AGGREGATE RESOURCE ASSESSMENT FOR THE LA POSTA BAND OF MISSION INDIANS RESERVATION, SAN DIEGO COUNTY, CALIFORNIA

by

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ABSTRACT

This investigation centers on an evaluation of both decomposed granite (DG) and crushed rock resources on the La Posta Band of Mission Indians Reservation in San Diego County, California. The quality and quantity of the potential aggregate sources are also estimated. The material studied is the Tonalite of La Posta, a hornblende-biotite tonalite emplaced during the Cretaceous Period.

Physical and geochemical testing of both surface and subsurface samples assessed the quality of the material. Subsurface samples showed significant differences in the physical testing results due to the two different drilling methods employed: sonic and wireline core. Overall, the DG fulfills the Caltrans requirements for class 2 base and all classes of subbase, with a potential for increasing the value of the material through processing, such as washing and screening. Crushed rock resources do not meet the specifications for Portland cement concrete or asphaltic concrete aggregate but may be blended with the DG to improve the quality of the base and subbase material. Geochemical analyses of both the DG and the rock indicate no high concentrations of elements that would be deleterious to the environment.

Quantity of DG within the study area was explored through seismic refraction and drilling and then a three-dimensional computer model was created to obtain a volume estimate. For this part of the project, the primary characteristic evaluated was the thickness of the rippable layer of decomposed rock, since this essentially identifies the amount of DG available for mining. Results from the refraction surveys show variations in the thickness of rippable DG across the study area, estimated from 15 feet to over 100 feet. The drilling program confirmed these results and provided additional depth information in areas where refraction was not performed. From modeling, there is a total of 31.6 million tons of DG present within the study area.

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LIST OF ABBREVIATIONS

ASTM	American Society of Testing and Materials
Caltrans	California Department of Transportation
DEMRM	Division of Energy and Mineral Resources Management
DG	decomposed granite
DH	drill hole
LA abrasion	Los Angeles abrasion
LA100	percent loss after 100 rotations of the Los Angeles abrasion drum
LA500	percent loss after 500 rotations of the Los Angeles abrasion drum
LPBMIR	La Posta Band of Mission Indians Reservation
Ma	million years ago
PCC	Portland cement concrete
ppm	parts per million
PRB	Peninsular Ranges Batholith
psi	pounds per square inch
Res	Reservation
RQD	rock quality designation
SE	sand equivalent
TS	thin section
USCS	Unified Soil Classification System

CHAPTER 1

INTRODUCTION

1.1 Purpose of Study

The La Posta Band of Mission Indians is interested in re-opening their Sand Pit. They requested technical assistance from the Bureau of Indian Affairs- Division of Energy and Mineral Resources Management (DEMRM) in 2003 for the evaluation of aggregate resources in the vicinity of the pit. The purpose of this study is to characterize the quality and quantity of aggregate resources near the existing pit on the La Posta Band of Mission Indians Reservation (LPBMIR).

1.2 Location

The Thirty Mission Indian Reservations of southern California is a group of reservations located between coastal California and the Salton Sea, as shown in Figure 1.1. The LPBMIR is approximately 50 miles east of San Diego and 10 miles north of the Mexican border in San Diego County.

The Reservation consists of 3,672 acres and is split into two parcels. Interstate 8 crosses the southwestern corner of the main parcel, with the smaller 200 acre portion located approximately one mile to the northwest. The Manzanita and Campo Indian Reservations lie immediately east of the Reservation. The LPBMIR consists of mountainous terrain with elevations from 3,500 feet in the west up to 4,500 feet in the southeast. Most of the Reservation is covered by scrub brush, with oak trees growing along ephemeral creek beds and residual boulders exposed along prominent ridges and mountain tops (Figure 1.2).

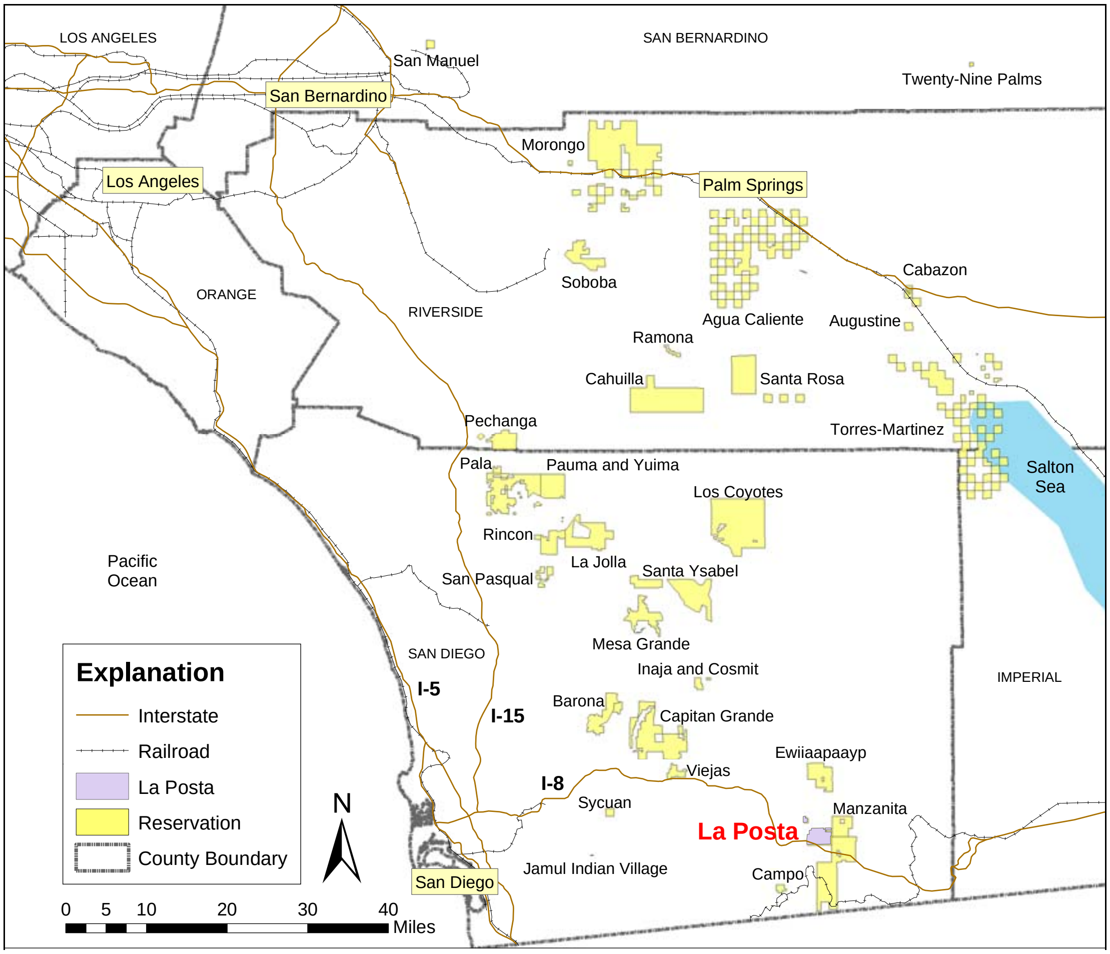

Figure 1.1: Location of the Thirty Mission Indian Reservations within five counties in Southern California.

The study area comprises about 200 acres surrounding the existing Sand Pit and is located in the southwestern part of the Reservation just north of I-8 (Figure 1.3). The study area boundaries were established during a planned expansion of the pit in 2001, but were modified to exclude riverbed material due to Tribal concerns and potential

Figure 1.2: Central valley of the La Posta Band of Mission Indians Reservation. Typically residual boulders are exposed on prominent ridges and mountaintops, scrub brush covers moderately sloping hillsides, and oak trees grow along major drainages.

environmental complications. The terrain consists of gently to moderately sloping hillsides with large boulders exposed at the surface.

1.3 Aggregate in Southern California

Aggregate sources close to the greater Los Angeles/San Bernardino and San Diego areas are quickly being depleted. Extrapolated from both current consumption and population forecasts, the estimated demand over the next 50 years is expected to be very

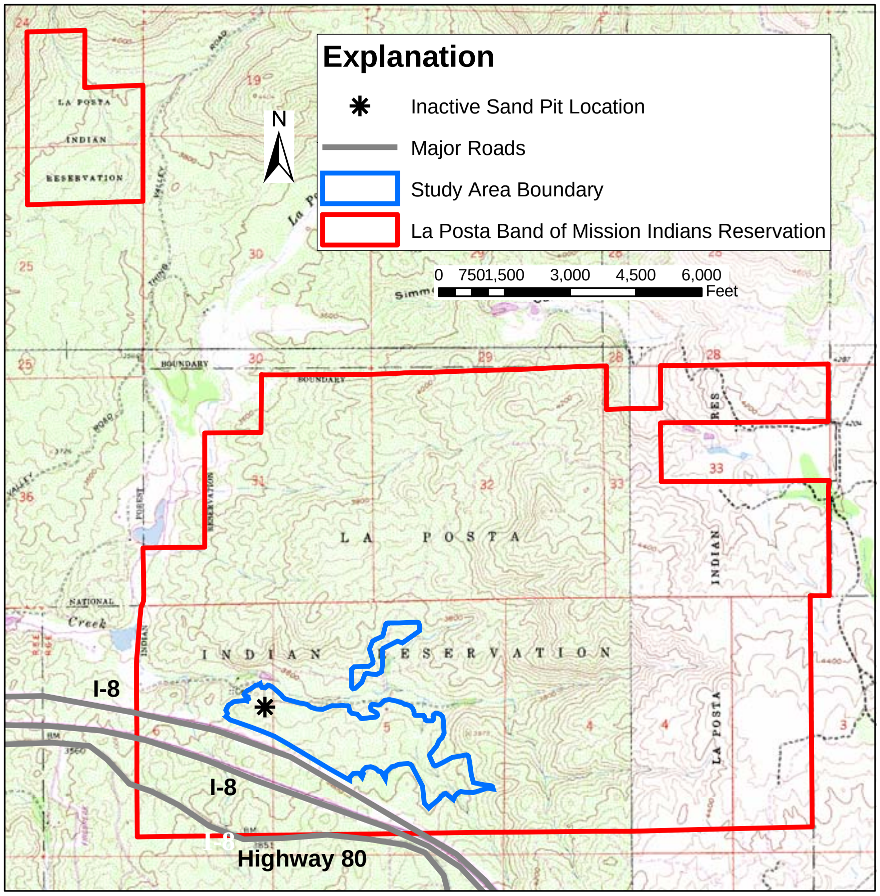

Figure 1.3: Location of study area (shown in blue) within the La Posta Band of Mission Indians Reservation in relation to existing pit and I-8.

