Revised Structure of the Westernmost San Jose Anticline, Southern California

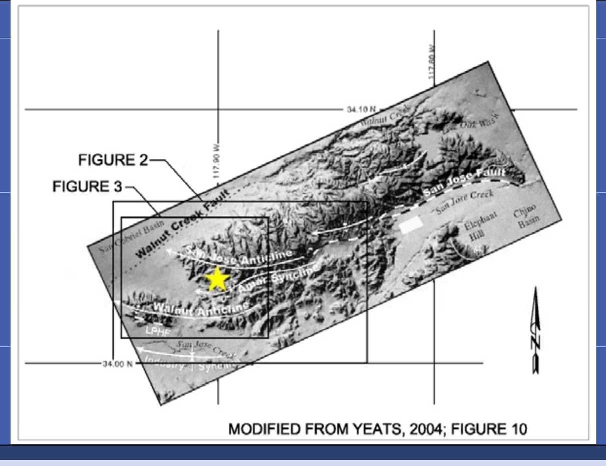

Figure 1: Aerial terrain map of the San Jose Hills showing the principle geologic structures, location of the BKK site (star), and locations of Figures 2 and 3; modified from Figure 10 of Yeats (2004). Note Walnut Anticline is herein called the Little Puente Hills Anticline.

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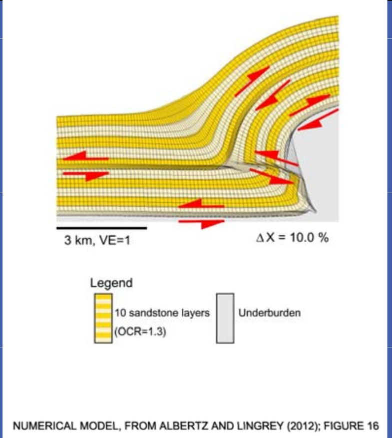


Figure 12: Synclinal crowding numerical model simulation.

Introduction. The west-plunging San Jose Anticline (SJA) is generally shown as a closed, nearly symmetrical and essentially featureless fold exposing the four members of the Puente Formation: Sycamore Canyon (youngest), Yorba, Soquel, and La Vida. Reevaluation of the geology of the BKK Landfill site (Figure 1), which spans the fold axis and south limb, suggests the SJA is highly asymmetrical and south verging. Five interpretations concerning the geologic structure and stratigraphy of the fold are presented below based on sandstone petrography, fault trenching, analysis of core, and synthesis of previous work by the authors and others.

Olmstead (1950) was first to provide comprehensive geologic mapping of the western San Jose Hills (Figure 2), dividing the Puente F. into upper and lower members. Later published maps by Dibblee (1999) and Tan (2000), and Figure 3 of this study, utilize Olmstead's mapped contacts with only slight alterations, but redefine the stratigraphy of the map area (Figures 4 and 5). Figure 3 revises the western one-half of Olmstead's map, adopting the four member division, and incorporating geologic structures in the south limb of the SJA known and inferred from previous unpublished and recent work at the BKK site and elsewhere. The nature of these structures is illustrated in six key cross sections (Figures 6 through 11) along which geologic data are relatively abundant.

Regional Considerations. The exposed geologic section of the map area includes middle Miocene through Quaternary sediments of the Puente and Fernando formations, and alluvium. The alluvium ranges from Pleistocene to recent deposits; the older deposits form elevated but low lying slopes and terraces, as illustrated in Section T-T' (Figure 7). The interpreted stratigraphy of the Puente F. based on the current study is shown in Figure 4, and incorporates two upward-coarsening depositional cycles proposed by Critelli et al. (1995), comprising in the older case La Vida → Soquel members, and in the younger case Yorba →Sycamore Canyon members (Figure 5).

Stratigraphic and paleotectonic models indicate the Puente Formation was deposited as submarine fans in a subsiding, transtensional basin between approximately 12 and 5 Ma (e.g., Blake, 1991; Critelli et al., 1995). The northern margin of the basin was formed by the precursor terrain of the San Gabriel Mountains, and bounded by the proto-San Andreas Fault (San Gabriel Fault), which then defined the North American Plate boundary. By 4 to 5 Ma basin subsidence was replaced by rapid uplift as the tectonic regime changed to transpression produced by shifting of the plate boundary to the present-day San Andreas Fault. This transition marks the onset of Transverse Range structures, and the presumably the earliest point in the structural development of the San Jose Anticline (SJA). Faulting related to growth of the anticline was likely younger because much or all of the overlying Fernando F. was deposited before folding began. The age of the earliest fold related faults probably lies between 2Ma (the approximate end of Fernando deposition) and 4 Ma. This estimate suggests that much of the SJA developed during Quaternary time.

