a-d).

Tertiary Rocks

Along the western flank of the Santa Clara Valley, the Tertiary section in the Santa Cruz Mountains consists of about 12,500 m of mostly marine conglomerate, sandstone, and shale, including minor siliceous, calcareous, and phosphatic rocks (Cummings and others, 1962; Wagner and others, 1990). Coeval rocks present on the east side of the valley include many rock types that are broadly similar to those on the west and some lithologies that are distinctive. In the Diablo Range, southeast of the Santa Clara Valley, the Tertiary units present are the Temblor Formation, Monterey Group, and Briones and Orinda formations.

Temblor Formation. Fossiliferous Miocene rocks mapped as Temblor Formation crop out in a small area east of Milpitas (Fig. 1), where they rest unconformably on the Franciscan Complex and grade upward into siliceous Monterey shale (Crittenden, 1951). The Temblor Formation consists of basal conglomerate overlain by yellow sandstone and pebbly sandstone (Crittenden, 1951).

Monterey Group. The Monterey Group is composed of calcareous, phosphatic, and siliceous rocks (Pisciotto and Garrison, 1981). Most notable of the stratigraphic units are rocks of the siliceous facies, locally referred to as the Claremont Formation (Blueford and others, 1989), that include white to pale yellow diatomite and diatomaceous mudrocks and their diagenentic equivalents: chert, laminated and unlaminated porcelanite, and siliceous mudrocks (Pisciotto and Garrison, 1981). The porcelanite commonly is white, massive, or laminated, with light and dark laminae (Pisciotto and Garrison, 1981). Rocks of the Monterey Group crop out on both sides of the Santa Clara Valley, but the Claremont Formation occurs only on the eastern side of the valley (Blueford and others, 1989).

Briones Formation. Rocks of the Briones Formation crop out along the east side of the Santa Clara Valley and depositionally overlie the Claremont Formation in most of the southeast Santa Clara Valley area (Graymer, 1995). The rocks are composed of gray to white sandstone and siltstone, shell-rich conglomeratic sandstone, and a few pebble and cobble conglomerate beds (Graymer, 1995). The shell-rich beds are characteristic of the Briones, and form prominent ridges and peaks (Graymer, 1995).

Orinda Formation. The Orinda Formation is made up of reddish-brown and green, subrounded to rounded, pebble- to boulder-sized conglomerate, conglomeratic sandstone, coarse- to medium-grained, lithic sandstone, and red to green siltstone and claystone (Coyle, 1984; Graymer, 1995). Clasts in the conglomerate consist of red and green chert, vein quartz, sandstone, white chert (possibly porcelanite), and various igneous rocks, including porphyritic volcanic rocks (Crittenden, 1951; Coyle, 1984).

Cenozoic Gravels

Many alluvial gravels are present along the east and west margins of the Santa Clara Valley and in nearby valleys; three of these are the subject of this study. Similar gravels of Miocene through Pleistocene age are shown as QTs on Figure 2. Dibblee (1972a-b, 1973a-d) referred to the gravels in the eastern Santa Clara Valley as the Santa Clara Formation.

METHODS

Sample locations were selected within the upper Cenozoic gravels in the eastern Santa Clara Valley based on maps presented by Dibblee (1972a-b, 1973a-d) and Graymer and DeVito (1993). At each sample location, a 1-m^2 area of the outcrop was sampled to insure a fully representative population of clasts. At most sample locations, a minimum of three hundred clasts was removed, broken and identified in the field using a 10x handlens or transported to the laboratory and identified using a binocular microscope.

Stratigraphic thicknesses of the gravel units were established using profiles drawn from geologic maps. These profile lines were chosen to give the best estimate of stratigraphic thickness and to interpret unique structural or stratigraphic relationships.

Wherever clasts are imbricated, the direction of imbrication was recorded. The imbrication direction of each clast was determined relative to the strike of the bedding. The beds were mentally restored to the horizontal while holding the angle between the imbrication and the strike constant. A Brunton compass was then placed parallel to the azimuth of the restored imbrication. Measurements of all imbricated clasts were recorded at outcrops where present, and the average is reported as the paleocurrent direction.

At each outcrop where samples were collected, the size of the four largest clasts from the entire exposure was measured parallel to the long axis of the clast. The average is reported as the maximum clast size.

GRAVEL UNITS OF THE SOUTHEASTERN SANTA CLARA VALLEY

Introduction

The upper Cenozoic gravels of southeast Santa Clara County were first studied by Tolman (1934), who described a series of outcrops in the lower part of Packwood Creek (Fig. 1). Tolman (1934) named these the Packwood gravels, and Crittenden (1951) correlated them with lithologically similar gravels along the Silver Creek fault zone to the north. No distinction was made by Tolman (1934) or Crittenden (1951) as to the lithologic differences between the gravels in Silver Creek Valley and those in Packwood Creek. Dibblee (1972a-b, 1973a-d) mapped the alluvial gravels along the eastern slope of the Santa Clara Valley as part of the Santa Clara Formation, which is present along the western slopes of the Santa Clara Valley. Graymer and DeVito (1993) first subdivided the gravels in Silver Creek Valley into two units, which they referred to as the Silver Creek and Packwood gravels, based on color, lithology, and occurrence.

General Clast Composition

Based mainly on composition of clasts in the conglomerate and on stratigraphic position, three different gravel units were recognized in the area of this study. Clast types representative of the differences in gravel composition are graywacke, red, brown, and green radiolarian chert, and black chert. These are plotted on a ternary diagram to graphically separate the units (Fig. 4). Sample locations are shown

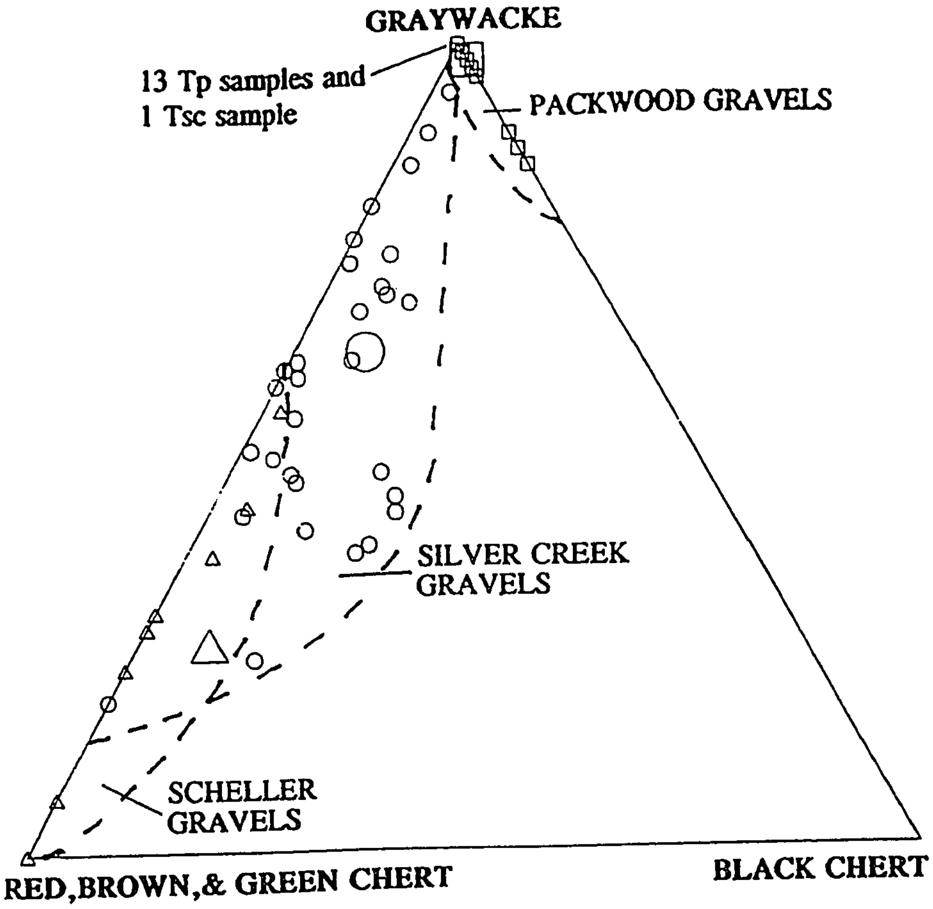


Figure 4. Relative proportions of selected framework clasts for all gravels studied. Larger symbols indicate average. Circles=Silver Creek gravels (Tsc); squares=Packwood gravels (Tp); triangles=Scheller gravels (Ts).

in Figures 5-9, and clast description and clast count results are tabulated in Appendix A. Important clasts not chosen for Figure 4 include porcelanite, porphyritic volcanic rocks, and serpentinite. The gravels are referred to as the Silver Creek, Packwood, and Scheller gravels. Figure 10 shows the general distribution of these gravel units; more detailed maps are presented in Plates 1-3.

Gravel Units

Recognition of the individual gravels was based primarily on the composition of clasts in the conglomerate. Each of the gravels also has distinctive lithology and stratigraphic position.

Silver Creek Gravels

Thirty-one pebble counts were taken from Silver Creek Valley to Anderson Reservoir (Figs. 5-8). Data obtained during this study show that the Silver Creek gravels consist of poorly- to well-lithified gray conglomerate, sandstone, and minor dark-red, gray, and green mudstone. The conglomerate is closely packed and clast-supported, and typically contains poorly to moderately sorted, subrounded to rounded pebbles in a moderately sorted sandy matrix (Fig. 11). The clasts in the conglomerate range in size up to 54 cm (Fig. 12), with an average clast size of about 4 cm. The amount of matrix generally is less than 20%. The sandstone is gray, medium- to coarse-grained, and poorly to moderately sorted. The mudstone ranges from dusky

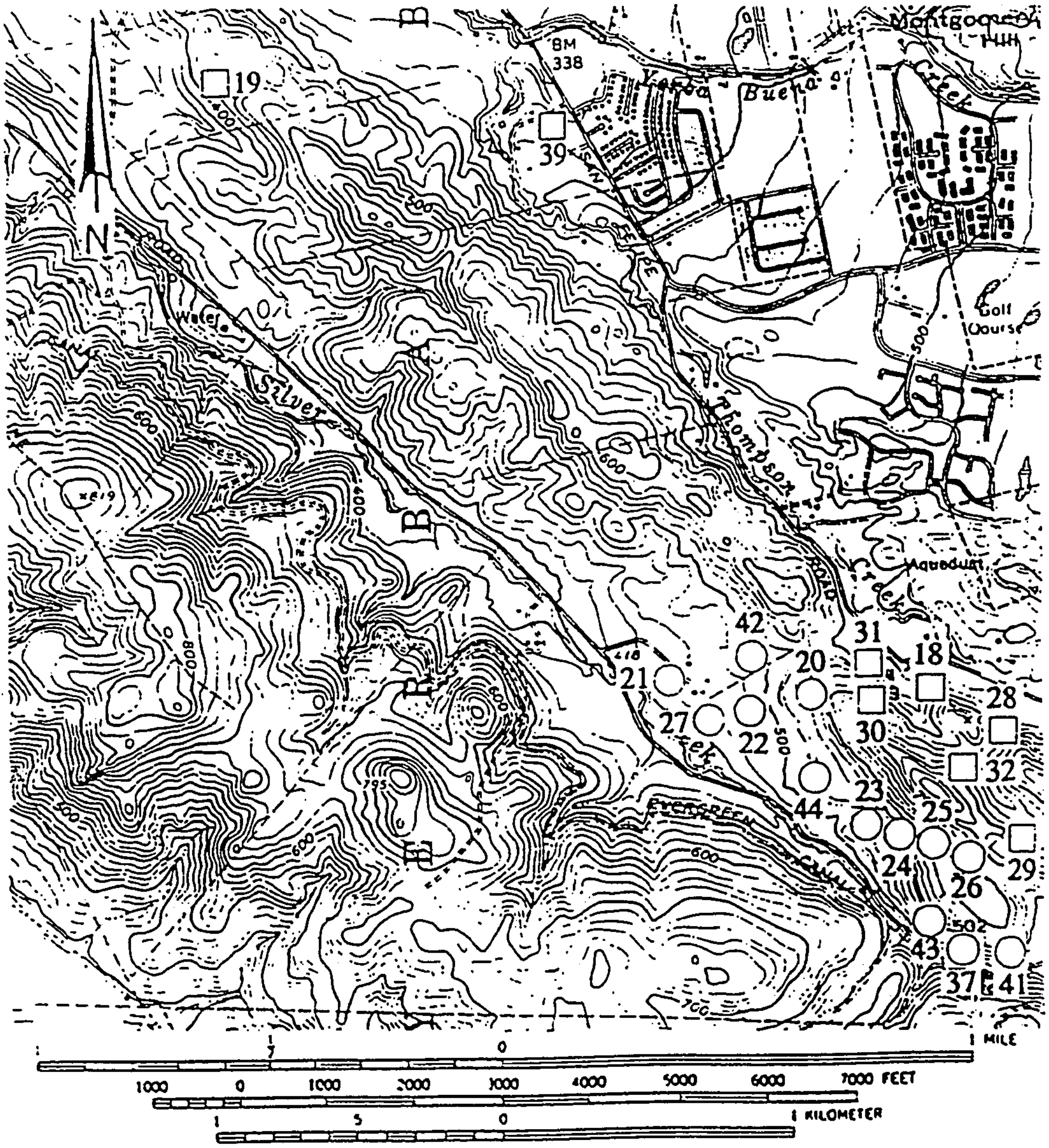


Figure 5. Sample location map of Silver Creek and Packwood gravels in Silver Creek Valley. Base map from U.S.G.S. 1:24,000 San Jose East quadrangle map. Circles=Silver Creek gravels; squares=Packwood gravels.

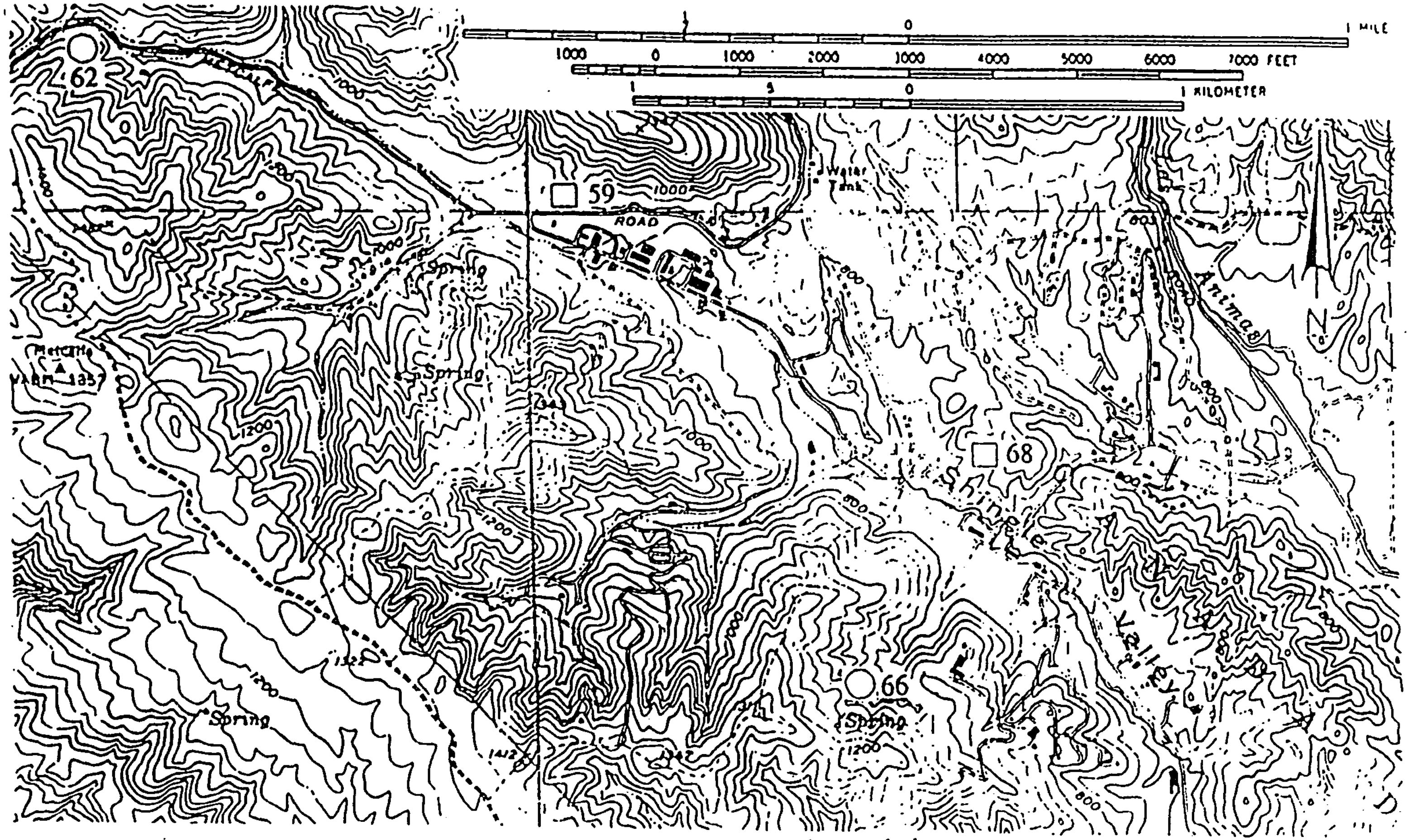


Figure 6. Sample location map of Silver Creek and Packwood gravels in Shingle Valley. Base map from U.S.G.S. 1:24,000 Morgan Hill quadrangle map. Circles = Silver Creek gravels; squares = Packwood gravels.

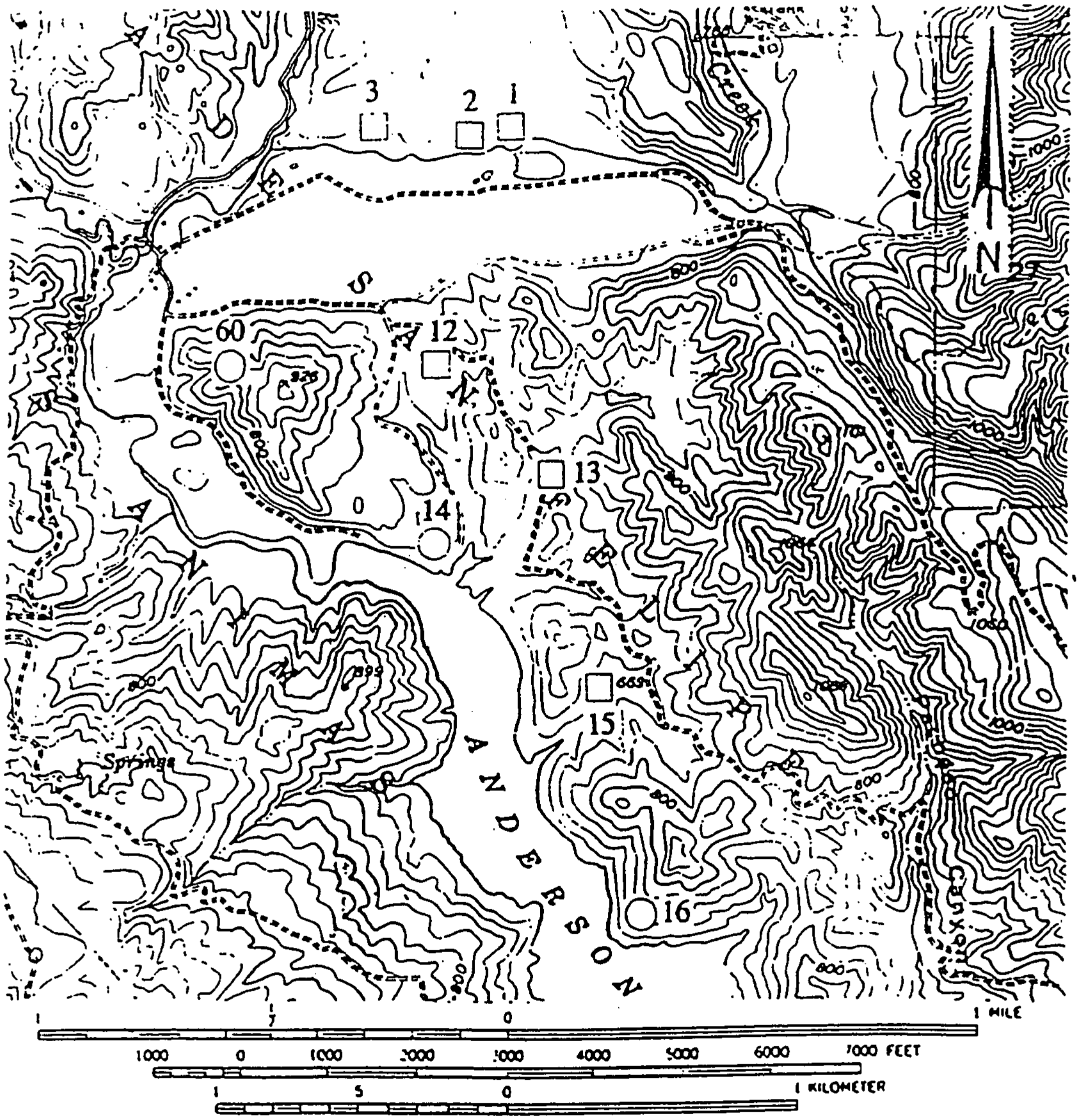


Figure 7. Sample location map of Silver Creek and Packwood gravels along north shore of Anderson Reservoir. Base map from U.S.G.S. 1:24,000 Morgan Hill quadrangle map. Circles=Silver Creek gravels; squares=Packwood gravels.

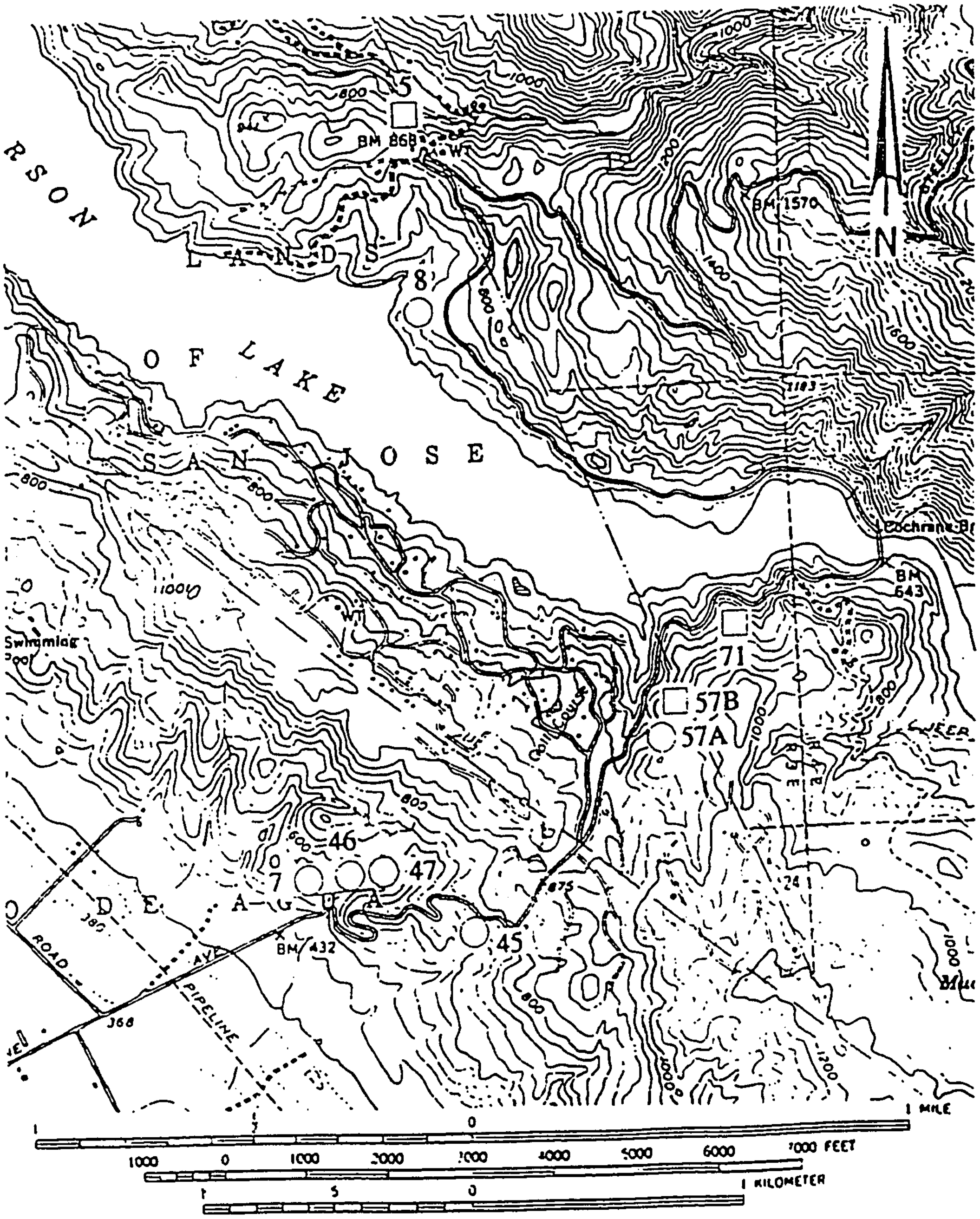


Figure 8. Sample location map of Silver Creek and Packwood gravels along south shore of Anderson Reservoir. Base map from U.S.G.S. 1:24,000 Mt. Sizer quadrangle map. Circles=Silver Creek gravels; squares=Packwood gravels.