high for both of these regions. However, currently permitted aggregate resources in these areas are much less than the expected demand (Kohler, 2002) as shown in Table 1.1:

Projected shortages of 71% for the greater Los Angeles/San Bernardino area and 75% for the greater San Diego area can be reduced by permitting new aggregate sources in the surrounding areas. According to the San Diego County Department of Public Works (2003), operating permits for several of the aggregate pits near the LPBMIR will

Table 1.1: Aggregate demand and availability in Southern California (Kohler, 2002).

	Estimated 50 Year Demand	**Currently Permitted Sources**	**Deficit**
Greater Los Angeles/San Bernardino area	4,328 Million Tons	1,545 Million Tons	3,090 Million Tons
Greater San Diego area	1,099 Million Tons	275 Million Tons	825 Million Tons

expire by the end of 2005. This creates an opportunity for the Tribe to reopen their Sand Pit and sell material in the San Diego market region.

Due to the proximity of the LPBMIR to the eastern San Diego suburbs (less than 35 miles), aggregate from their land is valuable as a construction material. As transportation costs can significantly increase the price of aggregate, material from the Reservation will become more attractive as resources closer to the San Diego market are depleted. Furthermore, the Reservation is located along Interstate 8, which connects to San Diego and surrounding cities and increases the marketability of the aggregate. I-8 is easily accessed from the Sand Pit and the haul to San Diego is downhill. Also, urban sprawl is pushing development east of San Diego, which is decreasing the distance necessary to transport the products to construction sites.

One material that these populated areas will need is decomposed granite (DG), a highly weathered granitic rock. At the surface, it weathers to sand and sometimes gravel, but grades into more competent rock at depth. In southern California, DG is used in a variety of ways. It is most commonly sold as class 2 road base, subbase, and structural fill due to its free-draining, non-expansive nature and its ability to support heavy loads. In places where the DG consists of predominantly sand-sized particles (between the #4 and #200 sieve), it is sometimes sold as concrete sand if the material is of high enough quality and processed (washed and screened) prior to use.

1.4 Scope of Work

This study evaluated the DG resources within the study area on the LPBMIR with respect to whether sufficient quality and quantity exists for either road improvement projects within the Reservation itself or throughout southern California. Since the most economical way to mine decomposed rock is through "ripping," or excavating without blasting such as by scraping the working face of the pit with a backhoe or track-hoe, the target material for this study consisted of tonalite that is decomposed enough to be "ripped" (Figure 1.4). The unweathered rock located at depth was also assessed in case the Tribe decides to pursue crushed rock resources in the future. Both geologic and engineering characterizations of the material are provided so that the Tribe can decide how to develop their resources. Suggestions were made for differentiating zones of high-quality versus low-quality material, end-products that can be marketed, and any benefication processes that may be necessary to meet California Department of Transportation specifications.

The project was divided into seven major phases. These included:

1. *Literature Review:* Reports, maps, and other publications were reviewed to learn about the geology of the area on large and small scales and to evaluate how aggregate sources are explored and tested in the San Diego area. This helped refine the later phases of the project.
2. *Airphoto and field mapping*: This phase involved identifying variations in the lithology, surface expression, or degree of weathering of the rock and noting any structural features, which were mapped and correlated to variations in engineering properties when possible. Lineaments identified in this phase were studied in two of the subsequent phases of the project to evaluate their influence on quality and quantity of material.

Figure 1.4: Benches on the south side of the inactive Sand Pit. All material previously excavated was “ripped” with a track-hoe. Note unweathered boulder protruding from the center of the ripped face.

3. *Preliminary surface sample collection and testing*: Samples were collected from the pit and other DG exposures across the Reservation during an initial field visit. Selected engineering tests were conducted to provide an idea of general quality and identify variations in surface material. Results of this phase supported the decision to further evaluate the study area.
4. *Seismic refraction surveys*: The thickness of the rippable layer was estimated via seismic refraction. This provided an initial evaluation of the quantity of the highly weathered rock nearest to the surface and the depth to competent rock below. These thicknesses were later used to investigate the subsurface expression

of lineaments, choose borehole locations, construct cross-sections, and calculate the volume of the deposit.

5. *Sonic and core drilling:* A total of 995 feet of core was recovered from 12 boreholes to investigate the lineaments, verify the geophysical data, obtain subsurface samples for further engineering testing and quality designation of both DG and non-rippable rock, construct cross-sections, and model the resource.
6. *Engineering testing:* Additional engineering tests were performed on the drill core to measure aggregate quality at depth across the study area for both DG and the more competent bedrock. A suite of tests was used to characterize the site in detail. This data was used to identify end-products that are best suited for the material within the study area. Suggestions for processing techniques were also made based on comparison of drilling sample and processed stockpile results.
7. *Analysis:* All of this data was then analyzed to evaluate the quality and quantity of material from within the study area on the LPBMIR. Quality was assessed by comparing testing results to standard specifications, while quantity was evaluated by creating a three-dimensional computer model using the depth information acquired through this study. Recommendations to the Tribe were made based on the results of this analysis.

CHAPTER 2

BACKGROUND INFORMATION

2.1 Previous Work

The LPBMIR is located within the La Posta pluton (Kimbrough et al, 2001) which was emplaced about 94 million years ago (Ma) and is zoned from a tonalite at the margins to a granodiorite core. Gastil (1983, 1975 *in* Clinkenbeard, 1987) separated the general lithology into four smaller zonations based on lithology and geochemistry. Clinkenbeard (1987) further described these units, as well as age-dated them and identified the temperature and pressure of emplacement. Riley (1978) conducted geochemical analyses on clay seams exposed in road cuts west of the Reservation in the same geologic unit.

Ritchey, et al. (1982) described the mineral potential of the LPBMIR. The Metal Mountain Mining District, one mile to the north of the Reservation, contains metamorphic rocks with tungsten, feldspar, and gold. These metamorphic rocks do not crop out within the Reservation boundary. The authors also indicated that significant quantities of DG are located on the Reservation and could potentially be used for road construction and repair.

Christian Wheeler Engineering performed two studies during an attempt by Four Eagle Materials LLC to expand the Sand Pit in 2001. One study examined the rippability of the DG at depth through the use of seismic refraction (2001a). Ten short seismic refraction lines between 80 and 150 feet in length were shot near the existing excavation site to evaluate the depth to non-rippable bedrock using seismic velocities. Forward and reverse shot data were also collected from each location to examine local fluctuations in this layer. The subsurface material was categorized as rippable (0-4,500 ft/s), marginally rippable (4,500-5,500 ft/s), and non-rippable (5,500 ft/s and greater) based on the performance of a Caterpillar D-9. In general, the depth to non-rippable rock was estimated at 45 feet, although the limited data may have been influenced by a "localized area of fresh rock". In addition, Christian Wheeler Engineering noted that the ease of rippability of the DG seemed to correspond to the topography, with gently sloping areas indicating more extensively decomposed rock, while steeper terrain suggested fresher, less rippable rock close to the surface.

A second report produced by Christian Wheeler Engineering (2001b) pertained to a preliminary analysis of slope stability, which would be used to design benches within the pit. In their study, an angle of friction of 36^{o} and an apparent cohesion of 100 pounds per square foot were obtained from a "disturbed" sample shear test, which was considered a conservative estimate since *in situ* material would have higher strength. The intended excavation characteristics included 2:1 Horizontal:Vertical slopes with 12- to 15-foot-wide benches every 40 vertical feet. Using these parameters, the PCSTABL6 program predicted a factor of safety of 1.7, indicating a stable design configuration.

Several other studies were also performed on the study area. Algert Engineering prepared both an operating plan (2001a) and a reclamation and closure plan (2001b). Laguna Resource Services, Inc. created a Final Supplemental Environmental Assessment (2001) to which a Finding of No Significant Impact was issued in 2001 by the Bureau of Indian Affairs- Southern California Agency. These reports served as a guide for some of the most recent work to reopen the Sand Pit.

2.2 Geologic Setting

The LPBMIR is situated within the Peninsular Range physiographic province, which extends from the Los Angeles Basin to the southern tip of Baja California. This northwest-southeast trending mountain range consists of smaller ranges separated by San Andreas-related faults that parallel the mountains, such as the Elsinore and San Jacinto

Faults. The entire region is approximately 900 miles long and averages 55 miles in width, bounded by the Pacific Ocean to the west and south, the Colorado Desert and Gulf of California to the east, and the Transverse Ranges to the north. Elevations range from sea level to nearly 11,000 feet at San Jacinto Peak, although mountain tops typically are less than 6,000 feet.