Yeats (2004) defined a deformational model of the region between the Sierra Madre Fault on the north and the southern limit of the Puente Hills Blind Thrust on the south that is undergoing north-south compression and east-west extension. The northeast- and northwest-trending faults are left-lateral and right-lateral respectively; those with oblique-reverse slip components are deemed transpressional. Strong east-west fault trends are associated with thrust faults and related folds. The strain pattern south of the San Gabriel Mountain block, andA the apparent stress related geometry of these fault groups, reflect the confluence of right lateral strike-slip and reverse fault motions. The San Jose Hills (SJH) are within a sub-region bounded by faults of late-Quaternary age: namely the Whittier Fault on the southwest, the Walnut Creek Fault on the northwest, and the Chino Fault on the southeast. Between these structures, the San Jose Fault demonstrates Holocene movement at the Cal Poly campus about 5 miles east of the site (Geocon, 2001), and crustal-strain accumulation is measurable within the SJH (Earth Consultants International, 2011). The San Jose Fault is apparently an oblique-slip reverse fault, with possible major strike-slip motion. Its mapped trace extends west to within a mile of the BKK site, suggesting that a westward projection of the fault would be a blind structure.

Barrier Structure and Synclinal Crowding. The south limb of the SJA incorporates a secondary, steeply-dipping monoclinal to overturned fold in the lower and middle Yorba Member (M.), adjacent to a subparallel south-adjacent crowded syncline (Figures 6, through 9, and Figures 12 and 13). The SJA is likely a fault propagation fold, similar to other related structures in the same tectonic setting to the south (Yeats, 2004). Shortening across the anticline is uncertain, but could well be more than 20%, most of it taken up in the south limb. This is evident by the steep to vertical and overturned structural dips in the lower to middle Yorba section that forms the south limb of the anticline (Figure 13). Also, thickening of the Yorba M. by bedding sub-parallel flexure slip has been a common observation of field exploration. This zone of steepened structure and formational thickening, here called the Barrier Structure, was recognized as early as 1984 when nine exploratory coreholes ranging to depths greater than 1,300 feet were drilled on the BKK site.

Fault propagation folds form above reverse faults when fault-slip during earthquake events is attenuated up-dip by deformation in overlying sedimentary beds. Blind faults may be associated with complex patterns of secondary faults and folds at the surface well before the approach of the main break. Erslev (1999) identified a pattern of surface deformation called "synclinal crowding", which appears applicable to the present case. In this model, as the verging limb of the anticline steepens, the strata are crowded into the adjacent synclinal trough. The strata thicken by ductile deformation, and if they contain weak layers they also deform by reverse-sense, bedding parallel and sub-parallel flexure-slip, and ultimately by cross-cutting faults, as illustrated in the numerical model simulation in Figure 12, from Albertz and Lingrey (2012). The simulation includes low and high angle reverse faults along weak layers, vertical and overturned beds in the hanging wall section, and formational thickening in the syncline and hanging wall sections (note the moderately over consolidated condition (OCR ratio 1.3), and no vertical exaggeration (VE = 1)).

Blue Streak-Nogales Fault. The transition from the steeply dipping Yorba section to the adjacent synclinal trough to the south is marked by the south-dipping Blue Streak-Nogales fault (BS-NF). This fault is interpreted as an antithetical back-thrust in a system of low-angle, north-dipping, bedding sub-parallel thrusts, which appear to be expressions of synclinal crowding, and may represent secondary structures above a north-dipping, blind extension of the San Jose fault (Figures 6, 7, and 9).

The synclinal section of Figure 9, observed in core and recent fault trenching, and previously mapped largely as Yorba M. (Dibblee, 1999; Tan, 2000) is now preliminarily interpreted as Sycamore Canyon M. on the basis of sandstone petrography. Petrographic analysis of detrital sandstone (Dickinson, 1970; Dickinson and Suczek, 1979) was applied to the Puente F. sandstones by Critelli et al. (1995) to differentiate the Puente members regionally. A similar but localized study of characteristic litho-mineralogic grain types at and near the BKK site. This study revealed differences in sandstone composition between the Yorba and Sycamore Canyon members in at least four tri-modal ratios (Figures 14A-D) along the south boundary of the site, where historically the inability to distinguish between Sycamore Canyon and Yorba members constrains structural interpretation. The apparent Sycamore Canyon section, possibly several hundred feet thick shown in Figure 9, is difficult to accommodate within the verging fold at depth without placing the steeply dipping Yorba section over shallow dipping beds in the synclinal section. Interpretations of structure zones in the along-section cores suggest the locations of possible discontinuities.

Miranda Spring Fault. To the north, the Miranda Spring fault (MSF) lies along a similar trend to the Barrier Structure and BS-NF. This fault is north-dipping reverse based on apparent offset of the Soquel- La Vida contact observed in core and trenches (Figure 10). The fault forms a groundwater barrier marked by springs, and east of the site it has geomorphic definition. To the west it appears to merge with the Barrier Structure and may be imbricate with the potential blind fault shown in Figure 9. To the east of the section in Figure 10, the MSF appears to link with a fault shown by Dibblee (1999) that in turn lies on trend with the San Jose Fault shown by Olmstead (1950) (Figure 2). To the west of the section in Figure 10 the MSF and the Barrier Structure appear to die out within the BKK site, coincident with an abrupt change in trend of the BS-NF (Figure 3).

