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Composition and Provenance of Sand from Wells, Santa Clara Valley, California

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COMPOSITION AND PROVENANCE OF SAND FROM WELLS,
SANTA CLARA VALLEY, CALIFORNIA

A Thesis

Presented to

The Faculty of the Department of Geology

San José State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

Karen M. Locke

December 2011

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The Designated Thesis Committee Approves the Thesis Titled

COMPOSITION AND PROVENANCE OF SAND FROM WELLS,
SANTA CLARA VALLEY, CALIFORNIA

by

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December 2011

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ABSTRACT

COMPOSITION AND PROVENANCE OF SAND FROM WELLS, SANTA CLARA VALLEY, CALIFORNIA

by Karen M. Locke

Medium sand samples from well cores taken in the Santa Clara Valley, California, were studied to determine their composition and, if possible, their provenance. Sand samples were taken from various depths from five wells distributed over the western and central parts of the valley. The oldest of these samples is known to date to about 800 ka.

Thin sections of sand samples were point counted to determine quartz, feldspar, and lithic percentages. The samples are very lithic, with some quartz and very little feldspar. Common lithic grains include argillite and graywacke. Less common are metavolcanics, serpentinite, and chert or metachert. Siltstone, sandstone, volcanics and volcanic porphyry are rare or absent in the samples. All of these grain types are represented in the mountains surrounding the Santa Clara Valley.

The composition of the well sand as well as the previously known composition of well gravel samples provided indicators of well sediment provenance. At lower depths, the well sands and gravels in the western wells came predominantly from south of the valley, although the modern drainage that feeds those locations is from the southwest, suggesting a change in drainage patterns over time.

A bedrock high ran down the center of the valley ca. 800 ka. Compositions of the well sand and gravel indicate that this high provided serpentinite to the eastern wells and Franciscan chert and metavolcanics to several wells. The abundance of chert and metavolcanics in some middle and upper well samples indicates that the bedrock high was a significant source of these rock types until at least 400 ka.

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INTRODUCTION

The Santa Clara Valley is a modern, subsiding alluvial basin located at the south end of the San Francisco Bay within the central Coast Ranges of California (Fig. 1). It is surrounded by the Santa Cruz Mountains to the west and south and the Diablo Range to the north and east and is bounded on the northwest by the San Francisco Bay. The valley floor is composed of sediment eroded from the two mountain ranges and deposited by streams that originate in the surrounding mountains and cross the valley to feed the bay. This study focuses on the composition and provenance of the subsurface sediment in the valley.

The opportunity to study the subsurface sediment in the Santa Clara Valley has come about through a project jointly executed by the U. S. Geological Survey and the Santa Clara Valley Water District. In this project, several water-monitoring wells were drilled in the Santa Clara Valley; during drilling, cores were extracted from sections of some of those wells (U.S. Geological Survey 2000, 2001a, 2001b, 2002a, 2002b; Newhouse et al., 2004). The U. S. Geological Survey made these cores available for study, and sediment from five cores forms the basis of this study.

Geologic Setting

The Santa Clara Valley is located within a tectonically active region, bounded by two active strike-slip fault zones, the San Andreas fault zone on the south and west and

Figure 1. Location of the study area. Map shows location within the San Francisco Bay Area and within California. The study area shown in subsequent maps is within the dashed outline. Map adapted from U.S. Geological Survey et al. (2004) and Bryant (2005).

the Calaveras fault zone on the north and east. Thrust fault zones are present in and near the Santa Cruz Mountains and along the eastern edge of the valley; these include the Monte Vista fault zone on the west and the Evergreen fault zone on the east (Brabb et al., 2000; Wentworth et al., 2010). The strike-slip Silver Creek fault crosses the valley in the subsurface and cuts the bedrock to the southeast (Fig. 2).

A cross section of the valley, marked as line A-AA on Figure 2, is shown in Figure 3. As shown in this cross section, the valley is underlain by 300 to 500 m of Quaternary sediment deposited above the Tertiary sedimentary Cupertino and Evergreen basins in the southwest and northeast. These basins are separated by a central basement bedrock high (Wentworth and Tinsley, 2005). The Quaternary sediment, as exposed by the well cores, consists of alternating layers of mud, sand, and gravel (Newhouse et al., 2004), indicating that the modern stream-dominated depositional environment has persisted over the Quaternary Period (Wentworth and Tinsley, 2005)

The mountains surrounding the valley are home to a wide array of rocks (Brabb et al., 1997; Wentworth et al., 1998; Brabb et al., 2000). Franciscan Complex rocks include argillite, graywacke, radiolarian chert, metavolcanics, blueschist, and copious *mélange*, which itself is a collection of many different rocks in an argillite matrix. Great Valley Group rocks include argillite and graywacke, which are less metamorphosed than their Franciscan neighbors, as well as conglomerate rich in volcanic, metavolcanic, and plutonic rocks. Coast Range Ophiolite includes large outcrops of serpentinite as well as mafic metavolcanics, diabase, and gabbro. Younger units include Tertiary marine

Study Area Geologic Setting

- Wells
- Faults
- ☞ Water bodies
- Streams
- Major roads
- Quaternary alluvium
- Bedrock

Figure 2. Geologic setting of the study area. Map shows the Santa Clara Valley and the surrounding mountains, including the distribution of bedrock and alluvium, as well as the major faults. Wells are CCOC (Coyote Creek Outdoor Classroom), GUAD (Guadalupe), MGCY (McGlinchey), STPK (Santana Park), and WLLO (Willow). Line A-AA refers to a schematic cross section of the valley shown in Figure 3. Map adapted from Brabb et al. (1997), Wentworth et al. (1998), Brabb et al. (2000), Santa Clara Valley Water District (2004), and Bryant (2005).

Figure 3. Schematic cross section A-AA across the Santa Clara Valley. See Figure 2 for location, and see caption of Figure 2 for names of wells. GV: Great Valley Group. Note that although the Silver Creek Fault and Calaveras Fault are primarily right-lateral strike slip faults, their dip-slip component of motion is shown here. Based on a figure in Wentworth et al. (2010).

sandstone, siltstone, and mudstone. There are also Upper Cenozoic volcanic rocks as well as gravel and other non-marine deposits.

The simplified geologic map in Figure 4 shows the bedrock sediment sources in the mountains surrounding the valley. Large swaths of Franciscan Complex are present in the west, south, and east. Significant exposures of Great Valley Group occur in the south and east, and serpentinite-rich Coast Range Ophiolite occurs in the south. Extensive Tertiary marine sedimentary rocks are present in the south and east, and gravel-rich upper Cenozoic nonmarine units occur primarily in the west and southeast. The latter date from the Pliocene and Pleistocene, and so were possibly coeval with part of the Quaternary sediment in the valley.

Purpose of the Study

The purpose of this study is to document the composition of medium-grained sand samples taken from wells drilled in the Santa Clara Valley; to determine, as far as possible, the provenance of the well sand in terms of its source rocks in the mountains surrounding the valley; and to discuss what implication that provenance might have for the evolution of the valley.

This study documents the overall composition of medium-grained sand samples from the cores of five wells collected between 2000 and 2002 during the joint U.S. Geological Survey / Santa Clara Valley Water District drilling project. The locations of these wells, CCOC (Coyote Creek Outdoor Classroom), GUAD (Guadalupe), MGCY

Source Rock Formations

Figure 4. Simplified geologic map, organized by rock formation. Map shows major source units in the mountains surrounding the Santa Clara Valley. Adapted from Brabb et al. (1997), Wentworth et al. (1998), Brabb et al. (2000), and Santa Clara Valley Water District (2004). See caption of Figure 2 for names of wells.

(McGlinchy), STPK (Santana Park), and WLLO (Willow), are shown on Figure 4. All are located over the central valley basement high or the Cupertino basin.

The compositions of the well samples are documented both by using the standard Gazzi-Dickinson categorization (Dickinson, 1970), and then identifying, as far as possible, the source rock types from which the well sands are derived. The samples come from units that are correlated with the timing of the last eight glacial cycles (C. Wentworth, personal communication, 2006), and compared with the depositional environments determined for the cores (C. Wentworth, personal communication, 2010). Composition results are compared to studies of fine-grained sand and pebbles from the wells documented by previous workers (Andersen et al., in press).

With the current locations of source rocks known in the Santa Cruz Mountains and the Diablo Range, some level of inference is made about the provenance of the well sources. To help constrain this level of inference, the compositions of modern medium sand samples taken from four valley streams are compared with the source rocks of their respective drainages. These streams are Los Gatos Creek, Penitencia Creek, Saratoga Creek, and Thompson Creek. Of the streams that drain the bedrock around the valley, these were chosen to give a wide variety of material without significant overlap in the source rock units. The drainages, along with the sample locations, are shown in Figure 5.

The final purpose of this study is to look at both spatial differences in composition and temporal patterns of change in composition that might indicate changes in source over time, and evaluate implications for the evolution of the valley and its drainage

Modern Stream Drainages

- Sand sample collection points
- ☞ Water bodies
- Streams
- Quaternary alluvium
- Los Gatos Creek drainage bedrock
- Penitencia Creek drainage bedrock
- Saratoga Creek drainage bedrock
- Thompson Creek drainage bedrock
- Other bedrock

Figure 5. Modern stream drainages sampled and locations of sampling points. Note that stream details are only shown on the bedrock in the drainages of interest. Map adapted from Santa Clara Valley Water District (1996), Brabb et al. (1997), Wentworth et al. (1998), Brabb et al. (2000), and Santa Clara Valley Water District (2004).

systems. Changes in source rock locations over time could have implications for the tectonic evolution of the valley and for changes in stream flow over time.

Previous Work

Previous work of note has been the geologic mapping of the area, the study of other sediment samples from the wells, the correlation of well depth with glacial/interglacial cycles, and the detailed geologic description of the complete well cores.

The modern geology of the Santa Clara Valley and the surrounding mountains has been documented in 1:62,500 and 1:100,000 geologic maps (Brabb et al., 1997; Wentworth et al., 1998; Brabb et al., 2000). These maps are used here for correlation between sand sample compositions and bedrock sediment sources.

Andersen et al. (in press) have studied gravel samples collected during the drilling of the wells, dense grains from fine sand sampled from the cores, and a small set of medium sand samples from the cores. The rock types of the gravels found in the wells and the kinds of heavy minerals found in the fine sand served as a guide for determining point-count categories for the current study. The results of the study of Andersen et al. (in press) are compared with the results of the current study in the Discussion section of this paper.

Newhouse et al. (2004) used geophysical logs collected from the drilled wells to establish the stratigraphy of the sediment surrounding each well. C. Wentworth (personal

communication, 2006) identified fining-upward sequences in the wells that he correlated with the last eight glacial/interglacial cycles of Shackleton et al. (1990). Eight such sequences were identified, though not all eight are present in each well, and the sequences were correlated between wells (Fig. 6). Medium sand samples for the current study were chosen to represent as many sequences as possible in each well, and the correlated sequences were used as proxies for time periods in looking for changes in sand composition over time.

John Tinsley created detailed descriptions for all the cores collected from the wells (C. Wentworth, personal communication, 2010). These descriptions provided a basis for determining the depositional environment of each medium sand sample collected from the cores.

Witter et al. (2006) mapped the Quaternary geology of the central San Francisco Bay region, and Wentworth et al. (2010) mapped the approximate extent of what they characterize as a modern subsurface serpentinite sheet beneath the valley, based on the aeromagnetic anomaly work of Roberts and Jachens (2003). This information was used in this paper to constrain the possible history of valley evolution.

Figure 6. Stratigraphic fining-upward sequences in the wells. These are associated with the last eight glacial/interglacial cycles, with correlations between the wells. Depths of sequence boundaries from Carl Wentworth (personal communication, 2006). See caption of Figure 2 for names of wells. Correlation lines follow sequences from well to well. No sequence 1 was identified in the MGCY well. The MGCY and WLLO wells were drilled to bedrock (diagonal lines).

METHODS

Three major steps were involved in acquiring data from well and stream sand samples. First, to accurately identify source rocks in the sands, a calibration process was required to learn to recognize specific source rocks and diagnostic minerals from the Santa Cruz Mountains and the Diablo Range in thin section. Second, thin sections of sand samples were prepared and point-counted to determine the source rock type of as many grains as possible in each sample, and identify any diagnostic minerals within the sand grains. Finally, the log of the well cores was consulted to determine the depositional environment for each well sample. The goal of these steps was to acquire sufficient data about the composition of well samples, and to correlate composition with depositional environment if possible, thereby producing results that give clues to the provenance of the well sands and the evolution of the valley.

Calibration Process

The calibration process involved studying thin sections of argillites, graywackes, greenstones and other metavolcanics, metadiabase, basalt, various schists, chert, metachert, cumulate and non-cumulate gabbros, and dioritic intrusive rocks. These thin sections came from various sources. Fragments from forty-two pebbles collected and identified by Andersen et al. (in press) were cut into ten thin sections. Seventeen described thin sections of rocks gathered in the Santa Cruz Mountains were lent to the

project by R. McLaughlin at the United States Geological Survey. Eleven thin sections from the San José State University Geology Department collection were also used.

One focus of the calibration process was to learn to recognize the textures of the various rock types as well as their characteristic minerals, so that they might be identified in sand grains. Another focus of the calibration process was to learn to recognize some of the more elusive but distinctive Franciscan minerals such as jadeite and lawsonite. Other minerals such as serpentine and blue amphibole had such unique optical properties that further study for identification of these minerals was unnecessary.

Sand Sample Processing

Sand samples were collected and processed by a team led by David Andersen under the auspices of the Santa Clara Valley Water District. Samples of material were taken from well cores and from modern valley streams. Each well sample represented an interval about 2 cm thick within the core. The samples were wet-sieved to remove the fraction smaller than 62- μm , washed and dried, and then dry-sieved to sort by size. Medium sand between 425- μm and 250- μm sieves was isolated. After visual inspection through a microscope, medium sand samples were commonly found to have aggregates of silt and mud. To break up and remove the aggregates, these samples were processed in an ultrasonic bath, washed and dried again, and resieved.

To create the thin sections of sand, holes were drilled through small blocks of acrylic about the length and width of a glass microscope slide and about 1.2 cm thick.

For each sample, the medium sand was poured into a hole and mixed with epoxy. After the epoxy set, the blocks were cut into thin sections.