Cretaceous igneous rocks constitute the majority of the Peninsular Ranges, although lesser amounts of Jurassic plutons and roof pendants are also exposed. The plutons that comprise the Peninsular Ranges Batholith (PRB) were formed during a period of continuous igneous activity starting approximately 125 Ma and ending about 90 Ma. This volcanism was caused by the subduction of the Farallon Plate (precursor to the Pacific Plate) under the North American plate. The PRB is generally divided into two regions, the older, magnetite-bearing western plutons and the younger, ilmenite-bearing eastern zones (Figure 2.1). The change in composition is attributed to a shift in plate directions, and therefore subduction angles, during the Mesozoic. The decrease in subduction angle caused a shift in the volcanic arc location tens of miles to the east, as well as changed the melt composition (Walawender, 2000).

The western plutons vary in composition from gabbroic, which tend to be the older rocks in the region, to younger tonalitic and monzogranitic rocks. In addition, plutons in this area are small, about 40 mi^2 or less, and commonly are formed from multiple injections of magma. Plutons in the eastern portion of the PRB, however, are predominantly tonalitic, were emplaced contemporaneously (about 94 Ma), and exhibit similar characteristics. Collectively, they are referred to as the La Posta-type plutons after the La Posta pluton itself, which is the largest one in the eastern zone at nearly 540 mi^2 currently exposed. Most significantly, these plutons were all formed from single pulses of magma that cooled inward from contacts with the host rock, creating concentric zonations in the rock units (Walawender, 2000).

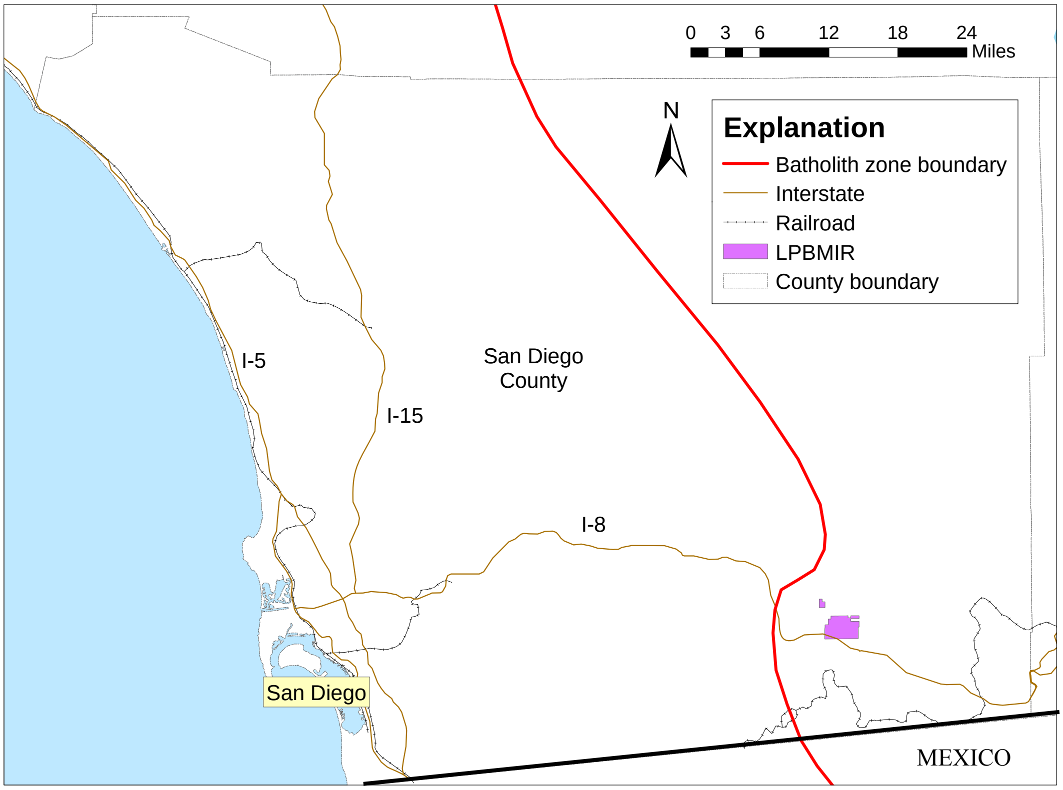

Figure 2.1: Western (>100 Ma) and eastern (<100 Ma) zones of the PRB in San Diego County separated by the red boundary line (modified after Walawender, 2000). The La Posta Band of Mission Indians Reservation (LPBMIR) is located in the eastern zone.

2.3 The La Posta Pluton

La Posta-type plutons display crystallization differentiation (Figure 2.2). The margins of the plutons are characterized by the more mafic rock types found in the complexes, such as tonalites, known as the hornblende-biotite facies because of the relative abundance of these minerals. Slightly aligned hornblende and biotite crystals show evidence of minor foliation near the outer edges of this zone. Inward from this zone is the large biotite facies, a generally granodioritic assemblage with biotite crystals averaging up to one centimeter in diameter. This grades into the small biotite facies, a monzogranite characterized by biotite crystals averaging only a few millimeters across. In the center of the pluton is the muscovite-biotite facies, another monzogranite, but with the addition of muscovite. Contacts between these zones are all gradational, ranging in width from tens to hundreds of meters (Walawender, 2000). The LPBMIR is located within both the large and small biotite facies, with the study area in the large biotite facies. When all of the facies are grouped together, they are referred to as the Tonalite of La Posta (Todd, 1995). This is also partly because the small percentage of potassium feldspar is nearly indistinguishable from plagioclase in hand sample, making classification between granodiorite and tonalite very difficult.

According to Clinkenbeard (1987), the primary components of all of the zones within the La Posta pluton include plagioclase, quartz, and biotite, with minor alkali feldspar. Biotite and hornblende are most common along the edges of the pluton and decrease in concentration towards the center, whereas the quartz and alkali feldspar contents increase closer to the core. In addition, muscovite is found only in the muscovite-biotite facies, the last phase of the pluton to cool. Accessory minerals found throughout the pluton include sphene, opaque minerals (ilmenite), apatite, zircon, and allanite. A summary of the most common minerals is provided in Table 2.1. Within each of the facies, mineral assemblages are generally uniform, except that rocks exposed on the eastern portion of the pluton have slightly larger crystals and the percentage of quartz and mafics is slightly higher than on the western side.

Within the pluton are three primary joint sets as described by Kimzey (1982 *in* Clinkenbeard, 1987). One set trends primarily north-south, another east-west, and the third is sub-horizontal. Ground water flow is concentrated along these fractures, which leads to an increased rate of weathering and erosion. Surface expression of these features includes linear arrangements of stream drainages, valleys, and vegetation that intersect each other at roughly right angles. Between these joint sets are less-weathered corestones, or localized areas of fresher rock, which form boulders and outcrops on

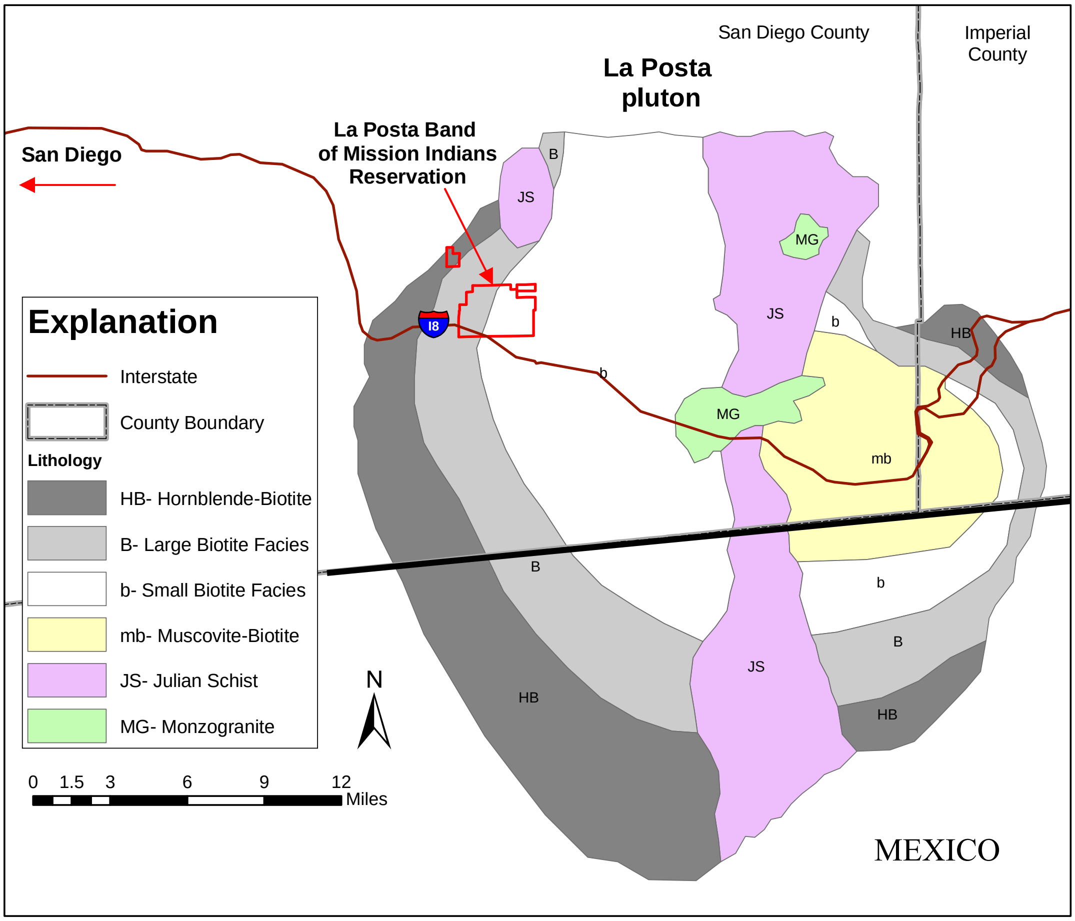

Figure 2.2: Concentric zonations within the La Posta pluton in San Diego and Imperial Counties, California, and Mexico (after Smith, 2002).

hillsides after the more easily eroded material along the fracture sets is removed (Figure 1.2). Faults in the area trend about N20°E and N81°E (Riley, 1978). These orientations roughly coincide with the joint sets, suggesting a possible relationship in genesis.