North Ridge Faults. North of the MSF, the continuity of the Yorba, Soquel, and La Vida member sequence across the nose of the SJA is interrupted by northeast trending high- and low-angle faults cutting the north ridgeline. Though poorly constrained to the southwest, at the ridgeline these faults affect groundwater, and one, a low-angle fault, separates two chemically distinct groundwater systems (Figure 11). In trend they are similar to the Walnut Creek fault to the west but the sense of motion appears to be mainly reverse-oblique. Figure 11 shows the hydrogeologic section I-J between locations of core drilling conducted in 1994, which incorporates high- and low angle reverse faults extrapolated from surface mapping in the La Vida M. Piezometric surfaces are color coded to well screens and groundwater barriers are numbered. At locations I and J the barrier labeled 2 confines Na-HCO_3-high pH groundwater from unconfined Ca-Mg-SO_4-neutral pH groundwater; the resulting hydraulic overpressure (coincident with high natural gas pressures) is consistent with compressive stresses implied in the regional tectonic model.

Little Puente Hills Fault. As noted, structures within the south limb of the SJA apparently die-out to the west, near the confluence of the Central Drainage (Figure 3) with Puente Creek. However, similar tectonic strain then appears to be expressed in structures in the Little Puente Hills to the southwest (Figures 2 and 3). The interpretive Section T-T' (Figure 7) is compiled from numerous sources, from which a relation between the SJA and the Little Puente Hills Anticline can be inferred. Of special note is the Pass and Covina Road Fault of Olmstead (1950) (Figure 2), which suggests a structural linkage with the BS-NF that could accommodate strain transfer.

Figure 4: Matrix diagram showing various stratigraphic conventions, equivalent map units and dominant lithologies applied to the map area.

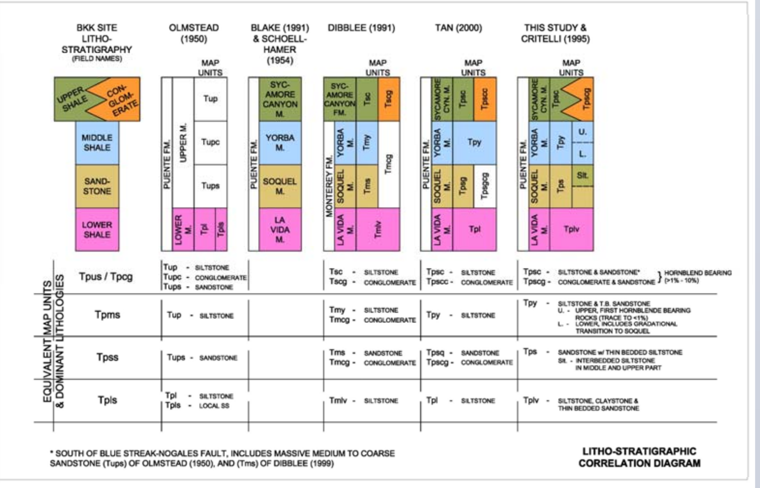


Figure 5: Estimated stratigraphic column of the western San Jose Hills scaled from cross sections and apparent thicknesses in drill core.

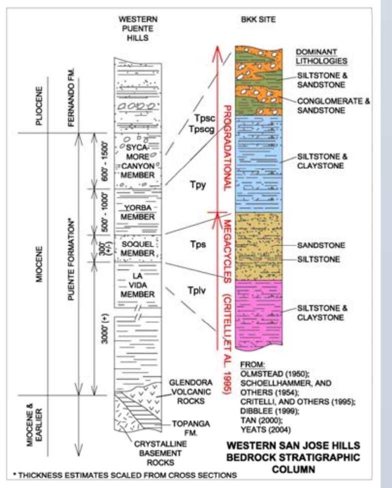


Figure 2: Colorized geologic map by Olmstead (1950) of the western San Jose Hills (scale 1" = 2000'), based on mapping from 1948.