Fifteen well-core thin sections were cut and underwent a preliminary analysis by this author and are reported in Andersen et al. (in press). Modern stream sample thin sections were also cut as part of that effort. An additional twenty-four thin sections of medium sand from the wells, each containing multiple samples, were manufactured for this study. These were chosen by depth from the previously processed sand, such that there would be at least one from every stratigraphic sequence (C. Wentworth, personal communication, 2006) where possible. All well samples came from cores, and not every sequence in every well was cored; furthermore, some cores contained only fine material and did not produce medium sand. Therefore it was not possible to match a sample to each sequence in each well. No samples were taken from sequence 1 (Fig. 6). The MGCY and WLLO wells terminated in sequence 7. Beyond those limitations, sequence coverage was relatively complete, missing only sequence 4 in MGCY and CCOC. Although there was no proper sequence 9 (because the bottom of the sequence was not reached in any of the wells), that identifier was used for samples collected below sequence 8. See sample depths, along with sequence number, listed in Table 1.

Counting Methodology

Sand grains were counted using an adaptation of the Gazzi-Dickinson counting method (Dickinson, 1970). The standard Gazzi-Dickinson counting method would have

dictated proceeding in fixed steps along rows that were a fixed length apart, and whatever was located under the microscope cross-hairs would be counted. Row and step spacing would be based on the size of the sample, such that a desired number of points could be counted with relatively even coverage over the entire sample. This procedure would have worked poorly for the scattered sand grains in the stream and well samples, which had epoxy separating the sand grains. With this type of sample preparation, the standard procedure would lead to missing too many of the grains, or would lead to an attempt to count too many spaces between the grains.

TABLE 1. WELL SAMPLES WITH DEPTH AND STRATIGRAPHIC SEQUENCE.

CCOC		GUAD		MGCY		STPK		WLLO	
Depth (m)	Seq*	Depth (m)	Seq*	Depth (m)	Seq*	Depth (m)	Seq*	Depth (m)	Seq*
29.4	2	40.1	2	16.6	2	14.0	2	26.0	2
80.2	3	82.1	3	45.6	3	72.9	3	33.7	3
152.0	5	110.0	3	76.0	3	99.3	4	90.2	4
174.6	6	127.8	4	131.5	5	139.3	5	149.4	5
204.8	6	153.0	5	151.5	5	174.0	6	206.0	6
249.4	7	186.5	6	177.1	6	202.4	6	237.8	7
271.8	8	205.8	6	191.1	6	245.3	7		
307.3	9	246.9	7	217.4	7	281.0	8		
		281.9	8			304.0	9		

*Seq indicates stratigraphic sequence number.

The adaptation of the counting method used rows of fixed separation, but adapted the steps along each row to be 100 μ m from the leading edge of each grain as it was encountered in scanning along the row. Samples from different manufacturing runs were of different sizes, so row spacing was varied from 0.6 mm to 1.0 mm according to the size of the sample.

Although an adaptation of the counting method was used in the actual counting, the standard Gazzi-Dickinson method (Dickinson, 1970) was used to identify categories for counting three main grain types: quartz (Q), feldspar (F), and lithic fragments (L). The quartz grain type was further subdivided into monocrystalline and polycrystalline quartz (Qm and Qp), and the lithic fragments grain type was further subdivided into volcanic fragments (Lv), sedimentary fragments (Ls), and metamorphic fragments (Lm). Monomineralic grains other than quartz and feldspar were counted as accessories (A) and not used in analysis. Crystals within the sand (Qm, F, or A) larger than 62.5 μm (very fine sand) were counted as distinct crystals, not lithic fragments. The resulting counting categories used are shown in Table 2.

The polycrystalline quartz (Qp) grain type was further subdivided into chert/metachert and other Qp to isolate chert/metachert, because there are chert/metachert source rocks. Other polycrystalline quartz refers to a texture coarser than chert/metachert, but finer than very fine sand.

Lithic fragments were subdivided into Lv, Ls, and Lm, and further subdivided into source rock types with distinctive textural characteristics: siltstone, sandstone, argillite, graywacke, serpentinite, greenstone, (meta)-volcanic porphyry, and other metavolcanics. These source rocks are all present in the modern valley drainage. Lithic fragments that did not display any of these textures were categorized as other/unidentified Lm or other/unidentified L.

Qm, F, and A sand-sized crystals within lithic fragments were counted in terms of their host lithic fragment, as shown in Table 2; for example, the raw counts distinguish

TABLE 2. CATEGORIES COUNTED FOR WELL AND
STREAM SAMPLES.

Category	Subcategory
Accessories (A)	n/a
Qm	n/a
Qp	chert/metachert
Qp	other Qp
F	n/a
Lv	lithic only
Lv	Qm in Lv
Lv	F in Lv
Lv	A in Lv
Ls: siltstone	n/a
Ls: sandstone	lithic only
Ls: sandstone	Qm in sandstone
Ls: sandstone	F in sandstone
Ls: sandstone	A in sandstone
Lm: argillite	n/a
Lm: graywacke	lithic only
Lm: graywacke	Qm in graywacke
Lm: graywacke	F in graywacke
Lm: graywacke	A in graywacke
Lm: serpentinite	n/a
Lm: greenstone	lithic only
Lm: greenstone	F in greenstone
Lm: volcanic porphyry (vp)	lithic only
Lm: volcanic porphyry (vp)	Qm in vp
Lm: volcanic porphyry (vp)	F in vp
Lm: volcanic porphyry (vp)	A in vp
Lm: other metavolcanics (mv)	lithic only
Lm: other metavolcanics (mv)	Qm in other mv
Lm: other metavolcanics (mv)	F in other mv
Lm: other metavolcanics (mv)	A in other mv
Other or unidentified Lm	lithic only
Other or unidentified Lm	Qm in other Lm
Other or unidentified Lm	F in other Lm
Other or unidentified Lm	A in other Lm
Other or unidentified L	lithic only
Other or unidentified L	Qm in other L
Other or unidentified L	F in other L
Other or unidentified L	A in other L

between lithic graywacke, Qm in graywacke, F in graywacke, and A in graywacke. Counts were done this way because it was not known at the time whether amounts of Qm, F, and/or A in the lithic grains might be significant; as it turned out, the quantities of Qm, F, and A crystals in lithic grains were quite small. For analysis of the sand, however, all the quartz crystals in lithic fragments were lumped into one Qm category with the rest of counted Qm, and feldspars and accessories were handled similarly.

Depositional Environment Determination

The core log database (C. Wentworth, personal communication, 2010) described the cores from which the well samples were taken. Well samples taken from core intervals that were described as predominantly clay and silt were interpreted to have been interchannel facies deposited on the floodplain, whereas those taken from core intervals that were described to be predominantly sand and gravel were interpreted to have been deposited in a stream channel. Table 3 shows the depositional environment inferred for each well sample.

TABLE 3. WELL SAMPLES WITH DEPTH AND DEPOSITIONAL ENVIRONMENT.

CCOC		GUAD		MGCY		STPK		WLLO	
Depth (m)	Depositional Environment	Depth (m)	Depositional Environment	Depth (m)	Depositional Environment	Depth (m)	Depositional Environment	Depth (m)	Depositional Environment
29.4	Interchannel	40.1	Interchannel	16.6	Channel	14.0	Channel	26.0	Channel
80.2	Channel	82.1	Interchannel	45.6	Interchannel	72.9	Interchannel	33.7	Interchannel
152.0	Channel	110.0	Channel	76.0	Channel	99.3	Channel	90.2	Interchannel
174.6	Channel	127.8	Interchannel	131.5	Channel	139.3	Interchannel	149.4	Interchannel
204.8	Channel	153.0	Interchannel	151.5	Interchannel	174.0	Interchannel	206.0	Interchannel
249.4	Channel	186.5	Interchannel	177.1	Interchannel	202.4	Interchannel	237.8	Channel
271.8	Interchannel	205.8	Channel	191.1	Channel	245.3	Interchannel		
307.3	Channel	246.9	Channel	217.4	Interchannel	281.0	Interchannel		
		281.9	Interchannel			304.0	Channel		

RESULTS

Compositionally, both the modern stream samples and the well samples are dominated by rock fragments, and to a lesser extent, quartz. They are low in feldspar. Notable rock fragments include argillite, graywacke, serpentinite, metavolcanics, and chert. Other types of rock fragments, such as siltstone, sandstone, volcanics, and volcanic porphyry, are rare or absent in the sand samples. Depending on the sample, between 11% and 40% of the rock fragments could not be identified. Detailed composition data are included in Appendix A.

Table 4 shows the range and mean proportions of the major grain types observed in the samples from the wells with the exclusion of the WLLO sample from 237.8m. That particular sample is significantly different from all the others, having been taken from the last core before the drill hit serpentinite bedrock; it consists of nearly 99% lithic fragments, of which 73% are serpentinite. Because the sample composition is so significantly different from the other samples, it would skew the representation of several compositional ranges.

In Table 4, chert and metachert are combined, because no real difference was observed between the two in thin sections of sand samples from either modern streams or well cores. In the rest of this paper, unless a distinction is made, the term “chert” will be used to refer to both chert and metachert.

TABLE 4. RANGE AND MEAN PROPORTIONS OF MAJOR COMPONENTS OF SAMPLES FROM THE WELLS.*

Component	Minimum (%)	Mean (%)	Maximum (%)
Monocrystalline quartz	15.9	33.8	53.4
Chert and Metachert	0.0	1.0	3.4
Other Polycrystalline Quartz	2.2	8.0	19.7
Feldspar	0.3	3.1	8.1
All Lithic Fragments	34.3	54.0	76.5
Argillite	7.8	18.9	36.5
Graywacke	0.3	3.5	10.2
Metavolcanics	0.6	3.3	10.4
Serpentinite	0.0	5.2	20.6
Unidentified Lithic Fragments	10.9	22.2	39.9

* The WLLO 237.8m sample is excluded.

QFL and QmFLt Analysis

As a first step in analyzing the composition of the sand, QFL and QmFLt ternary diagrams have been generated for the modern stream samples, for each of the wells, and for all the wells together. These diagrams show the relative proportions of quartz, feldspar, and lithic fragments in the samples. By convention (Dickinson, 1970), these diagrams are defined by their poles: all quartz (monocrystalline and polycrystalline) is plotted at the Q pole, feldspar is plotted at the F pole, and lithic fragments excluding polycrystalline quartz are plotted at the L pole to create QFL diagrams. For QmFLt diagrams, only monocrystalline quartz is plotted at the Qm pole, and the Lt pole is defined to include polycrystalline quartz along with lithic fragments.

These diagrams are shown in Figures 7 through 14. Figure 7 shows all of the stream samples together on one pair of diagrams. Figures 8 through 12 show the diagram pairs for each individual well, distinguishing samples by depositional environment.

QFL Diagram for Streams

QmFLt Diagram for Streams

Figure 7. QFL and QmFLt diagrams for the modern stream samples. LGC = Los Gatos Creek; PEC = Penitencia Creek; SAC = Saratoga Creek; THC = Thompson Creek.

QFL Diagram for CCOC

QmFLt Diagram for CCOC

Figure 8. QFL and QmFLt diagrams for CCOC well. Channel samples were deposited in the stream channel; floodplain samples were interchannel deposits on the floodplain.

QFL Diagram for GUAD

QmFLt Diagram for GUAD

Figure 9. QFL and QmFLt diagrams for GUAD well. Channel samples were deposited in the stream channel; floodplain samples were interchannel deposits on the floodplain.

Figure 10. QFL and QmFLt diagrams for MGCY well. Channel samples were deposited in the stream channel; floodplain samples were interchannel deposits on the floodplain.

Figure 11. QFL and QmFLt diagrams for STPK well. Channel samples were deposited in the stream channel; floodplain samples were interchannel deposits on the floodplain.

QFL Diagram for WLOO

QmFLt Diagram for WLOO

Figure 12. QFL and QmFLt diagrams for WLOO well. Channel samples were deposited in the stream channel; floodplain samples were interchannel deposits on the floodplain.

Figure 13. QFL and QmFLt diagrams for all wells. See caption of Figure 2 for names of wells. Note the relatively lithic character of CCOC.

QFL Diagram for All Wells

QmFLt Diagram for All Wells

Figure 14. QFL and QmFLt diagrams for all wells, only distinguishing between channel and floodplain deposits. Channel samples were deposited in the stream channel; floodplain samples were interchannel deposits on the floodplain. Note that the apparent trend of the channel deposits to be more lithic than the floodplain deposits is clearest in these diagrams.

Figure 13 shows the well samples together, sorted by well. Figure 14 shows the well samples together, but distinguished by depositional environment.

The lithic character of the samples is clearly shown in the QFL and QmFLt diagrams, with the distinction between them being the incorporation of polycrystalline quartz into Lt. The figures show that sand from all of the wells is very similar in composition. The small amounts of feldspar in the samples, generally less than 8%, cause the plots to fairly closely parallel the Q-L and Qm-Lt sides of the diagram. With the exception of the WLLO 237.8m sample, which is almost entirely lithic, all the samples can best be described as lithic with some quartz component. The amount of quartz present seems to be somewhat correlated with depositional environment in some wells, although there is considerable overlap.

Depositional environment was inferred from the well core descriptions of Tinsley (C. Wentworth, personal communication, 2010). In the samples from CCOC (Fig. 8) and to a lesser extent MGCY (Fig. 10), which show stream channel deposits versus floodplain deposits, the samples deposited on the floodplain tend to be slightly more quartz rich than those deposited in stream channels. This trend is not observed in the other wells. However, the CCOC and MGCY sample sets sufficiently influence the graph of Figure 14, showing stream channel deposits versus floodplain deposits for all the wells, that there appears to be a trend in the aggregate which is not supported by the individual well graphs (Figs. 7 through 12).

Depth Profiles

Figures 15 through 24 show depth profiles for various components of the well sand samples. These profiles show each sample depth, stratigraphic sequence as determined by C. Wentworth (personal communication, 2006), and whether the sample came from a floodplain or a stream channel. These components are all shown as percentages of total grains. Figures 15 and 16 show depth profiles for chert and feldspar respectively. Figures 17 and 18 show depth profiles for the lithics as a whole, both with and without polycrystalline quartz. Figures 19 through 22 show depth profiles for lithics of interest: serpentinite, metavolcanics, argillite, and graywacke. Figure 23 shows the depth profile of combined argillite and graywacke. This combination was chosen for study because the two rock types commonly are found together, especially on the east side of the valley. As a component of medium sand, graywacke is probably undercounted, because that rock type can be the source of quartz and feldspar grains.

Figure 19, serpentinite, does not include the WLL0 237.8m sample, which is 73% serpentinite, in order that the WLL0 graph may have the same X-axis scale as the other wells.