Riley (1978) studied clay seams that occur along fractures in a road cut within the large biotite facies of the La Posta pluton. In these clay seams, hornblende and biotite

Table 2.1: Mineralogy of each La Posta pluton zone (Clinkenbeard, 1987).

	Hornblende-Biotite			**Large Biotite**		
	Shape	**Percentage**	**Size**	**Shape**	**Percentage**	**Size**
Plagioclase	sub-eu	40-59%	2-10 mm	sub-eu	44-55%	3-4, up to 10 mm
Quartz	an-sub	22-32%	4-5 mm	an	27-39%	2-5 mm
Biotite	sub	12-24%	1-5 mm	eu	7-15%	1-10 mm
Hornblende	sub-eu	2-5%	3-7, up to 20 mm	sub-eu	0-3%	1-3 mm
Alkali Feldspar	oikocrysts	0-4%	n/a	oikocrysts	2-7%	up to 30 mm
Sphene	eu	0-2%	up to 10 mm	eu	accessory	up to 10 mm
Muscovite	x	x	x	x	x	X

	Small Biotite			**Muscovite-Biotite**		
	Shape	**Percentage**	**Size**	**Shape**	**Percentage**	**Size**
Plagioclase	sub-eu	45-54%	1-3 mm	sub-eu	42-53%	1-4 mm
Quartz	an-sub	29-37%	2-5 mm	an-sub	30-43%	1-5 mm
Biotite	eu	5-13%	1-4 mm	sub	4-10%	1-2 mm
Hornblende	eu	trace	up to 2 mm	x	x	X
Alkali Feldspar	oikocrysts	2-12%	up to 30 mm	oikocrysts; eu	6-13%	up to 30 mm; 2-4 mm
Sphene	eu	accessory	1-4 mm	x	x	X
Muscovite	x	x	x	sub-eu	0-3%	1-3 mm

eu = euhedral
sub = subhedral
an = anhedral

n/a= not provided by author
x = mineral not found in zone

altered to montmorillonite and oligoclase became kaolinite. Prehnite and laumontite, two types of zeolite minerals, also developed from the oligoclase. Due to the presence of the zeolites, this mineral assemblage was most likely caused by past moderate hydrothermal fluid activity around 100°C to 150°C. Today, the Agua Caliente hot springs exist about 20 mi to the north, indicating potential for past thermal activity in the LPBMIR area.

CHAPTER 3

METHODS

3.1 Literature Review

Reports, publications, and theses were reviewed at the start of this project and throughout its duration. In addition, maps, aerial photographs, and satellite imagery of the region surrounding the LPBMIR were studied to gain a better understanding of the structure and relationships between geologic units. All of this information was used to design the later phases of the project, including surface sampling, seismic refraction, and core drilling.

3.2 Mapping and Surface Sampling

In October 2003, the geology of the main part of the Reservation was mapped. Road cuts along I-8 were investigated to evaluate the thickness of DG and depth to competent rock, and to draw any possible correlations between surface expression and degree of weathering in the subsurface. Exposures within the Sand Pit were also examined for degree of weathering and extent of mineral alteration.

Surface samples were collected from DG exposures throughout the Reservation for preliminary quality testing. Six samples were collected from the Sand Pit to evaluate quality of existing in-place resources, three from stockpiles of washed and screened material to assess the change in quality after processing, and eight from various cuts or other exposures to evaluate variations in grain size or quality across the Reservation. Approximately 50 lbs of DG was obtained at each location, with samples collected according to standards set forth by the American Society for Testing and Materials

(ASTM) D 75-97 (2003). All ASTM standards used in this study are located in Appendix A. ASTM standards provided an approximation of quality on these reconnaissance samples. Physical tests performed on these samples include gradation (ASTM C 117-95 and C 136-01), sand equivalent (ASTM D 2419-02) on unwashed and washed DG, and one Los Angeles abrasion test (ASTM C 131-01) on a stockpile sample. All tests were performed at the testing facilities at the Colorado School of Mines. Engineering testing results were used to refine later work based on preliminary quality, including identification of appropriate physical tests to perform on subsurface samples and recommendation of processing techniques that would increase the quality of the material. For example, different types of degradation tests were performed depending on whether the sample consisted of DG or bedrock since certain tests are only appropriate for certain materials. Also, tests were performed on both processed and unprocessed material in order to evaluate changes in product quality so that recommendations could be made for future mining operations.

3.3 Seismic Refraction

Seismic refraction was used to investigate the thickness of DG and depth to competent rock. Refraction program results were used to refine cross sections through the study area, propose borehole locations, and aid in DG resource modeling. A 16 lb sledge hammer was struck against a steel plate (Figure 3.1) a total of nine times at each shot location to emit compressional waves into the ground. Waves increased in velocity as they arrived at more competent layers, an indication of harder rock, with the compressional energy partly reflected back to the surface and partly refracted into the layer beneath it. This scenario occurred each time a new, higher velocity layer was reached until the energy dissipated. As the energy was reflected back up to the surface, geophones recorded the arrival times used to calculate the apparent thickness and transmission velocity of the layer that reflected it. Since DG has a lower characteristic velocity range than competent rock, the type and condition of each unit was identified through the interpretation of the data collected. Data was recorded on a Geometrics StrataVisor NX in SEG-2 format, with a specified sample interval of 0.250 milliseconds and total record length of 0.5 seconds.

Seven seismic refraction lines were shot within the study area to obtain information on various anticipated subsurface conditions, such as thickness of DG overlying bedrock at depth, areas of DG mixed with boulders, thickness of alluvial deposits, and the influence of major joint sets on thicknesses of DG resources. Two lines verified a previous refraction study (Christian Wheeler Engineering, 2001a). Where possible, sites were selected with minimal changes in elevation to simplify the seismic modeling. All locations are shown in Plate 2.

All lines utilized 60 geophones, making six of the seven lines 118 m long using 2 m geophone spacing. The other seismic line, LP-S1, was 295 m long with geophones placed at 5 m intervals in an attempt to obtain deeper subsurface information. A rule of thumb is that data can be collected as deep as 1/3 of the total length of the refraction line, provided that enough energy is put into the ground. Therefore, the expected depth of resolution for these surveys was around 30-40 m, or about 100 ft. For six of the seven lines, shot points were spaced every five geophones, with an additional three off-end shots spaced 10 m apart used at both the start and end of the line (where possible). For LP-S1, shot points were located 50 m off one end and at the first, tenth, twentieth, thirtieth, and fortieth geophones. No shot points were located past the fortieth geophone on this line due to the insufficient length of the trigger extension reel (cable). The limiting length of the trigger extension reel led to the change in geophone spacing from 5 m to 2 m. Also, smaller geophone spacing is also more appropriate for a detailed near-surface evaluation (Redpath, 1973). Furthermore, the sledge hammer source used in this study did not produce enough energy to be recorded on geophones as far as 200-300 m away.

For each seismic line, locations and changes in elevation were recorded. The X, Y, and Z coordinates of the first and sixtieth geophones were recorded on a global

Figure 3.1: Sledge hammer impact on a steel plate was used as the seismic energy source for the geophysical surveys. Photograph shows LP-S5 location and computer used for data collection.

positioning system (GPS) device. Elevations of shot point locations were sited using a Brunton pocket transit (compass) and a survey staff, with the first geophone used as a base elevation (Figure 3.2).

Once the data was collected, the subsurface was modeled using two different types of software, both made available for use by Blackhawk GeoSciences of Golden, CO. After the data was filtered to remove noise caused by wind (for sledge hammers, typical low- and high-cut filters are 1 Hz and 250 Hz, respectively), first breaks were

Figure 3.2: At LP-S4, a Brunton pocket transit (compass) and survey staff were used to measure elevation changes.

chosen using PickWin95. These files were then imported into Gremix, a modeling program where travel-time curves are analyzed to identify changes in velocity and prepare cross-sections. Results from these surveys were used in selecting borehole locations and planning borehole depths.

3.4 Drilling

A drilling program was conducted in August 2004 to confirm the results of the seismic refraction surveys, obtain subsurface samples for quality testing, explore for any possible changes in subsurface lithology, and investigate the degree of alteration or weathering at depth. Boreholes were located in accessible areas to provide both good coverage of the site and to fill in gaps in the cross-sections. Two drilling methods were used in the study area: sonic and wireline core. The majority of the holes were vertical in orientation, with one hole drilled at a 45 degree angle to investigate lateral influences of joint sets on weathering. Some boreholes confirmed the seismic refraction line data, while other boreholes provided control for cross-sections and collect subsurface sample testing material from across the study area.

The drilling was started using sonic drilling, but was switched to wireline core partway through the project. Sonic drilling was originally selected for this project due to its reputation for high sample recovery in materials where low recovery is anticipated. It was also recommended by several drilling contractors during the site visit as the best way to sample DG. Other advantages for choosing sonic drilling were a fast drilling rate, low cost, fluid circulation needed only when drilling non-rippable rock, and a large core diameter. In addition, sonic drilling has been successfully used in the past to sample DG in the southern California area, and based on the appearance of the Sand Pit, sonic was anticipated to work well. Sonic drilling penetrates the subsurface by vibrating the drill stem with very little rotation and generally no fluid circulation. However, the vibratory nature of the sonic drilling broke down the DG from primarily sand and gravel to silty sand with gravel. This was most likely due to the DG not being decomposed enough to quickly clear away from the drill bit, and since no fluids or air was circulated to remove the material, it slowed down the drilling rate and caused the samples to be excessively vibrated. Therefore, the drilling method was switched to wireline core exclusively, which produced more representative samples.