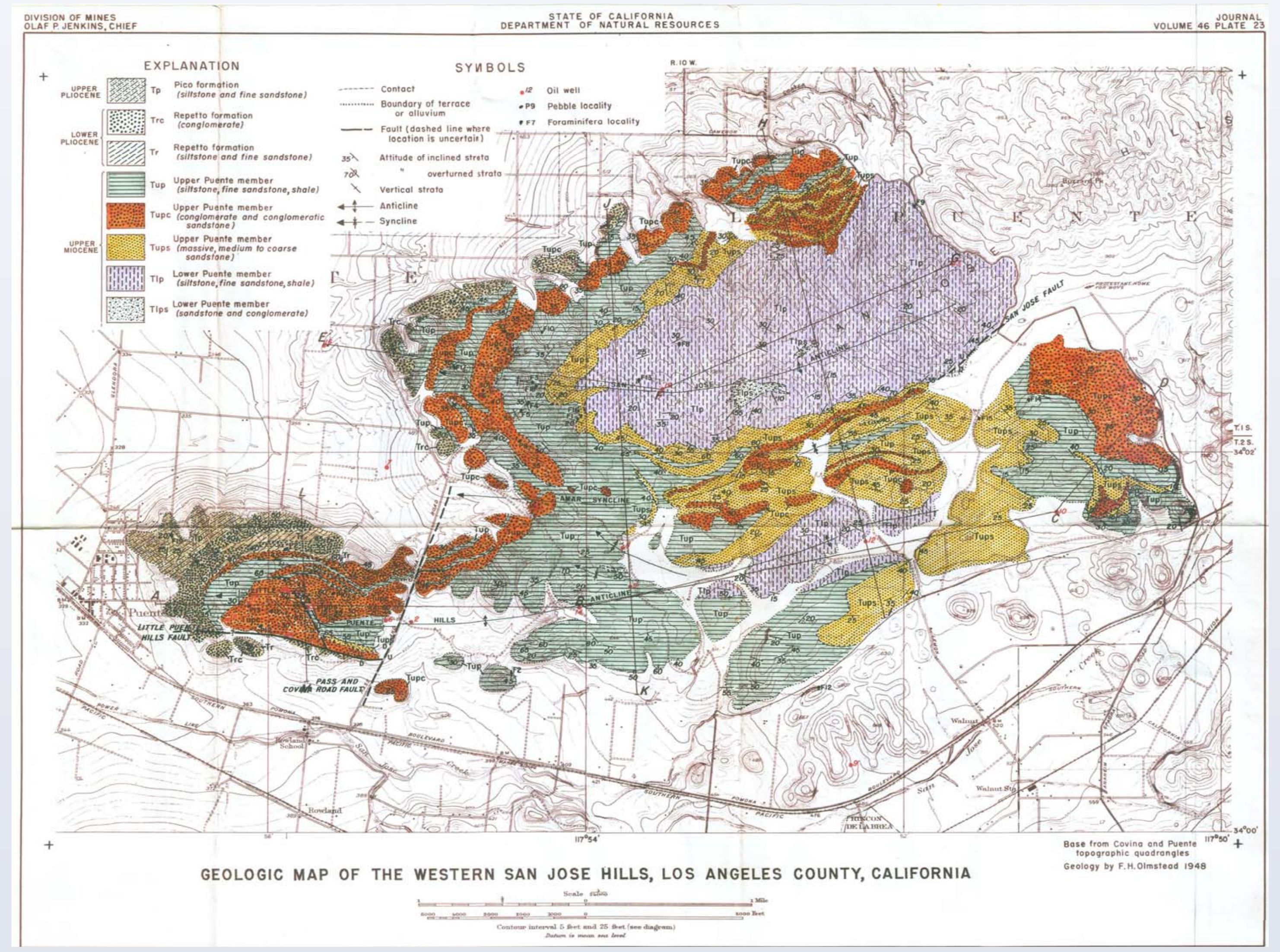


Figure 3: Preliminary revision of the structure and geology of the westernmost San Jose Hills after Olmstead (1950), Dibblee (1999), Tan (2000), and Yeats (2004), (scale 1" = 1000').