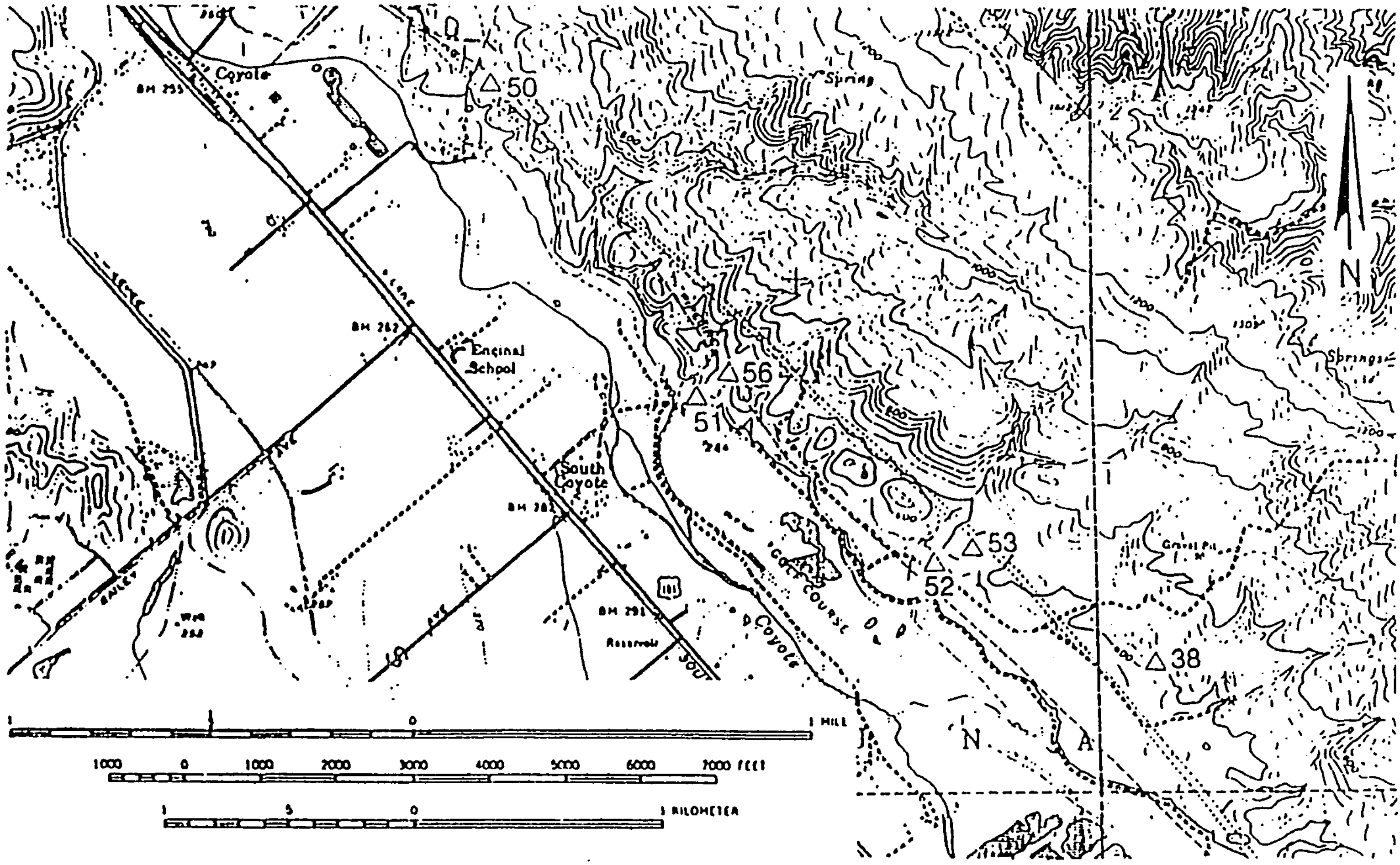


Figure 9. Sample location map of the Scheller gravels. Base map from U.S.G.S. 1:24,000 Mt. Sizer quadrangle map.

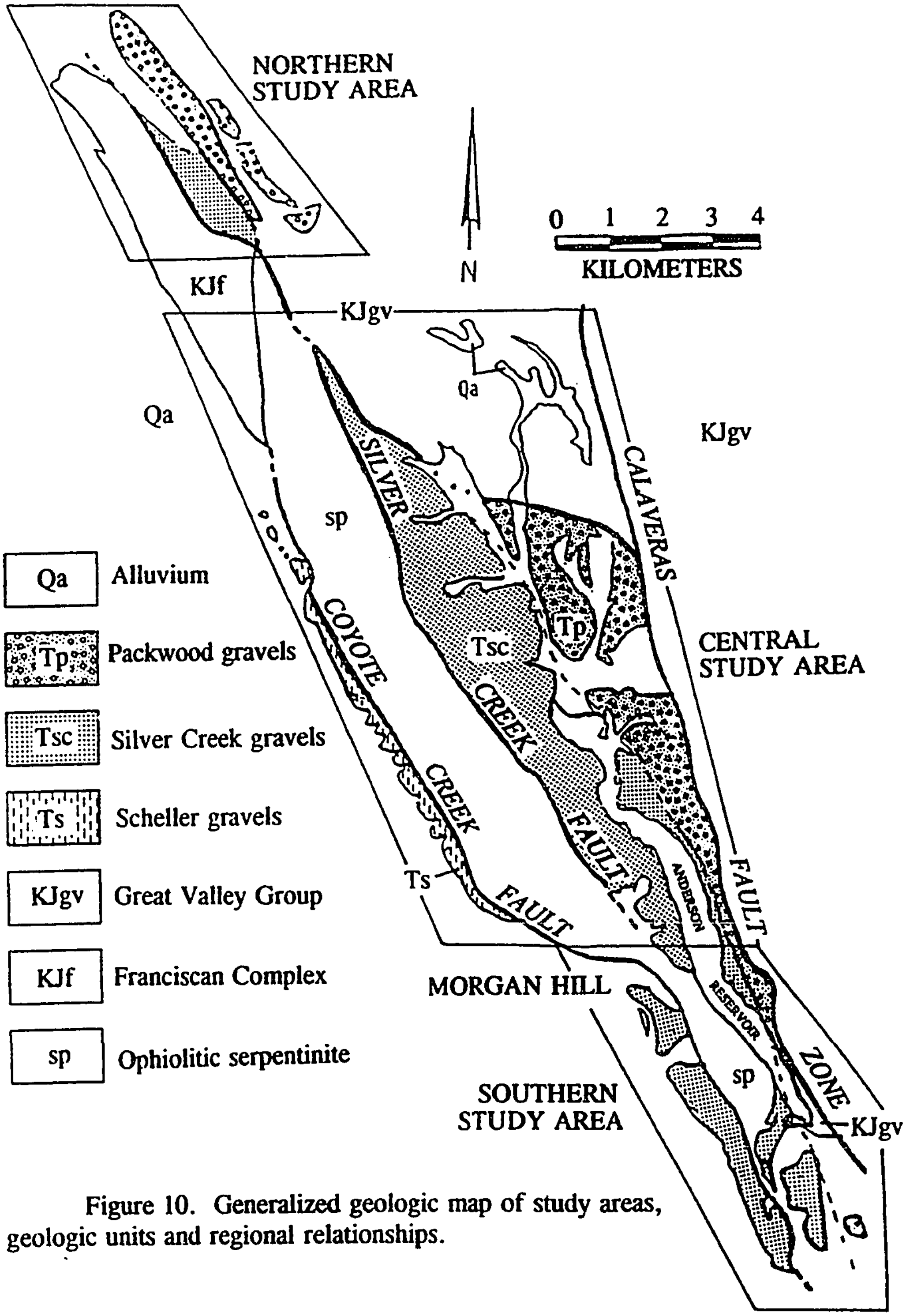


Figure 10. Generalized geologic map of study areas, geologic units and regional relationships.

Figure 11. Typical outcrop of Silver Creek gravels in Silver Creek Valley. Pencil shows scale.

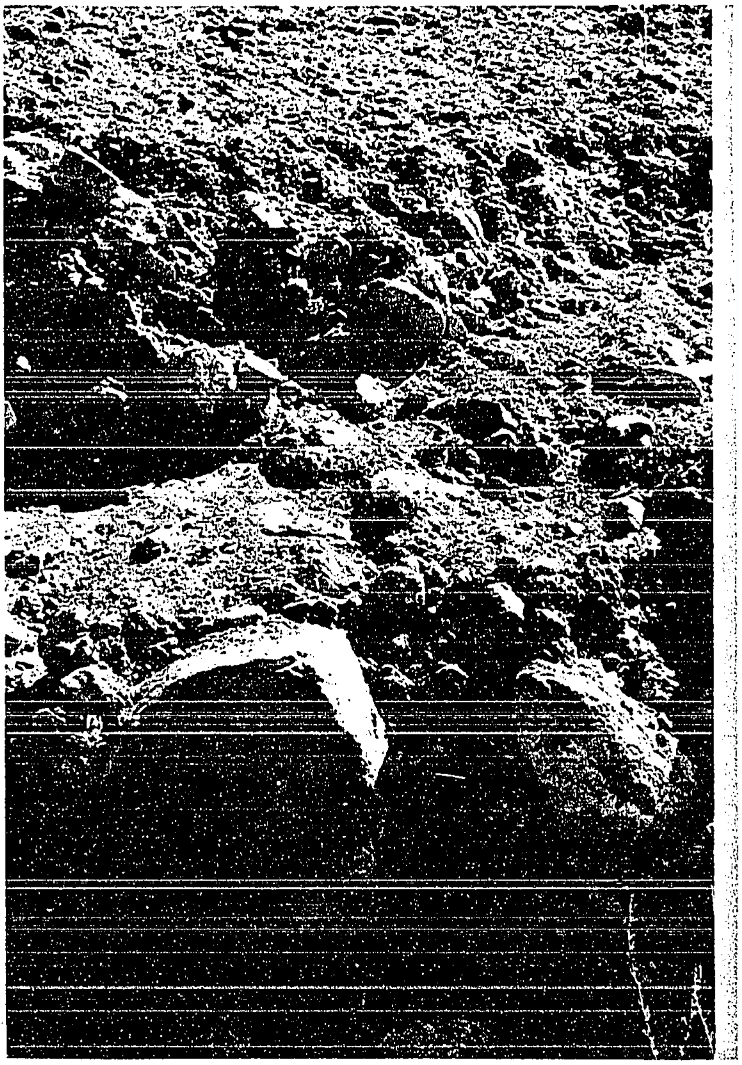


Figure 12. Boulder conglomerate unit in Silver Creek gravels in the Silver Creek Valley. Hammer shows scale.

red to green, and consists of unlaminated silt and clay.

Distribution and Thickness. The Silver Creek gravels form low-lying, elongate, northwest-trending foothills that parallel the eastern slopes of the Santa Clara Valley. Outcrops locally reach thicknesses of 20 m. In Silver Creek Valley, the gravels are bounded on the west by the Silver Creek fault and Franciscan Complex, and on the east by the Silver Creek fault, Great Valley Group rocks and the Packwood gravels (Plate 1). In Shingle Valley, the Silver Creek gravels are bounded on the west by the Silver Creek fault and on the east by the Packwood gravels (Plate 2). In the Anderson Reservoir area, the Silver Creek gravels are bounded on the west by the Coyote Creek fault and on the east by the Packwood gravels (Plate 3).

The Silver Creek gravels have a partial thickness of at least about 900 m in Shingle Valley, where the thickest section is present. No complete section of the Silver Creek gravels has been observed, so the actual thickness is unknown. The base of the Silver Creek gravels is covered or faulted in the study area, so the nature of the contact with the underlying units is unknown. Contacts between the Silver Creek gravels and serpentinite or Franciscan Complex rocks throughout the study area appear to be faults along which the Franciscan Complex rocks have been thrust over the Silver Creek gravels or where the Silver Creek gravels are faulted against the serpentinite (Plates 1-3).

Lithology. The conglomerate contains clasts of graywacke and associated arkosic sandstone and siltstone, serpentinite, radiolarian chert, laminated and unlaminated porcelanite, black chert, rare blueschist and greenstone, and various igneous rocks (Appendix A).

The graywacke clasts are subangular to subrounded, olive-green to gray and occur in two types. One type of graywacke is muscovite-rich and foliated, lacks biotite, and contains quartz veins. The other type of graywacke contains biotite and lacks foliation and quartz veins. Arkosic sandstone clasts are yellow to very pale brown, micaceous, and subrounded to rounded. Siltstone clasts are dark green or gray to black, fissile, and subangular to subrounded.

Serpentinite clasts, ranging in degree of serpentinization from slight to complete, are rounded to angular and range from black to dark greenish-brown. Angular to subangular red, brown, mottled green and brown, or light-olive-green radiolarian chert with 1-2 mm quartz veins is present within the Silver Creek gravels.

A conspicuous clast type in the Silver Creek gravels is porcelanite. These clasts are subrounded to subangular, white to dark brown, reddish brown, or gray, with many containing distinctive, 1-2 mm light and dark, parallel laminae. Although the porcelanite clasts generally constitute a small percentage of clasts in the Silver Creek gravels, they are fairly resistant to weathering and easily visible in the outcrop.

Black chert within the conglomerate consists of rounded whole and broken-rounded clasts. These broken-rounded clasts suggest that they are recycled from an older conglomerate.

Rare, dark-green greenstone and dark-blue blueschist clasts are angular to subangular. The igneous rocks are subangular to subrounded to rounded clasts of rhyolite, andesite, basalt, granite, diorite, gabbro, and diabase. Distinctive whole to broken-rounded siliceous porphyries constitute less than 1% of the clasts.

The finer-grained beds in the Silver Creek gravels consist of sandstone and mudstone. The sandstone generally is composed of medium- to coarse-grained, moderately well sorted, subangular to rounded sand. The thickness of the sandstone beds ranges from 1-3 m. The matrix sand in the conglomerate is coarser grained than that composing the sandstone beds. The mudstone beds, present in the lower part of the section, are light gray and green or dusky red, locally mottled pinkish-gray, laterally continuous, internally structureless, and tabular (Fig. 13). The thickness of the beds ranges from 40 cm to at least 1 m. On the east limb of an anticline in Silver Creek Valley, the mudstone is interbedded with sandstone and conglomerate in relatively thin, continuous beds.

A single tuffaceous bed is present in the Silver Creek gravels in the central portion of Silver Creek Valley near the axis of an anticline (Plate 1) and near the base of the unit. The tuff is white to pale yellow, contains glass shards, fine-sand and silt, and forms a single lenticular bed approximately 50 cm thick.

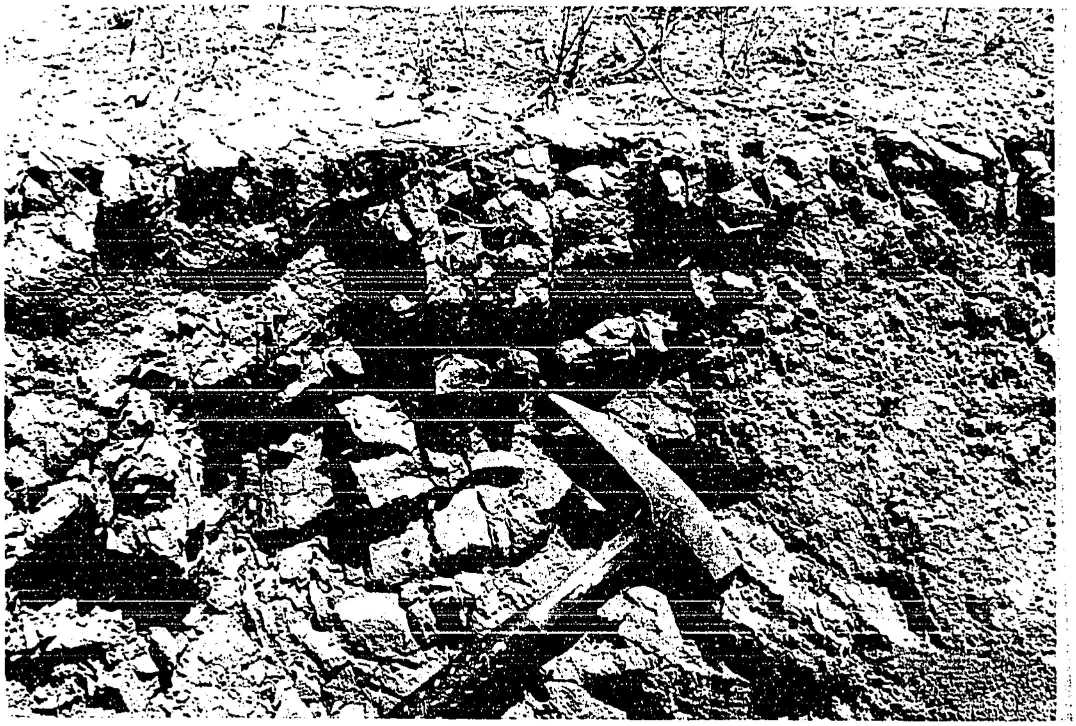


Figure 13. Mottled mudstone unit of the Silver Creek gravels in Silver Creek Valley. Hammer shows scale.

Age and Stratigraphic Relationships. John Nakata (personal communication, 1994) sampled the tuffaceous unit interbedded with the Silver Creek gravels in the central portion of the Silver Creek Valley. Charles Meyers of the U.S. Geological Survey analyzed the tuff and reported a chemical affinity with the Huitchica Tuff (Charles E. Meyers, personal communication, 1995), a volcanic unit derived from the Sonoma volcanics in northern California, with a reported age of about 4.0 Ma (Sarna-Wojcicki and others, 1991).

In the Anderson Reservoir area, the Silver Creek gravels are interbedded with the Anderson-Coyote basalts (Plate 3) which yielded K-Ar ages of 2.5-3.5 Ma (Nakata, 1977; Nakata and others, 1993). Based on the relationships with the Huitchica Tuff and the basalts, the Silver Creek gravels are considered to be Pliocene in age.

Two Miocene volcanic units in the northern portion of Silver Creek Valley yielded K-Ar ages of about 10.4 Ma and 13.6 Ma (Nakata and others, 1993). In trenches excavated for grading of the valley, Graymer and DeVito (1993) reported that a gravel unit appeared to be interbedded with both of the Miocene volcanic bodies. The trenches were not available during this study and this gravel unit was not observed or sampled. Based on the difference in age between the associated volcanic rocks and the Huitchica Tuff and Anderson-Coyote basalts, it is here inferred that the gravel unit described by Graymer and DeVito (1993) is not part of the Silver Creek gravels.

Sedimentary Features. Stratification and other sedimentary features in the Silver Creek gravels are absent or unrecognizable except where the rocks are well-lithified. Overall, the stratigraphic section in the eastern portion of Silver Creek Valley is a coarsening-upward sequence with lower, fine conglomerate and sandstone at the base grading up to coarser, boulder conglomerate at the top of the section (Fig. 14). The most common feature in both the sandstone and conglomerate beds is a local fining-upward sequence with conglomerate at the base grading into sandstone and mudstone at the top. Normal grading also is observed within some of the conglomerate and sandstone beds (Fig. 15).

The conglomerate ranges from thinly bedded to very thickly bedded, with thicker bedding in the coarser, boulder conglomerate. The conglomerate and sandstone beds are relatively continuous and can be traced for tens of meters along strike. Conglomerate beds typically are parallel stratified and tabular to lenticular in form. The coarser conglomerate beds are closely packed and commonly show alignment of elongated clasts parallel to bedding. Imbrication is rare. The conglomerate beds typically fine upward to sandstone (Fig. 15). The lower and upper surfaces of the conglomerate beds differ markedly. Exposed lower surfaces are erosional or undulatory, whereas the upper surfaces generally are planar or slightly undulating. The conglomerate typically grades upward into unstratified sandstone beds. Sandstone beds are tabular, massive or crudely stratified, and generally less than 2 m thick; trough cross-bedding and planar stratification locally are visible where

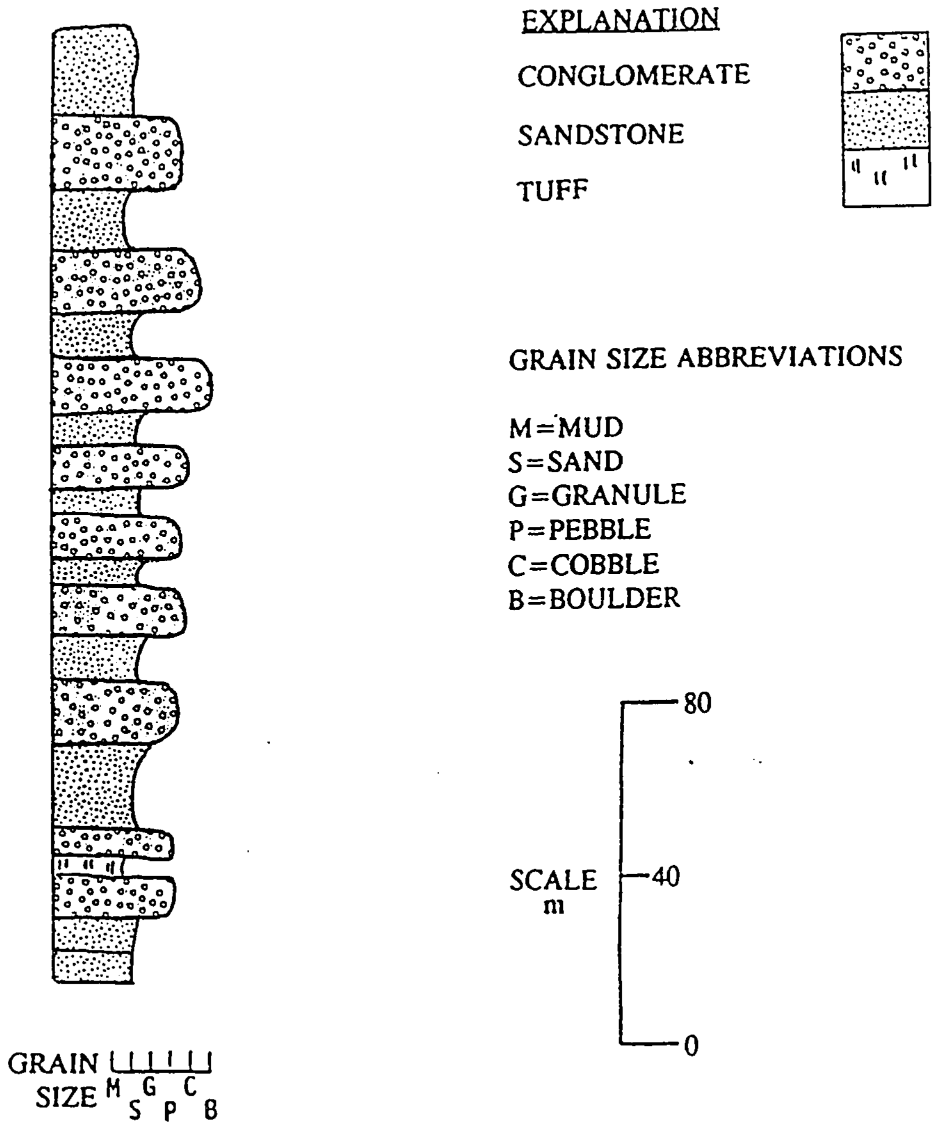


Figure 14. Columnar section of Silver Creek gravels in Silver Creek Valley (See Plate 1 for section line).

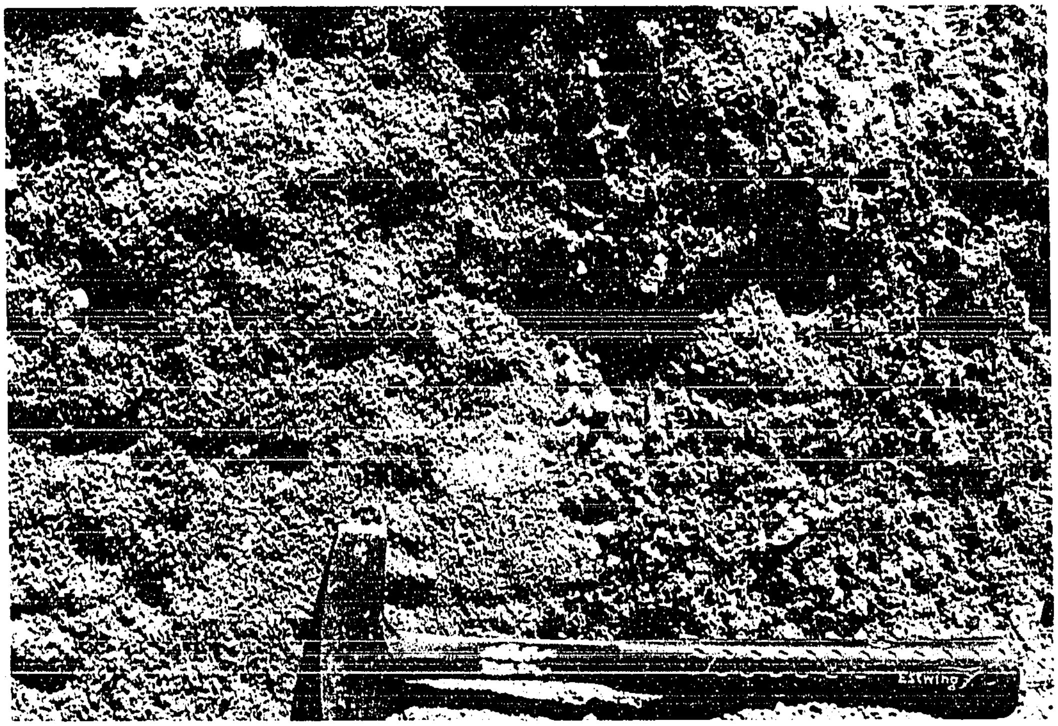


Figure 15. Vertical conglomerate beds of the Silver Creek gravels in Silver Creek Valley showing normal grading (top to left). Hammer shows scale.

the sandstone is well-lithified (Fig. 16). Thin (0.5-1 m) sandstone beds generally are massive and lack sedimentary structures, but they locally exhibit faint parallel or cross lamination. The mudstone occurs in thin, continuous, internally structureless, tabular beds commonly less than 1 m thick.

Depositional Environment. The Silver Creek gravels are interpreted to have been deposited in a nonmarine, prograding, braided fluvial environment. The massive to parallel-stratified, clast-supported conglomerate beds are interpreted to have been deposited by proximal braided steams. The degree of rounding indicates that the clasts were transported considerable distances from the source. The lack of angular clasts and matrix-supported conglomerate indicative of debris flows argues against deposition on alluvial fans (Rust and Gibling, 1989). Deposits studied here resemble the Pennsylvanian South Bar Formation, Canada, which Rust and Gibling (1989) interpreted as proximal deposits formed by migration of low-relief longitudinal bars or channels in shallow, high-velocity flows. The scarcity of trough cross-strata suggests that dunes were largely suppressed by the shallow, high velocity flow (Rust and Gibling, 1989). The presence of normally graded conglomerate units suggests waning flow velocities during bar development (Rust and Gibling, 1989).

The unstratified and internally structureless mudstone is interpreted as interchannel sediment. During quiescent periods, these interchannel deposits evidently were reworked by the fauna, destroying any lamination that may have been present.