Finally, Figure 24 shows depth profiles for unknown metamorphic lithics, which are the most problematic component. In general these have unidentifiable source rocks because they are either too fine-grained, naturally stained dark brown, or thoroughly chloritized, and could come from more than one source rock type. Also, almost all unknown lithic grains were identified as metamorphic because of fine grain size,

Figure 15. Depth profiles for chert grains as a percent of total grains. Squares represent channel deposits; diamonds represent floodplain deposits. Stratigraphic sequence boundaries are shown on the right of each graph. See caption of Figure 2 for names of wells.

Figure 16. Depth profiles for feldspar grains as a percent of total grains. Squares represent channel deposits; diamonds represent floodplain deposits. Stratigraphic sequence boundaries are shown on the right of each graph. See caption of Figure 2 for names of wells.

Figure 17. Depth profiles for all lithic grains (L) as a percent of total grains. Squares represent channel deposits; diamonds represent floodplain deposits. Stratigraphic sequence boundaries are shown on the right of each graph. See caption of Figure 2 for names of wells.

Figure 18. Depth profiles for all lithic grains including chert (Lt) as a percent of total grains. Squares represent channel deposits; diamonds represent floodplain deposits. Stratigraphic sequence boundaries are shown on the right of each graph. See caption of Figure 2 for names of wells.

Figure 19. Depth profiles for serpentinite grains as a percent of total grains. Squares represent channel deposits; diamonds represent floodplain deposits. Stratigraphic sequence boundaries are shown on the right of each graph. WLLO 237.8m serpentinite (72.9% of total grains) is not plotted so that the scales of these five graphs are consistent. See caption of Figure 2 for names of wells.

Figure 20. Depth profiles for metavolcanic grains as a percent of total grains. Squares represent channel deposits; diamonds represent floodplain deposits. Stratigraphic sequence boundaries are shown on the right of each graph. See caption of Figure 2 for names of wells.

Figure 21. Depth profiles for argillite grains as a percent of total grains. Squares represent channel deposits; diamonds represent floodplain deposits. Stratigraphic sequence boundaries are shown on the right of each graph. See caption of Figure 2 for names of wells.

Figure 22. Depth profiles for graywacke grains as a percent of total grains. Squares represent channel deposits; diamonds represent floodplain deposits. Stratigraphic sequence boundaries are shown on the right of each graph. See caption of Figure 2 for names of wells.

Figure 23. Depth profiles for graywacke grains plus argillite grains as a percent of total grains. Squares represent channel deposits; diamonds represent floodplain deposits. Stratigraphic sequence boundaries are shown on the right of each graph. See caption of Figure 2 for names of wells.

Figure 24. Depth profiles for unknown metamorphic lithic grains as a percent of total grains. Squares represent channel deposits; diamonds represent floodplain deposits. Stratigraphic sequence boundaries are shown on the right of each graph. See caption of Figure 2 for names of wells.

chloritization, or the presence of very fine-grained minerals with micaceous birefringence. Unknown metamorphic lithics probably include greenstone, metaclaystone, matrix material from volcanic porphyry, and other fine-grained rock fragments.

In general, very few trends are evident in the depth profiles. In WLLO and GUAD, metavolcanics in sequence 6 are fairly high at 8% to 9% compared to samples in the other wells, which are 6% or less (Fig. 20). WLLO also shows a marked increase in metavolcanics in sequence 4, greater than 10%, compared to the other wells, at 3% or less. Samples from sequence 2 and the upper part of sequence 3 tend to be slightly less lithic in most wells than are samples from deeper sequences, as shown in Figures 17 and 18. From these figures, it is clear that CCOC generally is the most consistently lithic-rich of the wells, especially below sequence 2. WLLO seems to have the least variation in lithic character as a function of depth, with the exception of the WLLO 237.8m sample.

One definite trend is shown in Figure 19. With the exception of the WLLO 237.8m sample, the eastern wells CCOC and GUAD are in general richer in serpentinite, with a few exceptions, than are the western wells MGCY, STPK, and WLLO.

Stream Samples

Compositions of sand samples collected downstream of each of the modern stream drainages (Fig. 5) are shown in Figures 25 through 28. Quartz (Qm and Qp), argillite, graywacke, and unknown lithics are relatively dominant components in all the

Figure 25. Los Gatos Creek sand sample composition.

Figure 26. Penitencia Creek sand sample composition.

Figure 27. Saratoga Creek sand sample composition.

Figure 28. Thompson Creek sand sample composition.

stream samples; each of these components is generally represented at more than 10% of the total for each stream. Varying amounts of chert, feldspar, and serpentinite are also present in the streams, though these components never contribute more than 3% of the total for each stream. Metavolcanics are somewhat abundant, contributing between about 4% and 9% depending on the stream. Interestingly, siltstone, sandstone, and volcanic porphyry, which are exceedingly rare in the well samples, do show up in small amounts in the stream samples, never contributing more than 4%.

Diagnostic Accessory Minerals

While they were being counted, sand grains from both modern streams and wells were studied to identify the presence of diagnostic accessory minerals, that is, those minerals which are particularly good indicators of sand source locations. Particular effort was made to find instances of pumpellyite, lawsonite, jadeite, blue amphibole, and chrome spinel. Of these, only one instance of blue amphibole was observed in the Penitencia Creek sample, and none of the others were observed. Blue amphibole and chrome spinel were easily recognized in thin section, and jadeite was moderately easy to identify in thin section, but the other diagnostic accessory minerals tended to be difficult to identify.

INTERPRETATION

Comparison of Stream Samples with Source Rocks in Drainages

Source rocks in each of the four drainages where stream samples were taken were analyzed to determine the compositions of the bedrock in the drainages. This analysis was done by using the ArcGIS computer program (Environmental Systems Research Institute, Inc., 2008) to compute a spatial intersection between the watershed boundaries (Santa Clara Valley Water District, 1996) and the geologic maps of the area (Brabb et al., 1997; Wentworth et al., 1998; Brabb et al., 2000).

Composition of bedrock units in the drainages are shown in Figures 29 through 32. These compositions show considerable variation from drainage to drainage. In each of these figures, Subfigure A shows the composition by percentage area of mapped major rock type. This graph shows the complete mapping of the drainage, and the sum of all the graphed items is 100%. Because graywacke and argillite commonly are combined in the same geologic map unit, as are siltstone and mudstone, those rock pairings are shown as combined units. “Conglomerate” includes both matrix-supported conglomerate and clast-supported gravel. The “Other” category includes silica-carbonate rock, limestone, and volcanic and plutonic rocks, which account for very small portions of the drainages and are not represented at all in the sand samples.

In Figures 29 through 32, Subfigure B shows the percentage of drainage basin areas that have “minor” inclusions of certain rock types; for example, areas mapped as

A. Los Gatos Creek Drainage Composition

B. Los Gatos Creek Minor Components

Figure 29. Los Gatos Creek drainage bedrock composition. A. Composition of bedrock by rock unit type. B. Portions of bedrock containing minor (too small to map) amounts of listed components.

A. Penitencia Creek Drainage Composition

B. Penitencia Creek Minor Components

Figure 30. Penitencia Creek drainage bedrock composition. A. Composition of bedrock by rock unit type. B. Portions of bedrock containing minor (too small to map) amounts of listed components.

A. Saratoga Creek Drainage Composition

B. Saratoga Creek Minor Components

Figure 31. Saratoga Creek drainage bedrock composition. A. Composition of bedrock by rock unit type. B. Portions of bedrock containing minor (too small to map) amounts of listed components.

A. Thompson Creek Drainage Composition

B. Thompson Creek Minor Components

Figure 32. Thompson Creek drainage bedrock composition. A. Composition of bedrock by rock unit type. B. Portions of bedrock containing minor (too small to map) amounts of listed components.

argillite, graywacke, or *mélange* commonly have small outcrops of chert and/or metavolcanics that are too small to be mapped, although they are mentioned in the descriptions of the units that accompany the geologic maps. Because these areas may make minor contributions to more than one major rock type, the sum of all the graphed items is meaningless. Because these minor inclusions are too small to be mapped, their frequencies of occurrence are unknown and are likely to be quite variable from one drainage to the next even within the same major rock type; they definitely complicate the association of drainage composition with sand sample composition.

In general, the compositions of the stream samples are similar to the compositions of the drainages, though there are a few interesting results to note. Monocrystalline quartz (Qm) is common in the bedrock of the drainages, primarily occurring in graywacke and sandstone. Non-chert polycrystalline quartz (other Qp) has quartz crystals with randomly varying extinction angles, with crystal sizes consistent with vein quartz. Quartz veins are most commonly found in Franciscan Complex rocks like graywacke, argillite, and *mélange*, though they can be found in other rock types. Although the Saratoga Creek stream sample (Fig. 27) has 10% non-chert Qp, there are few Franciscan Complex rocks in the drainage.

The Saratoga Creek stream sample (Fig. 27) also has quite a lot of argillite (22%) and graywacke (9%), although argillite, graywacke, and *mélange* together only comprise about 24% of the drainage. In the other drainages studied, areal distribution of argillite, graywacke and *mélange* correlate well with the composition of the sand samples. The Saratoga Creek drainage (Fig. 31) also has by far the largest areal exposure of arkosic

sandstone (43%), and the associated sand sample (Fig. 27) has the largest feldspar content (4%), suggesting that arkosic sandstone is an important source for feldspar.

Associating drainage composition with sand sample composition becomes extremely difficult when considering rock types that occur as components of units exposed over large areas. The Thompson Creek drainage (Fig. 32) has no major metavolcanic units, 59% of its area is covered by rock units that have minor exposures of metavolcanics, and the sand sample contains 9% metavolcanics (Fig. 28). Note that many of the metavolcanics on Figure 32 are clasts of porphyries in conglomerate (Seiders and Blome, 1984), though these are not included in the mapped rock descriptions of Wentworth et al. (1998). The Penitencia Creek drainage (Fig. 30) has a trace of mapped serpentinite, 21% of the area is covered by rock units that have small outcrops of serpentinite, and the corresponding sand sample (Fig. 26) is 2% serpentinite. By comparison, the Thompson Creek drainage (Fig. 32) has the largest quantity of mapped serpentinite of the four drainages (6%), but the sand sample contains less than 1% serpentinite (Fig. 28).

Comparison of Well Samples with Modern Source Rock Distributions

Major contributors to the sediment can be recognized within modern source rock distributions. Although those source rocks have been affected by both uplift and erosion since 800 ka, it seems reasonable to assume that the modern distributions bear some rough resemblance to earlier ones. Figure 33 shows the geology of the Santa Clara

Source Rocks By Rock Type

Figure 33. Simplified geologic map, organized by rock type. Map shows major source units in the mountains surrounding the Santa Clara Valley. Adapted from Brabb et al. (1997), Wentworth et al. (1998), Brabb et al. (2000), and Santa Clara Valley Water District (2004). See caption of Figure 2 for names of wells.

Valley and its surrounding mountains in terms of modern source rock types rather than named geologic formations. In simplifying the maps of Brabb et al. (1997), Wentworth et al. (1998), and Brabb et al. (2000) to create Figure 33, the goal was to identify rock types that had differing characteristic compositions that might be positively associated with lithics counted in the well sands. It is useful to look at some of these rock types in more depth, and Figures 34 through 38 were created from the same geologic maps, but with less simplification. On several of these figures, “minor” areas of certain rock types are shown. These are areas which are too small to be mapped units on the parent maps of Brabb et al. (1997), Wentworth et al. (1998), and Brabb et al. (2000), but are mentioned as constituents of mapped units in the text descriptions of the maps. See the figure captions for more details.

Monocrystalline quartz and, to a lesser extent, polycrystalline quartz other than chert are significant components of the well sand samples, ranging up to 53% and 20%, respectively. As discussed earlier, potential sources of medium sand-sized monocrystalline quartz grains include graywacke and sandstone. Figure 33 shows distributions of combined argillite and graywacke, as well as *mélange*, arkosic sandstones, and other sandstones; Figure 34 breaks down the argillite and graywacke into finer units. *Mélange* contains blocks of graywacke, making it an additional source of monocrystalline quartz. Both arkosic and non-arkosic sandstones are significant sources of quartz; Figure 35 shows the main sandstone units from Figure 33 as well as secondary sandstone sources, which are typically conglomerates or siltstones and mudstones with sandy lenses or sections. Polycrystalline quartz grains from the wells most commonly

Argillite, Graywacke, and Mélangé

- Wells
- ⬭ Water bodies
- Streams
- Quaternary alluvium
- Argillite with some graywacke
- Argillite and graywacke
- Graywacke with some argillite
- Graywacke
- Mélangé
- Other bedrock

Figure 34. Argillite, graywacke and mélangé source units in the mountains surrounding the Santa Clara Valley. Map adapted from Brabb et al. (1997), Wentworth et al. (1998), Brabb et al. (2000), and Santa Clara Valley Water District (2004). See caption of Figure 2 for names of wells.

Sandstones

- Wells
- ⬭ Water bodies
- Streams
- Quaternary alluvium
- Arkosic sandstone
- Minor arkosic sandstone
- Other sandstone
- Minor other sandstone
- Other bedrock

Figure 35. Sandstone source units in the mountains surrounding the Santa Clara Valley. 'Minor' sandstones are either areas where sandstone outcrops are too small to map, or areas where sandstones are mixed with other units. Map adapted from Brabb et al. (1997), Wentworth et al. (1998), Brabb et al. (2000), and Santa Clara Valley Water District (2004). See caption of Figure 2 for names of wells.

resemble vein quartz, which is common throughout most lithologies. Thus, quartz sources are ubiquitous around the valley.

Less than 4% of chert was found in the sand samples, which is consistent with the distribution of chert around the valley as shown in Figure 36. Both the Claremont and Franciscan cherts crop out in relatively small mappable units on the east side of the valley. Although Figure 36 shows a large area of secondary chert sources, these are small uncommon outcrops of Franciscan chert in argillite, graywacke, or *mélange* units or low-frequency components of Great Valley Group or Plio-Pleistocene sandstones and conglomerates (Fig. 4). Chert is relatively rare all around the valley. The depth profiles of Figure 15 show apparently trendless variation with depth, consistent with the exposure and erosion of small, localized sources.

Although there is more feldspar than chert, feldspar is still a very minor constituent of the well sands, comprising 8% or less of total composition of any sample. As the depth profiles of Figure 16 show, there is no clear temporal or spatial distribution pattern for feldspar. The most likely candidates for feldspar source rocks, arkosic sandstones, occur primarily on the west and south sides of the valley, as shown in Figure 35. Graywacke, by itself or in *mélange*, may also be a source rock for feldspar, and it occurs all around the valley as shown in Figure 34. Gabbro and volcanics, especially as found in ophiolite and as clasts in conglomerates, may be other sources of feldspar.