Where possible, drilling stopped 10 to 20 ft into competent rock to distinguish subsurface boulders from bedrock, since small boulders can be removed and do not represent the lower limit of mining. Two holes, DH-G and DH-H, were located along seismic lines in order to verify the refraction data (Plate 2). Two of the sonic holes, DH-B and DH-C, were also twinned by core holes DH-B2 and DH-C2, respectively, to help correlate subsurface features between the two drilling methods. The lower 26 ft of DH-C were drilled by wireline core since the sonic rig could not penetrate more than a few feet into bedrock at this location. DH-A was oriented at a 45 degree angle to the east to investigate weathering near a N-S trending joint set, since a high density of clay seams were observed close to this location within the Sand Pit. Ultimately, however, some stockpiles blocked the drill rig from drilling through the joint set, so the entire borehole is located east of the surface lineament and investigates the extent of weathering near the feature. All of these locations are shown in Plate 2.

3.4.1 Sonic Drilling

For holes completed with sonic drilling, a 4.5 inch diameter carbide tooth bit was used in conjunction with a Roto-Sonic drill rig. The company contracted for the drilling was Boart Longyear's Environmental Drilling Division of Peoria, AZ. When possible, the samples were dry-drilled. When the bit needed cooling such as during bedrock drilling, water was circulated through the system producing wet samples. Samples were retrieved from the subsurface through a vacuum system within the sampling tube of the drill stem. Once the sampling tube was removed from the hole, the vacuum pressure was released and the sample extruded into a plastic bag (Figure 3.3). Generally, two to four feet of sample were collected in each run. Boreholes drilled with the sonic rig include DH-B, C, D, E, F, G, and I.

3.4.2 Wireline Core Drilling

The wireline core portion of the drilling collected PQ (3.5 inch diameter) core using an LF-70 drill rig (Figure 3.4) and a diamond bit. Boart Longyear's Core Drilling Division performed this portion of the project. Generally, core was collected in five foot runs except where problems were experienced (such as lost circulation, anticipated low recovery, etc.). Manual breaks in the core were noted for Rock Quality Designation (RQD) purposes.

Figure 3.3: Sonic drilling sample being extruded from sampling tube.

The focus of the project shifted when wireline core drilling proved to collect more representative subsurface samples than sonic drilling. The original plan had been to collect samples of both the DG and hard rock from each borehole location, but since the sonic samples were broken down, the remaining drilling was reallocated from collecting hard rock samples to collecting representative DG samples, specifically around the Sand Pit. Sampling the DG was more important because this material would be the primary end-product. Two of the sonic holes were twinned with wireline core holes in an attempt to correlate sonic sample features and testing results to core samples. Two new boreholes were also added east of the Sand Pit, since this would likely be the direction in which mining would first expand. Wireline core holes include DH-A, B2, C2, H, J, and the lower 26 feet of DH-C.

Figure 3.4: Core drilling of an angled hole DH-A.

3.5 Core Logging

Upon completion of the drilling program, both sonic and core samples were logged using both geologic and engineering descriptors and photographed for future reference. Samples were described for degree of weathering, color (based on the Munsell soil color chart), strength, average maximum crystal size (i.e. medium-grained), lithology, moisture content (wet vs. dry), and any additional features such as fractures or clay seams in the rock. Graphic logs were used to supplement these descriptions, and soil was logged according to the Unified Soil Classification System (USCS) (U.S. Bureau of Reclamation, 1998). Mineral percentages, sizes, width of alteration rims around minerals, and average maximum particle size regardless of crystal size (i.e. pieces of DG up to ½" in diameter) were also recorded. Percent sample recovery was rated on a scale of 0 to 100%, degree of weathering was rated on a scale from W1-Fresh to W9-Decomposed (Table 3.1), and strength/hardness was assessed on a scale of H1-Extremely Hard to H7-Very Soft (Table 3.2). For sonic samples, these evaluations were made based on pieces of gravel, if any was recovered, as opposed to the disturbed samples of silty sand. Once geologic descriptions were completed, each box of core was photographed to preserve a visual record (see Appendix E).

Table 3.1: Degree of weathering used to describe core samples (modified after Bureau of Reclamation, 1998).

	Weathering	**Description**
W1	Fresh	No discoloration.
W2	Fresh to slightly	Minor discoloration near fractures.
W3	Slightly	Discoloration only near fractures.
W4	Slightly to moderately	Some discoloration throughout, some Fe-Mg minerals "rusty" and feldspars "cloudy".
W5	Moderately	Discoloration usually throughout, Fe-Mg minerals "rusty", feldspars "cloudy", no hammer ring when struck.
W6	Moderately to intensely	Discoloration throughout, some Fe-Mg minerals and feldspars somewhat altered to clay.
W7	Intensely	Discoloration throughout, all Fe-Mg minerals and feldspars somewhat altered to clay, requires moderate to heavy pressure or light hammer blow to break.
W8	Intensely to decomposed	Discoloration throughout, Fe-Mg minerals and feldspars mostly altered to clay, breaks with light to moderate pressure.
W9	Decomposed	Discoloration throughout, Fe-Mg minerals and feldspars all altered to clay, quartz still solid, can be granulated by hand.

Table 3.2: Degree of strength/hardness used to describe core samples (modified after Bureau of Reclamation, 1998).

	Strength	Description
H1	Extremely Hard	Cannot be scratched, can be chipped with hammer.
H2	Very Hard	Cannot be scratched, can be broken with many heavy hammer blows.
H3	Hard	Can be scratched with difficulty, requires heavy hammer blow to break.
H4	Moderately Hard	Can be scratched with light to moderate pressure, requires moderate hammer blow to break.
H5	Moderately Soft	Can be scratched 1/16” (2 mm) with moderate to heavy pressure, requires light hammer blow or heavy manual pressure to break.
H6	Soft	Can be grooved with light pressure, scratched with fingernail, requires light to moderate manual pressure to break.
H7	Very Soft	Easy to indent, requires light manual pressure to break.

3.6 Rock Quality Designation

The Rock Quality Designation (RQD) of rock core was calculated when appropriate. For this study, RQD was only applied when the material was competent enough for the fractures to be the most likely mode of failure. Therefore, RQD was not performed on DG. Deere (1968) developed RQD to classify rock mass for engineering purposes and quantify discontinuity spacing based on drill core. Within a sample run, the ratio of the summation of individual pieces of core greater than four inches long to the total length of the run is reported as percent recovery. In general, the higher the percent, the more competent the rock due to greater fracture spacing. The equation used is:

$$\text{RQD } (\%) = 100 \left[\left(\sum x \right) / L \right]$$

where x represents the length of pieces of sound rock core greater than four inches in a drill run and L is the length of the drill run. Mechanical breaks were ignored. The RQD for each drill run was also listed on the core log.

The RQD value corresponds to an approximate rock quality, although the rating system should not be the sole factor in evaluating rock competency. The relationship between RQD and *in situ* rock quality is shown in Table 3.3.

Table 3.3: Qualitative correlation between RQD and *in situ* rock quality (Deere, 1968).

RQD (%)	Rock Quality
0-25	Very poor
25-50	Poor
50-75	Fair
75-90	Good
90-100	Excellent

3.7 Physical Testing and Standards for Decomposed Granite

In order to obtain representative samples for both the physical and geochemical testing, each DG sample was split down the center and half was collected for testing and half was retained for storage. Approximately 100 pounds of DG were collected for each sample to ensure enough material to perform the desired tests. For the material acquired through sonic drilling, sample intervals of roughly 20 ft were used, whereas 25 ft was used for the core samples. Sample numbers and their corresponding depth intervals can be found in Appendix F for DG samples and Appendix G for rock samples. The difference in sample intervals was due to the larger diameter of the sonic drill bit, which created a larger volume of sample for the same amount of core length. Three stockpile samples (locations shown on Plate 2) were also collected from the Sand Pit as per ASTM D 75-97 standards (ASTM, 1997) and subjected to the same tests as the drilling samples.

Physical tests performed on the DG included gradation (ASTM C-117-95 and C-136-01), sand equivalent (California Test 217), durability index (ASTM D-3744-97), specific gravity (ASTM C-127-01 and C-128-01), R-Value (California Test 301), and organic impurities (ASTM C-40-99). Samples were characterized using these engineering tests because this phase of the project necessitated a more detailed investigation than the reconnaissance samples. State of California Department of Transportation (Caltrans) standard testing procedures were used on subsurface samples if a Caltrans test existed. Otherwise, ASTM standards were used. Caltrans engineering tests were performed on the subsurface and stockpile samples collected in this phase since any products from the Sand Pit would be sold and used in California and therefore needed to be tested according to Caltrans methodology. The actual testing procedures for the ASTM tests and their Caltrans equivalents are included in Appendix A. All tests on DG collected in this phase of the project were performed by Testing Engineers – U.S. Labs in San Diego, CA.

Subsurface samples collected through both the sonic and core drilling programs were tested using either a reduced or full suite of tests. The reduced suite included gradation, sand equivalent, durability index, and R-Value. The full suite of tests was performed on the majority of samples and included gradation, sand equivalent, durability index, specific gravity, R-Value, and organic impurities. Specific gravity and organic impurities were excluded from the reduced suite since these tests are not as critical for defining the quality of the material. Specific gravity was necessary for modeling the deposit, while the organic impurities test is required for concrete. For drill holes where more than two samples were sent for testing, the full suite was always performed on the upper sample and then alternated with the reduced suite on subsequent samples from deeper in the hole (for example, 0-20 ft = full suite, 20-40 ft = reduced suite, 40-60 ft = full suite, etc.). Also, the three stockpile samples collected during the drilling program phase were all subjected to the full suite of tests.