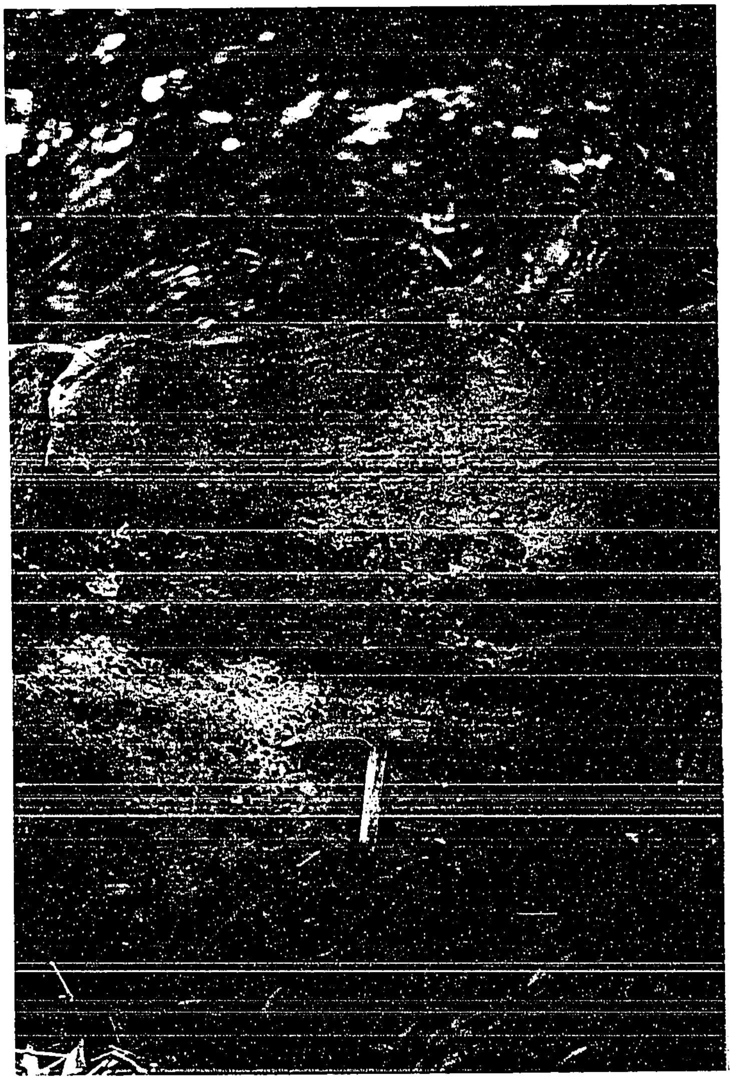
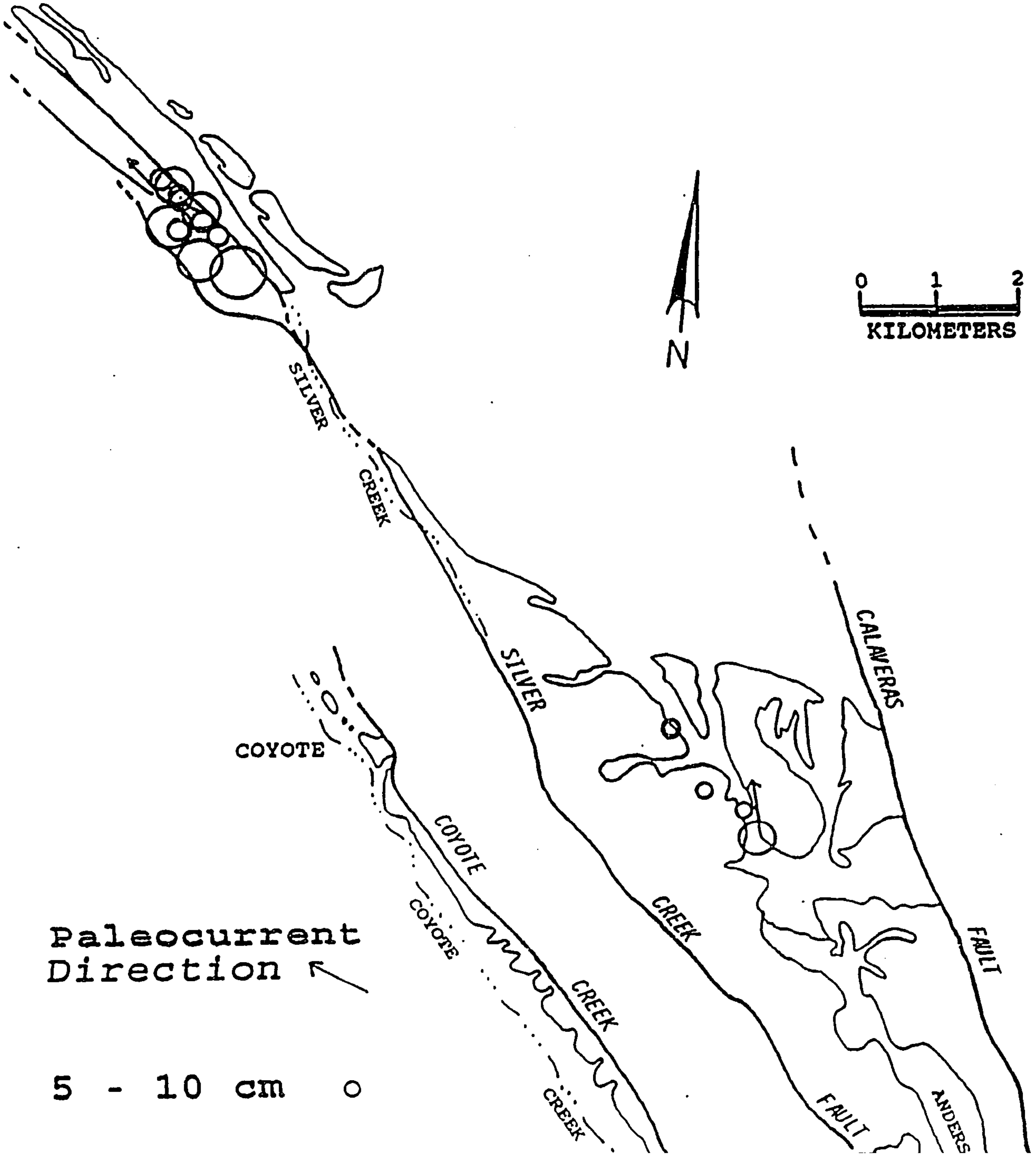


Figure 16. Conglomerate and sandstone beds containing parallel and trough cross-bedding in lithified unit of the Silver Creek gravels in Silver Creek Valley. Hammer shows scale.

Paleocurrents and Sediment Dispersal. Clast imbrication is present only rarely and was the most difficult parameter to identify in the gravels. The orientation of the B-axis of four imbricated clasts was measured at each of three sample locations. Their orientations indicate a general north-northwest paleocurrent direction (Fig. 17).

A map of the distribution of maximum clast sizes for the Silver Creek gravels is shown in Figure 17. The largest clasts occur in the north and south. This could be the result of multiple sources contributing detritus to the system in the northern and southern parts of the study area. Therefore, the sediment dispersal data are inconclusive at this time.

Provenance. Clasts interpreted to be from the Franciscan Complex are dominant with subordinate but important contributions from the Coast Range Ophiolite, Great Valley Group, and the Claremont Formation. Clasts derived from the Franciscan Complex are the muscovite-rich and foliated graywacke, olive green siltstone, and some of the igneous rocks. Red, brown, and green radiolarian chert occur both in the Franciscan Complex and the Coast Range Ophiolite, and clasts in the Silver Creek gravels may have come from both sources. Radiolaria analyzed by B.L. Murchey (personal communication, 1995) indicate that the chert studied by her originated in the Franciscan Complex (Appendix B). Serpentinite and some igneous rocks are interpreted to have been derived from the Coast Range Ophiolite. Biotite-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Paleocurrent Direction
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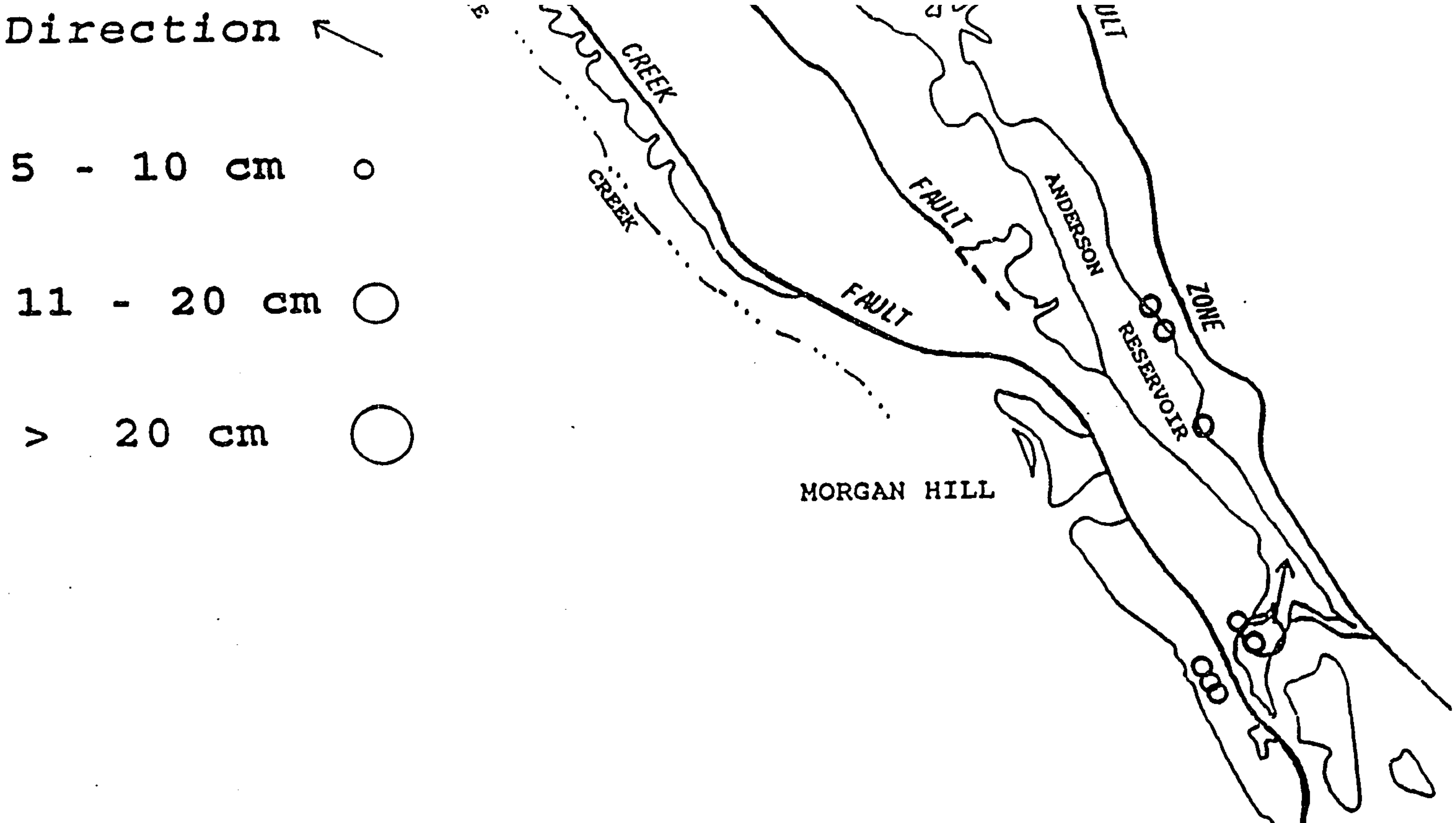


Figure 17. Map of outcrop area of Silver Creek gravels showing maximum conglomerate clast size and paleocurrent directions.

rich, non-foliated graywacke is interpreted to have been derived from the Great Valley Group; black chert and porphyritic volcanic rocks from the Oakland Conglomerate; and porcelanite from the Claremont Formation. Clasts of Tertiary sandstones have not been found in the Silver Creek gravels. With the exception of Great Valley Group and Claremont Formation rocks, all of the sources are prominent on both the east and west sides of the Santa Clara Valley. The Silver Creek gravels are interpreted to contain both Franciscan Complex and Great Valley Group graywackes. Analysis of the radiolaria in the chert indicates that the radiolarian chert originated in the eastern and central belts of the Franciscan Complex (Appendix B); both crop out in the Diablo Range and Santa Cruz Mountains east and west of the Silver Creek gravels (Fig. 3). Greenstone, which is absent or very rare in most samples of the Silver Creek gravels (Appendix A), occurs only in isolated outcrops along the east side of the valley, but it is abundant in the Santa Cruz Mountains to the west (Wagner and others, 1990).

The Great Valley Group crops out along both sides of the valley, but outcrops are geographically closer and more extensive on the east. Conglomerate of the Great Valley Group, which probably contributed the black chert and siliceous porphyries, is much more abundant along the eastern Santa Clara Valley east and northeast of the study area as the Oakland Conglomerate of Crittenden (1951) than to the west (Vanderhurst, 1981). Porcelanite of the Claremont Formation only crops out on the east side of the valley (Blueford and others, 1989).

It is proposed that the clasts in the Silver Creek gravels were derived mainly from source rocks east of the Calaveras fault in the Diablo Range.

Packwood Gravels

The gravels in the lower part of Packwood Creek (Fig. 1) were first described by Tolman (1934). Lithologically similar gravels, all considered here to be part of the Packwood gravels, are present from north to south in Silver Creek Valley, Shingle Valley, Las Animas Creek, and the Anderson Reservoir area. Twenty-one samples were taken from outcrops of the Packwood gravels between Silver Creek Valley and Gilroy (Figs. 5-8) and are tabulated in Appendix A.

Distribution and Thickness. The Packwood gravels form moderately high, elongate, north-northwest-trending foothills west of the Calaveras fault zone (Fig. 18). In Silver Creek Valley the Packwood gravels are bounded on the west by the Silver Creek gravels and Franciscan Complex rocks and on the east by Quaternary alluvium, Great Valley Group rocks, and serpentinite, with which they are in fault contact (Plate 1). Graymer and DeVito (1993) reported that, in isolated locations, the Packwood gravels in Silver Creek Valley conformably overlie the Silver Creek gravels. In Shingle Valley, the gravels are bounded on the east by the Calaveras fault zone and on the west by Quaternary alluvium and the Silver Creek gravels (Plate 2), and reach a maximum thickness of about 1560 m. In Packwood Creek, the gravels are bounded

Figure 18. Elongate foothills formed by the Packwood gravels east of Anderson Reservoir.

on the east by the Calaveras fault zone and on the west by the Silver Creek gravels along the eastern shore of Anderson Reservoir (Plates 2 and 3). On the southern shore of Anderson Reservoir, the Packwood gravels are interbedded with the Silver Creek gravels and the two units are folded into a complex series of north and northwest-trending anticlines and synclines (Plate 3). On the eastern limb of the eastern-most syncline, the Packwood gravels are interbedded with the Anderson-Coyote basalts (Plate 3). Due to faulting and cover, the total thickness of the Packwood gravels is unknown.

Lithology. The Packwood gravels consist mostly of reddish-brown to dark reddish-brown, moderately weathered, clast-supported, coarse-pebble conglomerate, medium-grained sandstone, and fine-grained rocks (Fig. 19). The clasts in the conglomerate are moderately sorted and rounded. The sandy silty matrix in the conglomerate is moderately to well sorted and constitutes less than 20% of the rock.

The clasts in the conglomerate are limited in diversity. They consist mostly of biotite-rich and non-foliated graywacke, minor muscovite-rich, foliated graywacke, arkosic sandstone, siltstone, black chert and some igneous rocks. Graywacke clasts are subangular to subrounded, light gray to olive brown, and medium to coarse grained. Arkosic sandstone clasts are yellow to very pale brown, micaceous, and subrounded to rounded. Siltstone clasts are dark gray to black, fissile, subangular to subrounded, and very fine grained.

Figure 19. Typical outcrop of the Packwood gravels in Packwood Creek with well-rounded conglomerate clasts. Hammer shows scale.

The black chert consists of broken-rounded clasts 1-10 cm in diameter. Igneous rocks are represented by weathered, light-gray granite, angular dark-brown to black basalt, angular to subangular diorite and diabase, and distinctive siliceous porphyries. The porphyries are rounded whole and broken-rounded clasts. The broken-rounded clasts suggest recycling of older conglomerate clasts.

The sandstone beds are composed of medium- to very coarse-grained, moderately to poorly sorted, subangular to rounded sand.

Geographically isolated gravels exposed on Montgomery Hill, at the intersection of Old Yerba Buena and Yerba Buena roads in southeast San Jose (Fig. 5) were considered by Graymer and DeVito (1993) to be part of the Packwood gravels. These gravels contain various clasts including black chert, siliceous porphyries, and radiolarian chert. Because radiolarian chert is not found in the Packwood gravels, and because the unit on Montgomery Hill appears to be very thin and nearly horizontal, these gravels are here considered to be young terrace deposits and not part of the Packwood gravels.

Age and Stratigraphic Relationships. Along the southern shore of Anderson Reservoir, the Packwood gravels are interbedded with the Anderson-Coyote basalts. The basalt has been described by Nakata (1977) and Nakata and others (1993) and has a reported radiometric age range from 2.5 to 3.5 Ma. Based on this relationship with the Anderson-Coyote basalts, the Packwood gravels are considered to be Pliocene in age.

The Packwood gravels also are interbedded with the Silver Creek gravels over a stratigraphic thickness of about 100 m along the southern shore of Anderson Reservoir (Plate 3). Near this location, a road cut exposes the contact between the Packwood and Silver Creek gravels together in the hinge of a northwest-trending syncline. Along East Dunne Avenue, southwest of Cochrane Bridge (Fig. 8), the Packwood and Silver Creek gravels are exposed in a landslide scarp (Fig. 20). The landslide scarp and the hinge of the syncline are the only locations found where the contact between the Packwood and Silver Creek gravels is exposed. At both locations the transition between the gravel units with different clast compositions is abrupt.

Graymer and DeVito (1993), proposed that the Packwood gravels are in conformable contact with the Silver Creek gravels in Silver Creek Valley. Throughout the study area the contact between the Packwood and Silver Creek gravels apparently is conformable, because beds of the two units generally are parallel and because there is no local evidence of faulting between the two units. Therefore, the Packwood gravels probably represent continued sediment accumulation in the fluvial system that deposited the Silver Creek gravels, but with a different source. The contact with the Great Valley Group in the northern portion of Silver Creek Valley is not exposed. This contact may be either an unconformity or a fault (Graymer and DeVito, 1993).

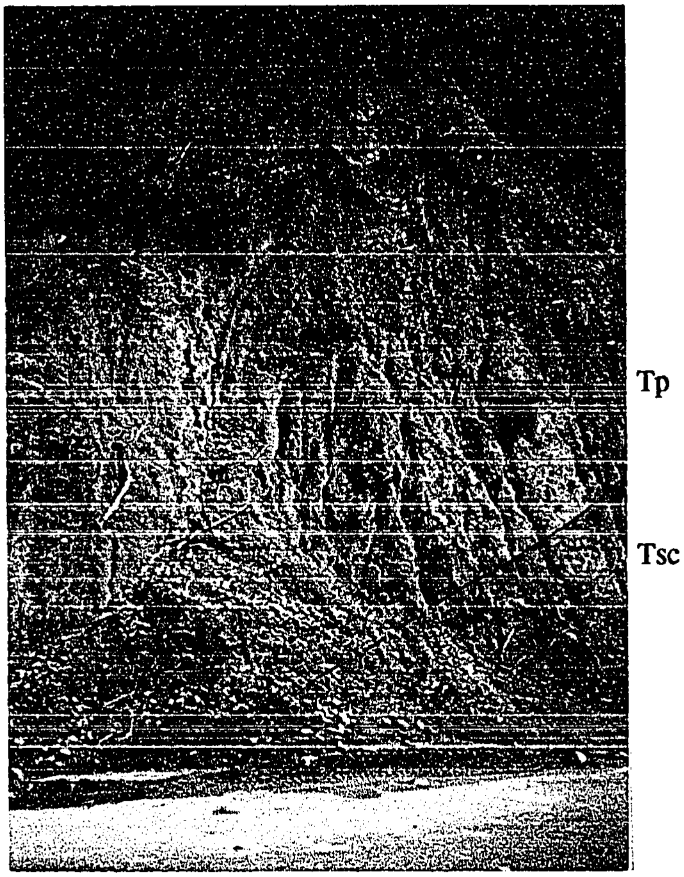


Figure 20. Packwood (Tp) and Silver Creek (Tsc) gravels exposed in a landslide scarp south of Anderson Reservoir. Outcrop is about 5 m high.

Sedimentary Features. Stratification and other sedimentary features in the Packwood gravels generally are absent or unrecognizable. The conglomerate ranges from thinly bedded to thickly bedded, and beds appear to increase in thickness up-section, where stratification is present. Conglomerate and sandstone typically are interbedded. Beds are discontinuous and nowhere traceable over more than 10 m due to alluvial cover, erosion, and faulting. The conglomerate and sandstone locally are clearly to indistinctly parallel stratified (Fig. 21) and normally graded, with no cross-stratification observed in any of the exposures.

Distinctive red, silty conglomerate to gravelly siltstone beds are common in the Packwood gravels. Walker (1967) considered redbeds in modern and ancient settings to have formed after deposition by the *in situ* alteration of iron-bearing detrital grains in hot, arid or semi-arid climates. Pale-brown to olive-green, mottled claystone is also present below the redbeds in the lower section of the Packwood gravels in Silver Creek Valley.

Depositional Environment. The Packwood gravels are considered to have been deposited by prograding, braided streams. Unstratified to parallel-stratified conglomerate beds in the Packwood gravels contain rounded, framework-supported clasts. Deposits studied here resemble the Pennsylvanian South Bar Formation, Canada, which Rust and Gibling (1989) interpreted as proximal deposits formed by migration of low-relief longitudinal bars or channels in shallow, high-velocity flows.

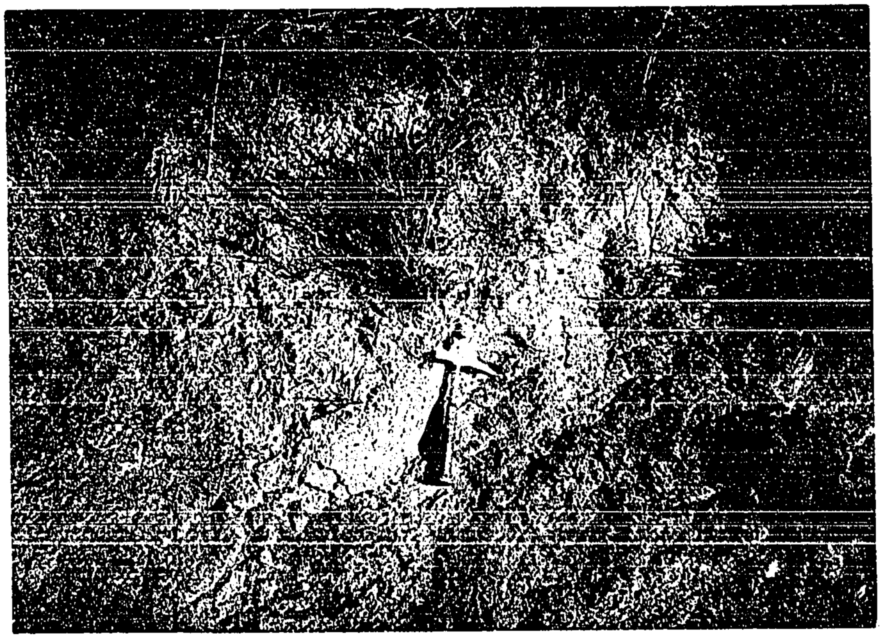
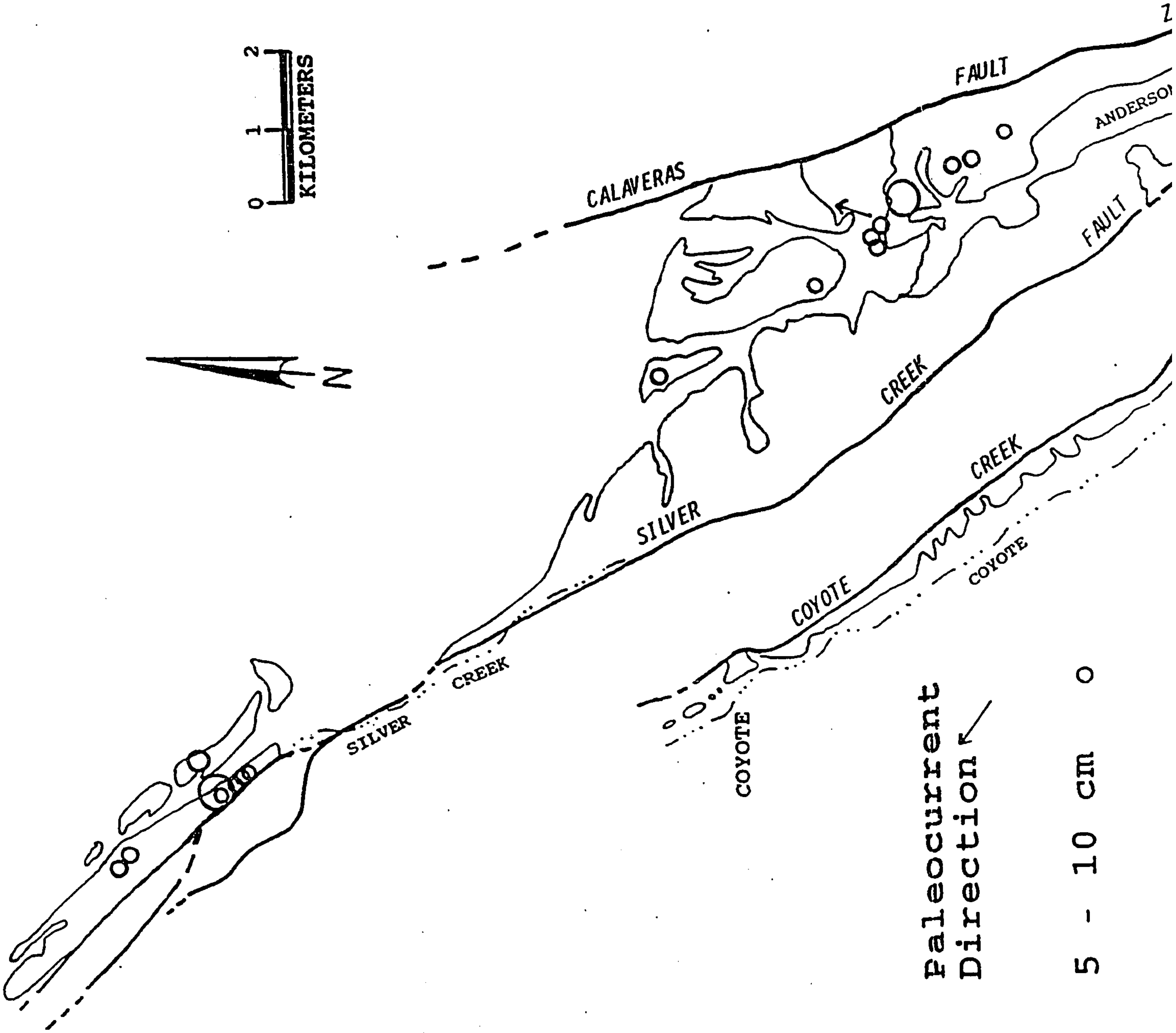


Figure 21. Parallel bedding in the Packwood gravels north of Shingle Valley. Hammer shows scale.

The scarcity of trough cross-strata suggests that dunes were largely suppressed by the flow (Rust and Gibling, 1989). The presence of normally graded conglomerate units suggests waning flow velocities during bar development (Rust and Gibling, 1989). Redbeds in the fine-grained rocks indicate that the sediments were oxidized shortly after burial.

Paleocurrents and Sediment Dispersal. The B-axis orientations of four imbricated clasts were measured at each of two sample locations; these indicate a generally north-northeast paleocurrent direction (Fig. 22). The distribution of maximum clast size for the Packwood gravels (Fig. 22) is fairly uniform, although a general north-northwest decrease in clast size is suggested. Imbrication data and sediment dispersal patterns indicate a northward-flowing stream system.