Argillite, at up to 37%, is a significant component of the well sands, whereas graywacke, at 10% or less, is not. This relative abundance cannot be considered reflective of the relative amounts of argillite and graywacke source rocks, however.

Chert

- Wells
- Water bodies
- Streams
- Quaternary alluvium
- Franciscan chert
- Claremont chert
- Minor chert
- Other bedrock

Figure 36. Chert source units in the mountains surrounding the Santa Clara Valley. 'Minor' chert refers to either units with small, unmapped beds or outcrops of chert, or to conglomerate/gravel units that contain chert clasts. Map adapted from Brabb et al. (1997), Wentworth et al. (1998), Brabb et al. (2000), and Santa Clara Valley Water District (2004). See caption of Figure 2 for names of wells.

Because graywacke constituent grains are commonly at least as large as medium sand, the actual contribution of the rock type to the sand samples is bound to be significantly undercounted in the lithic percentages. Argillite, like graywacke, occurs all around the Santa Clara Valley.

Metavolcanics are another minor component of the well sands, ranging up to above 10%, which is a somewhat surprising observation given their distribution in the mountains surrounding the Santa Clara valley, as shown in Figure 37. Admittedly, the major metavolcanic outcrop area is much smaller than the minor metavolcanic area, but the rocks within the latter are small and very widely scattered outcrops or minor constituents of conglomerates and sandstones. Still, the paucity of metavolcanic sand grains in the wells is surprising. It is likely that many metavolcanic grains were too fine-grained to be recognized and were counted as unknown metamorphic lithics.

Serpentinite is another minor constituent of the well sands, with the exception of the WLLO 237.8m sample. In STPK, WLLO, and MGCY, there appears to be a more significant occurrence of serpentinite in sequences 6 and 7 than in shallower sequences (Fig. 19); up to 21% for STPK in sequence 7. The eastern wells, GUAD and CCOC, do not show significantly more serpentinite in lower than in upper sequences. They do, however, contain generally higher serpentinite contributions, except in sequence 2 and except for STPK in sequence 7 and MGCY in sequences 6 and 7, than the western wells. Serpentinite is currently exposed in the southeast of the valley, as shown in Figure 38, and more serpentinite was undoubtedly exposed earlier, because a serpentinite sheet runs

Metavolcanics and Volcanics

Figure 37. Metavolcanic and volcanic source units in the mountains surrounding the Santa Clara Valley. 'Mixed' metavolcanics are both mafic and intermediate/felsic sources. 'Minor' refers to areas having outcrops that are too small to map. Int: intermediate. Map adapted from Brabb et al. (1997), Wentworth et al. (1998), Brabb et al. (2000), and Santa Clara Valley Water District (2004). See caption of Figure 2 for names of wells.

Serpentinite

● Wells	■ Serpentinite
☞ Water bodies	■ Minor serpentinite
— Streams	▨ Subsurface serpentinite sheet
■ Quaternary alluvium	■ Other bedrock

Figure 38. Serpentinite source units in the mountains surrounding the Santa Clara Valley, along with the approximate extent of a subsurface serpentinite body underlying the valley. ‘Minor’ serpentinite refers to units that may have small, unmapped serpentinite lenses. Bedrock, Quaternary alluvium, and streams map adapted from Brabb et al. (1997), Wentworth et al. (1998), Brabb et al. (2000), and Santa Clara Valley Water District (2004). Extent of subsurface serpentinite body adapted from Wentworth et al. (2010). See caption of Figure 2 for names of wells.

under the valley along the buried basement high between the Evergreen and Cupertino basins (Wentworth et al., 2010; Figs. 38, 3).

DISCUSSION

Comparison of Compositions of Sand and Gravel Well Samples

Andersen et al. (in press) studied medium-pebble gravel collected from the wells. These gravel samples are as extensive as the sand samples used in this study, except for GUAD, where only two gravel samples were collected, and MGCY and STPK, where gravel was not recovered below 125 m and 210 m, respectively. It is useful to compare percentages of some of the more common components of the gravel and the sand. For this comparison it is helpful to use sequence profiles. In these, component percentage is plotted against depth normalized to stratigraphic sequence. Note that in these figures, the lines connecting the samples are intended to make visualization of the graph easier, and are not intended as interpolation between the data points.

Figures 39 through 41 show sequence profiles for argillite, graywacke, and a combination of the two, in gravel and sand. Note the differing scales on the graphs. The sand contains up to 36% argillite but only as much as 10% graywacke. The gravel, on the other hand, contains no more than 12% argillite, but between 34% and 73% graywacke. This disparity is partly caused by the undercounting of graywacke sand grains discussed earlier; any graywacke grain at least as coarse as medium sand will appear to be not graywacke, but a constituent of graywacke. For example, a medium-sand-size quartz crystal that originally came from graywacke will be counted as Qm. Indeed, much of the quartz in the sand may have come from graywacke. Argillite, on the

Figure 39. Sequence profiles for argillite in gravel and sand samples. A. Gravel. B. Sand. All are expressed as percentages of total grains. Gravel data were taken from Andersen et al. (in press). The lines connecting the samples are intended to make visualization of the graph easier, and are not intended as interpolation between the data points. The vertical scale shows sequences, not depths; depth data for each well were independently scaled within each sequence. Sequences are labeled at the top. Note that the horizontal scales for the graphs of the gravel samples and those of the sand samples do not match. See text for a discussion of the differences. See caption of Figure 2 for names of wells.

Figure 40. Sequence profiles for graywacke in gravel and sand samples. A. Gravel. B. Sand. All are expressed as percentages of total grains. Gravel data were taken from Andersen et al. (in press). The lines connecting the samples are intended to make visualization of the graph easier, and are not intended as interpolation between the data points. The vertical scale shows sequences, not depths; depth data for each well were independently scaled within each sequence. Sequences are labeled at the top. Note that the horizontal scales for the graphs of the gravel samples and those of the sand samples do not match. See text for a discussion of the differences. See caption of Figure 2 for names of wells.

Figure 41. Sequence profiles for combined argillite and graywacke in gravel and sand samples. A. Gravel. B. Sand. All are expressed as percentages of total grains. Gravel data were taken from Andersen et al. (in press). The lines connecting the samples are intended to make visualization of the graph easier, and are not intended as interpolation between the data points. The vertical scale shows sequences, not depths; depth data for each well were independently scaled within each sequence. Sequences are labeled at the top. Note that the horizontal scales for the graphs of the gravel samples and those of the sand samples do not match. See text for a discussion of the differences. See caption of Figure 2 for names of wells.

other hand, being metamorphosed siltstone and mudstone, is still a polycrystalline rock fragment as a medium sand grain. The total percentages of argillite plus graywacke in sand, however, are still noticeably lower than those in gravel; 9% to 40% for sand vs. 39% to 77% for gravel. It is likely that argillite accounts for some significant percentage of metamorphic lithic unknowns in the sand, while graywacke contributed quartz and feldspar sand grains.

Figure 42 shows metavolcanic percentages in gravel and sand. The average percentage of the metavolcanics in gravel is about three times greater than that in sand, for two reasons. First, most metavolcanics in the mountains surrounding the valley are greenstones or other metamorphosed hard volcanic rocks; relatively few are metatuffs. Greenstones and other hard metavolcanics are fairly erosion-resistant rocks with irregular, widely-spaced cleavage/fracture patterns, and might preferentially erode into gravel rather than sand at the transport distances involved. Second, recognizing metavolcanics in medium sand is somewhat difficult, and it is likely that metavolcanics account for some significant percentage of metamorphic lithic unknowns in the sand.

Interestingly, metavolcanic percentages in the gravel (Fig. 42-A) gradually increase with increasing depth, whereas graywacke percentages in the gravel (Fig. 40-A) gradually decrease with increasing depth. Referring again to Figure 42, metavolcanics in the gravel are generally more abundant in CCOC than in the other wells, ranging up to 30%, but tend to also be abundant in WLLO in the lower sequences, ranging up to 28%. In the sand, however, metavolcanics are no more abundant in CCOC than in the other wells; instead, GUAD and WLLO show higher percentages of metavolcanics than the

Figure 42. Sequence profiles for metavolcanic clasts in gravel and sand samples. A. Gravel. B. Sand. All are expressed as percentages of total grains. Gravel data were taken from Andersen et al. (in press). The lines connecting the samples are intended to make visualization of the graph easier, and are not intended as interpolation between the data points. The vertical scale shows sequences, not depths; depth data for each well were independently scaled within each sequence. Sequences are labeled at the top. Note that the horizontal scales for the graphs of the gravel samples and those of the sand samples do not match. See text for a discussion of the differences. See caption of Figure 2 for names of wells.

other wells in sequence 6 (8% and 9% respectively), and WLLO again shows a higher percentage than the other wells in sequence 4, at 11%.

Figure 43 shows chert percentages in the gravel and the sand. Overall, the gravel samples contain higher percentages of chert than the sand samples, ranging up to 10% versus up to a little more than 3% respectively. This percentage disparity is more difficult to explain than the disparity in metavolcanics, because chert is commonly thin-bedded and finely fractured in outcrop; however, once weathered from the outcrop, it does tend to resist abrasion. This suggests it should produce both gravel and sand during weathering. Percentages of chert in the gravel in the wells MGCY, STPK, and GUAD are in the same range as percentages of chert in the sand, less than 4%. The chert percentages in the gravel in CCOC are relatively high throughout the sequences, mostly ranging between 5% and 9%, whereas chert percentages in the gravel in WLLO are high in the lower sequences generally, ranging up to 10%, although they drop off near the serpentinite at the bottom of the well in sequence 7. Chert abundance in the sand in WLLO seems to follow the same trend as chert abundance in the gravel in WLLO, but the other sand samples show no clear trend. Note that most of the chert found in the gravel was Franciscan (radiolarian) chert; only eight clasts in the gravel were Claremont (laminated) chert, and all of these but one were found either in CCOC or GUAD, the wells nearest the Claremont chert mapped in the Diablo Range. The remaining Claremont chert clast was found in WLLO in sequence 5, but its identification is somewhat suspect. The source type of the chert in the sand was not determined.

Figure 43. Sequence profiles for chert clasts in gravel and sand samples. A. Gravel B. Sand. All are expressed as percentages of total grains. Gravel data were taken from Andersen et al. (in press). The lines connecting the samples are intended to make visualization of the graph easier, and are not intended as interpolation between the data points. The vertical scale shows sequences, not depths; depth data for each well were independently scaled within each sequence. Sequences are labeled at the top. Note that the horizontal scales for the graphs of the gravel samples and those of the sand samples do not match. See text for a discussion of the differences. See caption of Figure 2 for names of wells.

Figure 44 shows serpentinite clast percentages in the gravel and the sand. As in the depth profile of Figure 19, the WLLO 237.8m sample is omitted from Figure 44-B in order that the rest of the samples not be indistinguishably condensed against the Y-axis. Here the sand samples from CCOC and GUAD are different from samples in the other wells, as noted in the discussion of Figure 19; CCOC and GUAD generally have more serpentinite in the sand than the western wells, mostly ranging from 5% to 15% versus generally less than 5% for the western wells. Exceptions to this are STPK, which shows a significant increase in sequence 7 (21%), and MGCY, which shows a lesser, but still significant, increase in sequence 6 (9%). In the gravel, serpentinite abundance is low in CCOC, at less than 2%, and there are not enough data to see a trend in GUAD. Oddly enough, serpentinite abundance in the gravel peaks in WLLO in sequence 6 (6%) and drops in sequence 7 (3%); this is surprising, given that the WLLO sequence 7 sand sample is 73% serpentinite and was taken just above serpentinite bedrock.

Over the distances of valley sediment transport, it may be that serpentinite preferentially weathers to sand-size grains rather than gravel-size grains, and this may explain the difference in the serpentinite percentages in gravel vs. sand. Serpentinite also is sufficiently fragile that it may have been preferentially broken by the drill bit when the wells were being drilled, artificially reducing the amount of serpentinite pebbles.

Figure 44. Sequence profiles for serpentinite clasts in gravel and sand samples A. Gravel. B. Sand. All are expressed as percentages of total grains. Gravel data were taken from Andersen et al. (in press). In the sand, WLLO 237.8m serpentinite (72.9% of total grains) is not plotted so that the scale of the graph is adequate to show the rest of the samples clearly. The lines connecting the samples are intended to make visualization of the graph easier, and are not intended as interpolation between the data points. The vertical scale shows sequences, not depths; depth data for each well were independently scaled within each sequence. Sequences are labeled at the top. Note that the horizontal scales for the graphs of the gravel samples and those of the sand samples do not match. See text for a discussion of the differences. See caption of Figure 2 for names of wells.

Heavy Minerals in Fine Sand

Andersen et al. (in press) also studied heavy minerals extracted from fine sand in the wells and intensively studied chrome spinel and blue amphibole. Small but significant amounts of these minerals were found. Data from Andersen et al. (in press) were used to create the sequence profiles shown in Figure 45.

Chrome spinel is an accessory mineral associated with ultramafic rocks such as serpentinite, and thus might be considered a rough proxy for serpentinite. As shown in Figure 45-A, the highest abundance of chrome spinel in the heavy minerals is in sequence 7 at the bottom of the WLLO well, just above serpentinite bedrock. Chrome spinel also is abundant in MGCY near the top of sequence 5, but there is no similar high concentration of serpentinite in the medium sand from the same sample (Fig. 44-B). Also, the graphs of the chrome spinel and serpentinite in sand in MGCY show that the contributions trend opposite each other in sequence 6. Finally, the notable abundance of serpentinite in sand in STPK in sequence 7, and the overall greater abundance of serpentinite in sand in CCOC and GUAD, are not mirrored in the data for chrome spinel in the heavy minerals. These discrepancies between relatively high and low percentages of chrome spinel in the heavy mineral fine sand fraction vs. serpentinite in medium sand suggest that chrome spinel is not necessarily a good proxy for the serpentinite sources surrounding the Santa Clara Valley. Although serpentinite is the only rock type around the valley associated with chrome spinel, the amount of chrome spinel in the serpentinite may be highly variable, based on these data.

**A. Chrome Spinel, %
(fine sand heavy minerals)**

**B. Blue Amphibole, %
(fine sand heavy minerals)**

Figure 45. Sequence profiles for heavy minerals in fine sand. Percentages are of total heavy minerals. A. Chrome spinel. B. Blue Amphibole. Data were taken from Andersen et al. (in press). The lines connecting the samples are intended to make visualization of the graph easier, and are not intended as interpolation between the data points. The vertical scale shows sequences, not depths; depth data for each well were independently scaled within each sequence. Sequences are labeled at the top. See caption of Figure 2 for names of wells.