3.7.1 Gradation

The distribution of grain sizes of DG was assessed through ASTM C-117-95 (2003) and ASTM C-136-01 (2003) for surface samples and California Test 202 (Caltrans, 2004b) for subsurface samples. The gradation of a sample is important in identifying potential construction uses of material. In order to obtain a representative portion of the whole sample for this test, all samples were mechanically split according to California Test 201 (Caltrans, 2004a). To evaluate the gradation, a known mass of sample is mechanically sieved on a stack of screens with successively smaller openings so that the percentage of each grain size range can be obtained by mass. Sieves used included the 2”, 1 ½”, 1”, ¾”, ½”, 3/8”, #4, #8, #16, #50, #100, and #200. Particles larger than 2” were measured by hand and the mass was evaluated separately. The amount of material sieved is dependent upon the nominal maximum grain size, so samples with larger diameter particles contained more material than finer grained samples. Samples with a nominal maximum grain size of 1/4” or less were dried, weighed, washed to remove the fines (minus #200 sieve portion), dried and weighed again, and then sieved. If the sample was coarse grained, then a separate sample was split out and washed to evaluate the amount of fines.

For the different types of end-products (road base, asphalt, etc.), different material gradations are needed. The Caltrans operating ranges for each of the end-uses is listed in Table 3.4. Exact gradations listed for asphalt can be adjusted by the engineer for certain projects, as signified in Table 3.4 by the X and corresponding ranges provided. The most common gradations for asphalt include Type A (3/4” maximum, coarse), Type B (3/4” maximum, medium), and open-graded (3/8” maximum).

Table 3.4: Gradations required by Caltrans for subbase, Class 2 base, asphalt base, and asphalt, X = gradation percentage determined by engineer (Caltrans, 2002).

Subbase	**Percentage Passing**		
	Class 1	**Class 2**	**Class 3**
3"	100	100	100
2.5"	90-100	90-100	90-100
#4	35-70	40-90	50-100
#200	0-20	0-25	0-30

Class 2 Base	**Percentage Passing**	
	1.5" Max	**3/4" Max**
2"	100	-
1.5"	90-100	-
1"	-	100
3/4"	50-85	87-100
#4	25-45	30-65
#30	10-25	5-35
#200	2-9	0-12

Asphalt Base		
	Percent Passing	
1 1/4"	100	-
1"	95-100	-
3/4"	80-10	-
3/8"	X ± 5	X = 55-60
#4	X ± 5	X = 40-45
#30	X ± 5	X = 14-19
#200	2-7	-

	Asphalt							
	Percentage Passing							
	3/4" Max Coarse		**3/4" Max Medium**		**1/2" Max Coarse**		**1/2" Max Medium**	
1"	100	-	100	-	-	-	-	-
3/4"	90-100	-	95-100	-	100	-	100	-
1/2"	-	-	-	-	95-100	-	95-100	-
3/8"	60-75	-	65-80	-	75-90	-	80-95	-
#4	X ± 5	X = 45-50	X ± 5	X = 49-54	X ± 5	X = 55-61	X ± 5	X = 59-66
#8	X ± 5	X = 32-36	X ± 5	X = 36-40	X ± 5	X = 40-45	X ± 5	X = 43-49
#30	X ± 5	X = 15-18	X ± 5	X = 18-21	X ± 5	X = 20-25	X ± 5	X = 22-27
#200	3-7	-	3-8	-	3-7	-	3-8	-

	Asphalt				**Open Graded Asphalt**			
	Percent Passing				**Percent Passing**			
	3/8" Max		**#4 Max**		**1/2" Max**		**3/8" Max**	
3/4"	-	-	-	-	100	-	-	-
1/2"	100	-	-	-	95-100	-	100	-
3/8"	95-100	-	100	-	X ± 4	X = 78-89	90-100	-
#4	X ± 6	X = 73-77	95-100	-	X ± 4	X = 28-37	X ± 4	X = 29-36
#8	X ± 6	X = 58-63	X ± 6	X = 72-77	X ± 4	X = 7-18	X ± 4	X = 7-18
#16	-	-	-	-	0-10	-	0-10	-
#30	X ± 6	X = 29-34	X ± 6	X = 37-43	-	-	-	-
#200	3-10	-	3-12	-	0-3	-	0-3	-

3.7.2 Sand Equivalent

ASTM D-2419-02 (2003) and California Test 217 (Caltrans, 2004c) describe the procedures used to calculate the sand to clay ratio in a sample. The amount of fines (clay-sized particles passing the #200 sieve) in aggregate will dictate potential end-uses as a construction material. Flocculating solution is placed into a graduated cylinder along with 85 mL+/-5 mL of the minus ¼" portion of a sample and allowed to sit for 10 minutes. The entire ensemble is then shaken for 45 seconds to thoroughly wet the sample and more flocculating solution is added. It is again allowed to settle, with the sand falling out of solution first and the fines settling out over time and located on top of the sand. After 20 minutes, the clay reading is recorded as the total height of the sediment column within the graduated cylinder. The sand reading is evaluated by lowering a weighted foot assembly into the graduated cylinder, through the clay (it will rest on the sand), and recording the height of the sand column. The sand equivalent (SE) is calculated as:

$$SE = (\text{sand reading} / \text{clay reading}) \times 100$$

The greater the percentage of sand-sized particles within a sample, the higher the SE value. Two SE tests are performed on separate samples and the average value is reported. Figure 3.5 shows an SE test being performed.

For selected surface samples, SE tests were also performed on material that had been washed during the fine gradation test. To conform to Caltrans requirements, SE values must meet or exceed the specifications set forth in Table 3.5.

3.7.3 Durability Index

ASTM D 3744-97 (2003) measures the resistance of aggregate to producing clay-sized fines when abraded in water. The coarse durability test is performed by agitating a sample of coarse-grained material in a wash vessel with water and then separating out the

Figure 3.5: Sand equivalent test on surface sample LP14.

Table 3.5: Minimum sand equivalent values for each end-product (Caltrans, 2002).

End-products	Minimum SE Value
Subbase (all classes)	21
Class 2 base	25
Asphalt- Type A	50
Asphalt- Type B	45
Asphalt- open graded	N/A
Asphalt base Type A	50
Asphalt base Type B	45
Portland cement concrete - fine	75

minus #200 sieve portion using a washing procedure similar to that used for the fine gradation test (ASTM C 117). The minus #200 sieve portion is then placed into a graduated cylinder with flocculating solution and the height of the sediment column is then read. This value is then compared to a chart (Appendix A, ASTM D 3744-97, page 403) to obtain the equivalent durability index value.

The fine durability test is identical to the sand equivalent test, except that the entire assembly is agitated in a mechanical shaker for 10 minutes rather than 45 seconds. The fine durability index is calculated in an identical manner as SE:

$$\text{Durability}_{\text{fine}} = (\text{sand reading} / \text{clay reading}) \times 100$$

The greater the percentage of sand-sized particles within a sample, the higher the fine durability value, indicating less break down due to interparticle abrasion in water.

Caltrans only has standards for fine durability index for Portland cement concrete (PCC) and class 2 base. The minimum passing values for each test are provided in Table 3.6.

Table 3.6: Caltrans standards for fine durability index (Caltrans, 2002).

End-Product	Minimum Fine Durability Index Value
Base	35
Portland cement concrete - fine	60

3.7.4 Specific Gravity and Absorption – Coarse and Fine

The DG was tested for both coarse and fine specific gravity and absorption according to ASTM C 127-01 (2003) and ASTM 128-01 (2003). Specific gravity measures the density of the material relative to the density of distilled water at a specified temperature. This value was used to calculate tonnages within the deposit. Absorption quantifies the mass of water which enters the pore spaces of a sample but not water that is on the surface of the material. For coarse-grained material, these values are obtained by oven drying the sample, soaking it in water for 24 hours, drying the surfaces of the sample, massing the saturated-surface-dry sample, taking the mass of the sample while immersed in water, oven drying again, and weighing again. The calculation for specific gravity (saturated-surface-dry) and absorption are:

$$\text{Relative Density (Specific Gravity)} = B / (B - C)$$

$$\text{Absorption, \%} = [\ (B - A) / A\ ] \times 100$$

where A = mass of oven-dry test sample in air (g)

B = mass of saturated-surface-dry test sample in air (g), and

C = apparent mass of saturated test sample in water (g).

For the fine-grained fraction of the sample, these properties were evaluated in essentially the same way, except that the volume of the material is found volumetrically using a Le Chatelier flask. The equations for specific gravity (saturated-surface-dry) and absorption are:

$$\text{Relative Density (Specific Gravity)} = S / [0.9975 (R_2 - R_1)]$$

$$\text{Absorption, \%} = 100 [(S - A) / A]$$

where A = mass of oven dry specimen, (g)

R_1 = initial reading of water level in Le Chatelier flask (mL)

R_2 = final reading of water level in Le Chatelier flask (mL)

S = mass of saturated-surface-dry specimen (g).

3.7.5 R-Value

California Test 301 (Caltrans, 2004d) was used to evaluate the material's R-Value, which is an index of the material's ability to resist lateral deformation when a vertical load is applied. It is a measure of shear strength under the worst-case scenario of saturation (Day, 1999). Water is added to the sample, it is allowed to cure, and then the sample is compacted by adding horizontal and vertical pressures. Compaction occurs in two stages, a preliminary compaction to evaluate if free water can be obtained initially from the sample at a pressure of 300 psi, and an exudation compaction, where an increasing load of 148 N are added per second until water is exuded from the specimen. The specimen is then allowed to expand under saturation and the expansion is measured. The horizontal pressure and displacement is measured by means of the stabiliometer. Several calculations are necessary to evaluate the R-Value and these can be found in Appendix A.