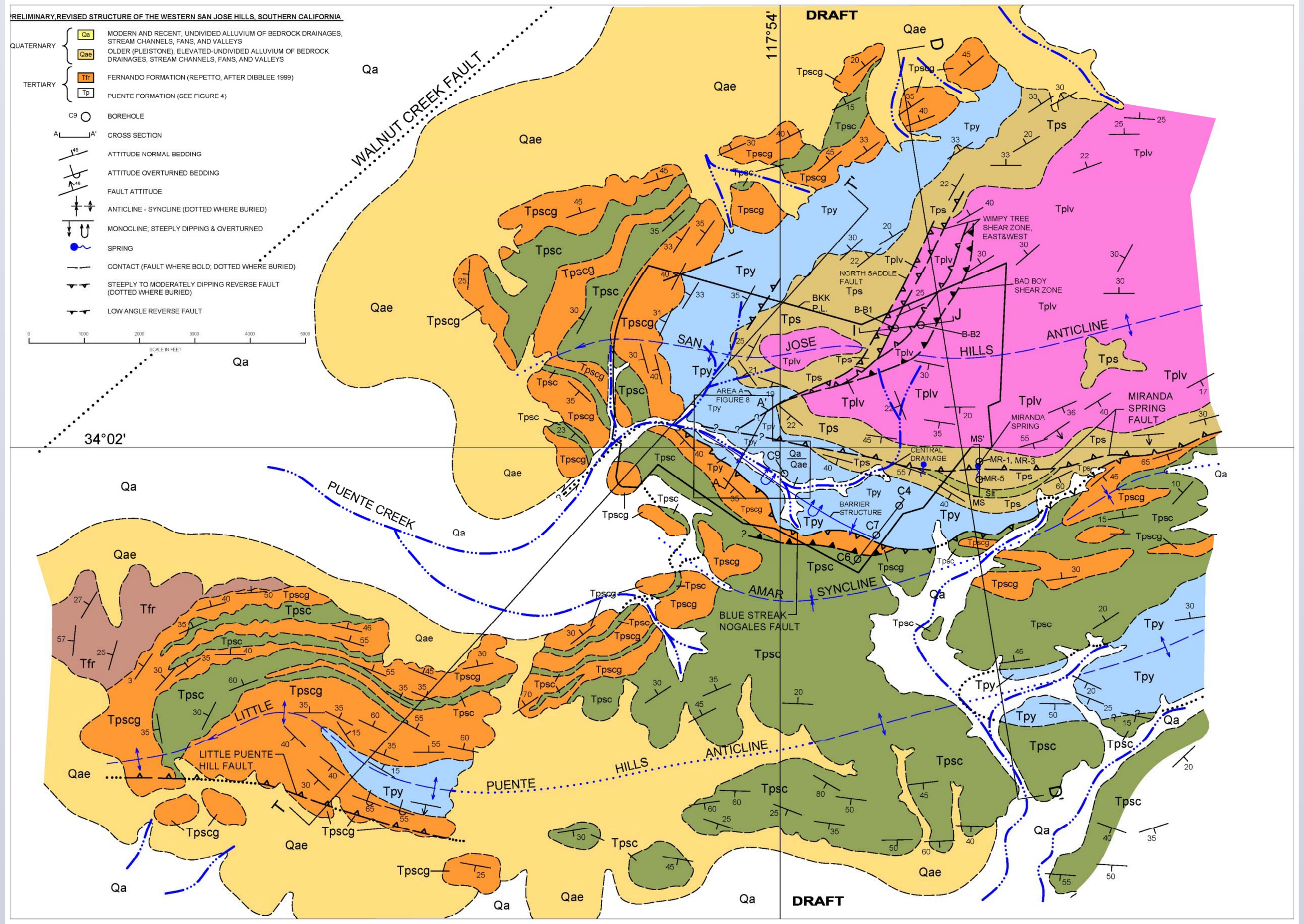


Figure 6: Geologic cross section D-D' (scale 1" = 1000") after Dibblee (1999), and Olmstead (1950).

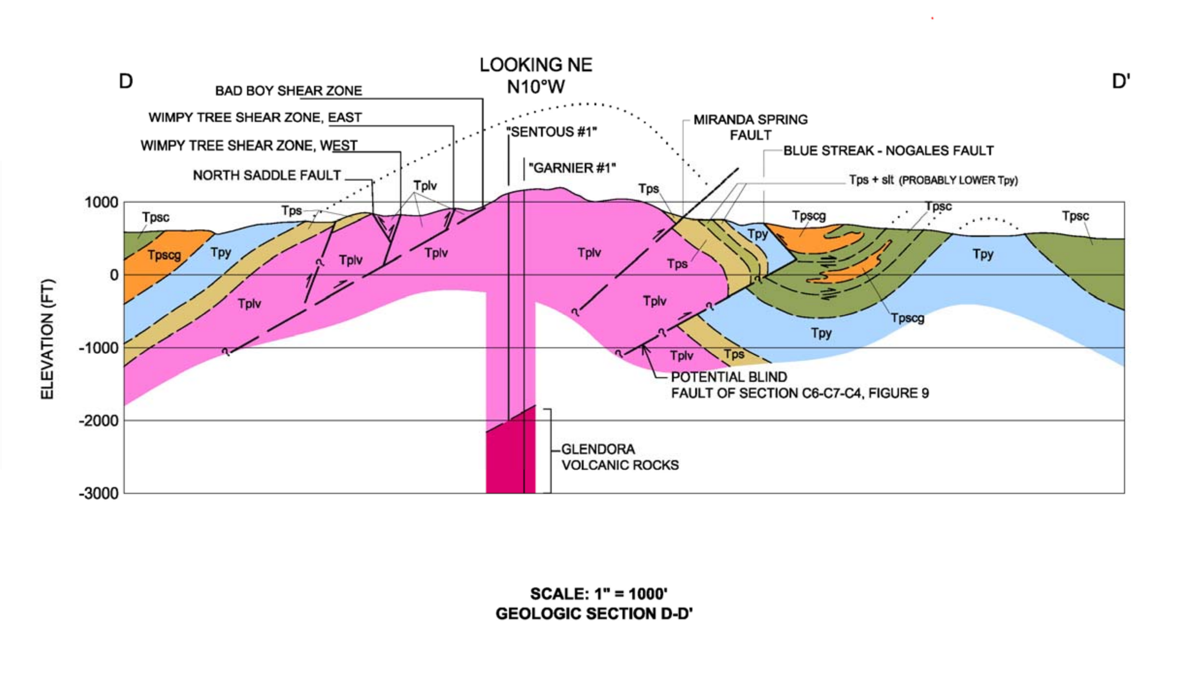


Figure 7: Geologic cross section T-T' (scale 1" = 1000') after Tan (2000); also Olmstead (1950), Crandall (ca. 1983-4), Dibblee (1999), and Yeats (2004).