Provenance. The Packwood gravels are composed primarily of clasts derived from the Great Valley Group with a few from the Franciscan Complex. Clasts from the Great Valley Group include graywacke containing biotite, and lacking foliation and quartz veins, yellow arkosic sandstone, dark-gray siltstone, black chert and porphyritic volcanic rocks. Minor Franciscan Complex clasts include muscovite-rich, foliated, biotite-poor, quartz-veined graywacke, and most of the igneous rocks. Basalt clasts were probably derived from the Anderson-Coyote basalts. Clasts of Tertiary sandstones have not been found in the Packwood gravels.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Paleocurrent Direction
5 - 10 cm

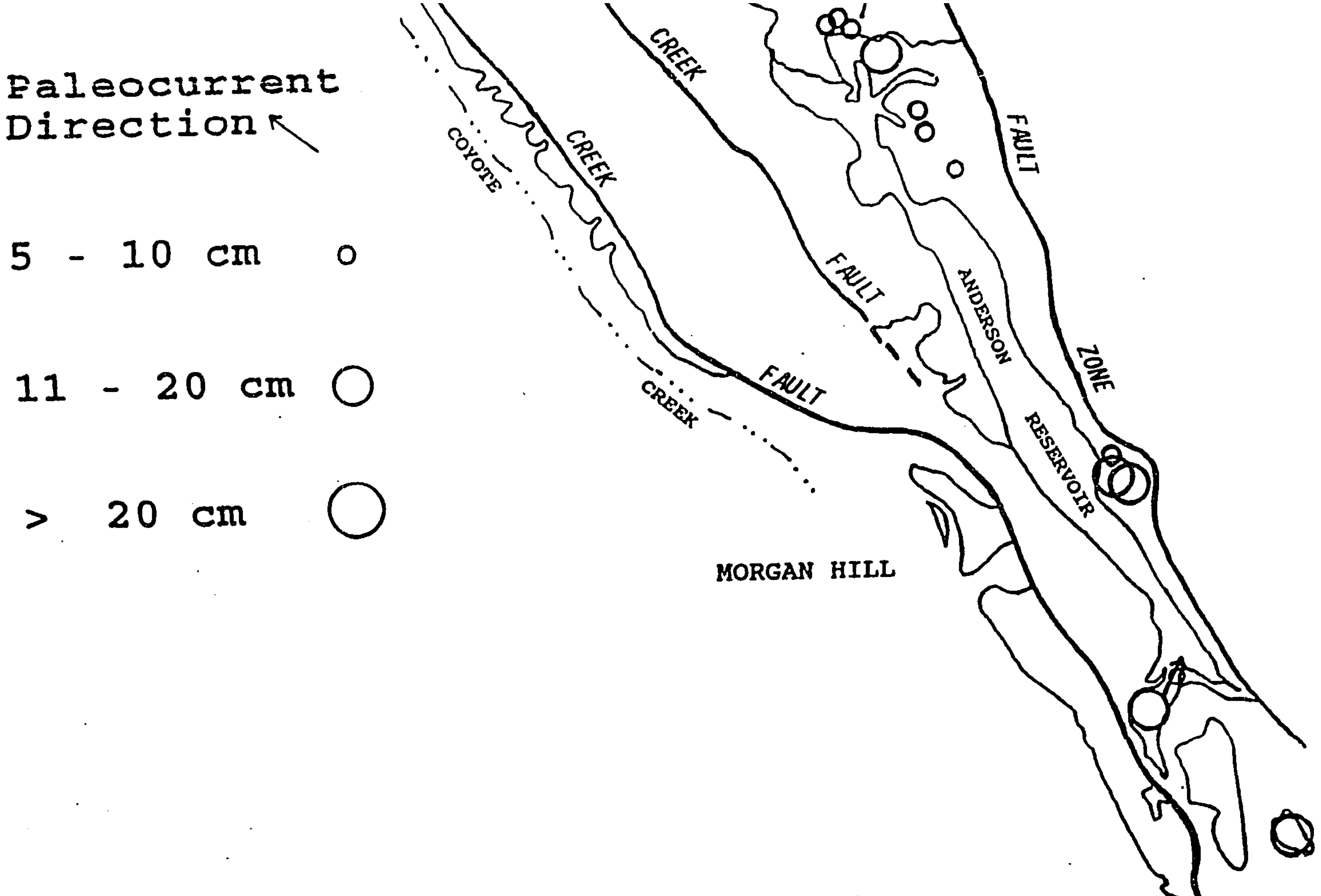


Figure 22. Map of outcrop area of Packwood gravels showing maximum conglomerate clast size and paleocurrent directions.

Both the Franciscan Complex and Great Valley Group are exposed on both sides of the Santa Clara Valley, although the Great Valley Group is most extensive on the east. Rounded black chert and porphyritic clasts are present in outcrops of the Oakland Conglomerate east and north of the Packwood gravels in Silver Creek Valley but are much less abundant along the western margin of the Santa Clara Valley (Plate 1 and Fig. 2). The scarcity of clasts of serpentinite, Franciscan chert, and Claremont Formation porcelanite suggests that these rocks were rare in the source area. It is suggested that outcrops of the Great Valley Group east of the Calaveras fault zone were the source of the material. It is likely that the uplifted Great Valley Group block that supplied sediment to the Packwood gravels was immediately to the east of the Calaveras fault and that it blocked sediment from the Franciscan Complex farther east.

Scheller Gravels

The Scheller gravels consist of moderately lithified, fairly well stratified, gray, framework-supported conglomerate, minor sandstone, and fine-grained rocks. Eight samples were taken from Malech Road to Scheller Avenue (Fig. 9, Plate 2). The conglomerate clasts consist of serpentinite, radiolarian chert, dark-green siltstone, muscovite-rich and foliated graywacke, and minor igneous rocks (Appendix A). The clast composition is similar to that of the Silver Creek gravels, and these rocks occupy very similar fields on Figure 4. However, the absence of porcelanite clasts in the Scheller gravels helps distinguish them from the Silver Creek gravels. Because these units occur in different structural blocks, the Scheller gravels are here treated as a separate unit, until further data are available to demonstrate a stratigraphic connection with the Silver Creek gravels.

Distribution and Thickness. From Malech Road to Scheller Avenue, the Scheller gravels form low-lying, elongate ridges west of the Coyote Creek fault and east of U.S. Highway 101 (Plate 2). The Scheller gravels strike northwest throughout their mapped extent, and they reach a thickness of at least 500 m at Scheller Avenue, where they are best exposed.

Lithology. The Scheller gravels consist of gray, moderately lithified, interbedded coarse-pebble conglomerate and medium-grained sandstone (Fig. 23). The lithology is consistent throughout the area. The conglomerate contains poorly sorted, subrounded, framework-supported clasts in a moderately to well sorted matrix that is generally less than 20% of the rock (Fig. 24).

The clasts in the conglomerate range up to 16 cm, with an average clast size of about 7 cm. Subangular to subrounded graywacke clasts are light gray to olive brown, muscovite-rich, foliated, quartz-veined, and lack biotite. Angular to rounded, black to dark-greenish-brown serpentinite clasts range in serpentinization from slight to complete. Angular to subangular chert clasts are red, brown, and mottled green and brown.

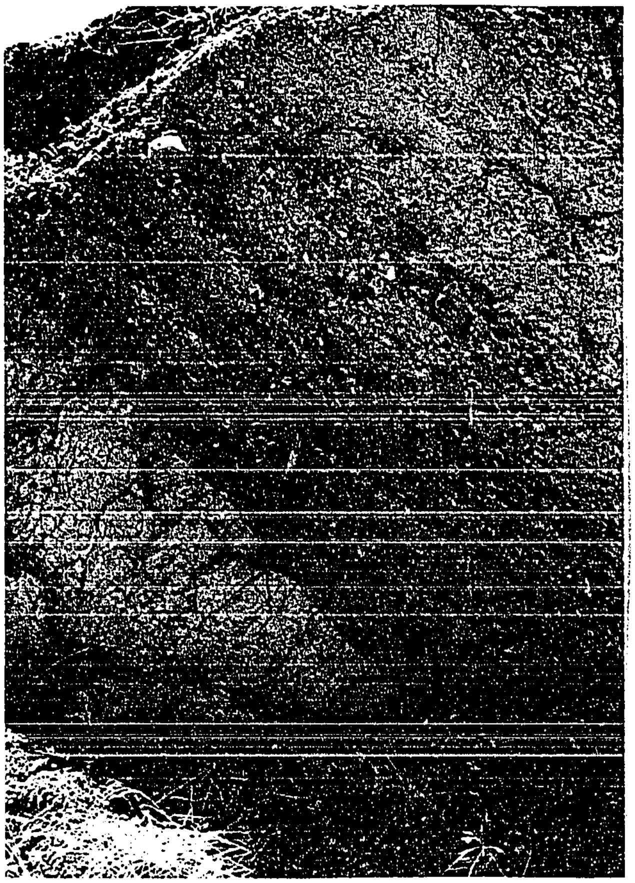


Figure 23. Outcrop of Scheller gravels north of Scheller Avenue. Hammer shows scale.

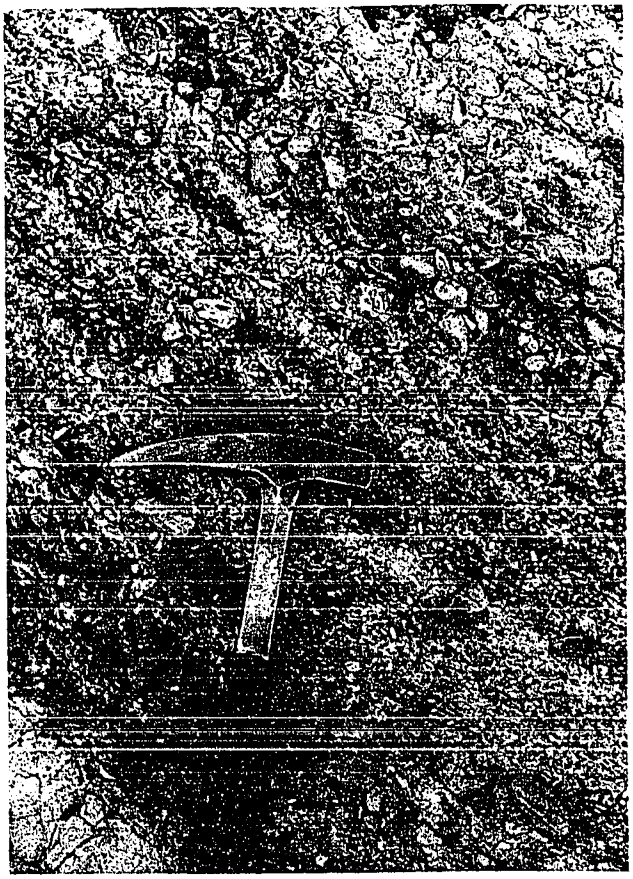


Figure 24. Outcrop of Scheller gravels north of Scheller Avenue showing subrounded to rounded clasts and framework-supported fabric. Hammer shows scale.

The igneous rocks are subangular to subrounded with no broken-rounded clasts observed. Igneous clasts present in the Scheller gravels are rhyolite, andesite, basalt, granite, diorite, gabbro, and diabase. At most localities, igneous rocks make up a very small percentage of the clasts; mafic rocks are relatively abundant locally (Appendix A).

The sandstone beds in the Scheller gravels represent a very minor portion of the unit. The sandstone is medium to very coarse grained, moderately to poorly sorted, and composed of subangular to rounded sand.

Several white, fine-grained units are interbedded with conglomerate in the lower portions of the section from Malech Road to south of Scheller Avenue (Fig. 25). Stratal thicknesses range from more than 2 m near the base, to tens of centimeters near the top of the deposits. X-ray diffraction of a sample of this sediment taken from the median of Highway 101 shows that it is composed of magnesite with subordinate amounts of aragonite.

Age and Stratigraphic Relationships. Sarna-Wojcicki (1985) collected a sample of the 400-ka Rockland Ash during construction of Highway 101 north of Scheller Avenue, but its relationship with the Scheller gravels is unknown. It is possible that the Rockland Ash is interbedded with the Scheller gravels, or it may have been deposited unconformably upon them. Presently, the age of the Scheller gravels is unknown. If the Scheller gravels are interbedded with the Rockland Ash, then they

Figure 25. Magnesite deposits near the base of the Scheller gravels north of Morgan Hill along Highway 101. Hammer shows scale.

are younger than the Silver Creek gravels and unrelated to them. Alternatively, the similarity of the Scheller gravels to the Silver Creek gravels suggests that they may be correlative. If this is true, then the Scheller gravels probably are Pliocene in age and are unconformably overlain by the Rockland Ash. Based on the abundance of fine-grained rocks and the structural position, they are most likely to be correlative with the lower part of the Silver Creek gravels. It is suggested here that the Scheller gravels are Pliocene in age.

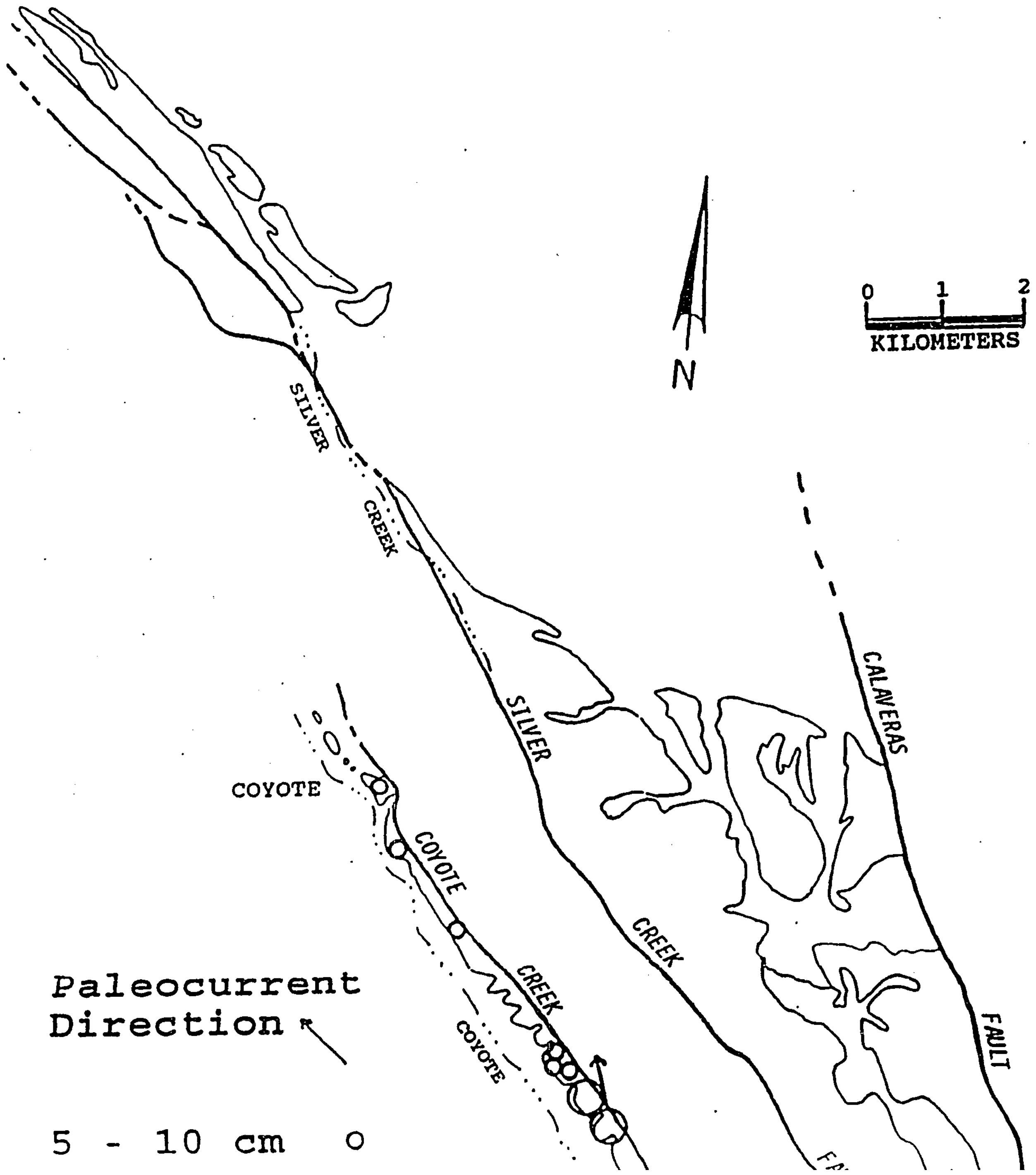
Sedimentary Features. The parallel-stratified conglomerate beds generally are thin and average about 0.5 m thick. Sandstone beds generally average about 1-2 m thick. The conglomerate and the sandstone beds generally are tabular, the conglomerate beds tend to be thinner than the sandstone (Fig. 23). The coarser conglomerate beds rarely contain crude arcuate bedding or trough cross-stratification (Fig. 23). Exposed lower surfaces are erosional or undulatory, whereas the upper surfaces generally are planar or slightly undulating. The conglomerate locally grades upward into massive sandstone beds.

Depositional Environment. The parallel stratified conglomerate beds in the Scheller gravels contain subrounded to rounded clasts. The degree of rounding indicates that they may have been transported relatively short distances from the source, but farther than the Silver Creek gravels. The lack of matrix-supported conglomerate, which would be indicative of debris flows, argues against deposition on alluvial fans (Rust and Gibling, 1989). The parallel-stratified conglomerates can be interpreted as proximal deposits formed by migration of low-relief longitudinal bars or channels in shallow, high-velocity flows. The scarcity of trough cross-strata suggests both that the dunes were largely suppressed by the shallow, high-velocity flow (Rust and Gibling, 1989) and that the deposits were proximal in the fluvial system. The magnesite deposits may represent pond deposits formed in areas of low gradient in the distal portions of the fluvial system or in proximal, rapidly subsiding portions close to an active fault.

Many depositional models can be applied to the Scheller gravels. The sediment may have been deposited in a locally restricted basin formed by thrust faulting along the Coyote Creek fault, or in the same prograding, braided fluvial system that deposited the Silver Creek gravels. In Silver Creek Valley the inferred base of the Silver Creek gravels contains more mudstone than the upper part of the section. It is expected that more fine-grained or lacustrine sediments would be present at the base of the section, representing the distal portions of the fluvial system. The geographic position of the Scheller gravels is where the lowest section of the Silver Creek gravels would have been prior to tectonic disruption. Based on the abundance of fine-grained rocks and on the geographic position relative to the Silver Creek gravels, the Scheller gravels are here inferred to be correlative with the base of the compositionally similar Silver Creek gravels. More data are needed to confirm this interpretation.

Paleocurrents and Sediment Dispersal. Imbrication of four clasts measured at one location suggests a north-northwest paleocurrent direction (Fig. 26). The distribution of maximum clast size for the Scheller gravels shows a slight decrease in size from southeast to northwest, also suggesting a northwest direction of sediment dispersal (Fig. 26).

Provenance. Clasts interpreted to be from the Coast Range Ophiolite are dominant with subordinate contributions from the Franciscan Complex and Oakland Conglomerate. Clasts derived from the Coast Range Ophiolite are the serpentinite and some igneous rocks. Red, green, brown, and mottled green and brown radiolarian chert, some of the igneous rocks, possibly the granite, and muscovite-rich and foliated graywacke are interpreted to have been derived from the Franciscan Complex; radiolaria analyzed by B.L. Murchey (personal communication, 1995) indicate that the chert samples analyzed originated in the Franciscan Complex (Appendix B). Rare black chert is inferred to have been reworked from Mesozoic conglomerate, such as the Oakland Conglomerate. Clasts of Tertiary sandstones have not been found in the Scheller gravels.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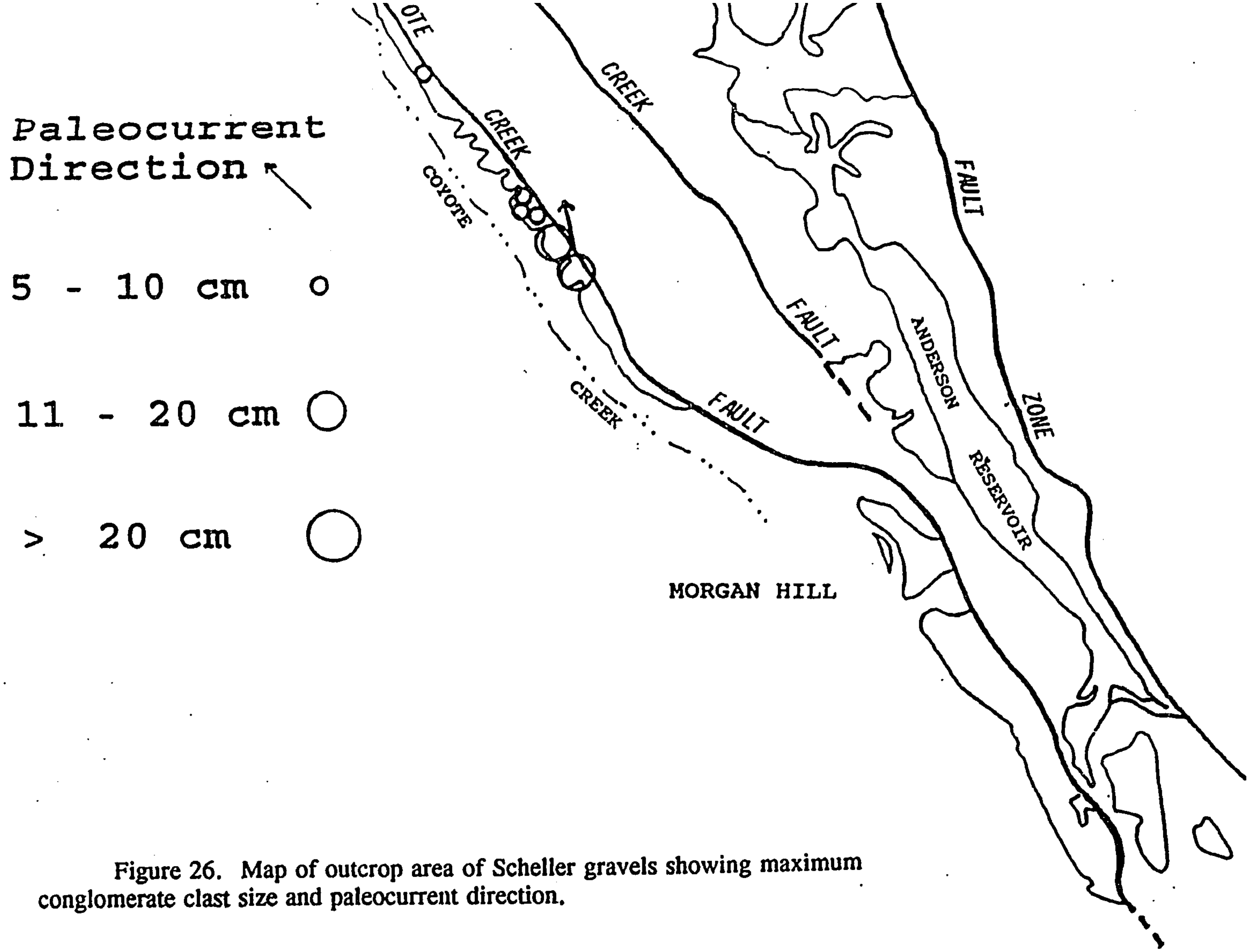

Figure 26. Map of outcrop area of Scheller gravels showing maximum conglomerate clast size and paleocurrent direction.

All of the sources are prominent on both the east and west sides of the Santa Clara Valley. Serpentinite, which is in fault contact with the Scheller gravels along the Coyote Creek fault (Plate 2), also is abundant further east in the north-central Diablo Range, with minor outcrops on the west in the Santa Cruz Mountains (Fig. 2). Chert analyzed by B.L. Murchey (personal communication, 1995) probably originated in the central belt terranes of the Franciscan Complex (Appendix B). Central belt terranes are most abundant east of the Scheller gravels with lesser amounts northwest, on the west side of the Santa Clara Valley (Fig. 3). Rare clasts in the Scheller gravels are rounded black chert (Appendix A) probably derived from the Oakland Conglomerate, which is most abundant along the eastern Santa Clara Valley east and northeast of the study area (Vanderhurst, 1981). Conspicuously missing from the Scheller gravels are biotite-rich, non-foliated graywacke clasts from the Great Valley Group, volcanic porphyries from the Oakland Conglomerate and porcelanite from the Claremont Formation. The absence of these clasts in the Scheller gravels may indicate that the Great Valley Group and Claremont Formation were not involved in the initial drainage area at the time the Scheller gravels were being deposited. The proposed sources of the Scheller gravels, in the eastern Diablo Range, are consistent with the proposed initial sources of the Silver Creek gravels.

It is suggested that the clasts in the Scheller gravels were derived mainly from Coast Range Ophiolite with minor contributions from Franciscan Complex and Oakland Conglomerate rocks east of the Calaveras fault in the Diablo Range.

DISCUSSION

Upper Cenozoic Gravels

In addition to the three gravel units studied here, other lithologically similar alluvial gravels are present along both the east and west margins of the Santa Clara Valley. They include the Santa Clara Formation on the west side of the valley and the Irvington gravels on the east (Fig. 27). It is possible that these deposits represent parts of a single, large depositional system that existed for millions of years, or that they are separate deposits formed in unrelated and geographically distinct stream systems.

Santa Clara Formation

The Santa Clara Formation consists of nonmarine conglomerate, sandstone, and fine-grained rocks west of the Santa Clara Valley from south of San Jose northward to beyond Palo Alto (Cummings, 1972). The Santa Clara Formation reaches a reported maximum thickness of 700 m (Cummings, 1972), and is late Pliocene to early Pleistocene in age (Vanderhurst and others, 1982; Adam and others, 1983).