R-Value tests are primarily run on base and subbase material. The minimum values to pass Caltrans specifications are listed in Table 3.7.

3.7.6 Organic Impurities

To identify if fine aggregates contain organic impurities that may be detrimental to the production of hydraulic cement mortar or concrete, procedures were followed from

Table 3.7: Caltrans minimum standards for the R-Value test (Caltrans, 2002).

End-Products	Minimum R-Value
Class 2 Base	78
Class 1 Subbase	60
Class 2 Subbase	50
Class 3 Subbase	40

ASTM C 40-99 (2003). In this test, an aggregate sample is added to a sodium hydroxide solution and shaken briefly. After 24 hours, the color of the solution is compared to a suite of standard colors called the Gardner Color Standard and the best match is recorded using the corresponding Organic Plate number.

This test is required by Caltrans for PCC. The allowable amount of impurities is established by the engineer on a project by project basis, but generally the allowable amount of organics for fine concrete aggregate ranges from zero to three.

3.8 Physical Testing and Standards for Crushed Rock

For the less-weathered rock that necessitated crushing prior to testing, a total of eight samples four to eight feet in length were collected from a total of seven drill holes, including two samples from borehole DH-G. The sample from borehole DH-B was a composite sample, while samples from the other boreholes were representative of the material collected. DH-G contained significant quantities of both highly and less weathered non-rippable rock, therefore two samples were tested from this hole. The rock was then crushed using a jaw crusher to the sizes and quantities required for the Los Angeles (LA) abrasion and sodium sulfate soundness tests. The crushing was performed by Hazen Research, Inc. of Golden, CO. Eight samples were then tested for LA abrasion and sodium sulfate soundness according to ASTM standards. LA abrasion tests were conducted at the Colorado School of Mines materials testing laboratory, while sodium sulfate soundness testing was performed by CTL Thompson, Inc. in Denver, CO.

3.8.1 Los Angeles (LA) Abrasion

ASTM C 131-01 (2003) was used on the competent rock collected in the study area during the drilling. LA abrasion is a measure of how quickly a rock breaks down when tumbled and abraded and is an index of the quality of the rock as a construction material. The "A" gradation of material (Table 3.8) and 12 steel ball bearings were placed into a steel drum that rotates. A shelf is fixed onto the wall of the drum, which serves to lift and then drop the contents as the drum spins. After 100 rotations of the drum, the entire sample is removed and screened to quantify how much material passes through the #12 (1.7 mm) sieve, or the amount "lost". All of the material is then returned to the drum for an additional 400 rotations and screened again. The ratio of mass of material lost, or passing the #12 sieve, to the original sample mass is reported as the percent wear, or loss. This value is calculated for both 100 and 500 rotations as:

$$\text{Percent Loss (\%)} = [(A - B) / A] \times 100$$

where A = total original mass (g)
B = mass of sample retained on #12 sieve after either 100 or 500 rotations (g)

The uniform hardness is the ratio between the amount of material coarser than the #12 sieve after 100 rotations compared to that after 500 rotations and is used to assess whether the majority of the breakdown of the rock occurs initially with little subsequent wear, or if it is more gradual. A uniform hardness of 0.2 indicates uniform breakdown of the rock. An LA abrasion machine is shown in Figure 3.6. The LA abrasion test is used for both asphalt concrete and PCC. Caltrans standards for maximum percentage lost are provided in Table 3.9.

Table 3.8: Grain size distribution for the "A" gradation used in the LA abrasion test (ASTM C 131-01, 2003).

Sieve Size		Mass
Passing	Retained on	A gradation
1.5"	1"	1,250 +/- 25 g
1"	3/4"	1,250 +/- 25 g
3/4"	1/2"	1,250 +/- 25 g
1/2"	3/8"	1,250 +/- 25 g

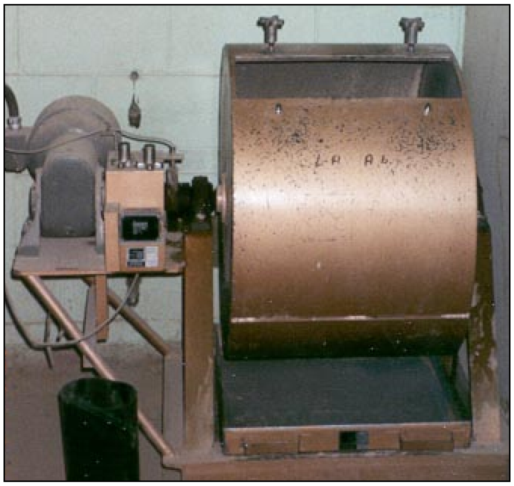

Figure 3.6: Los Angeles abrasion machine.

3.8.2 Sodium Sulfate Soundness

In order to assess the material's susceptibility to break down by freeze-thaw, ASTM C 88-99a (2003) was performed by CTL Thompson, Inc., of Denver, CO. In this test, a predefined gradation of material (Table 3.10) is subjected to five cycles of immersion in sodium sulfate solution that is maintained at constant specific gravity, followed by oven drying. The expansion of dry sodium sulfate salt upon re-immersion in

Table 3.9: Maximum loss for LA abrasion as per Caltrans standards (Caltrans, 2002).

End-Products	Maximum Loss after 100 turns	Maximum Loss after 500 turns
Asphalt concrete- Type A	10%	45%
Asphalt concrete- Type B	-	50%
Open graded asphalt concrete	10%	40%
Asphalt concrete base Type A	10%	45%
Asphalt concrete base Type B	-	50%
Portland cement concrete - coarse	-	45%

solution imitates the expansion of water as it freezes. The breakdown of grains is quantified by the loss of fines. Loss is quantified by the amount of material that passes the 5/8" sieve for the original ¾" to 1.5" fraction, the 5/16" sieve for the initial 3/8" to ¾" material, and the #5 sieve for the original ¼" to 3/8" material. The calculations needed for this test are in Appendix A.

This test is only required by Caltrans for PCC. The maximum allowable loss after five cycles for coarse aggregate is 10% (Caltrans, 2002).

3.9 Geochemical Analysis

From the material split for physical testing, a small (about 0.5-2 pound), representative portion of each sample was used for geochemical analysis. Additional samples were analyzed if they contained atypical features such as reddish clay infillings or bright orange residue on surfaces to evaluate variations in chemical composition. Both 34-element and whole rock analyses were performed on each sample to evaluate if any elements are present in the rock that are considered deleterious materials and could lower quality, such as mercury, cadmium, or sulfur. Both types of geochemical analyses were

Table 3.10: Grain size distribution used for sodium sulfate soundness test (ASTM C 88-99a, 2003)

Sieve Size		Mass
Passing	Retained on	Coarse Aggregate
1.5"	3/4"	1,500 +/- 50 g
Consisting of		
1.5"	1"	1,000 +/- 50 g
1"	3/4"	500 +/- 30 g
3/4"	3/8"	1,000 +/- 10 g
Consisting of		
3/4"	1/2"	670 +/- 10 g
1/2"	3/8"	330 +/- 5 g
3/8"	1/4"	300 +/- 5 g

performed by ALS Chemex with all 27 samples (including one duplicate) submitted to their Elko, NV laboratory.

3.9.1 34 Element Analysis

All geochemical samples were tested for the presence of 34 base metals and major rock-forming elements, listed in Appendix H. Sample preparation included fine crushing and pulverization, followed by aqua regia (acid) digestion to put the elements into solution. Samples were then analyzed using inductively coupled plasma with atomic emission spectroscopy to evaluate elemental concentrations in each sample.

While aqua regia only partially digests elements such as aluminum or barium, it is more appropriate for evaluating concentrations of volatile trace elements such as arsenic, mercury, and antimony, which was the intent of this analysis. Since aqua regia digestion involves lower temperatures than the more complete digestive methods, the volatile elements were not driven off, thereby making their analyzed concentrations more accurate. The major rock-forming and resistive elements in this analysis that the aqua regia digestion method only yields partial results include aluminum, boron, barium, beryllium, calcium, chromium, gallium, potassium, lanthanum, magnesium, sodium, scandium, strontium, titanium, thallium, and tungsten (Ramshaw, 2005).

This geochemical test analyzed the concentrations of elements that could potentially be harmful to the environment if released, such as arsenic or cadmium. High sulfur content could indicate a high percentage of sulfide minerals, which would be deleterious if the rock was used in concrete, since the weathering of sulfide minerals leads to discoloration of concrete and popouts. Results were then reviewed to evaluate whether or not elemental concentrations in the samples were high enough to be of concern.

3.9.2 Whole Rock Analysis

A whole rock analysis was also performed on each of the samples submitted to ALS Chemex. Whole rock analysis quantifies the amount of each major and minor oxide in a rock, which should add up to 100% of the total composition in non-ore-bearing rocks. The samples were first crushed and pulverized to expose more surface area and then tested with an x-ray fluorescence machine to identify the percentages of each oxide, plus loss on ignition. This test is primarily used to evaluate whether mineralogical anomalies, such as high levels of strontium or chromium, exist within the major rock-forming elements, since this analysis more accurately reflects concentrations of non-trace elements, such as aluminum or calcium, than the 34 element analysis.