No blue amphibole minerals were observed in the medium sand from the wells. The blue amphibole in the heavy mineral fraction of the fine sand, however, is notable for having significant amounts in some samples in all the wells (nearly 8%) in sequences 6 through 8, and 10% and 12% respectively in the CCOC samples in sequence 3 (Fig. 45-B). Blue amphibole in the areas around the Santa Clara Valley occurs in blueschist, commonly found in *mélange*, metabasalt, and graywacke. These data suggest that there were blueschist sources for all the wells at various times during deposition of the deeper sequences, and there was a definite blueschist source for CCOC in sequence 3.

Provenance and Implications for Evolution of the Santa Clara Valley

Tracing the sand and gravel back to their sources has implications for the evolution of the Santa Clara Valley. First, it is unlikely that much of the sand or gravel came from the Diablo Range to the east of the valley. The relatively high levels of metavolcanics and the general lack of Claremont chert in gravel in the wells, despite the finding of a few Claremont chert pebbles and some blue amphibole in the heavy minerals in CCOC sequence 3, suggest that very little of the gravel came from the east, which has at least some Claremont chert but very few metavolcanics. It is possible that some of the sand in CCOC may have come from the east, but it seems more likely in this setting that gravel and sand would have followed the same drainages. It is possible that some of the sediment in GUAD came from the east. It is extremely unlikely that any of the sediment in the other wells came from the east. Their composition suggests that the basement high

represented an obstacle to sediment flow from that direction during deposition of the lower sequences; later, after the basement high was covered, the axial drainage of the valley was east of them.

The basement high in the center of the Santa Clara Valley was not always buried; Andersen et al. (in press) suggested that it was once a major contributor to the sediment of the valley. A rough model of this exposed basement high can be constructed, subject to various constraints. Figure 46 shows these constraints, including a map distinguishing ages of alluvial bodies (Witter et al., 2006), along with a possible reconstruction of the basement high circa 800 ka.

This early basement high could extend no further northeast than the Silver Creek fault (Bryant, 2005), although the early-middle Pleistocene fan at the canyon mouth of Silver Creek suggests that the real boundary of exposed rock was somewhat southwest of the fault itself. The exposed basement high could not extend southwest of the edge of the Cupertino basin (Fig. 3). To the south, the early-middle Pleistocene fans in the Almaden Valley suggest that the basement high was not then exposed in that valley. To the southeast, there are minimal constraints on how much bedrock was exposed. The alluvium in the southern part of the Coyote Narrows is bounded by Holocene fans, suggesting that the basement high was exposed at least as far south as the end of the map of Witter et al. (2006); however, to be conservative, Figure 46 shows a possible basement high ending at the narrowest point of the Coyote Narrows.

The serpentinite sheet underlying the valley suggests that a considerable amount of the exposed basement high may have been serpentinite. Until the middle of the time

Exposed Basement High Circa 800 Ka

Figure 46. Proposed extent of basement high circa 800 ka. A: Almaden Valley. M: Silver Creek canyon mouth. C: Coyote Narrows. Cupertino basin based on preliminary gravity inversion (Jachens et al., 1997). Extent of subsurface serpentinite body adapted from Wentworth et al. (2010). Quaternary alluvial bodies from Witter et al. (2006); the extent of that map is outlined. Bedrock map adapted from Brabb et al. (1997), Wentworth et al. (1998), and Brabb et al. (2000). See caption of Figure 2 for names of wells.

of deposition of sequence 7, the site of WLLO was exposed serpentinite bedrock. While the early sequences were being deposited, the serpentinite-rich bedrock high most likely fed sand into streams reaching CCOC and GUAD; during deposition of later sequences, the sites of those wells still were well-placed to receive serpentinite sand from the shrinking exposure of the basement high. By the time of deposition of sequence 6, however, only a modest amount of serpentinite sand (less than 5%) reached WLLO, suggesting that the basement high, or at least the local serpentinite component of it, had been covered sufficiently that stream channels bypassed it. The sample from sequence 6 in WLLO is also interpreted to have been deposited on the flood plain (Fig. 19). Notable serpentinite reached STPK (21%) during the deposition of sequence 7 but did not reach MGCY (9%) until the time of deposition of sequence 6. Neither well is particularly near the reconstructed basement high, though STPK may be near enough to have received serpentinite-rich sediment in sequence 7. The existence of the basement high, however, may not explain the serpentinite in MGCY in sequence 6.

Another potential source of serpentinite for MGCY is the southern Santa Cruz Mountains (Fig. 46). Serpentinite bodies feed streams that drain into the modern Almaden Valley. Although the modern streams drain north out of the valley, a sediment-shedding exposed basement high might have shifted them northwest in the early-mid Pleistocene, toward MGCY. Thus, sand from the southern serpentinite bodies may have been deposited at MGCY in sequence 6 (Fig. 44-B).

Chert shows elevated levels (in excess of 3%) in some sand samples from the deeper sequences (Fig. 43-B); blue amphibole also shows elevated levels (up to 8%) in

some samples from sequences 6 through 8 (Fig. 45-B). For the western wells (MGCY, STPK, and WLLO), the presence of chert and blue amphibole are suggestive of drainage from the southern Santa Cruz Mountains, which contain many outcrops of *mélange* (Fig. 46) and constituent blueschist and chert outcrops that are too small to map. Significant amounts of metavolcanic clasts in gravel (up to 30%) are present in STPK and WLLO in sequences 5 through 7 (Fig 42-A; MGCY and GUAD do not have gravel data in those sequences) and nontrivial amounts of metavolcanic sand grains (up to 9%) are also present in those sequences. The only data inconsistent with a source in the Santa Cruz Mountains are the significant levels of chert in gravel (8% to 10%) in the lower sequences of WLLO. These suggest that WLLO might have had a nearer source for chert pebbles, possibly even in the basement high. Although it might have not received serpentinite after the deposition of sequence 7, it could have received chert from the basement high.

In CCOC, in the deeper sequences, significant levels of blue amphibole (3%), metavolcanic sand (5%), and chert (up to 2% in the sand; between 5% and 8% in the gravel) are not explained by drainage from the Santa Cruz Mountains. The exposed basement high is inferred to have been in the way, preventing such drainage. *Mélange* in the southern Diablo Range, along the drainage that follows the Silver Creek fault, may have been a source of blue amphibole for CCOC (Fig. 46). There are also metavolcanic blocks along the same drainage. If these rocks were the source of the blue amphibole and metavolcanics in CCOC, then they are likely to be the source of the chert in the CCOC gravel. This would definitely constrain the sediment flow to be very close to the Silver

Creek fault, because the chert in the gravel is almost all Franciscan, although there are significant outcrops of Claremont chert just to the east (Fig. 46).

It is also possible that the exposed basement high contained *mélange* with blueschist, chert, and/or metavolcanic blocks. In fact, the consistently high metavolcanic and chert values in CCOC, especially in the gravel, argue for a source in the basement high.

GUAD may have received sediment flow from either the east or west of the basement high, in addition to receiving sediment from the basement high itself. Figure 47 shows a cartoon summarizing the inferred sediment dispersal paths at the time of deposition of the earliest sequences.

Figure 48 shows one interpretation of how the basement high may have been reduced in size during the time of deposition of the middle sequences. This reconstruction is based on the idea that the basement high was increasingly covered in the northwest and south, remaining exposed only near the basement high remnants that are still exposed today. However it remained near enough to WLLO to be a source for chert, and near enough to CCOC to provide metavolcanics. Meanwhile the paucity of metavolcanics and chert in sand in MGCY and STPK suggest that the major stream flow out of the Santa Cruz Mountains moved westward to be more similar to what it is today. This is shown in Figure 49.

Finally there is the issue of the blue amphibole in the heavy minerals, and the Claremont chert pebbles in CCOC and GUAD. It is possible that the sediment flow from the southeast contributed to deposition at CCOC. However, the shallower sequences in

Figure 47. Inferred sediment dispersal paths within the Santa Clara Valley circa 800 ka. Arrows indicate general sediment dispersal. Darker gray shape is proposed extent of exposed basement high. See caption of Figure 2 for names of wells.

Exposed Basement High Circa 400 Ka

Figure 48. Proposed extent of basement high circa 400 ka. A: Almaden Valley. M: Silver Creek canyon mouth. C: Coyote Narrows. Cupertino basin based on preliminary gravity inversion (Jachens et al., 1997). Extent of subsurface serpentinite body adapted from Wentworth et al. (2010). Quaternary alluvial bodies from Witter et al. (2006); the extent of that map is outlined. Bedrock map adapted from Brabb et al. (1997), Wentworth et al. (1998), and Brabb et al. (2000). See caption of Figure 2 for names of wells.

Figure 49. Inferred sediment dispersal paths within the Santa Clara Valley circa 400 ka. Arrows indicate general sediment dispersal. Darker gray shape is proposed extent of exposed basement high. See caption of Figure 2 for names of wells.

CCOC are rich in metavolcanic gravel (between 15% and 20%), and metavolcanics are present but not common in the Diablo Range east of CCOC. So another source, perhaps the basement high or the drainage along the Silver Creek fault, continued to supply some of the sediment.

A third source for chert, metavolcanics, and blue amphibole is the southern Santa Cruz mountains (not shown in Figure 49). This source would have been available if sediment south and west of the basement high was transported northwest through Coyote Narrows and then northeast to CCOC. Andersen et al. (including this author; in press) argue that this might be a likely source. However, this seems unlikely especially during the time of deposition of the deeper sequences, when the exposure of the basement high was so large. Even today, the exposed remnants of the basement high almost block stream flow northwest through Coyote Narrows. The biggest argument against pre-Holocene sediment transport through Coyote Narrows is the lack of late Pleistocene alluvium along that route, based on the map by Witter et al. (2006), which was released after Andersen et al. (in press) went to press. Only small Holocene fans lie along the narrows, suggesting that the modern drainage flow northwest up the narrows is a relatively recent development.

CONCLUSIONS

Sand Composition

The medium sand grains in the wells and stream samples are predominantly lithic, with some quartz. They contain very little feldspar. When deposited, some of the sand may have even been more lithic than is now observed, because lithics may get preferentially weathered relative to quartz after deposition on the flood plain.

The lithic medium sand grains are predominantly metamorphic. Common rock types in the mountains around the Santa Clara Valley that are represented in the sand are argillite, graywacke, serpentinite, and metavolcanics. Chert, or metachert, is also present in small quantities in the source rocks and the sand. Graywacke is probably not present in the sand in amounts that reflect its distribution in the source rocks because it breaks down to its constituent grains at medium sand size. Common rock types that are not found or rarely found in the well sands are siltstone, sandstone, volcanics, and volcanic porphyry.

Only one trend stands out in the compositional distinction between the wells: with the exception of the WLLO 237.8m sample, the western wells MGCY, STPK, and WLLO generally have less serpentinite than the eastern wells CCOC and GUAD.

Although the rock types found in the wells and the stream samples are primarily metamorphic, diagnostic accessory minerals associated with these metamorphic rocks by other workers (Wentworth et al., 1998; Oze et al., 2003), such as pumpellyite, lawsonite,

jadeite, blue amphibole, and chrome spinel, are very rare, absent, or unrecognized in the medium well sands. Only one example of blue amphibole was recorded, in the Penitencia Creek sample.

Unidentified metamorphic lithics are significant components of the medium well sands and may represent undercounting of metavolcanics and argillite in particular.

Analysis and Provenance

Sources of the medium sand samples from the wells were investigated by comparing the sample compositions to those of the rock types surrounding the Santa Clara Valley. Although there are a few minor inconsistencies between them, analysis of stream samples relative to drainage compositions shows that comparison of well samples to surrounding rocks is useful.

Some source rocks are present all around the valley and are not at all diagnostic of provenance. Sources of quartz, argillite, graywacke, *mélange*, and feldspar are especially ubiquitous. Chert is rare in source rocks and also occurs in the sands in very small quantities. Metavolcanics are present in small, widely-scattered outcrops around the valley but are concentrated to the south and far west of the valley. Serpentinite is concentrated to the south-southeast of the valley, is also present in a sheet underlying the mid-valley basement high, and was probably more widely exposed in the past. Chert, metavolcanics, and serpentinite are key to determining the provenance of the well sands and the well gravels, because they are likely to have come down the same drainages.

There are some key differences between the well gravel studied by Andersen et al. (in press) and the medium sands in the wells. Gravels have much more graywacke than argillite, whereas medium sands have much more argillite than graywacke, possibly due to the contrasting weathering patterns of the two rocks. Metavolcanics are significantly higher in gravels than the sands, due to preferential weathering. Serpentinite is more prevalent in the sands than the gravels, again probably due to preferential weathering. Chert is much more prevalent in CCOC and WLLO gravels than in the other gravels and in all of the medium sands.

The current drainage into the western wells, MGCY, STPK, and WLLO, is from the southwest. An elevated level of serpentinite in MGCY in sequence 6 and significant levels of metavolcanic gravels in lower sequences in STPK and WLLO, however, suggest a paleodrainage from the south out of the Almaden Valley. The lower sequences of the western wells were strongly influenced by sediment coming from the south rather than the southwest of the valley.

Interpretation of the provenance of the well sands and gravels must consider the once-exposed basement high that ran down the middle of the valley. This high was bounded by the Cupertino basin on the west, by the Silver Creek fault on the northeast, and by the Almaden Valley on the south, because early-mid Pleistocene fans show that the Almaden Valley was a drainage filled with Pleistocene sediment during that time. The northwestern and southeastern extents of the basement high are poorly constrained; the northwestern boundary was probably somewhere to the south of the GUAD well, and the southeastern boundary was somewhere near or south of what is now Coyote Narrows.

Serpentinite sand is more common overall at all depths in the CCOC and GUAD wells than in other wells, suggesting that deposition at the locations of both wells was fed by the serpentinite of the basement high. The basement high could have fed serpentinite to the location of CCOC from the east side of the basement high and could have fed drainages that led to the location of GUAD from the west side of the basement high. As the basement high was buried, a southeastern drainage along the Silver Creek fault might have continued to feed sand from exposed serpentinite to the location of CCOC, whereas drainage from Almaden Valley and from around the remnants of the basement high to the west continued to feed deposition at the location of GUAD.

Although the basement high was rich in serpentinite, two pieces of evidence suggest that it also contained other Franciscan outcrops. The chert gravels of WLLO suggest a nearby chert source. The chert gravels of CCOC might also have been sourced from the basement high. The other evidence for Franciscan outcrops in the basement high is the significant amount of metavolcanics in CCOC. Although metavolcanics exposed along the Silver Creek fault could have been fed to the location of CCOC along its associated drainage, the amount of metavolcanics suggests a more nearby source, perhaps in the basement high.