Vanderhurst (1981) showed that the Arastradero lithofacies is the oldest and most widespread unit in the Santa Clara Formation. Cummings (1972), Vanderhurst (1981), and Vanderhurst and others (1982) showed that the Arastradero lithofacies conglomerate contains clasts of graywacke, greenstone, chert, siliceous laminated shale (porcelanite), and siliceous porphyries. Vanderhurst (1981) suggested that the

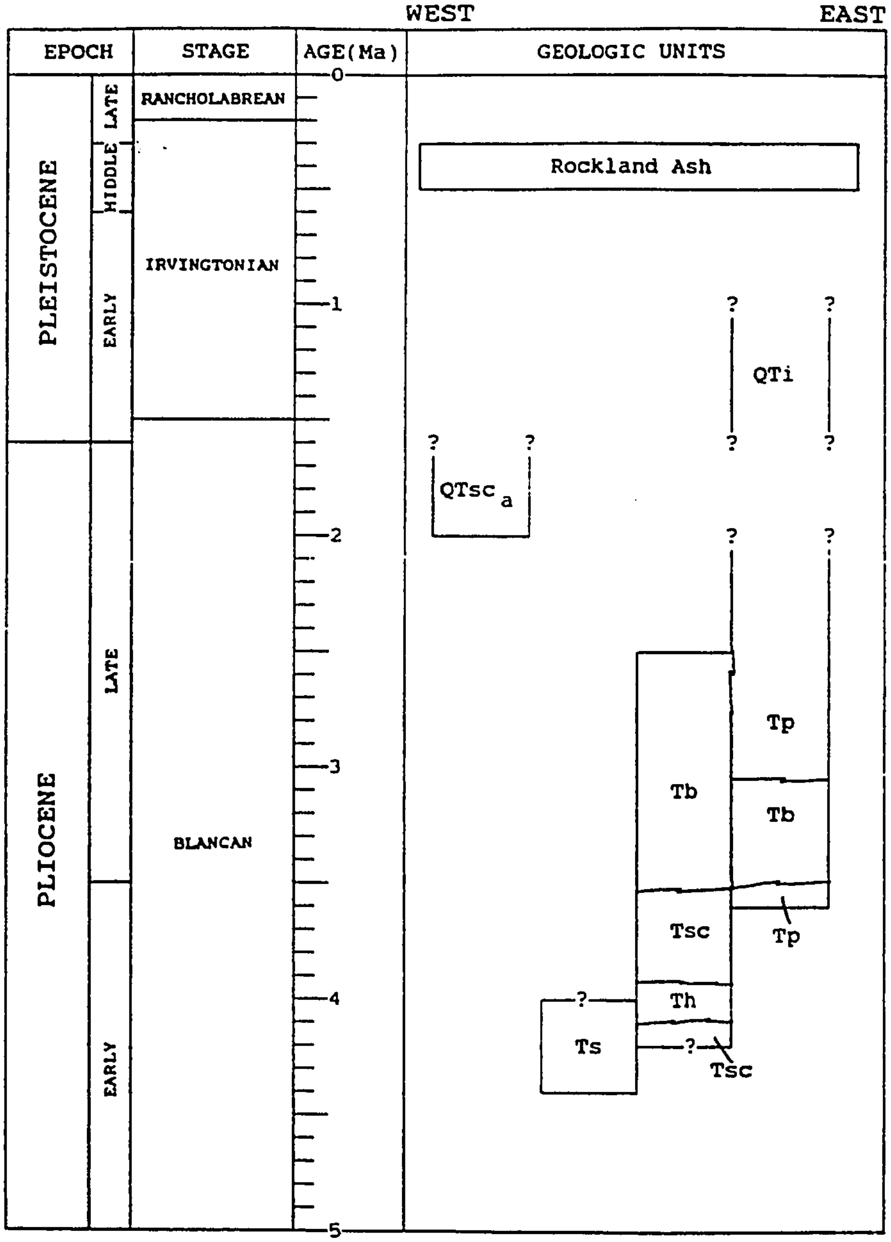

Figure 27. Correlation of geologic units in Santa Clara Valley. Ts=Scheller gravels; Tsc=Silver Creek gravels; Tp=Packwood gravels; QTsc$_a$=Arastradero lithofacies of the Santa Clara Formation (Vanderhurst, 1981); QTi=Irvington gravels (Savage, 1951). Th=Huitchica Tuff (Sarna-Wojcicki and others, 1991); Tb=Anderson-Coyote Basalts (Nakata and others, 1993); Age of the Rockland Ash is from Sarna-Wojcicki (1985). North American land mammal stages after Berggren and others (1985).

graywacke was derived from outcrops of the Franciscan Complex and Great Valley Group south or east of the present site of the gravels; greenstone and some of the chert from the Franciscan Complex south and west of the present site of the gravels; siliceous laminated chert from the Claremont Formation along the western foothills of the Diablo Range east of the Arastradero exposures; and siliceous porphyries from the Oakland Conglomerate east and south of the Arastradero exposures along the western flank of the Diablo Range.

Because the clast assemblage is diverse and includes many rock types not present in the nearby Santa Cruz Mountains, the Arastradero lithofacies was inferred by Cummings (1972), Vanderhurst (1981), and Vanderhurst and others (1982) to represent the western extent of a larger depositional system that covered much of the Santa Clara Valley and had a sediment source that included the Diablo Range to the east.

Cummings (1972) and Adam and others (1983) reported a late Pliocene age for the Arastradero lithofacies based on interfingering relationships with the Pliocene marine Merced Formation near Palo Alto and on ages of molluscan and mammalian fossils in the deposits.

Irvington Gravels

The Irvington gravels are poorly consolidated, red to gray conglomerate and sandstone. Graymer (1995) suggested that the Irvington gravels are composed of roughly 45% micaceous sandstone probably eroded from the Great Valley Group, 45% metamorphic rocks and chert probably from the Franciscan Complex, and 10% laminated chert from the Claremont Formation. Savage (1951) described a mammalian assemblage within the Irvington gravels, originally studied in the Irvington District of Fremont, and established the early to middle Pleistocene Irvingtonian land mammal age. Although the fossils studied by Savage (1951) are Pleistocene in age, the complete age range of the Irvington gravels is not known. The total thickness also is unknown.

Provenance

Based on clast composition, the sources of the gravels along the margins of the Santa Clara Valley can be identified and used to interpret the timing of uplifts. The Scheller and Silver Creek gravels contain Franciscan Complex and Coast Range Ophiolite clasts, which are interpreted to have been shed west off of uplifts in the eastern part of the central Diablo Range. Additional clasts from eastern sources are rocks derived from the Great Valley Group, Oakland Conglomerate, and Claremont Formation, and are interpreted to have come from outcrops in the western Diablo Range west of and adjacent to the Franciscan Complex and Coast Range Ophiolite blocks. Thus, the Scheller and Silver Creek gravels are an amalgamation of debris derived from multiple sources over a large area in the central Diablo Range.

The Packwood gravels contain clasts interpreted to have been shed west from an uplifted Great Valley Group block in the western part of the central Diablo Range. This uplifted block completely obstructed the earlier Franciscan Complex and Coast Range Ophiolite uplifts that had previously contributed debris to the Scheller and Silver Creek gravels.

The upper Cenozoic gravels along the east and west sides of the Santa Clara Valley are interpreted to have similar composition and sources, although spatially, they are now isolated from the older gravels in this study. The Arastradero lithofacies contains Franciscan Complex clasts, which could have been shed northward from the southeastern Santa Cruz Mountains, westward from the central Diablo Range, or both. These clasts are mixed with clasts of the Great Valley Group, Oakland Conglomerate, and Claremont Formation interpreted to have been shed west from uplifts in the central Diablo Range. The Irvington gravels contain clasts from the Franciscan Complex, Great Valley Group, and Claremont Formation. These resemble clasts in the Silver Creek and Scheller gravels and the Arastradero lithofacies, and they are interpreted to be sediment that was shed north and west from uplifts in the northern and eastern parts of the central Diablo Range. Although they share this common source, the Silver Creek and Scheller gravels are early Pliocene in age, whereas the Arastradero lithofacies and Irvington gravels are Pliocene and early Pleistocene, so they are not considered to be correlative. Instead, uplifted Franciscan rocks in the eastern Diablo Range evidently first supplied sediment to the Santa Clara Valley in the southeastern part of the valley in the early Pliocene, forming the Scheller and Silver Creek gravels. Later, in the late Pliocene and the early Pleistocene, detritus from the eastern Diablo Range entered the Santa Clara Valley only to the north, near Fremont, forming the Arastradero lithofacies and the Irvington gravels. It is suggested here that the uplift of the western Diablo Range around 3.5 Ma that provided the source for the Packwood gravels also diverted the drainages that carried sediment from the eastern Diablo Range to the north.

Cenozoic Tectonics

The late Cenozoic tectonic history of the Santa Clara Valley and central Diablo Range is interpreted using published information on the faults present and new information on provenance developed in this study.

The southeastern Santa Clara Valley contains a complex system of north- and northwest-trending, dextral strike-slip faults and northwest-trending reverse or thrust faults. The two major dextral strike-slip faults recognized in the eastern Santa Clara Valley are the Calaveras and Hayward fault zones. The time of initiation and net dextral slip on both of these faults are controversial. Page (1982) suggested that movement on the Calaveras fault zone probably began about 3.5 Ma, and that the fault has a total slip of approximately 20 km. McLaughlin and others (1990) argued that the East Bay fault system, which includes the Calaveras fault zone, was active by 8 Ma, and they infer 135 ± 10 km of dextral slip based on offset of what they interpret to be the compositionally similar Berkeley Hills and Quien Sabe volcanics. If slip on the Calaveras, Hayward, or parallel faults east of the Calaveras fault, was as great as McLaughlin and others (1990) proposed, then by assuming a constant slip rate since 8 Ma, net movement on the faults at 4 Ma would have been about 70 km, and the Quien Sabe volcanics would have been at a latitude northeast of the study area and southeast of Milpitas. At this latitude, the Quien Sabe volcanics would be in a position to contribute detritus west, to the Scheller and Silver Creek gravels. The Quien Sabe volcanic field also would have moved past the study area and been directly across the Calaveras fault during deposition of the Packwood gravels. Additionally, if the Quien Sabe volcanoes originally were adjacent to the East Bay Hills and some of the slip was on faults east of the Calaveras fault, then at 8 Ma they would have been at a latitude to contribute detritus east to the Neroly Formation in the Livermore basin. Andersen and others (1995) reported that the Neroly Formation consists mostly of andesitic rock fragments derived from the active Sierran volcanic arc to the east. The absence of Quien Sabe volcanic clasts in any of the gravels in this study or in the Livermore basin suggests that the slip proposed by Page (1982) is the more likely measure of offset on the Calaveras fault since about 4 Ma. At 4 Ma, the Quien Sabe volcanics evidently were at a latitude southeast of the study area and not involved in the westward transport of the gravels.

Late Cenozoic shortening also has affected much of the Bay Area and its surroundings, from the offshore regions to the western Central Valley (Sedlock, 1995). The broad distribution of late Cenozoic folds, thrust faults, and uplifted blocks indicates that local and possibly regional compressive deformation has affected many areas within the northern and central portions of the Coast Ranges (Jones and others, 1994; Sedlock, 1995). Such shortening may have been caused in at least three ways: 1) shortening attributed to the orthogonal component of relative motion between the Pacific and North American plates, 2) shortening occurring at restraining bends and stepovers in dextral fault systems such as the Calaveras and Hayward fault zones, or 3) shortening caused by rotations of large crustal blocks, as in the Transverse Ranges of southern California and possibly the East Bay Hills in northern California (Sedlock, 1995). All of these mechanisms could be working separately or collectively to influence the tectonic and depositional history of the San Francisco Bay area and specifically, the eastern Santa Clara Valley.

Uplift east of the Calaveras fault zone may have started as early as 10 Ma (Bartow, 1987; Andersen and others, 1995). These uplifts are here interpreted to reflect contractional deformation related to one or more of the factors described above. The uplifts in the eastern part of the central Diablo Range were contributing sediment that was reaching the southeastern Santa Clara Valley by approximately 4 Ma, when the Silver Creek and Scheller gravels and the Huitchica Tuff were deposited. Later uplift at 3.5 Ma, when the Packwood gravels and the Anderson-Coyote basalts were deposited, involved the western edge of the Diablo Range. Therefore, contraction progressed east-to-west in the Diablo Range, uplifting blocks that contributed sediment to the fluvial system during Pliocene and early Pleistocene time. The Scheller, Silver Creek, and Packwood gravels also are folded and faulted, suggesting that contraction continued into the Pleistocene, and possibly the Quaternary. The thrust faults that disrupted the gravels are younger than the initial thrust faults that uplifted the source rocks, suggesting westward migration of the thrust front.

GEOLOGIC HISTORY

The tectonic history the central Diablo Range since about 10 Ma began with erosion of uplifted Franciscan Complex and Great Valley Group rocks north and west of Mount Hamilton and deposition of sediments in the western Great Valley (Bartow, 1987) and the Livermore Basin (Andersen and others, 1995). About 4 Ma, renewed uplift in the Diablo Range shed sediments southward from Mount Diablo to the northern Livermore Basin (Fig. 28) in coarse-grained, high-gradient, braided streams (Andersen and others, 1995). Farther south in the central Diablo Range, detritus was being transported west from uplifts in the eastern part of the central Diablo Range beginning at about 4 Ma. Uplifted Franciscan Complex, Coast Range Ophiolite, and minor Great Valley Group blocks resulted in deposition of the Scheller gravels (Fig. 28). The thickness of channel-fill sequences, lack of continuous fine-grained overbank deposits, and coarseness of the bedload indicate that the Scheller gravels were deposited by coarse-grained, high-gradient, braided streams. Imbrication measurements indicate that the stream system flowed north-northwest. Deposition of fine-grained sediments, including stratiform magnesite units, occurred in lakes or ponds at the margins of the fluvial system.

Further uplift within the west-central Diablo Range combined Claremont Formation porcelanite with the initial sources, resulting in deposition of the Silver Creek gravels (Fig. 28). The Huitchica Tuff was deposited at 4 Ma, soon after the fine-grained Silver Creek sediments began to accumulate. The drainage basin is

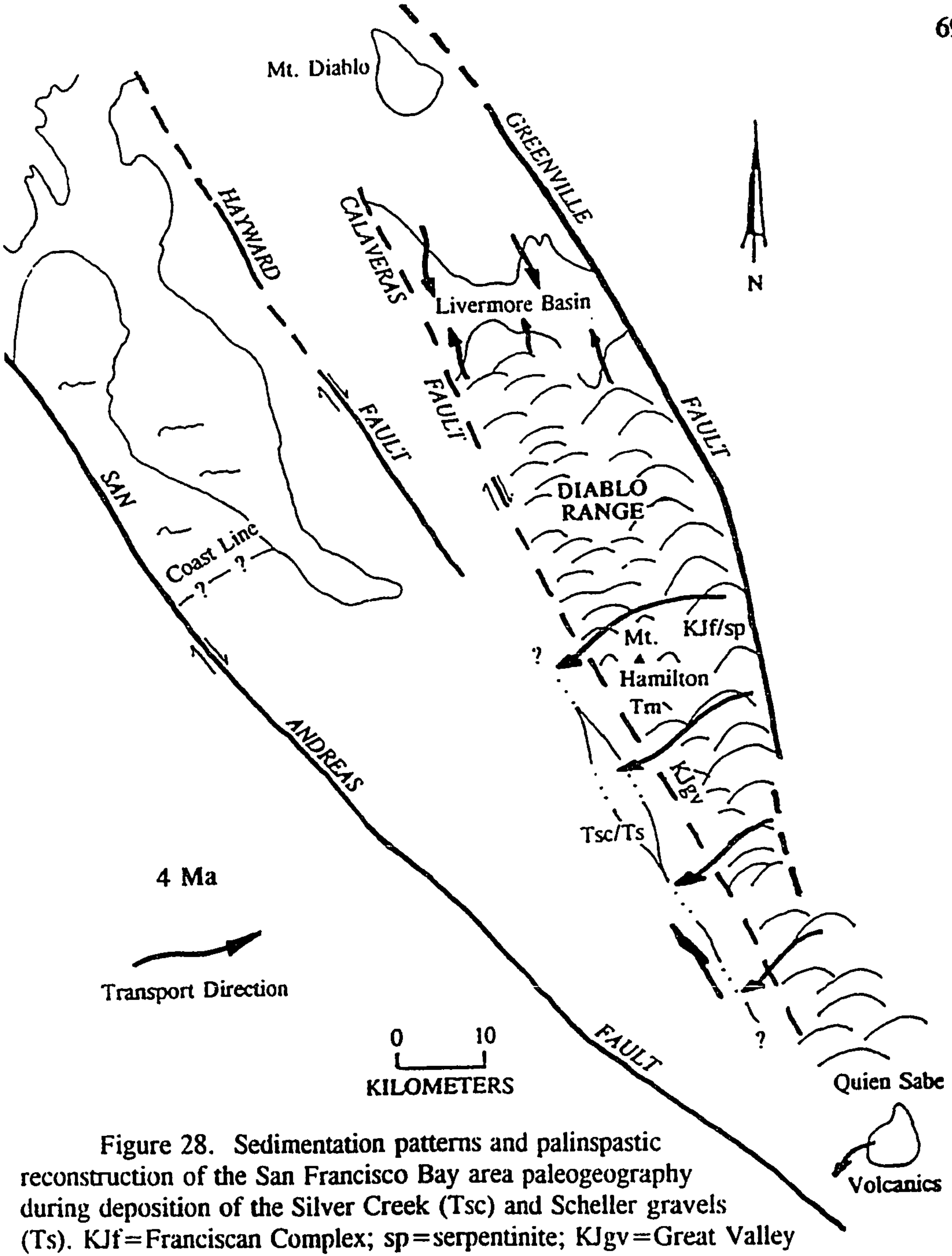

Figure 28. Sedimentation patterns and palinspastic reconstruction of the San Francisco Bay area paleogeography during deposition of the Silver Creek (Tsc) and Scheller gravels (Ts). KJf=Franciscan Complex; sp=serpentinite; KJgv=Great Valley Group; Tm=Claremont Formation. Restoration of the Calaveras fault zone is based on 20 km of total slip since 4 Ma as proposed by Page (1982).

inferred to have extended at least as far east as the center of the present Diablo Range.

At about 3.5 Ma, the Pliocene Anderson-Coyote basalts were extruded and became interbedded with both the Packwood and Silver Creek gravels. Within the western Diablo Range, uplift of what probably was a localized Great Valley Group block supplied clasts to the Packwood gravels and completely obstructed all previously uplifted sources to the east that had contributed to the earlier Scheller and Silver Creek gravels. Detritus from the Franciscan Complex and Claremont Formation was blocked from flowing west to the site of Packwood deposition.

By late Pliocene or early Pleistocene, the Irvington and Arastradero depositional sites received sediment from the northern part of the central Diablo Range. These clasts probably originated near the source of the Silver Creek gravels; they could have been diverted northward by the uplift that blocked them from the site of the Packwood gravel deposition, or they were eroded from a source farther north that was not blocked (Fig. 29). These sediments may represent a large depositional system that extended westward across the Santa Clara Valley terminating to the northwest in a shallow marine embayment, represented by the Merced Formation (Vanderhurst, 1981; Hunter and others, 1984). If the depositional site of the Packwood gravels was still receiving sediment in the late Pliocene, its source was from that of the Arastradero and Irvington systems; it may have been a tributary to these systems, or possibly part of a different drainage that was not involved in the fluvial system that deposited the Irvington and Arastradero alluvium.

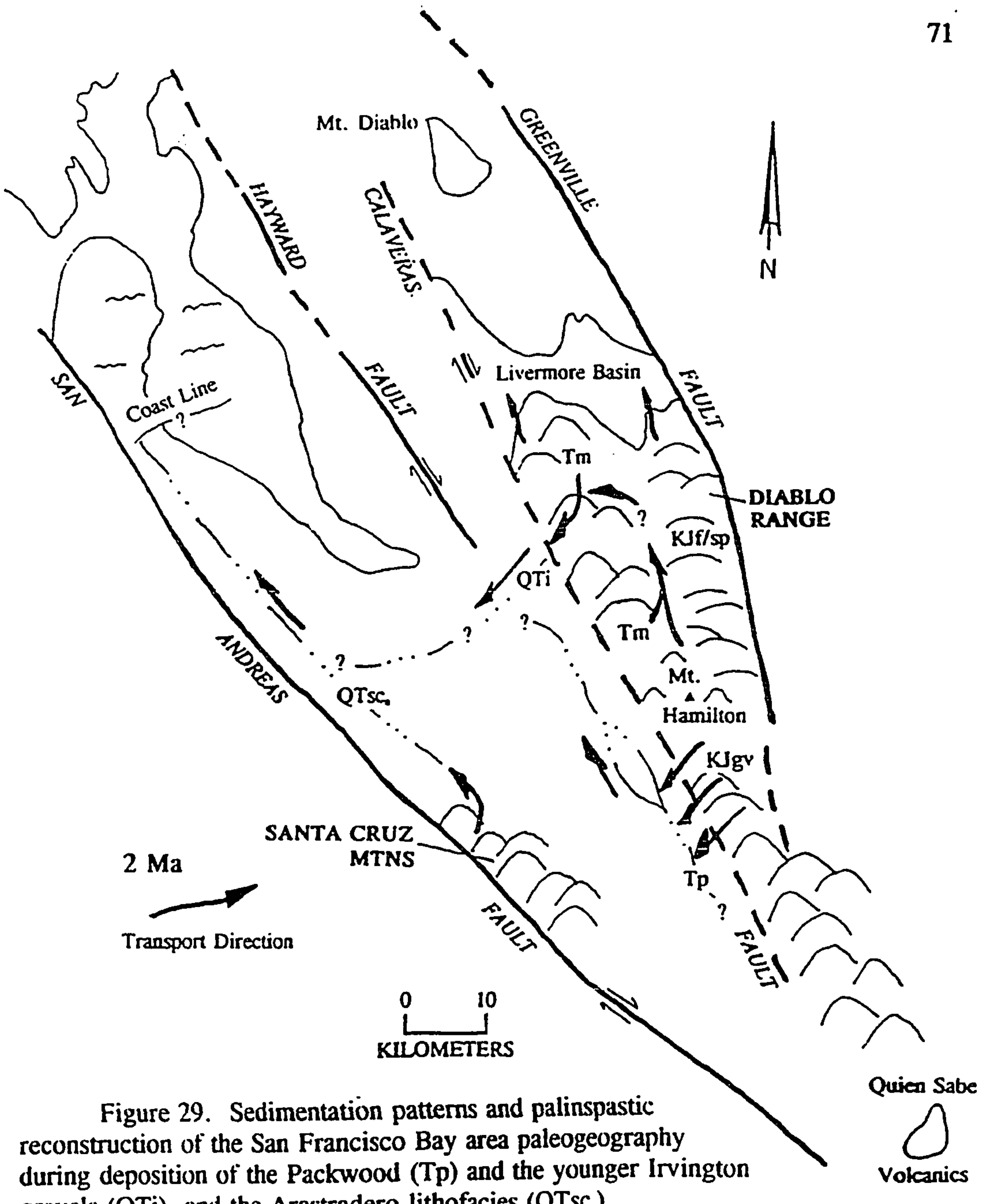

Figure 29. Sedimentation patterns and palinspastic reconstruction of the San Francisco Bay area paleogeography during deposition of the Packwood (Tp) and the younger Irvington gravels (QTi), and the Arastradero lithofacies (QTsc$_a$). KJf=Franciscan Complex; sp=serpentinite; KJgv=Great Valley Group; Tm=Claremont Formation. Restoration of the Calaveras fault zone is based on 10 km of total slip since 2 Ma as proposed by Page (1982).

Within the depositional site of the Scheller, Silver Creek, and Packwood gravels, thrusting on the Silver Creek and the Coyote Creek faults resulted in the emplacement of serpentinite blocks on and deformation of the Pliocene gravels. The thrusting must be younger than the gravels, although the age is not yet constrained. Harden and Gallego (1992) suggested that, prior to truncation by right-lateral faulting, Packwood Creek flowed into San Felipe Creek near the site of extensive Pleistocene gravel terraces (Fig. 30). Packwood Creek was at least partly dammed, and disruption of the drainage by displacement on the Calaveras Fault may have resulted when a shutter ridge blocked the drainage near Dairy Flat (Fig. 30) long enough for a 10-m-thick deposit of clay to accumulate (Harden and Gallego, 1992). The thrust faulting that disrupted the gravels and the lateral faulting that truncated Packwood Creek is related to tectonic events that continue to influence the geology and geography of the eastern Santa Clara Valley.

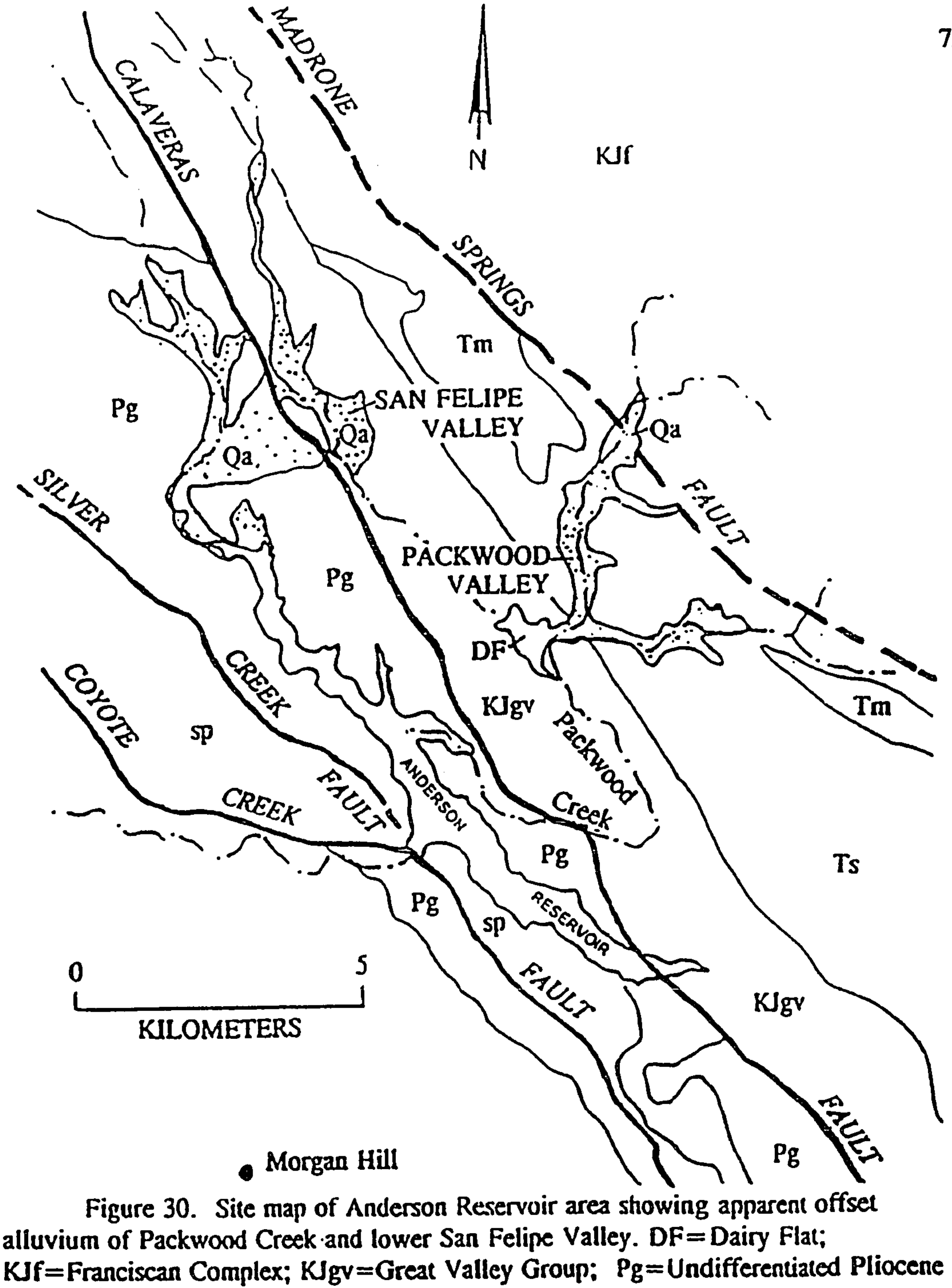

Figure 30. Site map of Anderson Reservoir area showing apparent offset alluvium of Packwood Creek and lower San Felipe Valley. DF=Dairy Flat; KJf=Franciscan Complex; KJgv=Great Valley Group; Pg=Undifferentiated Pliocene Scheller, Silver Creek, and Packwood gravels; Qa= terrace gravel and modern alluvium; sp=serpentinite; Ts=Hoover Valley Formation; Tm=Monterey Group (after Harden and Gallego, 1992).