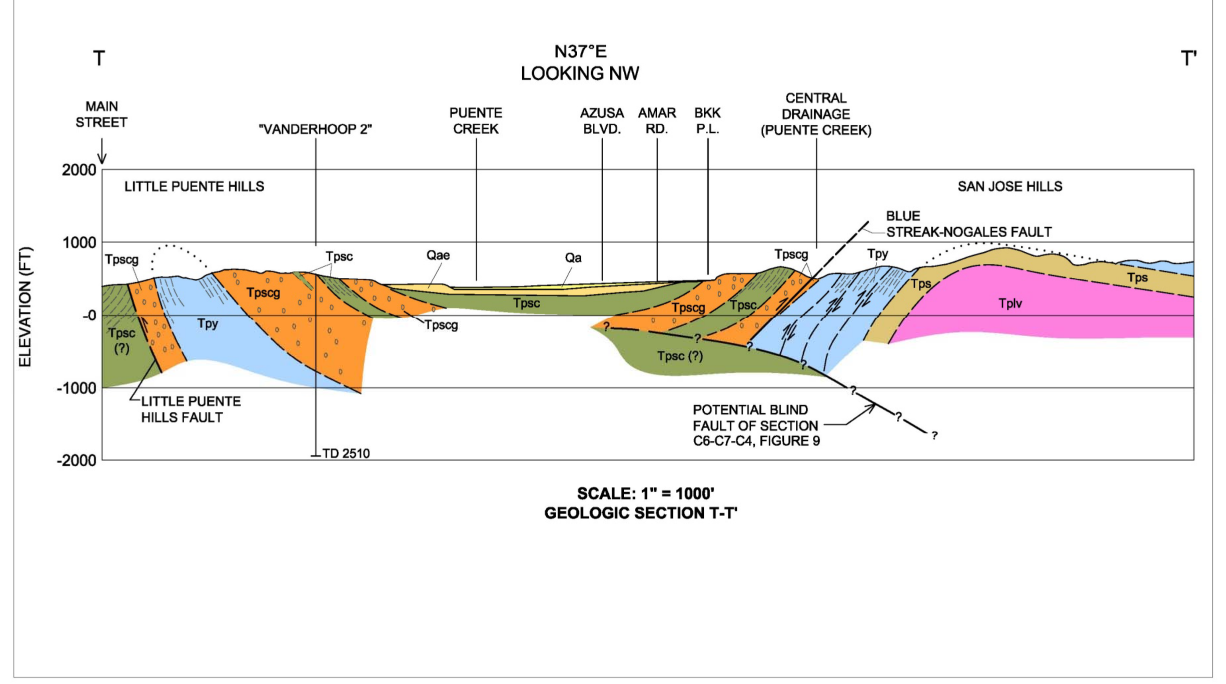


Figure 8: Geologic map Area A (scale 1" = 200'), and cross section A-A'.

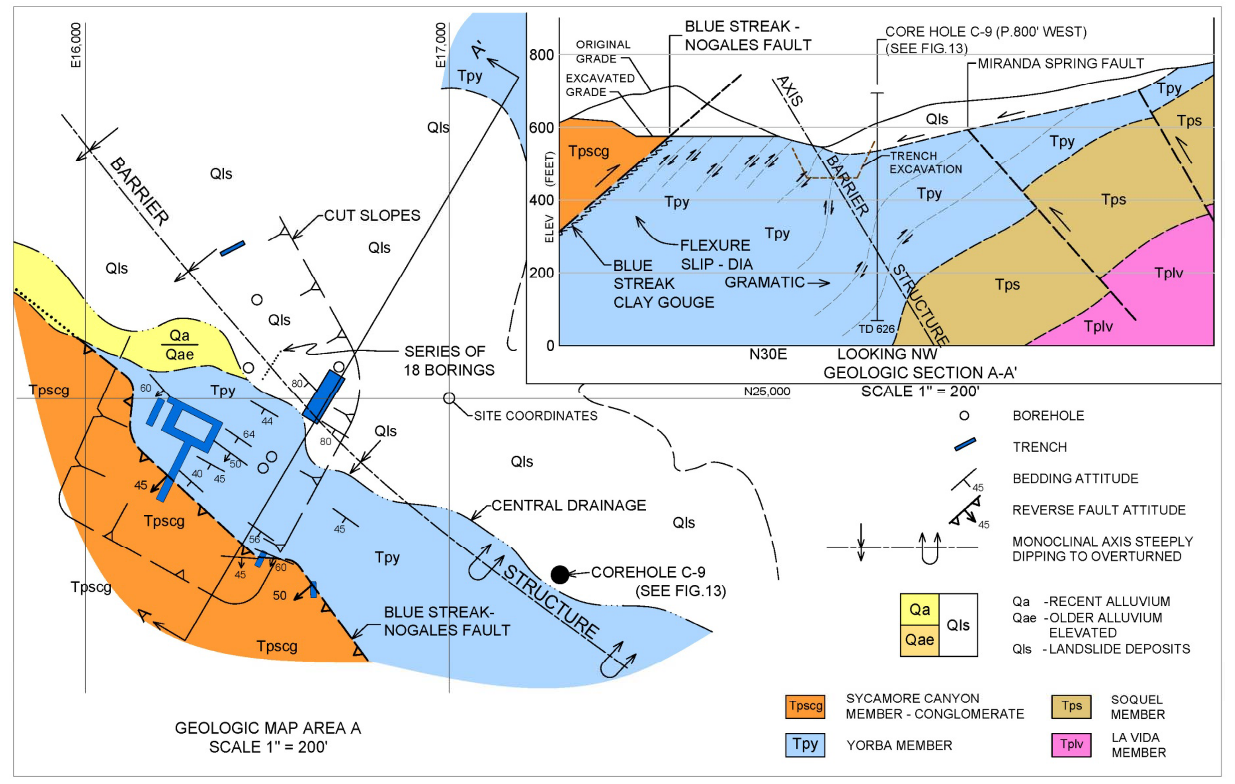


Figure 9. Geologic cross section C6-C7-C4 (scale 1" = 200').