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APPENDIX A: ORIGINAL GRAIN COUNTS

The following tables contain the original count data for both the streams and the wells. Table A1 presents the extensive abbreviations used in the following tables. Tables A2 through A7 present the data as numbers of grains counted, and Tables A8 through A13 present the grain counts as percentages of total grains. Note that Tables A8 through A13 additionally show the accumulated percentage values for monocrystalline quartz, feldspar, and accessories. These are the sums of the percentages of whole grains plus those grain types counted in lithic grains, as per the Gazzi-Dickinson reapportionment discussed in the Methods section.

TABLE A1. LIST OF ABBREVIATIONS USED IN
TABLES A2 THROUGH A13

Abbreviation	Meaning
A	accessories
accum	accumulated
F	feldspar
gs	greenstone
L	lithic fragment
Lm	metamorphic lithic fragment
Ls	sedimentary lithic fragment
Lv	volcanic lithic fragment
mchert	metachert
mv	metavolcanic lithic fragment
n/a	not applicable
o/u	other or unidentified
Qm	monocrystalline quartz
Qp	polycrystalline (non-chert) quartz
ss	sandstone
unid.	unidentified
vp	volcanic porphyry

TABLE A2. ORIGINAL GRAIN COUNTS FOR STREAMS

Stream		Los Gatos	Penitencia	Saratoga	Thompson
Creek		Creek	Creek	Creek	Creek
Sample		LGC-B-M	PEC-A-M	SAC-B-M	THC-B-M
Category	Subcategory				
Accessories	n/a	3	0	4	0
Qm	n/a	41	48	52	25
Qp	chert/mchert	0	3	1	3
Qp	other Qp	23	48	32	44
F	n/a	3	5	9	5
Lv	lithic only	0	0	0	0
Lv	Qm in Lv	0	0	0	0
Lv	F in Lv	0	0	0	0
Lv	A in Lv	0	0	0	0
Ls: siltstone	n/a	1	0	3	1
Ls: sandstone	lithic only	1	2	2	0
Ls: sandstone	Qm in ss	0	0	0	0
Ls: sandstone	F in ss	0	0	0	0
Ls: sandstone	A in ss	0	0	0	0
Lm: argillite	n/a	55	68	71	86
Lm: graywacke	lithic only	34	34	29	43
Lm: graywacke	Qm in gw	9	8	7	8
Lm: graywacke	F in gw	2	1	2	2
Lm: graywacke	A in gw	0	0	0	0
Lm: serpentinite	n/a	6	8	1	2
Lm: greenstone	lithic only	6	0	0	1
Lm: greenstone	F in gs	0	0	0	0
Lm: vp	lithic only	3	5	7	10
Lm: vp	Qm in vp	0	0	0	2
Lm: vp	F in vp	0	0	0	1
Lm: vp	A in vp	0	0	0	0
Lm: other mv	lithic only	21	20	12	27
Lm: other mv	Qm in mv	0	1	0	0
Lm: other mv	F in mv	0	0	0	0
Lm: other mv	A in mv	0	0	0	0
Other/unid. Lm	lithic only	102	58	76	51
Other/unid. Lm	Qm in o/u Lm	7	0	2	0
Other/unid. Lm	F in o/u Lm	0	0	2	1
Other/unid. Lm	A in o/u Lm	0	1	2	0
Other/unid. L	lithic only	2	17	7	0
Other/unid. L	Qm in o/u L	0	1	0	0
Other/unid. L	F in o/u L	0	0	0	0
Other/unid. L	A in o/u L	0	0	0	0
Total grains		319	328	321	312
Total - A		316	327	315	312

See Table A1 for a list of abbreviations.

TABLE A3. ORIGINAL GRAIN COUNTS FOR COYOTE CREEK OUTDOOR CLASSROOM (CCOC) WELL

Sample		CCOC-29M	MS1-a	CCOC-152M	MS1-b	MS1-c	MS1-d	MS6-a	CCOC-307M
Depth, m		29	80.2	152	174.6	204.7	249.4	271.8	307
Category	Subcategory								
Accessories	n/a	0	0	2	0	0	2	0	7
Qm	n/a	126	60	45	46	47	38	72	55
Qp	chert/mchert	0	3	4	6	2	0	4	2
Qp	other Qp	13	46	28	34	39	21	35	15
F	n/a	3	11	3	7	5	7	3	1
Lv	lithic only	0	0	0	0	0	0	0	0
Lv	Qm in Lv	0	0	0	0	0	0	0	0
Lv	F in Lv	0	0	0	0	0	0	0	0
Lv	A in Lv	0	0	0	0	0	0	0	0
Ls: siltstone	n/a	0	0	0	1	0	0	1	0
Ls: sandstone	lithic only	0	0	0	0	0	0	0	0
Ls: sandstone	Qm in ss	0	0	0	0	0	0	0	0
Ls: sandstone	F in ss	0	0	0	0	0	0	0	0
Ls: sandstone	A in ss	0	0	0	0	0	0	0	0
Lm: argillite	n/a	48	29	64	43	56	44	34	54
Lm: graywacke	lithic only	7	20	13	19	12	14	6	10
Lm: graywacke	Qm in gw	5	3	4	5	4	5	4	4
Lm: graywacke	F in gw	0	0	1	1	1	1	0	0
Lm: graywacke	A in gw	0	0	0	0	0	0	0	0
Lm: serpentinite	n/a	6	25	29	22	30	30	37	34
Lm: greenstone	lithic only	0	1	0	0	4	4	6	6
Lm: greenstone	F in gs	0	0	0	0	0	0	0	0
Lm: vp	lithic only	0	4	0	0	0	5	0	1
Lm: vp	Qm in vp	0	0	0	0	0	0	0	0
Lm: vp	F in vp	0	0	0	0	0	0	0	0
Lm: vp	A in vp	0	0	0	0	0	0	0	0
Lm: other mv	lithic only	2	11	6	17	11	11	10	10
Lm: other mv	Qm in mv	0	0	0	0	0	0	0	0
Lm: other mv	F in mv	0	0	0	0	0	1	0	0
Lm: other mv	A in mv	0	0	0	0	0	0	0	0

TABLE A3. ORIGINAL GRAIN COUNTS FOR CCOC WELL, CONTINUED

Sample		CCOC-29M	MS1-a	CCOC-152M	MS1-b	MS1-c	MS1-d	MS6-a	CCOC-307M
Category	Subcategory								
Other/unid. Lm	lithic only	65	93	89	91	89	119	82	136
Other/unid. Lm	Qm in o/u Lm	27	4	3	3	1	7	12	3
Other/unid. Lm	F in o/u Lm	2	2	1	1	1	3	3	0
Other/unid. Lm	A in o/u Lm	0	0	0	0	1	0	0	1
Other/unid. L	lithic only	0	2	0	6	0	2	0	2
Other/unid. L	Qm in o/u L	0	0	0	0	0	0	0	0
Other/unid. L	F in o/u L	0	0	0	0	0	0	0	0
Other/unid. L	A in o/u L	0	0	0	0	0	0	0	0
Total grains		304	314	292	302	303	314	309	341
Total - A		304	314	292	302	302	314	309	340

See Table A1 for a list of abbreviations.

TABLE A4. ORIGINAL GRAIN COUNTS FOR GUADALUPE (GUAD) WELL

Sample		GUAD-40M	MS5-a	MS5-b	MS5-c	MS5-d	GUAD-187M	MS2-d	MS6-b	GUAD-282M
Depth, m		40	82.1	110	127.8	153	187	205.8	246.9	282
Category	Subcategory									
Accessories	n/a	2	0	2	2	3	0	1	0	2
Qm	n/a	97	90	95	100	90	68	88	95	103
Qp	chert/mchert	4	9	1	3	3	1	0	4	6
Qp	other Qp	32	26	15	20	25	24	16	14	35
F	n/a	5	2	5	8	8	5	13	9	2
Lv	lithic only	0	0	0	0	0	0	0	0	0
Lv	Qm in Lv	0	0	0	0	0	0	0	0	0
Lv	F in Lv	0	0	0	0	0	0	0	0	0
Lv	A in Lv	0	0	0	0	0	0	0	0	0
Ls: siltstone	n/a	0	0	0	0	0	0	0	0	0
Ls: sandstone	lithic only	0	0	0	0	0	0	0	0	0
Ls: sandstone	Qm in ss	0	0	0	0	0	0	0	0	0
Ls: sandstone	F in ss	0	0	0	0	0	0	0	0	0
Ls: sandstone	A in ss	0	0	0	0	0	0	0	0	0
Lm: argillite	n/a	28	25	69	66	61	119	55	69	42
Lm: graywacke	lithic only	10	4	8	11	6	2	16	8	6
Lm: graywacke	Qm in gw	5	2	5	5	7	2	16	8	2
Lm: graywacke	F in gw	0	0	0	0	0	0	1	0	0
Lm: graywacke	A in gw	0	0	0	0	0	0	2	0	0
Lm: serpentinite	n/a	9	48	31	17	17	17	17	10	36
Lm: greenstone	lithic only	0	1	0	1	0	0	2	0	0
Lm: greenstone	F in gs	0	0	0	0	0	0	0	0	0
Lm: vp	lithic only	0	0	0	0	0	0	1	0	0
Lm: vp	Qm in vp	0	0	0	0	0	0	0	0	0
Lm: vp	F in vp	0	0	0	0	0	0	1	0	1
Lm: vp	A in vp	0	0	0	0	0	0	0	0	0
Lm: other mv	lithic only	3	3	4	1	10	2	22	12	5
Lm: other mv	Qm in mv	0	0	0	0	0	0	0	0	0
Lm: other mv	F in mv	0	0	0	0	0	0	0	0	0
Lm: other mv	A in mv	0	0	0	0	0	0	0	0	0

TABLE A4. ORIGINAL GRAIN COUNTS FOR GUAD WELL, CONTINUED

Sample		GUAD-40M	MS5-a	MS5-b	MS5-c	MS5-d	GUAD-187M	MS2-d	MS6-b	GUAD-282M
Category	Subcategory									
Other/unid. Lm	lithic only	109	86	72	54	52	69	52	69	76
Other/unid. Lm	Qm in o/u Lm	14	16	8	11	20	11	7	10	5
Other/unid. Lm	F in o/u Lm	1	1	0	3	5	5	3	3	2
Other/unid. Lm	A in o/u Lm	4	0	0	0	0	0	0	0	0
Other/unid. L	lithic only	1	6	1	0	1	1	0	0	0
Other/unid. L	Qm in o/u L	0	0	0	0	0	0	0	0	0
Other/unid. L	F in o/u L	0	0	0	0	0	0	0	0	0
Other/unid. L	A in o/u L	0	0	0	0	0	0	0	0	0
Total grains		324	319	316	302	308	326	313	311	323
Total - A		320	319	316	302	308	326	311	311	323

See Table A1 for a list of abbreviations.

TABLE A5. ORIGINAL GRAIN COUNTS FOR MCGLINCY (MGCY) WELL

Sample		MGCY-17M	MS3-a	MS3-b	MGCY-132M	MGCY-152M	MS3-c	MS6-d	MGCY-217M
Depth, m		17	45.6	76	132	152	177.1	191.1	217
Category	Subcategory								
Accessories	n/a	1	1	2	0	1	1	0	4
Qm	n/a	91	145	74	85	113	93	74	93
Qp	chert/mchert	0	1	3	3	8	2	5	6
Qp	other Qp	10	10	7	40	63	14	37	29
F	n/a	5	14	5	1	1	3	6	4
Lv	lithic only	0	0	0	0	0	0	0	0
Lv	Qm in Lv	0	0	0	0	0	0	0	0
Lv	F in Lv	0	0	0	0	0	0	0	0
Lv	A in Lv	0	0	0	0	0	0	0	0
Ls: siltstone	n/a	0	0	0	1	0	0	0	0
Ls: sandstone	lithic only	0	0	0	0	0	0	0	0
Ls: sandstone	Qm in ss	0	0	0	0	0	0	0	0
Ls: sandstone	F in ss	0	0	0	0	0	0	0	0
Ls: sandstone	A in ss	0	0	0	0	0	0	0	0
Lm: argillite	n/a	37	53	115	66	57	67	45	44
Lm: graywacke	lithic only	25	13	11	7	6	17	5	11
Lm: graywacke	Qm in gw	9	11	6	3	1	8	9	1
Lm: graywacke	F in gw	0	2	1	0	0	0	0	0
Lm: graywacke	A in gw	0	1	0	0	0	1	0	0
Lm: serpentinite	n/a	1	2	1	2	0	6	28	25
Lm: greenstone	lithic only	0	0	0	0	3	0	0	6
Lm: greenstone	F in gs	0	0	0	0	0	0	0	0
Lm: vp	lithic only	1	0	1	0	0	0	0	0
Lm: vp	Qm in vp	0	0	0	0	0	0	0	0
Lm: vp	F in vp	0	0	0	0	0	0	0	0
Lm: vp	A in vp	0	0	0	0	0	0	0	0
Lm: other mv	lithic only	3	5	10	10	10	14	5	6
Lm: other mv	Qm in mv	0	0	0	0	0	0	0	0
Lm: other mv	F in mv	0	0	0	0	0	0	0	0
Lm: other mv	A in mv	0	0	0	0	0	0	0	0

TABLE A5. ORIGINAL GRAIN COUNTS FOR MGCY WELL, CONTINUED

Sample		MGCY-17M	MS3-a	MS3-b	MGCY-132M	MGCY-152M	MS3-c	MS6-d	MGCY-217M
Category	Subcategory								
Other/unid. Lm	lithic only	37	48	65	84	43	73	81	90
Other/unid. Lm	Qm in o/u Lm	17	10	12	5	8	8	10	8
Other/unid. Lm	F in o/u Lm	7	4	2	2	5	5	1	1
Other/unid. Lm	A in o/u Lm	0	0	2	0	0	0	0	0
Other/unid. L	lithic only	0	0	0	0	1	0	1	0
Other/unid. L	Qm in o/u L	0	0	0	0	0	0	0	0
Other/unid. L	F in o/u L	0	0	0	0	0	0	0	0
Other/unid. L	A in o/u L	0	0	0	0	0	0	0	0
Total grains		244	320	317	309	320	312	307	328
Total - A		244	319	315	309	320	311	307	328
See Table A1 for a list of abbreviations.									