CONCLUSIONS

The nonmarine Scheller, Silver Creek, and Packwood gravels record the paleogeographic development of the southeastern Santa Clara Valley, and they have yielded valuable data about the depositional and tectonic history of this part of the central Coast Ranges. The southeastern portion of the valley began to receive sediment by about 4 Ma, and changes in conglomerate composition reflect uplift of sources first in the eastern part of the central Diablo Range, then farther west along the western flank of the central Diablo Range. The initial uplifts in the central and western Diablo Range provided sediment derived from rocks of the Franciscan Complex, Coast Range Ophiolite, Claremont Formation, and Great Valley Group, resulting in deposition of the Scheller and Silver Creek gravels. By about 3.5 Ma, uplift and erosion of Great Valley Group along the western flank of the central Diablo Range completely blocked the initial sources, resulting in deposition of the Packwood gravels.

The absence of Quien Sabe volcanic debris in any of the gravels in the southeastern Santa Clara Valley suggests that the maximum amount of offset on the Calaveras fault zone in this area since about 4 Ma is 20 km. Late Cenozoic shortening that began by early Pliocene time has continued, resulting in the uplift and disruption of these gravels. The Irvington gravels and the Arastradero lithofacies of the Santa Clara Formation are not correlative with the Silver Creek gravels but possibly represent younger remnants of a larger fluvial system that, over millions of years, deposited alluvium during multiple phases of tectonic activity in the Santa Clara Valley.

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APPENDIX A: CLAST COUNT DATA FOR ALL GRAVELS

SILVER CREEK GRAVELS

STATION NUMBER	6	8	14	16	20	21	22	23
FIGURE NUMBER	7	7	6	6	4	4	4	4
NUMBER OF CLASTS COUNTED	319	314	319	311	310	304	316	326
SEDIMENTARY ROCKS	95.4%	74.6%	99.1%	91.6%	71.5%	86.9%	84.7%	83.2%
Graywacke Sandstone	53.1	23.3	37.7	36.0	7.7	26.0	38.9	18.1
Green Siltstone	0.0	0.0	0.0	0.0	0.3	0.0	0.6	0.0
Yellow Sandstone	12.2	4.8	42.9	4.2	4.8	1.3	23.4	16.0
Dark-gray Siltstone	11.6	0.0	0.3	1.9	0.0	0.0	0.0	1.5
Limestone/Caliche	0.0	3.0	0.0	0.3	7.4	6.6	0.0	0.0
Porcelanite	0.0	13.3	0.0	6.4	26.5	11.2	3.8	20.9
Red, Brown, & Green Chert	15.4	19.6	15.4	36.0	20.3	28.3	12.3	21.2
Black Chert	3.1	10.6	2.8	6.8	4.5	13.5	5.7	5.5
VOLCANIC ROCKS	1.2%	17.2%	0.0%	5.8%	18.7%	3.0%	6.6%	10.7%
Rhyolite	0.6	0.0	0.0	5.8	1.3	0.0	0.0	0.0
Andesite	0.0	0.0	0.0	0.0	0.6	2.0	0.0	1.2
Basalt	0.6	17.2	0.0	0.0	16.8	1.0	6.6	9.5
Siliceous Porphyries	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PLUTONIC ROCKS	1.2%	0.0%	0.3%	1.6%	8.9%	6.5%	4.8%	0.6%
Granite	0.3	0.0	0.0	0.3	0.6	0.0	0.6	0.3
Diorite	0.0	0.0	0.3	0.0	0.6	2.6	1.4	0.3
Gabbro	0.0	0.0	0.0	1.3	7.7	3.9	2.8	0.0
Diabase	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
METAMORPHIC ROCKS	2.2%	8.2%	0.6%	1.0%	0.9%	3.6%	3.9%	5.5%
Metasedimentary Rocks/Schist	1.3	0.0	0.3	0.0	0.0	0.0	0.0	0.0
Quartzite/Vein Quartz	0.6	0.0	0.0	1.0	0.3	0.0	0.6	0.9
Serpentinite/Silica Carbonate	0.3	8.2	0.3	0.0	0.6	3.6	2.7	4.3
Blueschist	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.3
Greenstone	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTALS	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

SILVER CREEK GRAVELS

STATION NUMBER	24	25	26	27	37	41	42	43A
FIGURE NUMBER	4	4	4	4	4	4	4	4
NUMBER OF CLASTS COUNTED	320	310	314	308	325	313	311	317
SEDIMENTARY ROCKS	78.4%	64.9%	81.5%	85.1%	28.2%	24.3%	72.4%	25.5%
Graywacke Sandstone	40.3	18.7	28.7	27.3	11.1	12.5	43.1	11.4
Green Siltstone	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0
Yellow Sandstone	16.3	9.4	17.2	12.7	0.3	0.3	23.2	0.3
Dark-gray Siltstone	0.0	0.0	1.3	0.0	0.0	0.6	0.3	0.0
Limestone/Caliche	0.0	0.0	0.3	0.3	5.2	2.2	0.6	5.4
Porcelanite	5.0	4.2	2.2	7.5	4.6	0.3	0.0	0.6
Red, Brown, & Green Chert	13.4	22.3	21.3	24.0	5.8	7.7	4.2	7.6
Black Chert	3.4	10.0	10.5	13.3	1.2	0.3	1.0	0.3
VOLCANIC ROCKS	9.7%	11.6%	9.3%	12.4%	4.4%	0.0%	3.2%	1.6%
Rhyolite	0.0	4.8	1.9	0.0	0.0	0.0	1.3	0.0
Andesite	2.5	0.0	4.7	1.3	2.2	0.0	0.0	0.0
Basalt	7.2	6.8	2.7	11.1	2.2	0.0	1.9	1.6
Siliceous Porphyries	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PLUTONIC ROCKS	7.5%	20.0%	5.1%	0.6%	3.1%	3.8%	13.2%	1.3%
Granite	2.5	0.7	0.0	0.0	0.0	0.0	1.3	0.0
Diorite	1.2	15.8	1.0	0.3	1.8	0.0	7.1	0.0
Gabbro	2.5	1.9	4.1	0.0	1.2	3.8	4.8	1.3
Diabase	1.3	1.6	0.0	0.3	0.0	0.0	0.0	0.0
METAMORPHIC ROCKS	4.4%	3.5%	4.1%	1.9%	64.3%	71.9%	11.2%	71.6%
Metasedimentary Rocks/Schist	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0
Quartzite/Vein Quartz	0.0	0.0	0.0	1.3	0.0	0.0	0.3	0.0
Serpentinite/Silica Carbonate	4.4	2.6	3.8	0.6	62.5	71.9	10.9	71.3
Blueschist	0.0	0.3	0.3	0.0	1.8	0.0	0.0	0.3
Greenstone	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTALS	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

SILVER CREEK GRAVELS

STATION NUMBER	43B	44A	44B	45A	45B	46A	46B	47A
FIGURE NUMBER	4	4	4	7	7	7	7	7
NUMBER OF CLASTS COUNTED	325	320	337	317	317	307	305	302
SEDIMENTARY ROCKS	32.9%	85.6%	88.4%	71.8%	84.2%	0.0%	3.0%	27.8%
Graywacke Sandstone	14.8	45.0	17.5	14.8	48.9	0.0	1.0	4.6
Green Siltstone	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Yellow Sandstone	0.0	22.8	15.1	35.6	15.8	0.0	1.3	2.7
Dark-gray Siltstone	0.0	14.1	0.3	0.9	0.9	0.0	0.0	0.0
Limestone/Caliche	5.5	0.9	10.0	0.0	0.6	0.0	0.0	0.3
Porcelanite	0.0	0.0	25.8	0.0	0.0	0.0	0.0	1.0
Red, Brown, & Green Chert	11.4	1.9	17.2	18.9	17.5	0.0	0.7	19.2
Black Chert	1.2	0.9	2.4	1.6	0.6	0.0	0.0	0.0
VOLCANIC ROCKS	0.0%	5.0%	2.4%	27.1%	5.9%	26.0%	33.7%	29.8%
Rhyolite	0.0	0.3	0.9	4.7	0.6	0.0	2.6	0.0
Andesite	0.0	0.3	0.6	8.8	0.3	0.0	0.3	0.0
Basalt	0.0	4.4	0.9	13.6	5.0	25.7	30.8	29.8
Siliceous Porphyries	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0
PLUTONIC ROCKS	5.3%	2.8%	6.0%	0.5%	1.3%	19.2%	23.3%	0.7%
Granite	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0
Diorite	3.1	0.9	2.4	0.5	1.3	0.0	0.0	0.7
Gabbro	2.2	0.0	1.2	0.0	0.0	19.2	23.3	0.0
Diabase	0.0	1.9	1.2	0.0	0.0	0.0	0.0	0.0
METAMORPHIC ROCKS	61.8%	6.6%	3.3%	0.6%	8.5%	54.8%	40.0%	41.7%
Metasedimentary Rocks/Schist	0.0	0.0	1.5	0.0	0.0	0.7	0.0	0.0
Quartzite/Vein Quartz	0.9	0.0	1.8	0.6	0.9	1.0	1.3	2.0
Serpentinite/Silica Carbonate	60.6	6.6	0.0	0.0	7.6	53.1	37.4	39.7
Blueschist	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Greenstone	0.0	0.0	0.0	0.0	0.0	0.0	1.3	0.0
TOTALS	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

SILVER CREEK GRAVELS

STATION NUMBER	47B	47C	57A	60	62	66A	66B
FIGURE NUMBER	7	7	7	6	5	5	5
NUMBER OF CLASTS COUNTED	311	311	312	314	303	300	313
SEDIMENTARY ROCKS	21.9%	86.7%	88.4%	75.3%	76.3%	53.0%	45.9%
Graywacke Sandstone	7.4	53.4	67.9	42.4	47.5	36.0	16.6
Green Siltstone	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Yellow Sandstone	4.2	14.1	15.7	5.1	15.5	5.7	3.8
Dark-gray Siltstone	2.6	9.6	4.8	0.3	1.7	0.0	0.6
Limestone/Caliche	0.0	0.0	0.0	0.0	0.0	0.0	1.6
Porcelanite	0.0	0.0	0.0	8.0	0.0	0.0	6.7
Red, Brown, & Green Chert	7.1	8.0	0.0	15.0	11.6	11.3	16.3
Black Chert	0.6	1.6	0.0	4.5	0.0	0.0	0.3
VOLCANIC ROCKS	54.7%	6.2%	4.9%	4.3%	2.2%	17.3%	5.6%
Rhyolite	0.7	0.0	0.0	0.0	1.0	1.0	0.0
Andesite	2.6	3.3	1.1	0.5	0.2	0.0	1.1
Basalt	51.4	2.9	1.6	3.2	1.0	16.3	2.9
Siliceous Porphyries	0.0	0.0	2.2	0.6	0.0	0.0	1.6
PLUTONIC ROCKS	1.6%	1.3%	6.4%	7.0%	3.0%	0.0%	6.7%
Granite	0.3	0.0	1.9	0.3	0.0	0.0	0.0
Diorite	1.3	1.3	0.0	0.6	2.3	0.0	0.3
Gabbro	0.0	0.0	0.0	0.0	0.7	0.0	1.6
Diabase	0.0	0.0	4.5	6.1	0.0	0.0	4.8
METAMORPHIC ROCKS	21.8%	5.8%	0.3%	13.4%	18.5%	29.7%	41.8%
Metasedimentary Rocks/Schist	0.0	0.0	0.0	0.0	0.7	0.0	0.0
Quartzite/Vein Quartz	1.9	4.2	0.3	1.0	0.0	0.0	0.3
Serpentinite/Silica Carbonate	19.9	1.3	0.0	12.4	16.5	29.7	41.5
Blueschist	0.0	0.3	0.0	0.0	0.0	0.0	0.0
Greenstone	0.0	0.0	0.0	0.0	1.3	0.0	0.0
TOTALS	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

PACKWOOD GRAVELS

STATION NUMBER	1	2	3	5A	5C	5D	12
FIGURE NUMBER	6	6	6	7	7	7	6
NUMBER OF CLASTS COUNTED	312	202	303	303	312	305	297
SEDIMENTARY ROCKS	97.8%	100.0%	96.4%	69.7%	95.8%	87.6%	99.7%
Graywacke Sandstone	51.0	47.5	25.4	24.2	58.0	66.9	50.2
Green Siltstone	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Yellow Sandstone	21.8	24.8	25.8	41.6	37.8	20.7	25.9
Dark-gray Siltstone	23.4	25.7	44.9	0.3	0.0	0.0	23.6
Limestone/Caliche	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Porcelanite	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Red, Brown, & Green Chert	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Black Chert	1.6	2.0	0.3	3.6	0.0	0.0	0.0
VOLCANIC ROCKS	0.3%	0.0%	2.6%	24.4%	2.6%	9.8%	0.0%
Rhyolite	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Andesite	0.3	0.0	2.6	14.5	0.0	1.3	0.0
Basalt	0.0	0.0	0.0	9.9	2.6	4.6	0.0
Siliceous Porphyries	0.0	0.0	0.0	0.0	0.0	3.9	0.0
PLUTONIC ROCKS	0.0%	0.0%	1.0%	0.0%	1.6%	2.6%	0.3%
Granite	0.0	0.0	1.0	0.0	1.6	0.0	0.3
Diorite	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gabbro	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Diabase	0.0	0.0	0.0	0.0	0.0	2.6	0.0
METAMORPHIC ROCKS	1.9%	0.0%	0.0%	5.9%	0.0%	0.0%	0.0%
Metasedimentary Rocks/Schist	0.0	0.0	0.0	5.6	0.0	0.0	0.0
Quartzite/Vein Quartz	0.0	0.0	0.0	0.3	0.0	0.0	0.0
Serpentinite/Silica Carbonate	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Blueschist	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Greenstone	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTALS	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

PACKWOOD GRAVELS

STATION NUMBER	13	15	18	19	28	29	30
FIGURE NUMBER	6	6	4	4	4	4	4
NUMBER OF CLASTS COUNTED	314	309	311	321	306	305	319
SEDIMENTARY ROCKS	95.2%	100.0%	100.0%	100.0%	99.7%	100.0%	100.0%
Graywacke Sandstone	46.5	34.0	37.3	42.7	46.7	48.9	19.1
Green Siltstone	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Yellow Sandstone	34.1	60.2	36.3	32.1	32.0	51.1	67.1
Dark-gray Siltstone	14.6	1.6	23.2	25.2	20.9	0.0	13.5
Limestone/Caliche	0.0	0.0	3.2	0.0	0.0	0.0	0.0
Porcelanite	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Red, Brown, & Green Chert	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Black Chert	0.0	4.2	0.0	0.0	0.0	0.0	0.3
VOLCANIC ROCKS	0.0%	0.0%	0.0%	0.0%	0.3%	0.0%	0.0%
Rhyolite	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Andesite	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Basalt	0.0	0.0	0.0	0.0	0.3	0.0	0.0
Siliceous Porphyries	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PLUTONIC ROCKS	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Granite	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Diorite	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gabbro	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Diabase	0.0	0.0	0.0	0.0	0.0	0.0	0.0
METAMORPHIC ROCKS	4.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Metasedimentary Rocks/Schist	4.8	0.0	0.0	0.0	0.0	0.0	0.0
Quartzite/Vein Quartz	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Serpentinite/Silica Carbonate	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Blueschist	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Greenstone	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTALS	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

PACKWOOD GRAVELS

STATION NUMBER	31	32	39	57B	59	68	71
FIGURE NUMBER	4	4	4	7	5	5	7
NUMBER OF CLASTS COUNTED	311	303	312	304	305	303	200
SEDIMENTARY ROCKS	100.0%	100.0%	84.0%	88.5%	95.4%	97.4%	100.0%
Graywacke Sandstone	35.7	52.1	34.0	64.1	53.8	59.1	78.6
Green Siltstone	0.0	0.0	0.0	0.0	0.0	0.0	1.5
Yellow Sandstone	33.4	26.7	18.6	13.5	12.8	20.5	15.5
Dark-gray Siltstone	30.9	21.1	25.6	10.9	28.9	17.8	4.4
Limestone/Caliche	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Porcelanite	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Red, Brown, & Green Chert	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Black Chert	0.0	0.0	5.8	0.0	0.0	0.0	0.0
VOLCANIC ROCKS	0.0%	0.0%	13.1%	7.6%	4.6%	2.6%	0.0%
Rhyolite	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Andesite	0.0	0.0	1.9	0.3	0.0	0.0	0.0
Basalt	0.0	0.0	2.6	3.9	1.6	1.3	0.0
Siliceous Porphyries	0.0	0.0	8.7	3.3	3.0	1.3	0.0
PLUTONIC ROCKS	0.0%	0.0%	0.0%	3.3%	0.0%	0.0%	0.0%
Granite	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Diorite	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gabbro	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Diabase	0.0	0.0	0.0	3.3	0.0	0.0	0.0
METAMORPHIC ROCKS	0.0%	0.0%	2.9%	0.6%	0.0%	0.0%	0.0%
Metasedimentary Rocks/Schist	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Quartzite/Vein Quartz	0.0	0.0	2.9	0.6	0.0	0.0	0.0
Serpentinite/Silica Carbonate	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Blueschist	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Greenstone	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTALS	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

SCHELLER GRAVELS

STATION NUMBER	38A	38B	50A	50B	51	52	53	56
FIGURE NUMBER	8	8	8	8	8	8	8	8
NUMBER OF CLASTS COUNTED	315	318	326	326	305	323	316	301
SEDIMENTARY ROCKS	**50.2%**	**47.2%**	**12.3%**	**13.2%**	**5.6%**	**1.6%**	**5.7%**	**25.0%**
Graywacke Sandstone	22.5	16.7	3.7	3.1	0.3	0.0	1.6	9.3
Green Siltstone	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Yellow Sandstone	8.9	7.2	0.0	0.0	1.0	0.0	0.0	0.0
Dark-gray Siltstone	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Limestone/Caliche	0.3	0.9	0.0	0.0	0.0	1.3	0.0	0.0
Porcelanite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Red, Brown, & Green Chert	17.5	20.8	8.6	10.1	4.3	0.3	4.1	15.0
Black Chert	1.0	1.6	0.0	0.0	0.0	0.0	0.0	0.7
VOLCANIC ROCKS	**2.5%**	**0.3%**	**0.3%**	**0.0%**	**1.6%**	**0.0%**	**0.0%**	**4.0%**
Rhyolite	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Andesite	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0
Basalt	2.2	0.3	0.0	0.0	1.3	0.0	0.0	4.0
Siliceous Porphyries	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0
PLUTONIC ROCKS	**1.3%**	**3.1%**	**0.3%**	**0.0%**	**0.3%**	**0.6%**	**0.3%**	**7.6%**
Granite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Diorite	0.0	0.0	0.0	0.0	0.3	0.6	0.3	1.0
Gabbro	1.3	3.1	0.3	0.0	0.0	0.0	0.0	3.3
Diabase	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.3
METAMORPHIC ROCKS	**46.0%**	**49.4%**	**87.1%**	**86.8%**	**92.5%**	**97.8%**	**94.0%**	**63.4%**
Metasedimentary Rocks/Schist	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Quartzite/Vein Quartz	0.0	0.0	0.9	2.4	0.7	0.3	0.0	0.3
Serpentinite/Silica Carbonate	46.0	49.4	86.2	84.4	91.8	97.5	94.0	50.8
Blueschist	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Greenstone	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTALS	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

APPENDIX B: RADIOLARIAN CHERT SAMPLE PROVENANCE DATA

List of Abbreviations

CRO	Coast Range Ophiolite
MH	Marin Headlands Type Section (Murchey and Hagstrum, 1993)
Ts	Scheller gravels
Tsc	Silver Creek gravels

Age Zones (after Murchey and Hagstrum, 1993)

MH-1: Late Pliensbachian to middle Toarcian, early Jurassic
MH-2: Middle or late Toarcian to Aalenian, early-middle Jurassic
MH-3: Bajocian, middle Jurassic
MH-4: Bathonian to Callovian or early Oxfordian, middle-late Jurassic
MH-5: Late Tithonian? to Hauterivian or early Barremian, late Jurassic-early Cretaceous
MH-6: Hauterivian? to Albian?, early Cretaceous
MH-7: Late Albian to early Cenomanian, early-late Cretaceous

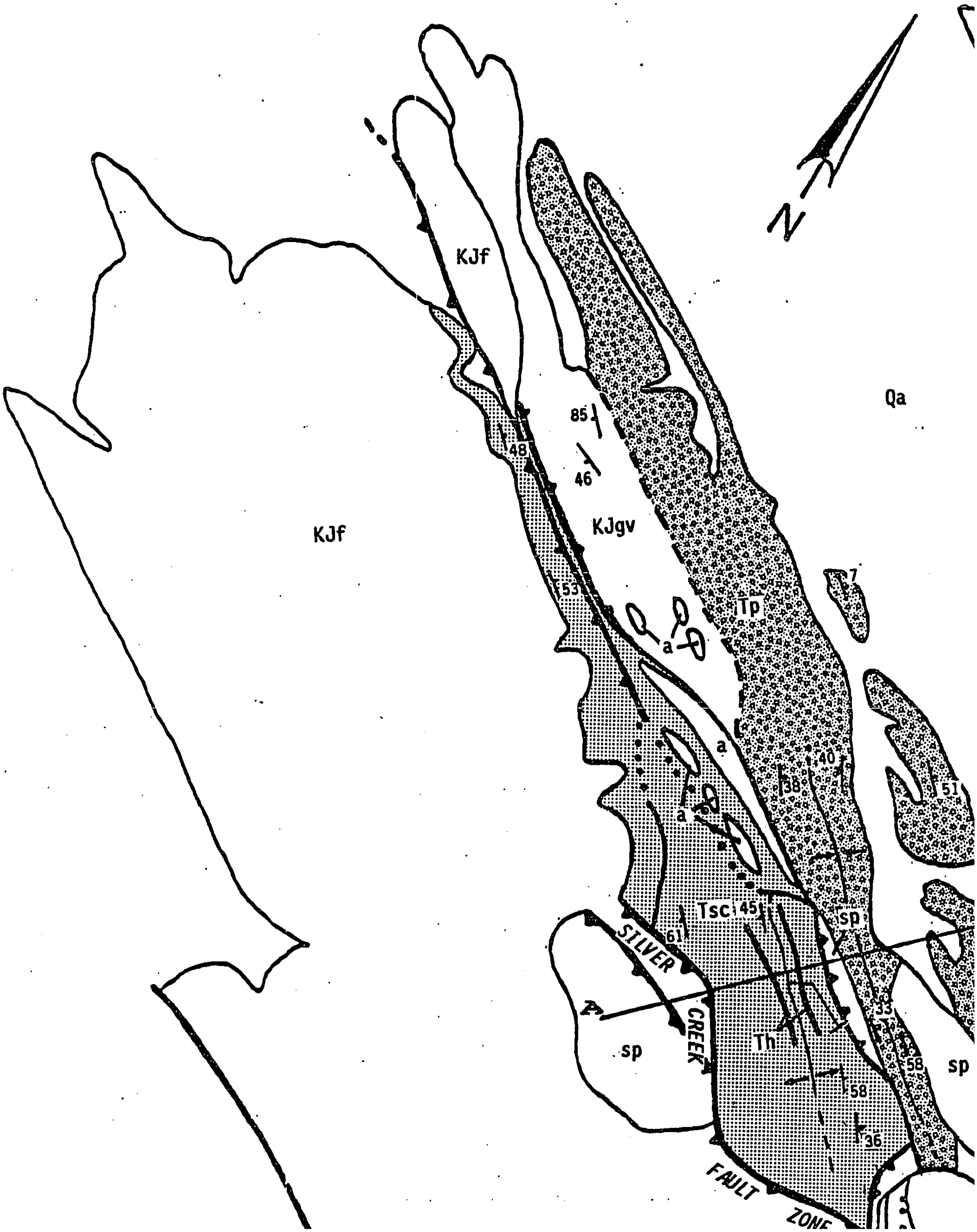
Provenance data for clasts of Franciscan Complex and Great Valley Group radiolarian chert samples.

STATION	GRAVEL	AGE ZONES	PROVENANCE*
24A	Tsc	MH-4, Bathonian-early Callovian	Franciscan-central belt
24B	Tsc	MH-4, Bathonian-early Callovian	Franciscan-central belt
27	Tsc	MH-7, Late Cretaceous	Great Valley
43A	Tsc	MH-1, Pliensbachian-early Toarcian	Franciscan-central belt
44A	Tsc	MH-4, Bathonian-early Callovian	Franciscan-central belt
45A	Tsc	Mid Jurassic	Franciscan-eastern belt/CRO
47C	Tsc	Jurassic	Franciscan-eastern belt
50B	Ts	Jurassic	Franciscan-possibly central belt?
56	Ts	MH-2?, Toarcian-Aalenian; MH-4, Bathonian-early Callovian	Franciscan-central belt

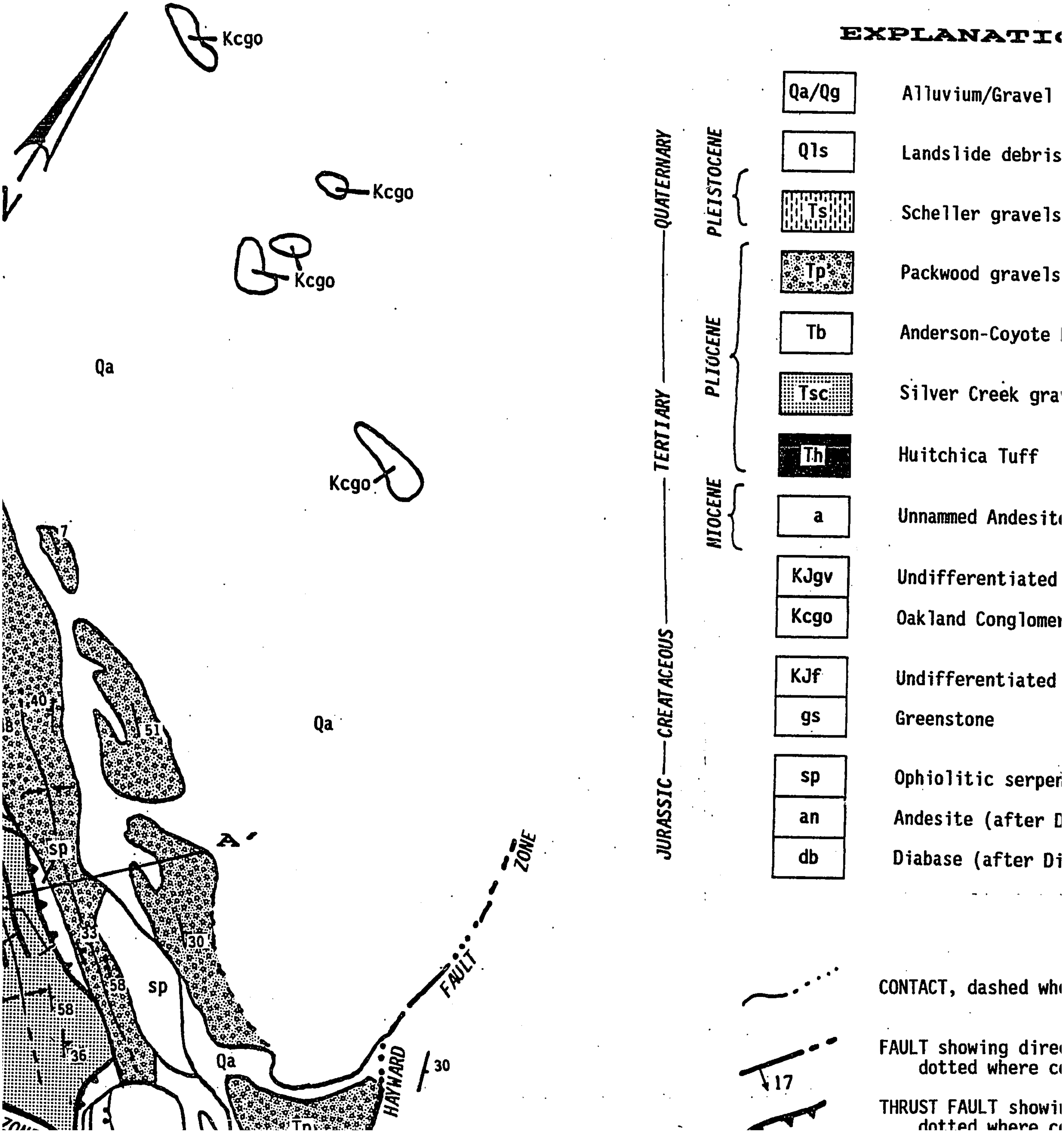
<u>FOOTNOTES</u>

*After McLaughlin and others (1988). See Figure 3 for terrane locations.