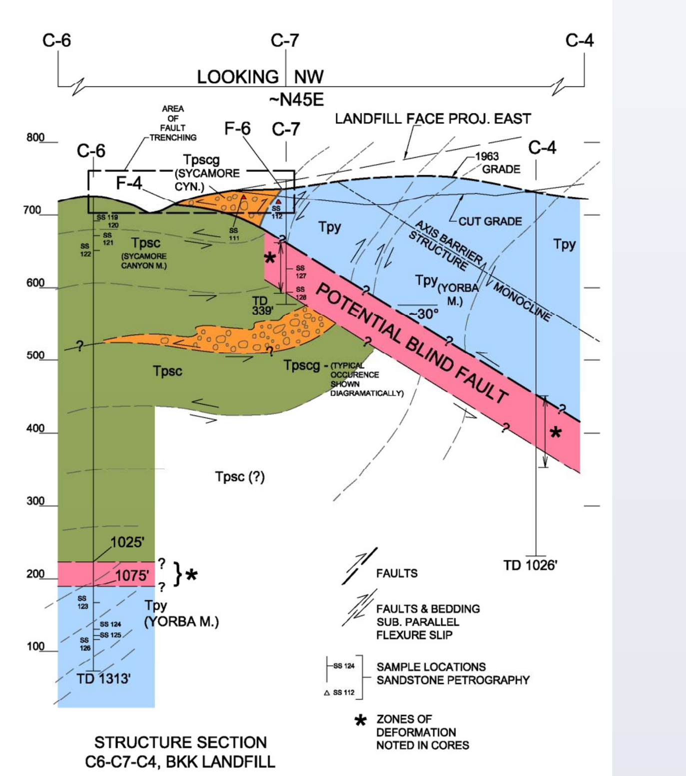
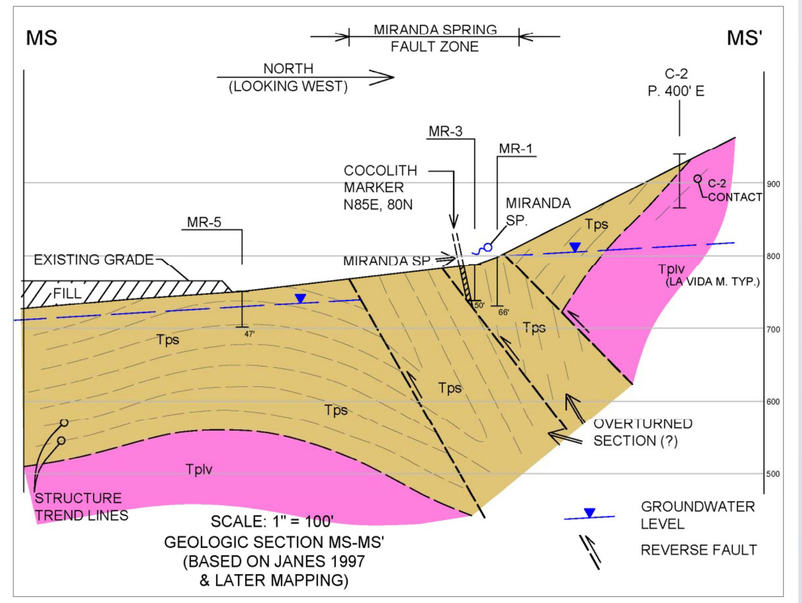


Figure 10. Geologic cross section MS-MS' (scale 1" = 100').



Revised Structure of the Westernmost San Jose Anticline, Southern California
Abstract No. 227949

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The Quaternary, west-plunging San Jose Anticline (SJA) is shown as a nearly symmetrical and essentially featureless fold exposing the four members of the Puente Formation: Sycamore Canyon (SC; youngest), Yorba (Y), Soquel (SQ), and La Vida (LV). Reevaluation of the geology of the BKK Landfill, which spans the fold axis and south limb, suggests the SJA is highly asymmetrical and south verging. Five interpretations follow based on sandstone petrography, fault trenching, analysis of core, and synthesis of previous work. 1) The south limb incorporates a secondary, steeply-dipping monoclinal to overturned fold in the lower and middle Y adjacent to a subparallel south-adjacent crowded syncline. The synclinal section, previously mapped largely as Y is now interpreted as SC. This section, possibly several hundred feet thick, is difficult to accommodate within the verging fold at depth without placing overturned Y over shallow dipping SC. 2) The transition at the surface is marked by the south-dipping Blue Streak-Nogales fault (BS-NF), interpreted as a back-thrust antithetical to a system of low-angle, north-dipping or flat, bedding sub-parallel thrusts in the SC section. The BS-NF and the bedding sub-parallel faults appear to be expressions of synclinal crowding, and may represent secondary structures above a north-dipping, blind extension of the San Jose fault. 3) To the north, the Miranda Spring fault (MSF) lies along a similar trend. This fault is north-dipping reverse based on apparent offset of the SQ-LV contact, and forms a groundwater barrier marked by springs. East of the site it has geomorphic definition. To the west it merges with the monoclinal fold and may be imbricate with a deeper blind structure. 4) North of the MSF the continuity of the Y, SQ, and LV sequence is interrupted by northeast trending high- and low-angle faults cutting the north ridgeline. Poorly constrained to the southwest, at the ridgeline these faults affect groundwater, and one, a low-angle fault, separates two chemically distinct groundwater systems. In trend they are similar to the Walnut Creek fault to the west but the sense of motion appears to be mainly reverse. 5) These structures (1 through 4) apparently die-out near the western boundary of the site; tectonic strain then appears to be expressed in similar structures to the southwest.