TABLE A6. ORIGINAL GRAIN COUNTS FOR SANTANA PARK (STPK) WELL

Sample		STPK-14M	MS4-a	MS4-b	MS4-c	STPK-174M	MS4-d	MS3-d	MS6-c	STPK-304M
Depth, m		14	72.9	99.3	139.3	174	202.4	245.3	281	304
Category	Subcategory									
Accessories	n/a	0	0	0	1	0	1	2	0	0
Qm	n/a	92	127	121	131	171	119	98	66	85
Qp	chert/mchert	1	0	2	0	4	0	3	2	7
Qp	other Qp	33	24	19	13	28	25	26	21	41
F	n/a	4	11	1	13	7	5	4	3	1
Lv	lithic only	0	0	0	0	0	0	0	0	0
Lv	Qm in Lv	0	0	0	0	0	0	0	0	0
Lv	F in Lv	0	0	0	0	0	0	0	0	0
Lv	A in Lv	0	0	0	0	0	0	0	0	0
Ls: siltstone	n/a	0	0	0	0	0	0	0	0	0
Ls: sandstone	lithic only	0	0	0	0	0	0	0	0	0
Ls: sandstone	Qm in ss	0	1	0	0	0	0	0	0	0
Ls: sandstone	F in ss	0	0	1	0	0	0	0	0	0
Ls: sandstone	A in ss	0	0	0	0	0	0	0	0	0
Lm: argillite	n/a	100	57	69	79	64	77	40	60	53
Lm: graywacke	lithic only	17	12	21	16	1	3	9	11	9
Lm: graywacke	Qm in gw	6	6	13	6	1	2	4	3	6
Lm: graywacke	F in gw	0	0	1	0	0	2	1	0	0
Lm: graywacke	A in gw	0	0	0	1	0	0	0	0	0
Lm: serpentinite	n/a	8	3	5	2	11	4	65	6	14
Lm: greenstone	lithic only	0	3	0	0	1	1	0	0	0
Lm: greenstone	F in gs	0	0	0	0	0	0	0	0	0
Lm: vp	lithic only	0	0	0	0	0	0	0	0	0
Lm: vp	Qm in vp	0	0	0	0	0	0	0	0	0
Lm: vp	F in vp	0	0	0	0	0	0	0	0	0
Lm: vp	A in vp	0	0	0	0	0	0	0	0	0
Lm: other mv	lithic only	8	14	10	10	3	6	13	11	6
Lm: other mv	Qm in mv	0	0	0	0	0	1	0	0	0
Lm: other mv	F in mv	0	0	0	0	0	1	0	0	0
Lm: other mv	A in mv	0	0	0	0	0	0	0	0	0

TABLE A6. ORIGINAL GRAIN COUNTS FOR STPK WELL, CONTINUED

Sample		STPK-14M	MS4-a	MS4-b	MS4-c	STPK-174M	MS4-d	MS3-d	MS6-c	STPK-304M
Category	Subcategory									
Other/unid. Lm	lithic only	52	46	46	45	37	48	49	107	67
Other/unid. Lm	Qm in o/u Lm	10	9	14	8	10	9	1	12	7
Other/unid. Lm	F in o/u Lm	4	5	2	2	3	6	0	3	6
Other/unid. Lm	A in o/u Lm	1	0	0	0	0	0	1	1	0
Other/unid. L	lithic only	0	0	0	0	0	0	0	0	0
Other/unid. L	Qm in o/u L	0	0	0	0	0	0	0	0	0
Other/unid. L	F in o/u L	0	0	0	0	0	0	0	0	0
Other/unid. L	A in o/u L	0	0	0	0	0	0	0	0	0
Total grains		336	318	325	327	341	310	316	306	302
Total - A		335	318	325	326	341	310	315	305	302

See Table A1 for a list of abbreviations.

TABLE A7. ORIGINAL GRAIN COUNTS FOR WILLOW (WLLO) WELL

Sample		WLLO-26M	MS2-a	MS2-b	WLLO-149M	MS2-c	WLLO-238M
Depth, m		26	33.6	90.2	149	205.9	238
Category	Subcategory						
Accessories	n/a	0	0	0	0	5	0
Qm	n/a	120	120	93	42	66	2
Qp	chert/mchert	3	4	2	7	8	0
Qp	other Qp	16	14	10	19	31	0
F	n/a	13	20	11	2	7	1
Lv	lithic only	0	0	0	0	0	0
Lv	Qm in Lv	0	0	0	0	0	0
Lv	F in Lv	0	0	0	0	0	0
Lv	A in Lv	0	0	0	0	0	0
Ls: siltstone	n/a	0	1	0	0	0	0
Ls: sandstone	lithic only	0	0	0	0	0	0
Ls: sandstone	Qm in ss	0	0	0	0	0	0
Ls: sandstone	F in ss	0	0	0	0	0	0
Ls: sandstone	A in ss	0	0	0	0	0	0
Lm: argillite	n/a	86	70	42	59	33	28
Lm: graywacke	lithic only	15	7	16	5	7	0
Lm: graywacke	Qm in gw	6	8	11	0	4	0
Lm: graywacke	F in gw	1	3	3	0	0	0
Lm: graywacke	A in gw	0	0	2	1	0	1
Lm: serpentinite	n/a	1	14	5	3	13	229
Lm: greenstone	lithic only	0	5	1	0	3	0
Lm: greenstone	F in gs	0	0	0	0	0	0
Lm: vp	lithic only	0	1	1	0	1	0
Lm: vp	Qm in vp	0	1	0	0	0	0
Lm: vp	F in vp	0	2	0	0	0	0
Lm: vp	A in vp	0	0	0	0	0	0
Lm: other mv	lithic only	4	8	27	5	20	1
Lm: other mv	Qm in mv	1	0	0	0	0	0
Lm: other mv	F in mv	0	0	1	0	0	0
Lm: other mv	A in mv	0	0	0	0	0	0

TABLE A7. ORIGINAL GRAIN COUNTS FOR WILLO WELL, CONTINUED

Category	Sample	WLLO-26M	MS2-a	MS2-b	WLLO-149M	MS2-c	WLLO-238M
	Subcategory						
Other/unid. Lm	lithic only	48	43	41	53	64	52
Other/unid. Lm	Qm in o/u Lm	4	0	1	6	4	1
Other/unid. Lm	F in o/u Lm	1	1	1	3	3	0
Other/unid. Lm	A in o/u Lm	0	0	0	1	2	0
Other/unid. L	lithic only	0	0	0	0	0	0
Other/unid. L	Qm in o/u L	0	0	0	0	0	0
Other/unid. L	F in o/u L	0	0	0	0	0	0
Other/unid. L	A in o/u L	0	0	0	0	0	0
Total grains		319	322	268	206	271	315
Total - A		319	322	266	204	269	314

See Table A1 for a list of abbreviations.

TABLE A8. PERCENTAGE* GRAIN COUNTS FOR STREAMS

Stream		Los Gatos	Penitencia	Saratoga	Thompson
Creek		Creek	Creek	Creek	Creek
Sample		LGC-B-M	PEC-A-M	SAC-B-M	THC-B-M
Category	Subcategory				
Accessories	n/a	0.9	0.0	1.2	0.0
Qm	n/a	12.9	14.6	16.2	8.0
Qp	chert/mchert	0.0	0.9	0.3	1.0
Qp	other Qp	7.2	14.6	10.0	14.1
F	n/a	0.9	1.5	2.8	1.6
Lv	lithic only	0.0	0.0	0.0	0.0
Lv	Qm in Lv	0.0	0.0	0.0	0.0
Lv	F in Lv	0.0	0.0	0.0	0.0
Lv	A in Lv	0.0	0.0	0.0	0.0
Ls: siltstone	n/a	0.3	0.0	0.9	0.3
Ls: sandstone	lithic only	0.3	0.6	0.6	0.0
Ls: sandstone	Qm in ss	0.0	0.0	0.0	0.0
Ls: sandstone	F in ss	0.0	0.0	0.0	0.0
Ls: sandstone	A in ss	0.0	0.0	0.0	0.0
Lm: argillite	n/a	17.2	20.7	22.1	27.6
Lm: graywacke	lithic only	10.7	10.4	9.0	13.8
Lm: graywacke	Qm in gw	2.8	2.4	2.2	2.6
Lm: graywacke	F in gw	0.6	0.3	0.6	0.6
Lm: graywacke	A in gw	0.0	0.0	0.0	0.0
Lm: serpentinite	n/a	1.9	2.4	0.3	0.6
Lm: greenstone	lithic only	1.9	0.0	0.0	0.3
Lm: greenstone	F in gs	0.0	0.0	0.0	0.0
Lm: vp	lithic only	0.9	1.5	2.2	3.2
Lm: vp	Qm in vp	0.0	0.0	0.0	0.6
Lm: vp	F in vp	0.0	0.0	0.0	0.3
Lm: vp	A in vp	0.0	0.0	0.0	0.0
Lm: other mv	lithic only	6.6	6.1	3.7	8.7
Lm: other mv	Qm in mv	0.0	0.3	0.0	0.0
Lm: other mv	F in mv	0.0	0.0	0.0	0.0
Lm: other mv	A in mv	0.0	0.0	0.0	0.0
Other/unid. Lm	lithic only	32.0	17.7	23.7	16.3
Other/unid. Lm	Qm in o/u Lm	2.2	0.0	0.6	0.0
Other/unid. Lm	F in o/u Lm	0.0	0.0	0.6	0.3
Other/unid. Lm	A in o/u Lm	0.0	0.3	0.6	0.0
Other/unid. L	lithic only	0.6	5.2	2.2	0.0
Other/unid. L	Qm in o/u L	0.0	0.3	0.0	0.0
Other/unid. L	F in o/u L	0.0	0.0	0.0	0.0
Other/unid. L	A in o/u L	0.0	0.0	0.0	0.0
Total		100.0	100.0	100.0	100.0
accum Qm	n/a	17.9	17.7	19.0	11.2
accum F	n/a	1.6	1.8	4.0	2.9
accum A	n/a	0.9	0.3	1.9	0.0

*Percentage of total grains (see Table A2).

See Table A1 for a list of abbreviations.

TABLE A9. PERCENTAGE* GRAIN COUNTS FOR COYOTE CREEK OUTDOOR CLASSROOM (CCOC) WELL

Sample		CCOC-29M		MS1-a CCOC-152M		MS1-b		MS1-c		MS1-d		MS6-a CCOC-307M	
Depth, m		29.0	80.2	152.0	174.6	204.7	249.4	271.8	307.0				
Category	Subcategory												
Accessories	n/a	0.0	0.0	0.7	0.0	0.0	0.6	0.0	2.1				
	n/a	41.4	19.1	15.4	15.2	15.5	12.1	23.3	16.1				
Qp	chert/mchert	0.0	1.0	1.4	2.0	0.7	0.0	1.3	0.6				
Qp	other Qp	4.3	14.6	9.6	11.3	12.9	6.7	11.3	4.4				
F	n/a	1.0	3.5	1.0	2.3	1.7	2.2	1.0	0.3				
Lv	lithic only	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0				
Lv	Qm in Lv	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0				
Lv	F in Lv	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0				
Lv	A in Lv	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0				
Ls: siltstone	n/a	0.0	0.0	0.0	0.3	0.0	0.0	0.3	0.0				
Ls: sandstone	lithic only	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0				
Ls: sandstone	Qm in ss	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0				
Ls: sandstone	F in ss	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0				
Ls: sandstone	A in ss	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0				
Lm: argillite	n/a	15.8	9.2	21.9	14.2	18.5	14.0	11.0	15.8				
Lm: graywacke	lithic only	2.3	6.4	4.5	6.3	4.0	4.5	1.9	2.9				
Lm: graywacke	Qm in gw	1.6	1.0	1.4	1.7	1.3	1.6	1.3	1.2				
Lm: graywacke	F in gw	0.0	0.0	0.3	0.3	0.3	0.3	0.0	0.0				
Lm: graywacke	A in gw	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0				
Lm: serpentinite	n/a	2.0	8.0	9.9	7.3	9.9	9.6	12.0	10.0				
Lm: greenstone	lithic only	0.0	0.3	0.0	0.0	1.3	1.3	1.9	1.8				
Lm: greenstone	F in gs	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0				
Lm: vp	lithic only	0.0	1.3	0.0	0.0	0.0	1.6	0.0	0.3				
Lm: vp	Qm in vp	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0				
Lm: vp	F in vp	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0				
Lm: vp	A in vp	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0				
Lm: other mv	lithic only	0.7	3.5	2.1	5.6	3.6	3.5	3.2	2.9				
Lm: other mv	Qm in mv	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0				
Lm: other mv	F in mv	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0				
Lm: other mv	A in mv	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0				

TABLE A9. PERCENTAGE* GRAIN COUNTS FOR CCOC WELL, CONTINUED

Sample		CCOC-29M	MS1-a	CCOC-152M	MS1-b	MS1-c	MS1-d	MS6-a	CCOC-307M
Category	Subcategory								
Other/unid. Lm	lithic only	21.4	29.6	30.5	30.1	29.4	37.9	26.5	39.9
Other/unid. Lm	Qm in o/u Lm	8.9	1.3	1.0	1.0	0.3	2.2	3.9	0.9
Other/unid. Lm	F in o/u Lm	0.7	0.6	0.3	0.3	0.3	1.0	1.0	0.0
Other/unid. Lm	A in o/u Lm	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.3
Other/unid. L	lithic only	0.0	0.6	0.0	2.0	0.0	0.6	0.0	0.6
Other/unid. L	Qm in o/u L	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other/unid. L	F in o/u L	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other/unid. L	A in o/u L	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total		100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
accum Qm	n/a	52.0	21.3	17.8	17.9	17.2	15.9	28.5	18.2
accum F	n/a	1.6	4.1	1.7	3.0	2.3	3.8	1.9	0.3
accum A	n/a	0.0	0.0	0.7	0.0	0.3	0.6	0.0	2.3

*Percentage of total grains (see Table A3).
See Table A1 for a list of abbreviations.