PLATE 1:
section of
Silver Cree



E 1: Geologic map and cros
of the northern study are
Creek Valley, California.



nd cross-
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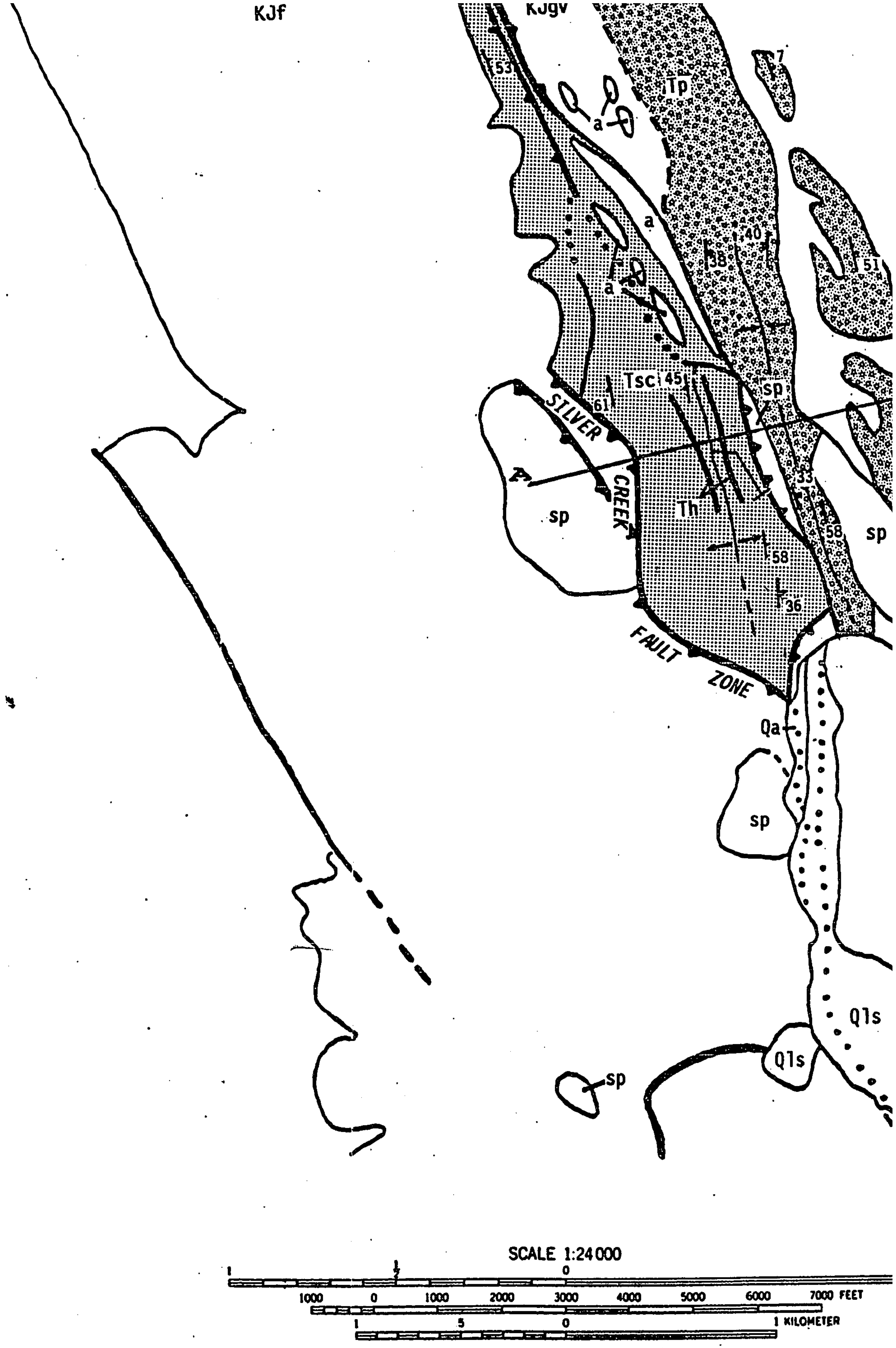
EXPLANATION

Qa/Qg	Alluvium/Gravel
Qls	Landslide debris
Ts	Scheller gravels
Tp	Packwood gravels
Tb	Anderson-Coyote Basalts
Tsc	Silver Creek gravels
Th	Huitchica Tuff
a	Unnammed Andesite
KJgv	Undifferentiated Great Valley Group
Kcgo	Oakland Conglomerate (after Crittenden, 1951)
KJf	Undifferentiated Franciscan Complex
gs	Greenstone
sp	Ophiolitic serpentinite or serpentinized ultramafic rocks
an	Andesite (after Dibblee, 1972b)
db	Diabase (after Dibblee, 1973d)

- · · · CONTACT, dashed where approximated, dotted where concealed

— • • FAULT showing direction of dip, dashed where approximated,
dotted where concealed

— THRUST FAULT showing direction of dip, dashed where approximated,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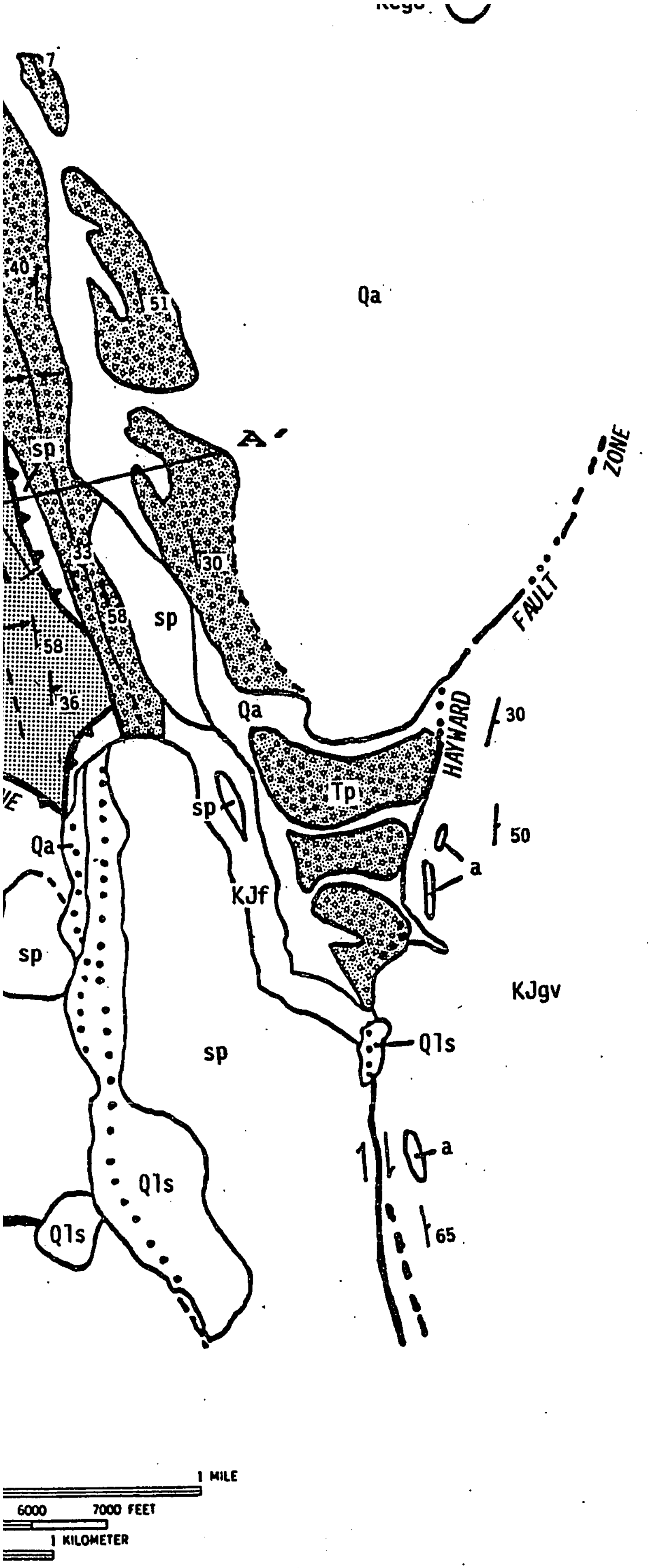

MIOCEN	a	Unnammed Andesite
JURASSIC——CREATACEOUS	KJgv	Undifferentiated
	Kcgo	Oakland Conglomer
	KJf	Undifferentiated
	gs	Greenstone
	sp	Ophiolitic serpent
	an	Andesite (after D
	db	Diabase (after Dib

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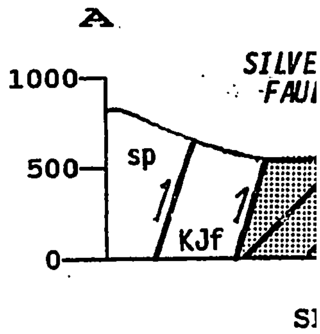

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(VERTIC

a	Unnammed Andesite
KJgv	Undifferentiated Great Valley Group
Kcgo	Oakland Conglomerate (after Crittenden, 1951)
KJf	Undifferentiated Franciscan Complex
gs	Greenstone
sp	Ophiolitic serpentinite or serpentinized ultramafic rocks
an	Andesite (after Dibblee, 1972b)
db	Diabase (after Dibblee, 1973d)

CONTACT, dashed where approximated, dotted where concealed

FAULT showing direction of dip, dashed where approximated, dotted where concealed

17

THRUST FAULT showing direction of dip, dashed where approximated, dotted where concealed, barbs on upper plate

ANTICLINE dotted where concealed, end arrow points in direction of plunge

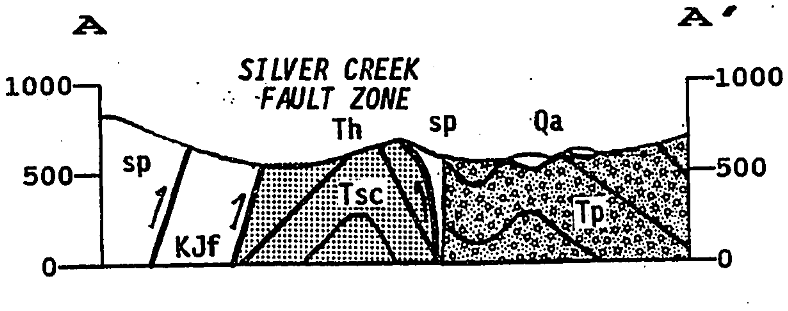
SYNCLINE dotted where concealed, end arrow points in direction of plunge

STRIKE AND DIP of bedding, vertical bedding, overturned bedding

20

A' LINE OF CROSS-SECTION

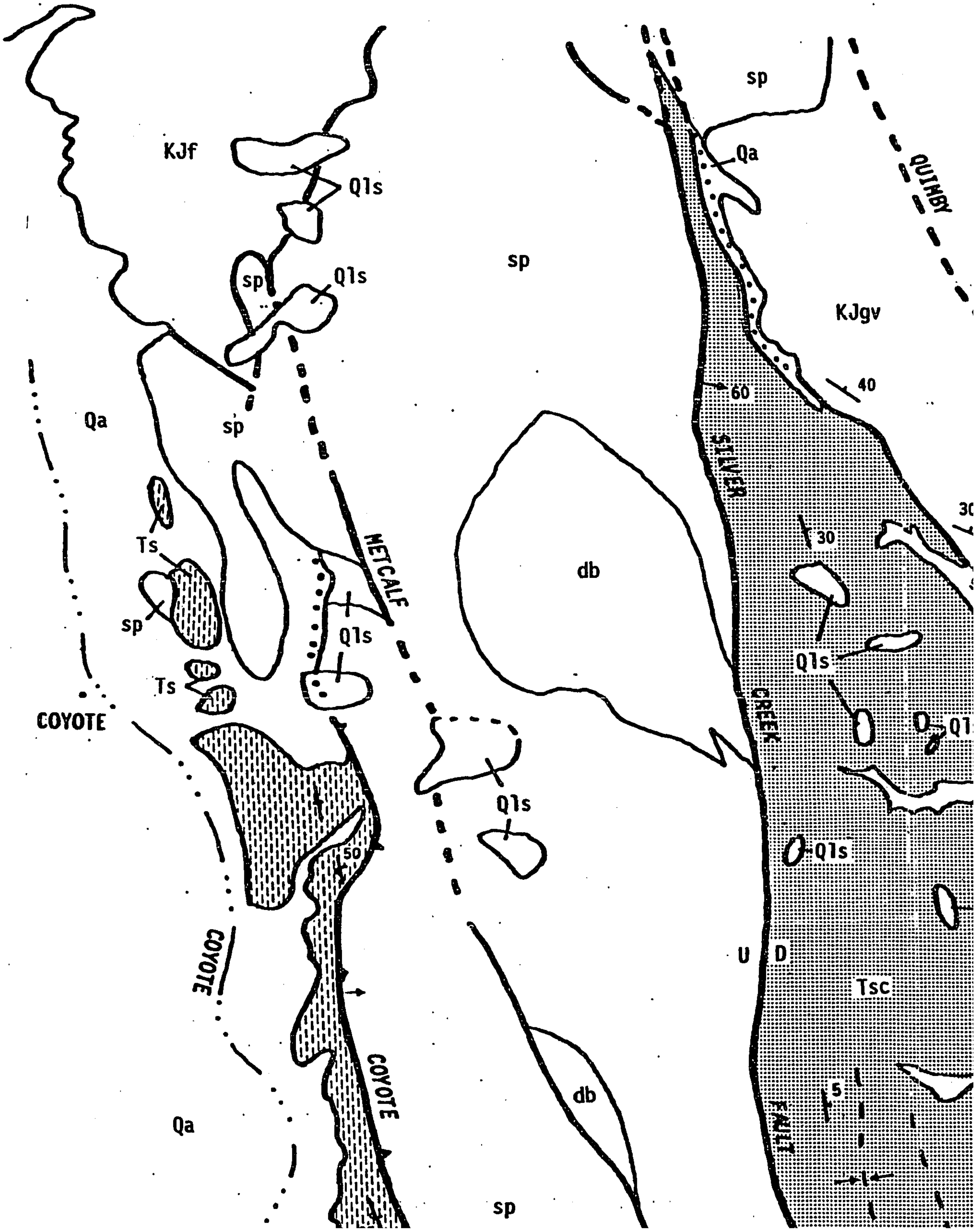
LINE OF COLUMNAR SECTION



SECTION A-A'

(VERTICAL EXAGGERATION=2x)

PLATE 2: Geologic section of the central Valley and north Reservoir, California.



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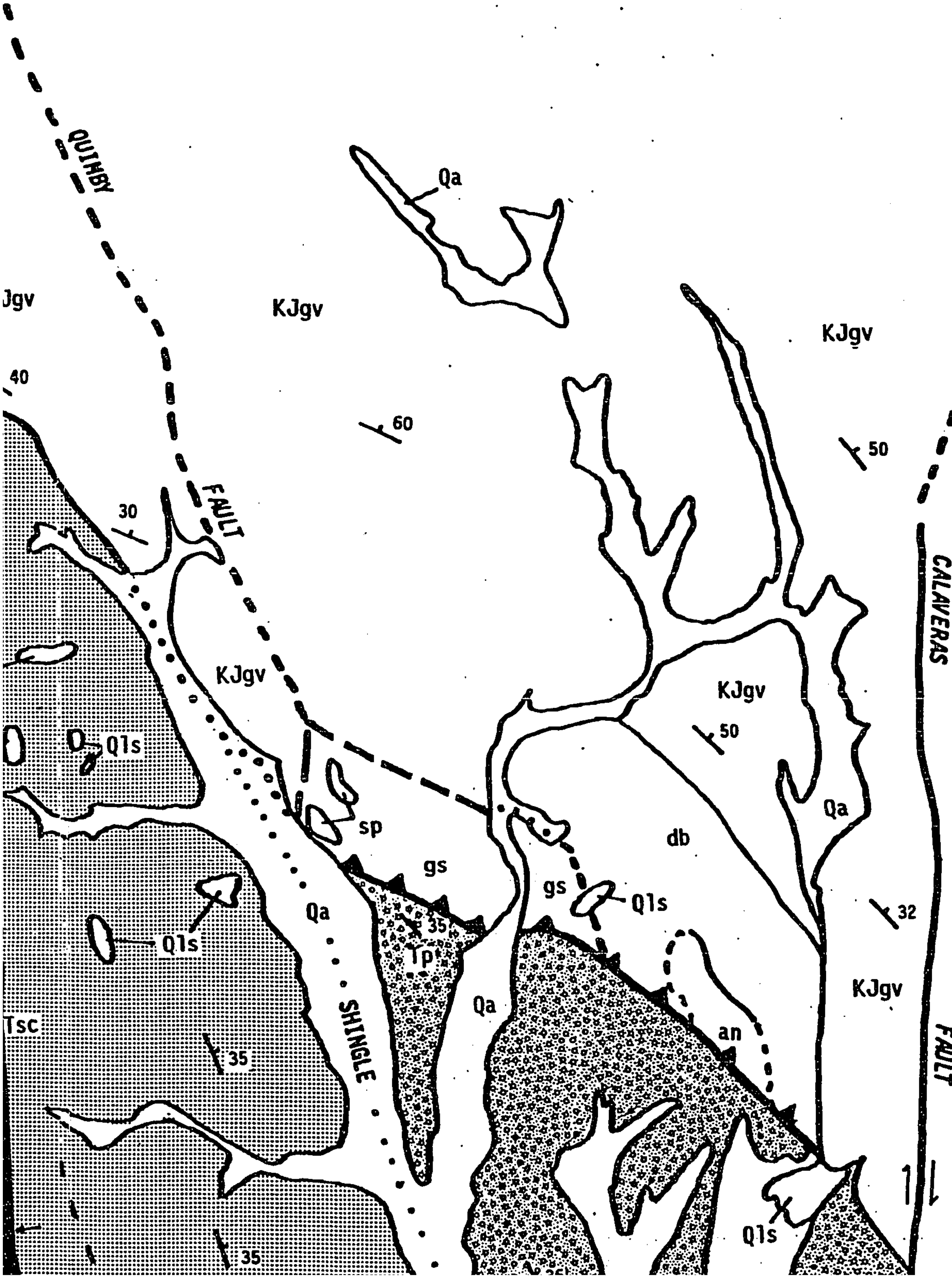

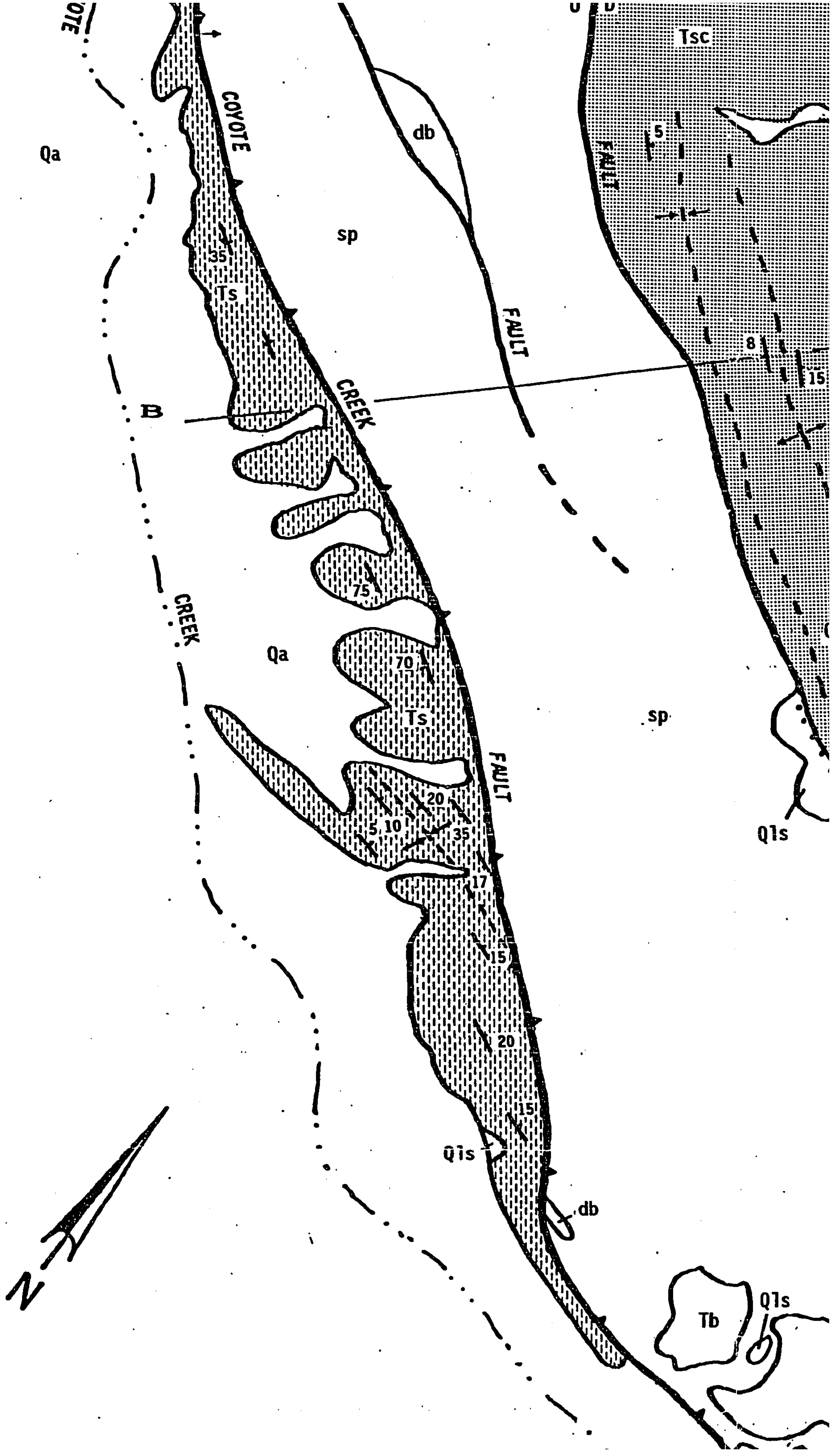
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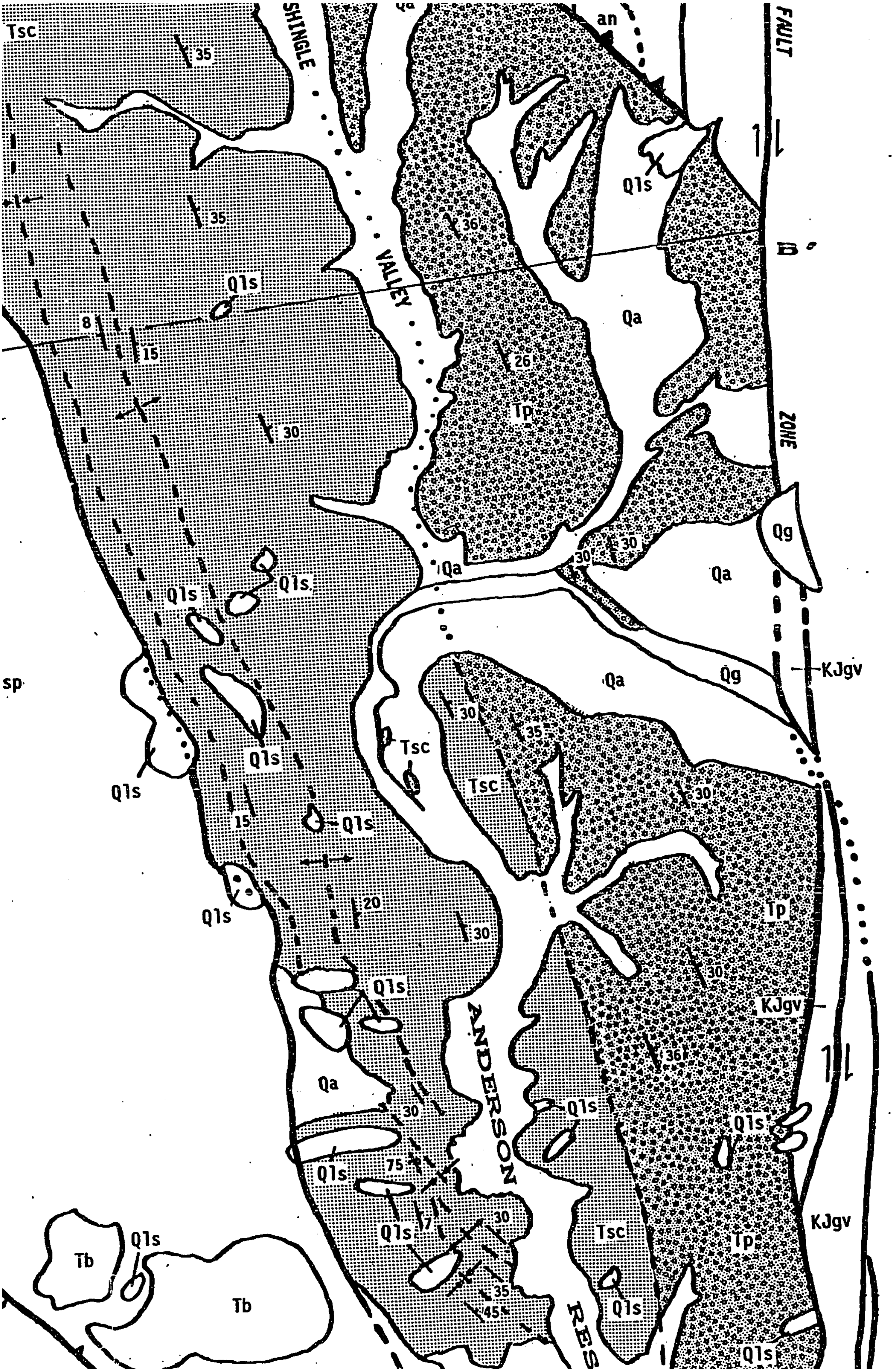
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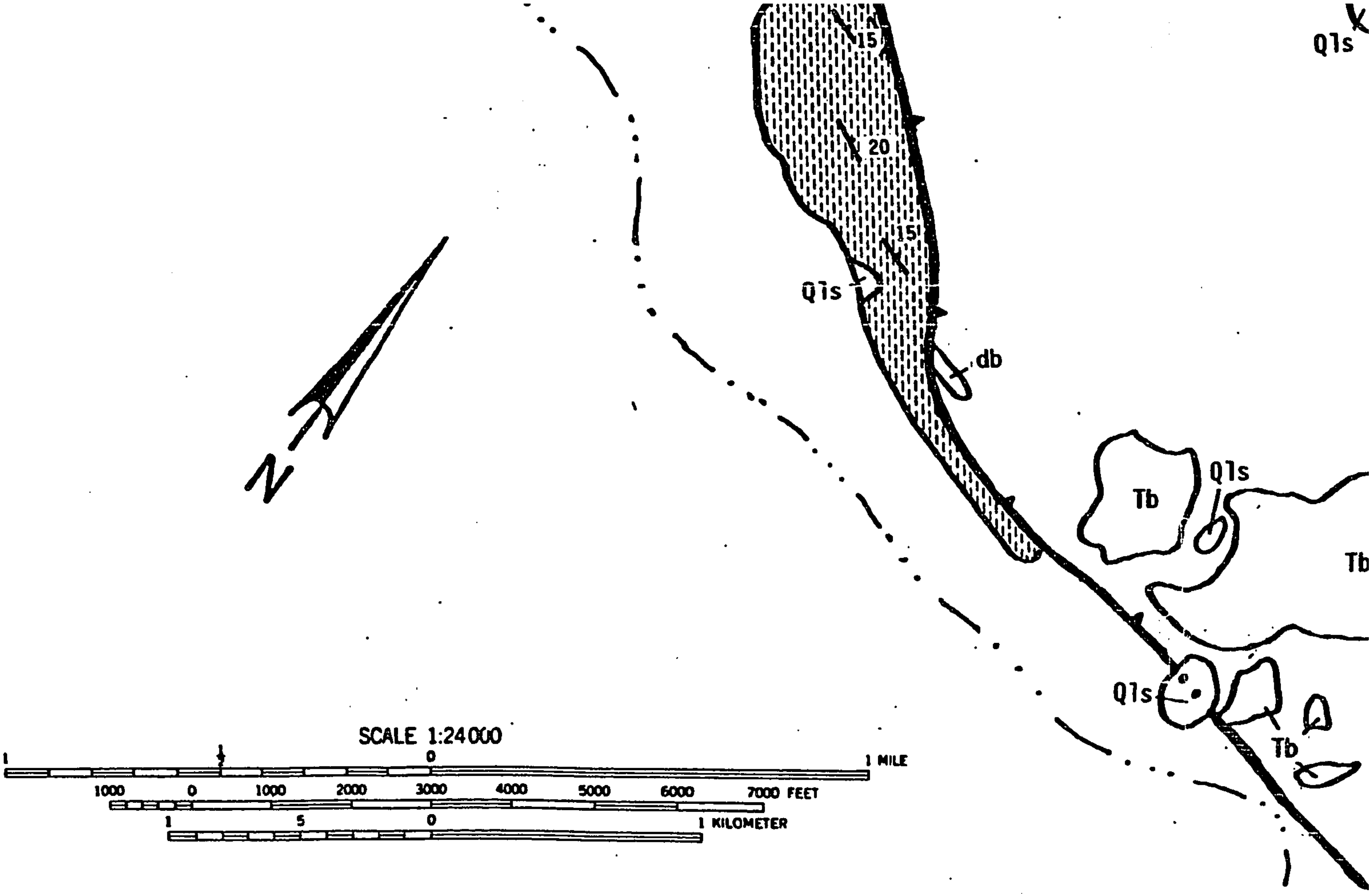