Figure 11: Hydrogeologic cross section I-J (scale 1" = 100').

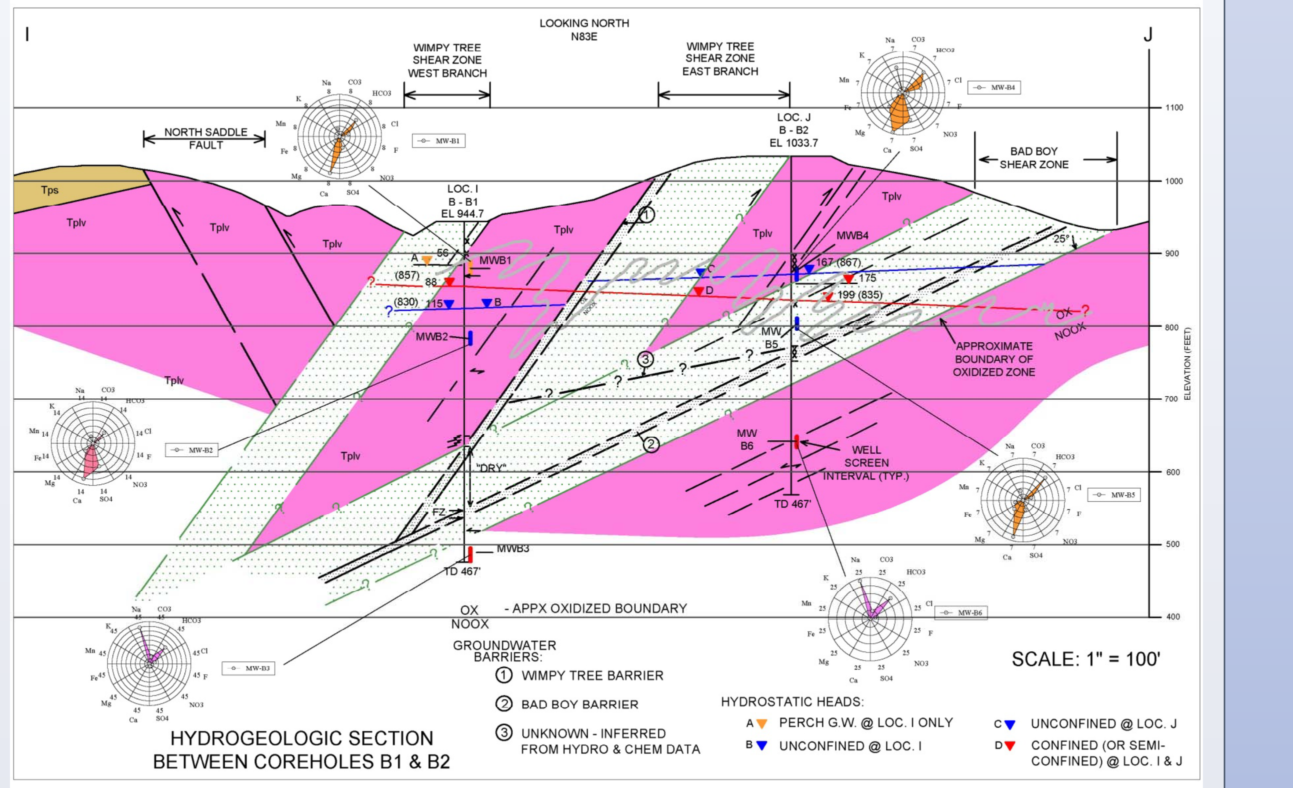

Figure 13: Photos of core drilled in 1984, from corehole C-9 in the south limb of the San Jose Anticline, showing an interval of vertical and sub-vertical bedding between depths 358 to 391 feet. Light colored layers are thin-bedded turbidites; darker layers are siltstone and claystone.

Figure 14A-D: Detrital sandstone modes from Yorba and Sycamore Canyon members of the Puente Formation. A. through C. are comparisons of lithic grain types: plutonic (Rg), volcanic (Rv; Lv; Lvm), metamorphic (Rm; Lm;), sedimentary (Ls; Lsm), and polycrystalline quartz (Qp). D. compares heavy mineral associations hornblende plus epidote (Hb+Ep), garnet plus sphene (Gr+Sp), and opaques plus other grains types (Opq+other).