TABLE A10. PERCENTAGE* GRAIN COUNTS FOR GUADALUPE (GUAD) WELL

Sample		GUAD-40M	MS5-a	MS5-b	MS5-c	MS5-d	GUAD-187M	MS2-d	MS6-b	GUAD-282M
Depth, m		40.0	82.1	110.0	127.8	153.0	187.0	205.8	246.9	282.0
Category	Subcategory									
Accessories	n/a	0.6	0.0	0.6	0.7	1.0	0.0	0.3	0.0	0.6
Qm	n/a	29.9	28.2	30.1	33.1	29.2	20.9	28.1	30.5	31.9
Qp	chert/mchert	1.2	2.8	0.3	1.0	1.0	0.3	0.0	1.3	1.9
Qp	other Qp	9.9	8.2	4.7	6.6	8.1	7.4	5.1	4.5	10.8
F	n/a	1.5	0.6	1.6	2.6	2.6	1.5	4.2	2.9	0.6
Lv	lithic only	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lv	Qm in Lv	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lv	F in Lv	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lv	A in Lv	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ls: siltstone	n/a	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ls: sandstone	lithic only	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ls: sandstone	Qm in ss	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ls: sandstone	F in ss	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ls: sandstone	A in ss	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lm: argillite	n/a	8.6	7.8	21.8	21.9	19.8	36.5	17.6	22.2	13.0
Lm: graywacke	lithic only	3.1	1.3	2.5	3.6	1.9	0.6	5.1	2.6	1.9
Lm: graywacke	Qm in gw	1.5	0.6	1.6	1.7	2.3	0.6	5.1	2.6	0.6
Lm: graywacke	F in gw	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0
Lm: graywacke	A in gw	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0
Lm: serpentinite	n/a	2.8	15.0	9.8	5.6	5.5	5.2	5.4	3.2	11.1
Lm: greenstone	lithic only	0.0	0.3	0.0	0.3	0.0	0.0	0.6	0.0	0.0
Lm: greenstone	F in gs	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lm: vp	lithic only	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0
Lm: vp	Qm in vp	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lm: vp	F in vp	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.3
Lm: vp	A in vp	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lm: other mv	lithic only	0.9	0.9	1.3	0.3	3.2	0.6	7.0	3.9	1.5
Lm: other mv	Qm in mv	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lm: other mv	F in mv	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lm: other mv	A in mv	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

TABLE A10. PERCENTAGE* GRAIN COUNTS FOR GUAD WELL, CONTINUED

Category	Sample	GUAD-40M	MS5-a	MS5-b	MS5-c	MS5-d	GUAD-187M	MS2-d	MS6-b	GUAD-282M
	Subcategory									
Other/unid. Lm	lithic only	33.6	27.0	22.8	17.9	16.9	21.2	16.6	22.2	23.5
Other/unid. Lm	Qm in o/u Lm	4.3	5.0	2.5	3.6	6.5	3.4	2.2	3.2	1.5
Other/unid. Lm	F in o/u Lm	0.3	0.3	0.0	1.0	1.6	1.5	1.0	1.0	0.6
Other/unid. Lm	A in o/u Lm	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other/unid. L	lithic only	0.3	1.9	0.3	0.0	0.3	0.3	0.0	0.0	0.0
Other/unid. L	Qm in o/u L	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other/unid. L	F in o/u L	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other/unid. L	A in o/u L	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total		100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
accum Qm	n/a	35.8	33.9	34.2	38.4	38.0	24.8	35.5	36.3	34.1
accum F	n/a	1.9	0.9	1.6	3.6	4.2	3.1	5.8	3.9	1.5
accum A	n/a	1.9	0.0	0.6	0.7	1.0	0.0	1.0	0.0	0.6

*Percentage of total grains (see Table A4).
See Table A1 for a list of abbreviations.

TABLE A11. PERCENTAGE* GRAIN COUNTS FOR MCGLINCY (MGCY) WELL

Sample		MGCY-17M	MS3-a	MS3-b	MGCY-132M	MGCY-152M	MS3-c	MS6-d	MGCY-217M
Depth, m	Subcategory	17.0	45.6	76.0	132.0	152.0	177.1	191.1	217.0
Category	Subcategory								
Accessories	n/a	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Qm	n/a	0.4	0.3	0.6	0.0	0.3	0.3	0.0	1.2
Qp	chert/mchert	37.3	45.3	23.3	27.5	35.3	29.8	24.1	28.4
Qp	other Qp	0.0	0.3	0.9	1.0	2.5	0.6	1.6	1.8
F	n/a	4.1	3.1	2.2	12.9	19.7	4.5	12.1	8.8
Lv	lithic only	2.0	4.4	1.6	0.3	0.3	1.0	2.0	1.2
Lv	Qm in Lv	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lv	F in Lv	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lv	A in Lv	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ls: siltstone	n/a	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0
Ls: sandstone	lithic only	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ls: sandstone	Qm in ss	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ls: sandstone	F in ss	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ls: sandstone	A in ss	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lm: argillite	n/a	15.2	16.6	36.3	21.4	17.8	21.5	14.7	13.4
Lm: graywacke	lithic only	10.2	4.1	3.5	2.3	1.9	5.4	1.6	3.4
Lm: graywacke	Qm in gw	3.7	3.4	1.9	1.0	0.3	2.6	2.9	0.3
Lm: graywacke	F in gw	0.0	0.6	0.3	0.0	0.0	0.0	0.0	0.0
Lm: graywacke	A in gw	0.0	0.3	0.0	0.0	0.0	0.3	0.0	0.0
Lm: serpentinite	n/a	0.4	0.6	0.3	0.6	0.0	1.9	9.1	7.6
Lm: greenstone	lithic only	0.0	0.0	0.0	0.0	0.9	0.0	0.0	1.8
Lm: greenstone	F in gs	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lm: vp	lithic only	0.4	0.0	0.3	0.0	0.0	0.0	0.0	0.0
Lm: vp	Qm in vp	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lm: vp	F in vp	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lm: vp	A in vp	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lm: other mv	lithic only	1.2	1.6	3.2	3.2	3.1	4.5	1.6	1.8
Lm: other mv	Qm in mv	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lm: other mv	F in mv	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lm: other mv	A in mv	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

TABLE A11. PERCENTAGE* GRAIN COUNTS FOR MGCY WELL, CONTINUED

Sample		MGCY-17M	MS3-a	MS3-b	MGCY-132M	MGCY-152M	MS3-c	MS6-d	MGCY-217M
Category	Subcategory								
Other/unid. Lm	lithic only	15.2	15.0	20.5	27.2	13.4	23.4	26.4	27.4
Other/unid. Lm	Qm in o/u Lm	7.0	3.1	3.8	1.6	2.5	2.6	3.3	2.4
Other/unid. Lm	F in o/u Lm	2.9	1.3	0.6	0.6	1.6	1.6	0.3	0.3
Other/unid. Lm	A in o/u Lm	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0
Other/unid. L	lithic only	0.0	0.0	0.0	0.0	0.3	0.0	0.3	0.0
Other/unid. L	Qm in o/u L	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other/unid. L	F in o/u L	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other/unid. L	A in o/u L	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total		100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
accum Qm	n/a	48.0	51.9	29.0	30.1	38.1	34.9	30.3	31.1
accum F	n/a	4.9	6.3	2.5	1.0	1.9	2.6	2.3	1.5
accum A	n/a	0.4	0.6	1.3	0.0	0.3	0.6	0.0	1.2

*Percentage of total grains (see Table A5).

See Table A1 for a list of abbreviations.

TABLE A12. PERCENTAGE* GRAIN COUNTS FOR SANTANA PARK (STPK) WELL

Sample		STPK-14M	MS4-a	MS4-b	MS4-c	STPK-174M	MS4-d	MS3-d	MS6-c	STPK-304M
Depth, m		14.0	72.9	99.3	139.3	174.0	202.4	245.3	281.0	304.0
Category	Subcategory									
Accessories	n/a	0.0	0.0	0.0	0.3	0.0	0.3	0.6	0.0	0.0
Qm	n/a	27.4	39.9	37.2	40.1	50.1	38.4	31.0	21.6	28.1
Qp	chert/mchert	0.3	0.0	0.6	0.0	1.2	0.0	0.9	0.7	2.3
Qp	other Qp	9.8	7.5	5.8	4.0	8.2	8.1	8.2	6.9	13.6
F	n/a	1.2	3.5	0.3	4.0	2.1	1.6	1.3	1.0	0.3
Lv	lithic only	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lv	Qm in Lv	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lv	F in Lv	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lv	A in Lv	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ls: siltstone	n/a	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ls: sandstone	lithic only	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ls: sandstone	Qm in ss	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ls: sandstone	F in ss	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0
Ls: sandstone	A in ss	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lm: argillite	n/a	29.8	17.9	21.2	24.2	18.8	24.8	12.7	19.6	17.5
Lm: graywacke	lithic only	5.1	3.8	6.5	4.9	0.3	1.0	2.8	3.6	3.0
Lm: graywacke	Qm in gw	1.8	1.9	4.0	1.8	0.3	0.6	1.3	1.0	2.0
Lm: graywacke	F in gw	0.0	0.0	0.3	0.0	0.0	0.6	0.3	0.0	0.0
Lm: graywacke	A in gw	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0
Lm: serpentinite	n/a	2.4	0.9	1.5	0.6	3.2	1.3	20.6	2.0	4.6
Lm: greenstone	lithic only	0.0	0.9	0.0	0.0	0.3	0.3	0.0	0.0	0.0
Lm: greenstone	F in gs	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lm: vp	lithic only	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lm: vp	Qm in vp	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lm: vp	F in vp	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lm: vp	A in vp	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lm: other mv	lithic only	2.4	4.4	3.1	3.1	0.9	1.9	4.1	3.6	2.0
Lm: other mv	Qm in mv	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0
Lm: other mv	F in mv	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0
Lm: other mv	A in mv	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

TABLE A12. PERCENTAGE* GRAIN COUNTS FOR STPK WELL, CONTINUED

Sample		STPK-14M	MS4-a	MS4-b	MS4-c	STPK-174M	MS4-d	MS3-d	MS6-c	STPK-304M
Category	Subcategory									
Other/unid. Lm	lithic only	15.5	14.5	14.2	13.8	10.9	15.5	15.5	35.0	22.2
Other/unid. Lm	Qm in o/u Lm	3.0	2.8	4.3	2.4	2.9	2.9	0.3	3.9	2.3
Other/unid. Lm	F in o/u Lm	1.2	1.6	0.6	0.6	0.9	1.9	0.0	1.0	2.0
Other/unid. Lm	A in o/u Lm	0.3	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.0
Other/unid. L	lithic only	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other/unid. L	Qm in o/u L	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other/unid. L	F in o/u L	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other/unid. L	A in o/u L	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total		100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
accum Qm	n/a	32.1	45.0	45.5	44.3	53.4	42.3	32.6	26.5	32.5
accum F	n/a	2.4	5.0	1.5	4.6	2.9	4.5	1.6	2.0	2.3
accum A	n/a	0.3	0.0	0.0	0.6	0.0	0.3	0.9	0.3	0.0

*Percentage of total grains (see Table A6).
See Table A1 for a list of abbreviations.

TABLE A13. PERCENTAGE* GRAIN COUNTS FOR WILLOW (WLLO) WELL

Sample		WLLO-26M	MS2-a	MS2-b	WLLO-149M	MS2-c	WLLO-238M
Depth, m		26.0	33.6	90.2	149.0	205.9	238.0
Category	Subcategory						
Accessories	n/a	0.0	0.0	0.0	0.0	1.8	0.0
Qm	n/a	37.6	37.3	34.7	20.4	24.4	0.6
Qp	chert/mchert	0.9	1.2	0.7	3.4	3.0	0.0
Qp	other Qp	5.0	4.3	3.7	9.2	11.4	0.0
F	n/a	4.1	6.2	4.1	1.0	2.6	0.3
Lv	lithic only	0.0	0.0	0.0	0.0	0.0	0.0
Lv	Qm in Lv	0.0	0.0	0.0	0.0	0.0	0.0
Lv	F in Lv	0.0	0.0	0.0	0.0	0.0	0.0
Lv	A in Lv	0.0	0.0	0.0	0.0	0.0	0.0
Ls: siltstone	n/a	0.0	0.3	0.0	0.0	0.0	0.0
Ls: sandstone	lithic only	0.0	0.0	0.0	0.0	0.0	0.0
Ls: sandstone	Qm in ss	0.0	0.0	0.0	0.0	0.0	0.0
Ls: sandstone	F in ss	0.0	0.0	0.0	0.0	0.0	0.0
Ls: sandstone	A in ss	0.0	0.0	0.0	0.0	0.0	0.0
Lm: argillite	n/a	27.0	21.7	15.7	28.6	12.2	8.9
Lm: graywacke	lithic only	4.7	2.2	6.0	2.4	2.6	0.0
Lm: graywacke	Qm in gw	1.9	2.5	4.1	0.0	1.5	0.0
Lm: graywacke	F in gw	0.3	0.9	1.1	0.0	0.0	0.0
Lm: graywacke	A in gw	0.0	0.0	0.7	0.5	0.0	0.3
Lm: serpentinite	n/a	0.3	4.3	1.9	1.5	4.8	72.7
Lm: greenstone	lithic only	0.0	1.6	0.4	0.0	1.1	0.0
Lm: greenstone	F in gs	0.0	0.0	0.0	0.0	0.0	0.0
Lm: vp	lithic only	0.0	0.3	0.4	0.0	0.4	0.0
Lm: vp	Qm in vp	0.0	0.3	0.0	0.0	0.0	0.0
Lm: vp	F in vp	0.0	0.6	0.0	0.0	0.0	0.0
Lm: vp	A in vp	0.0	0.0	0.0	0.0	0.0	0.0
Lm: other mv	lithic only	1.3	2.5	10.1	2.4	7.4	0.3
Lm: other mv	Qm in mv	0.3	0.0	0.0	0.0	0.0	0.0
Lm: other mv	F in mv	0.0	0.0	0.4	0.0	0.0	0.0
Lm: other mv	A in mv	0.0	0.0	0.0	0.0	0.0	0.0

TABLE A13. PERCENTAGE* GRAIN COUNTS FOR WLO WELL, CONTINUED

Category	Sample	WLO-26M	MS2-a	MS2-b	WLO-149M	MS2-c	WLO-238M
	Subcategory						
Other/unid. Lm	lithic only	15.0	13.4	15.3	25.7	23.6	16.5
Other/unid. Lm	Qm in o/u Lm	1.3	0.0	0.4	2.9	1.5	0.3
Other/unid. Lm	F in o/u Lm	0.3	0.3	0.4	1.5	1.1	0.0
Other/unid. Lm	A in o/u Lm	0.0	0.0	0.0	0.5	0.7	0.0
Other/unid. L	lithic only	0.0	0.0	0.0	0.0	0.0	0.0
Other/unid. L	Qm in o/u L	0.0	0.0	0.0	0.0	0.0	0.0
Other/unid. L	F in o/u L	0.0	0.0	0.0	0.0	0.0	0.0
Other/unid. L	A in o/u L	0.0	0.0	0.0	0.0	0.0	0.0
Total		100.0	100.0	100.0	100.0	100.0	100.0
accum Qm	n/a	41.1	40.1	39.2	23.3	27.3	1.0
accum F	n/a	4.7	8.1	6.0	2.4	3.7	0.3
accum A	n/a	0.0	0.0	0.7	1.0	2.6	0.3

*Percentage of total grains (see Table A7).
See Table A1 for a list of abbreviations.