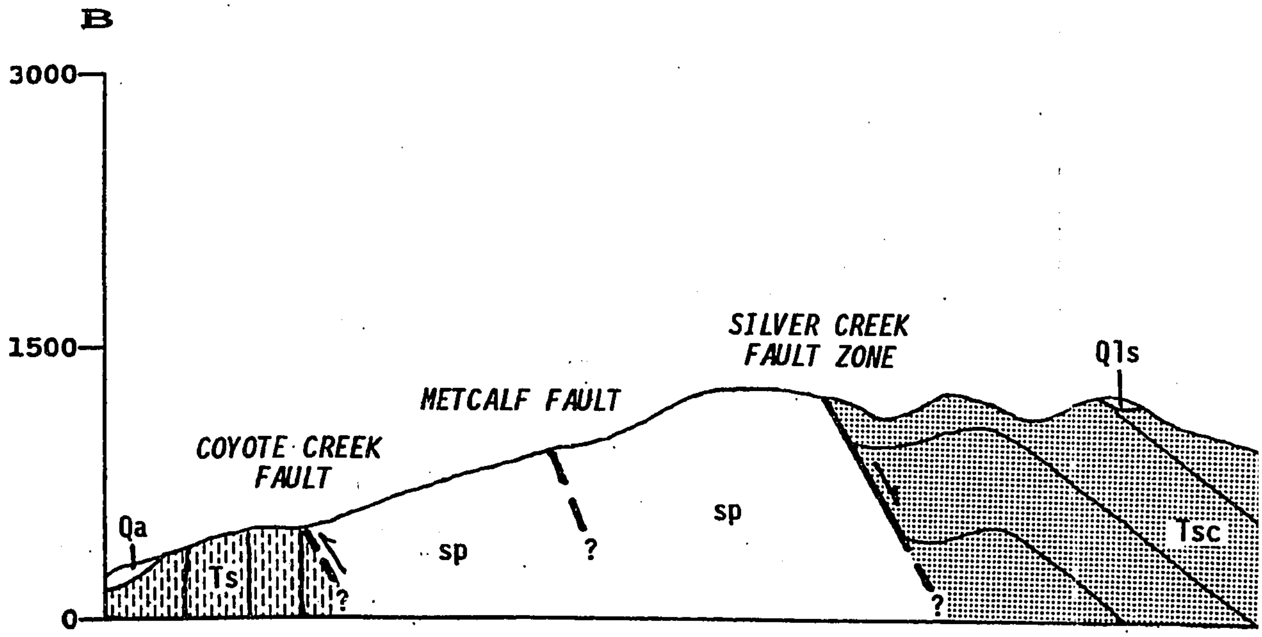

SECTION B-B′

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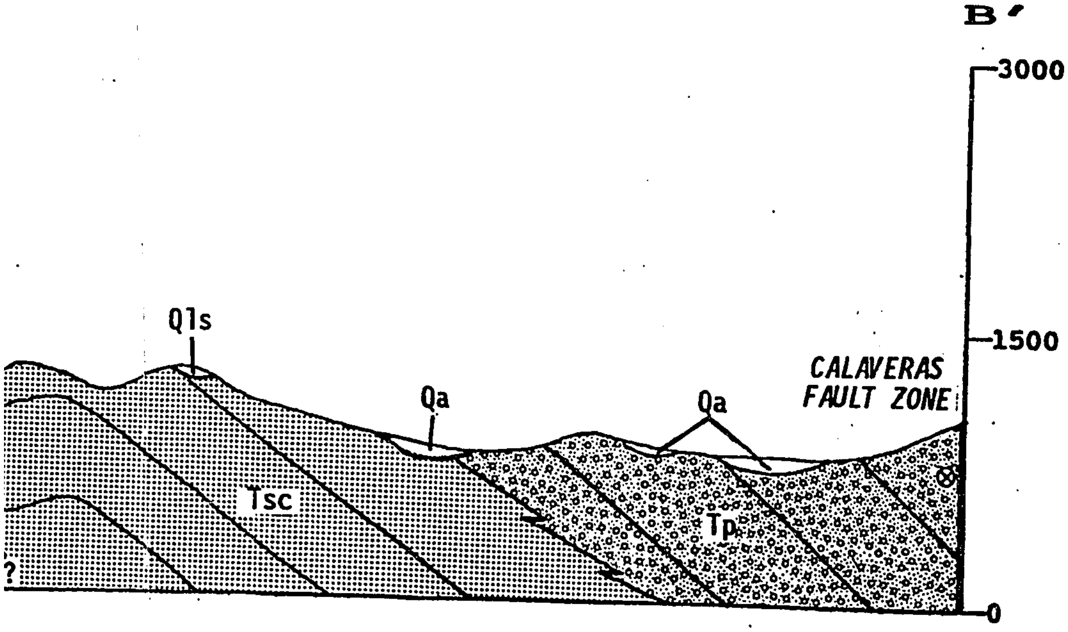
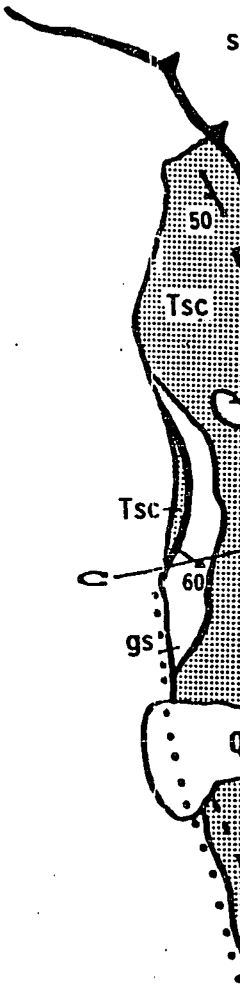
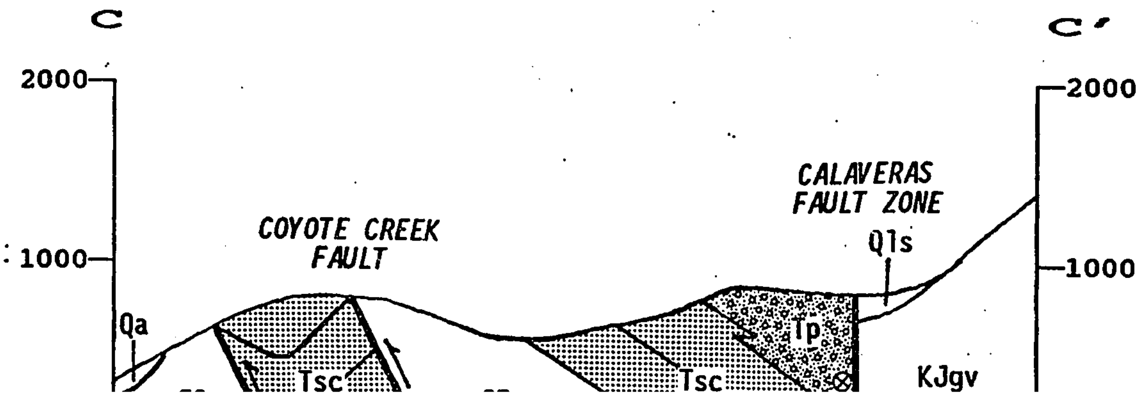


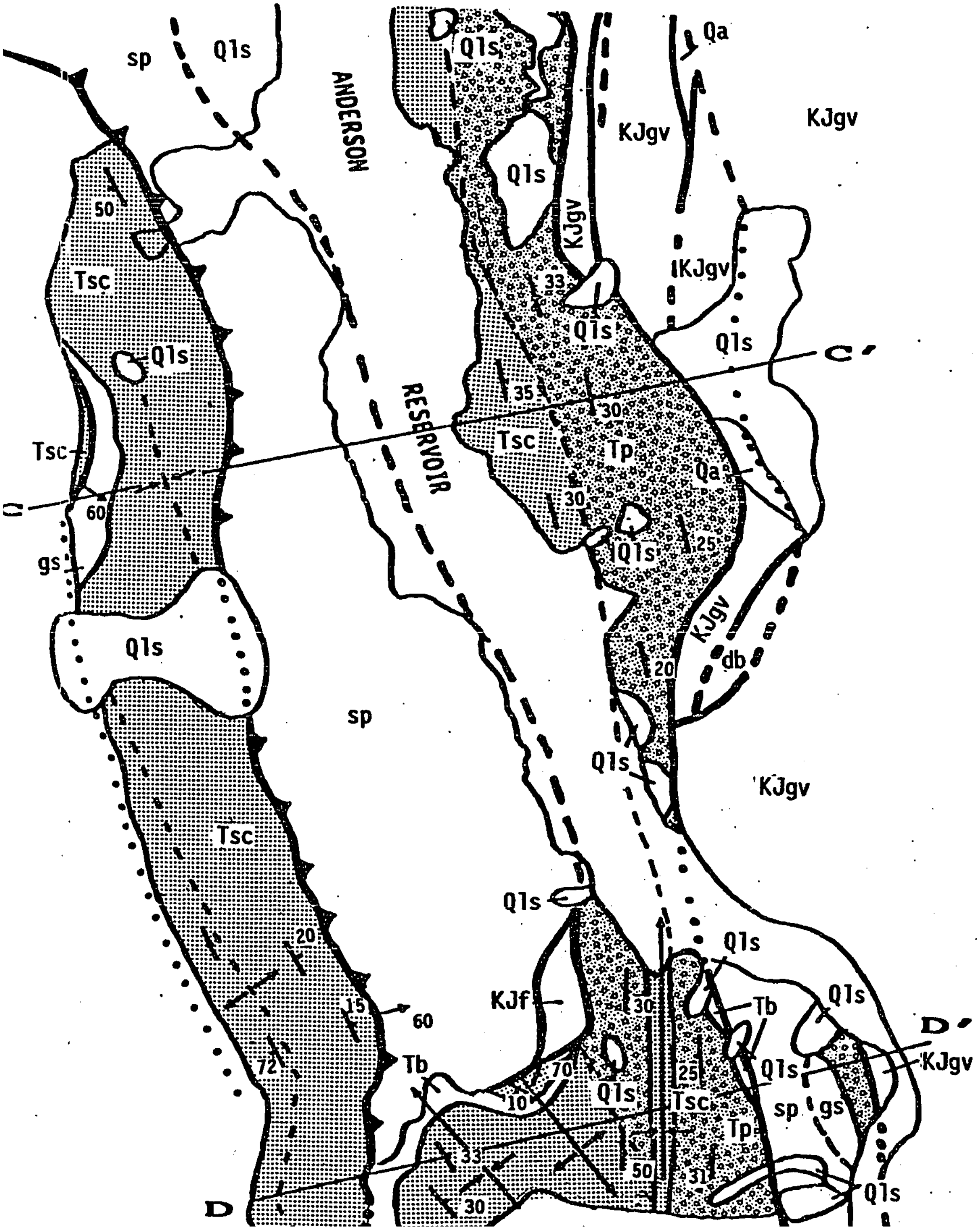
SECTION B-B′
TICAL EXAGGERATION=2x)

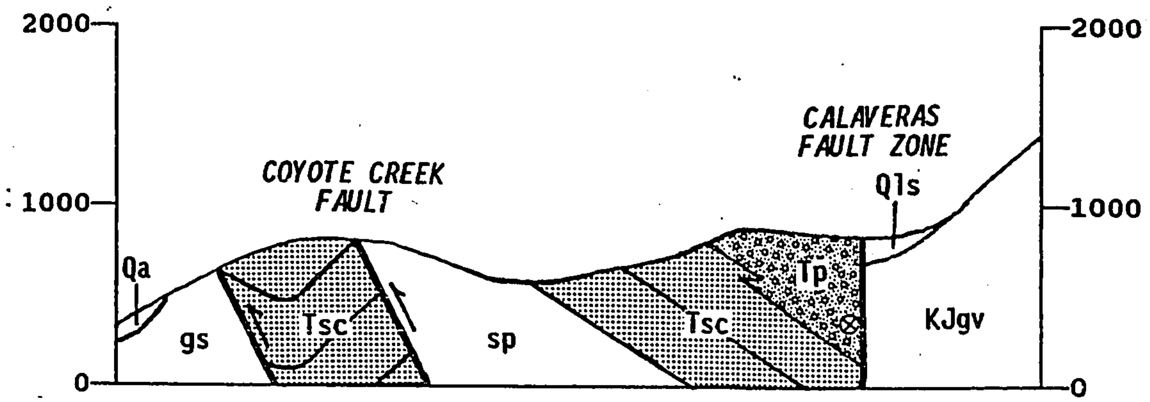
PLATE 3: Geologic ma
sections of the southern
shore Anderson Reserv
Reservoir.



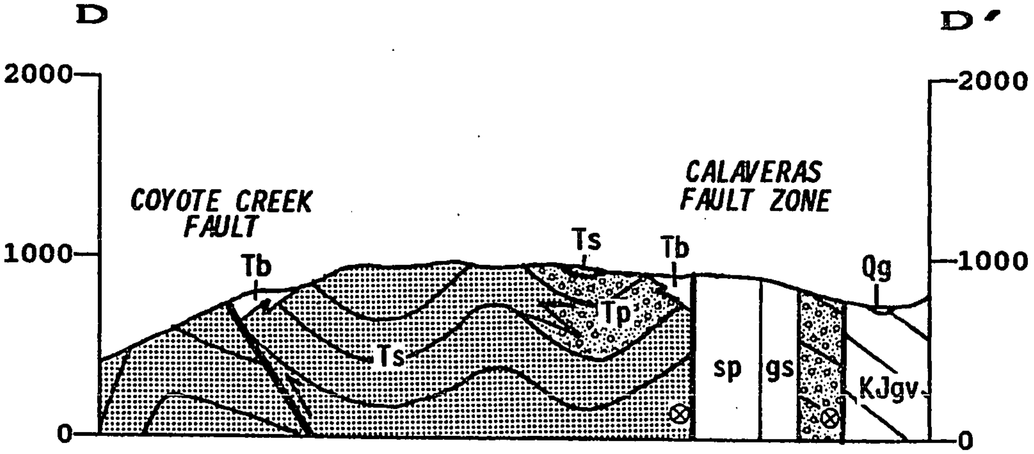


map and cross-
ern study area-south
ervoir and Coyote

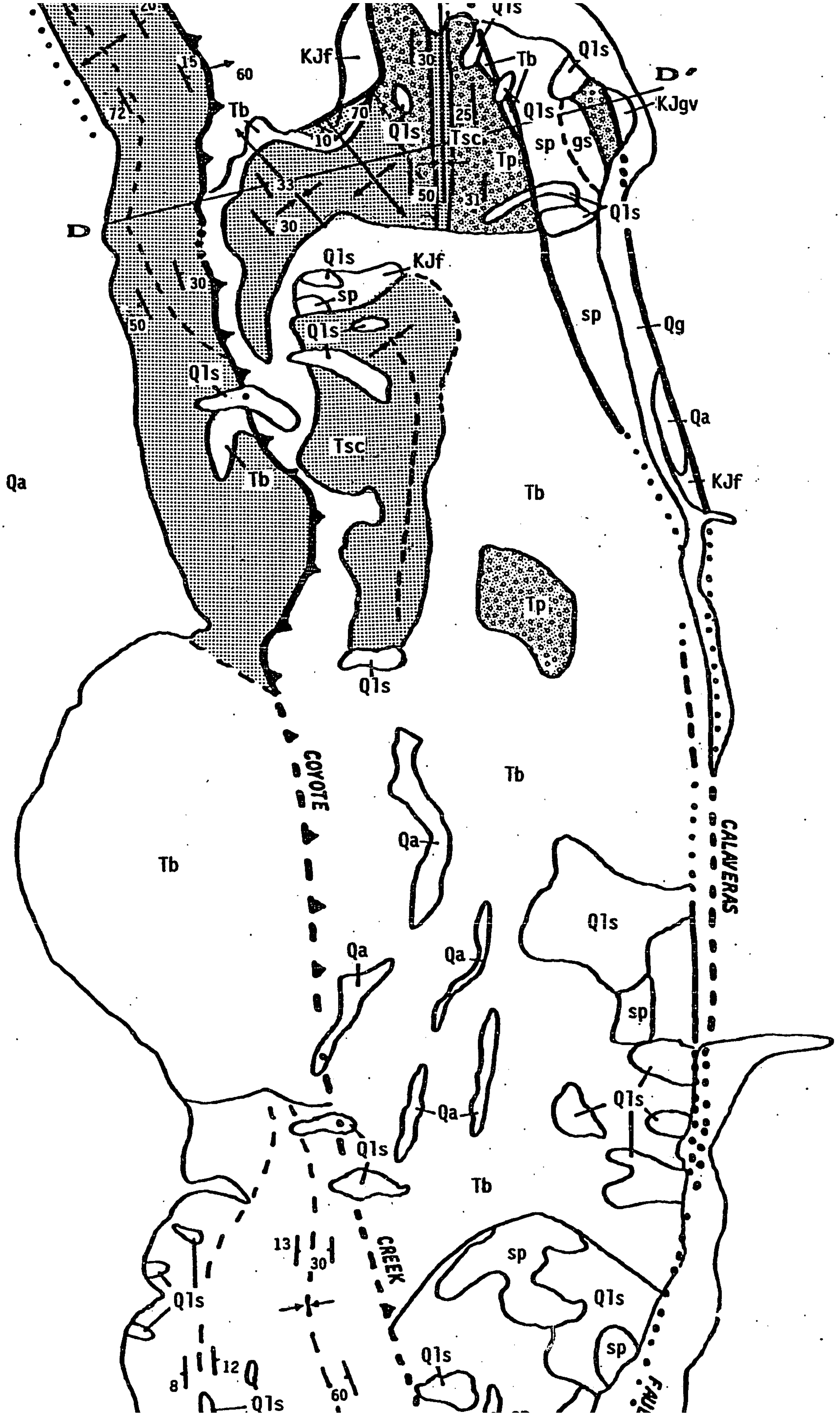




SECTION C–C′
(VERTICAL EXAGGERATION=2x)



SECTION D–D′
(VERTICAL EXAGGERATION=2x)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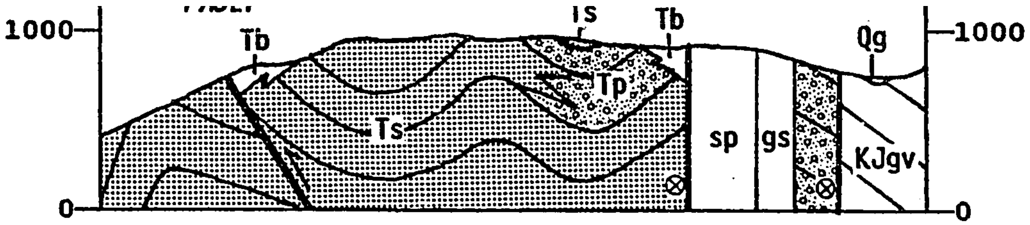

SECTION D-D′

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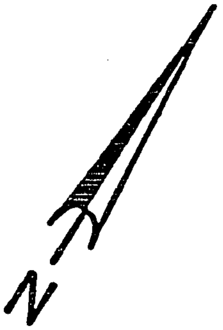

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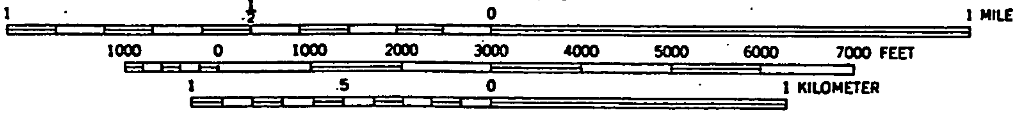

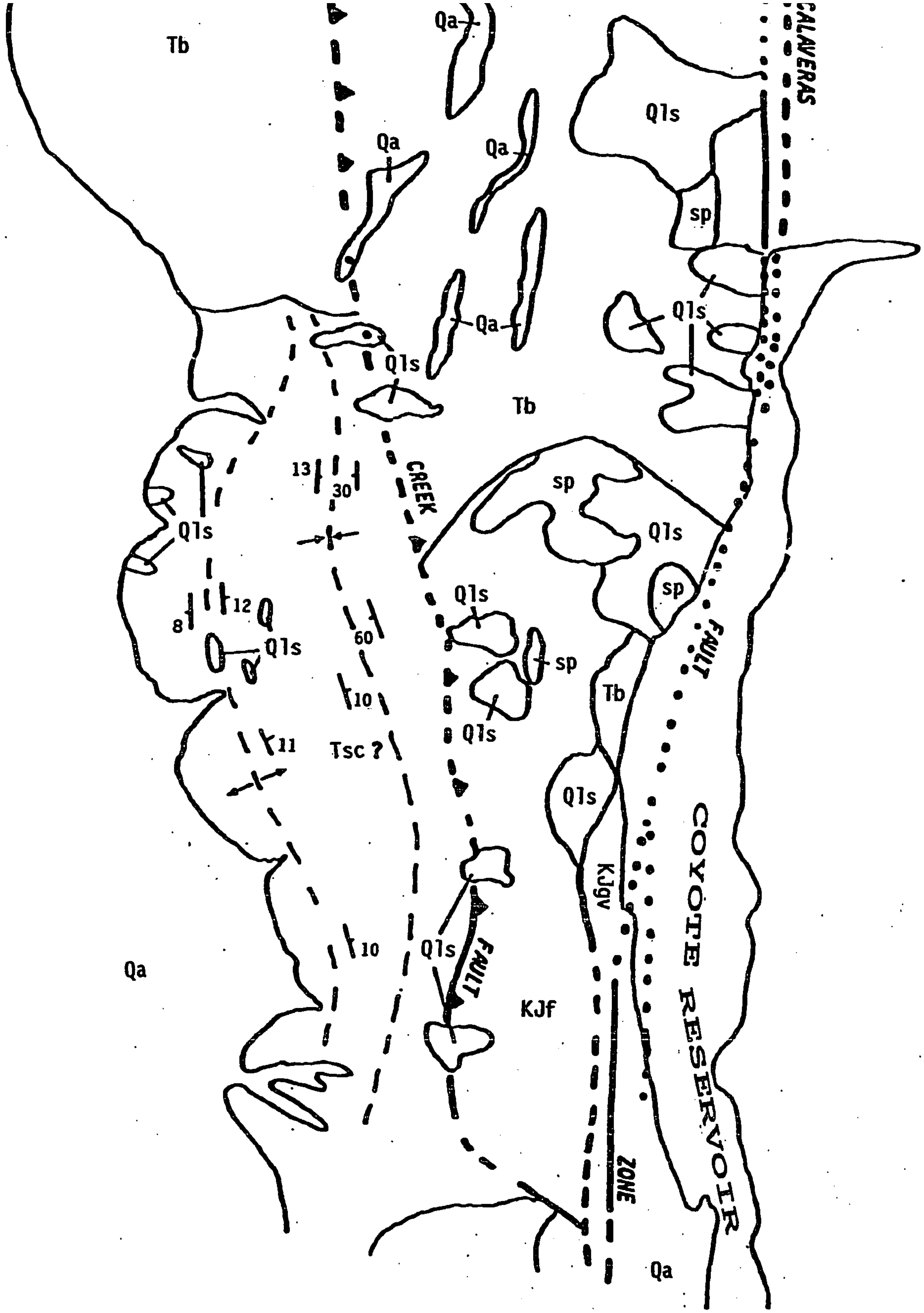
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