Loss on ignition results from the sample being heated to 900^{o}C and can be caused by several factors. If the sample contains any free moisture, it will be evaporated, causing the sample to lose weight. This is especially problematic if the sample is subjected to extensive grinding, thereby generating excess fines which adsorb moisture from the atmosphere more easily. High clay percentages in rock samples also increase the fines percentage and loss of water weight when heated, making loss on ignition a possible indicator of degree of alteration or weathering as well. Calcite can also decompose at this temperature, releasing carbon dioxide gas to the atmosphere. All of these factors can lead to a higher loss on ignition (Peterman, 2005).

3.10 Petrographic Analysis

Twelve samples obtained from the drilling program were prepared for petrographic analysis, which was performed according to ASTM C 295-98 (2003). Thin sections were examined under a polarized light microscope and descriptions were made regarding mineralogical composition, crystal shape and size, degree and type of weathering or alteration, and heterogeneities. Thin sections were also evaluated for any minerals that could be deleterious to the manufacture of concrete, such as soluble sulfates, unstable sulfides, volumetrically unstable minerals, and minerals which are alkali-silica reactive. Thin section preparation and examination were conducted at the Colorado School of Mines.

3.11 Resource Modeling

In order to estimate the volume and tonnage of the DG resources within the study area, the project site was modeled in cooperation with the Bureau of Indian Affairs-DEMRM mining engineer, using the Vulcan mine modeling program. A two foot contour interval topographic map of the study area created during a previous study was digitized and entered into Vulcan. Files with fault locations and the geometry of the study area were also imported into the program to define the aerial extent of the region to be modeled. All geologic and testing information from the seismic refraction surveys and drill holes were used to define the geologic materials in the model. Cross-section data was also extrapolated in order to input rippable DG thickness parameters into the program in areas where no data was collected. The database also included numeric abbreviations for the different materials encountered (i.e. 1 for soil, 2 for rippable rock/DG/velocity under 5000 ft/s, 3 for non-rippable rock/velocity above 5000 ft/s).

The thickness and extent of the rippable material was then defined using the locations of the faults, refraction surveys, and boreholes and the geologic and engineering properties of the material. This was done by creating a “surface” (boundary between the rippable and non-rippable layers) based on subsurface data and extrapolating it to just beyond the bounds of the study area, and then cutting the surface to the study area boundary. This process created a 3-dimensional model of rippable resources bounded above by the surface topography, laterally by faults and study area boundary, and below by the rippable/non-rippable boundary surface. Vulcan was then used to calculate the volume of the rippable DG resources, which was then converted to tonnage using the specific gravity from the laboratory tests.

Quality of the DG resources was not modeled due to the significant testing result variations between sonic and core drilling samples. Results of sonic drilling samples alone were not modeled since they would not be an accurate portrayal of the deposit. Results from the core drilling were not modeled separately because of the limited amount of material sent for testing (only eight samples total). Instead, testing results for these samples were compared without the use of Vulcan to see if any trends exist.

CHAPTER 4

RESULTS

4.1 Mapping and Surface Sampling

The geologic map of the Reservation is located in Plate 1. The majority of the LPBMIR is comprised of the Tonalite of La Posta, as named and described by Todd (1995). Rock found within the study area is part of the large biotite facies (Clinkenbeard, 1987), or more specifically a hornblende-biotite tonalite. It is composed of about 48% subhedral to euhedral plagioclase, 30% anhedral quartz, 15% euhedral biotite, 5% euhedral hornblende, and up to 2% euhedral sphene based on field observations within the study area. Plagioclase, biotite, and hornblende crystals are generally medium to coarse grained, while quartz and sphene are finer-grained. Crystal size decreases on the eastern part of the Reservation as the tonalite grades into the small biotite facies (Clinkenbeard, 1987). Biotite sometimes shows weathering rims that can extend up to 2 mm around the crystal. The majority of this rock is fairly decomposed at the surface resulting in sand-and-gravel-sized material at the surface (DG), although boulders of fresher tonalite are found on hillsides.

Other geologic units found on the southern part of the Reservation include alluvium and the Julian Schist. Alluvium is located along stream valleys and generally consists of transported, sand-sized DG. The Julian Schist is a mixture of granitic and metamorphic rocks and is found primarily as roof pendants on the tops of hills. The roof pendants are zones where the upper parts of the La Posta pluton did not intrude into the existing Julian Schist, and weathering has now exposed the Julian Schist as isolated bodies of rock within the Tonalite of La Posta. Xenoliths of the Julian Schist are also found within the tonalite, but are generally less than a few feet in diameter.

Lineaments were also observed on the surface (Plate 1), indicating structural control by major joint sets. The lineaments trend approximately north-south, N20E, N20W, and N75E and sometimes extend for several miles. Both surface and ground water flow are concentrated along these features, which increases the amount of weathering and erosion at these locations. Vegetation growth is also promoted due to the higher water content. Since the joint sets create pathways for fluid flow today, the moderate temperature hydrothermal fluids described by Riley (1978) likely migrated along these features as well. Since the hydrothermal fluids formed clay seams (Riley, 1978), this suggests an increase in clay seam density near the lineaments. This was confirmed by the east wall of the Sand Pit. At this location, numerous clay seams were observed in close proximity to a N-S trending lineament.

Roadcuts along I-8 indicate at least 30 to 50 ft thick zones, or layers, of DG sometimes overlying competent rock. In general, the more boulders that are located on the surface above the roadcut, the greater the chance of finding less weathered, solid rock within the roadcut. Fewer to no boulders are an indicator of intensely weathered rock which may or may not show evidence of solid rock at depth within the roadcut. There are several exceptions, so this was only used as a guide when evaluating DG thickness across the study area.

Within the Sand Pit, exposures on bench faces were examined for degree of weathering. The southern and western faces of the Sand Pit are composed of moderately weathered tonalite that stands in near-vertical slopes but is easily broken into ¾” or less material. Overall, the degree of weathering decreases with depth, indicating that surface water plays a significant role in the weathering of material. The east wall of the pit shows a large number of clay seams, shown in Figure 4.1. Clay seams are usually less than 2” wide and are surrounded on each side by a band of intensely weathered to decomposed material. Some clay seams offset each other an average of 1” to 4”, indicating at least two generations of movement during formation. These clay seams are identical to those studied by Riley (1978). When struck with a hammer, the DG from the east wall breaks into sand-sized particles.

Figure 4.1: Clay seams along the southeastern wall of the Sand Pit, hammer for scale. Also visible are tooth marks made by ripping during the previous mining operation.

A total of 18 DG surface samples were collected from across the Reservation. Six samples were collected from within the existing Sand Pit, four from stockpiles of previously washed and screened material, eight from roadcuts and similar exposures throughout the Reservation. An additional sample, LP-12, was accidentally collected from outside the Reservation boundary and not used for testing since it would not benefit the Tribe to know the quality off their Reservation. Table 4.1 provides the location descriptions for each sample, with actual locations shown in Plate 1. ASTM tests performed on 17 of the surface samples include gradation and sand equivalent. The results of the gradation tests are provided in Figure 4.2 and Appendix B, with Figure 4.3 highlighting the percentage of fines in each of the surface samples and Caltrans maximum allowable percentages for classes 1, 2, and 3 subbase. Figure 4.4 contains the results for the SE test. An additional SE test was run on a washed fraction of selected samples in order to evaluate whether or not processing increases material quality, with a comparison of unwashed and washed sample SE values in Figure 4.5. Caltrans standard cutoff values for subbase, class 2 base, asphalt concrete, and PCC are superimposed onto the graphs where appropriate.

Sample LP-6 was collected to perform an LA abrasion test (from the same location as LP-10). After 100 rotations, there was 29.4% loss, which increased to 75.3% loss after 500 rotations. The uniform hardness ratio is 39%. This was the only LA abrasion test performed on a DG sample.

From the gradation tests, the majority of surface samples are well-graded sands with gravel, with less than 10% fines in all samples and an average of 2.5% fines. There is a relatively even distribution of grain sizes between the ¾” and #50 sieves for most samples. Samples collected from similar locations (bench faces within the pit, roadcuts along I-8, etc.) are identified in Figure 4.2 with the same color for comparison purposes.

From these tests, the average SE value is 81; however, the readings range from 61 to 100. Since there is a wide range of values even in the samples that came from the Sand Pit, eight of the DG samples were re-evaluated after washing. This simulated typical material processing that could be conducted at the site to increase product quality, since washing removes fines. The eight unwashed samples (including five collected from the pit) averaged an SE of 71. After washing, the eight surface samples yielded an average SE of 83.

Table 4.1: Brief description of surface sample locations within the La Posta Band of Mission Indians Reservation. Locations are plotted on Plate 1.

Sample Number	Location Description
LP-1	Shallow (three feet deep) pipeline trench on eastern side of Reservation
LP-2	In pit, bottom bench face
LP-3	In pit, second-from-bottom bench face
LP-4	In pit, third-from-bottom bench face
LP-5	In pit, fourth-from-bottom bench face
LP-6	Main stockpile in center of pit, gradation collected for LA abrasion only
LP-7	Stockpile in pit next to eastern wall of pit, actual gradation of stockpile
LP-8	Highly weathered east wall of pit, evidence of hydrothermal fluid migration and clay seams
LP-9	Knob on west wall of pit, three feet below soil layer
LP-10	Main stockpile in center of pit, actual gradation of stockpile
LP-11	Stockpile to NE of pit, actual gradation of stockpile
LP-12	Accidentally collected from off the Reservation - not used for testing
LP-13	Roadcut on I-8 eastbound, about 20’ from top of cut
LP-14	Roadcut on eastern side of Reservation, north of headquarters building
LP-15	Weathered boulder near road on eastern side of Reservation
LP-16	Cut made for well in southeast corner of Reservation
LP-17	Roadcut in northeast portion of Reservation
LP-18	Roadcut in northeast corner of Reservation, next to gate, east of LP-17
LP-19	Roadcut on I-8 westbound

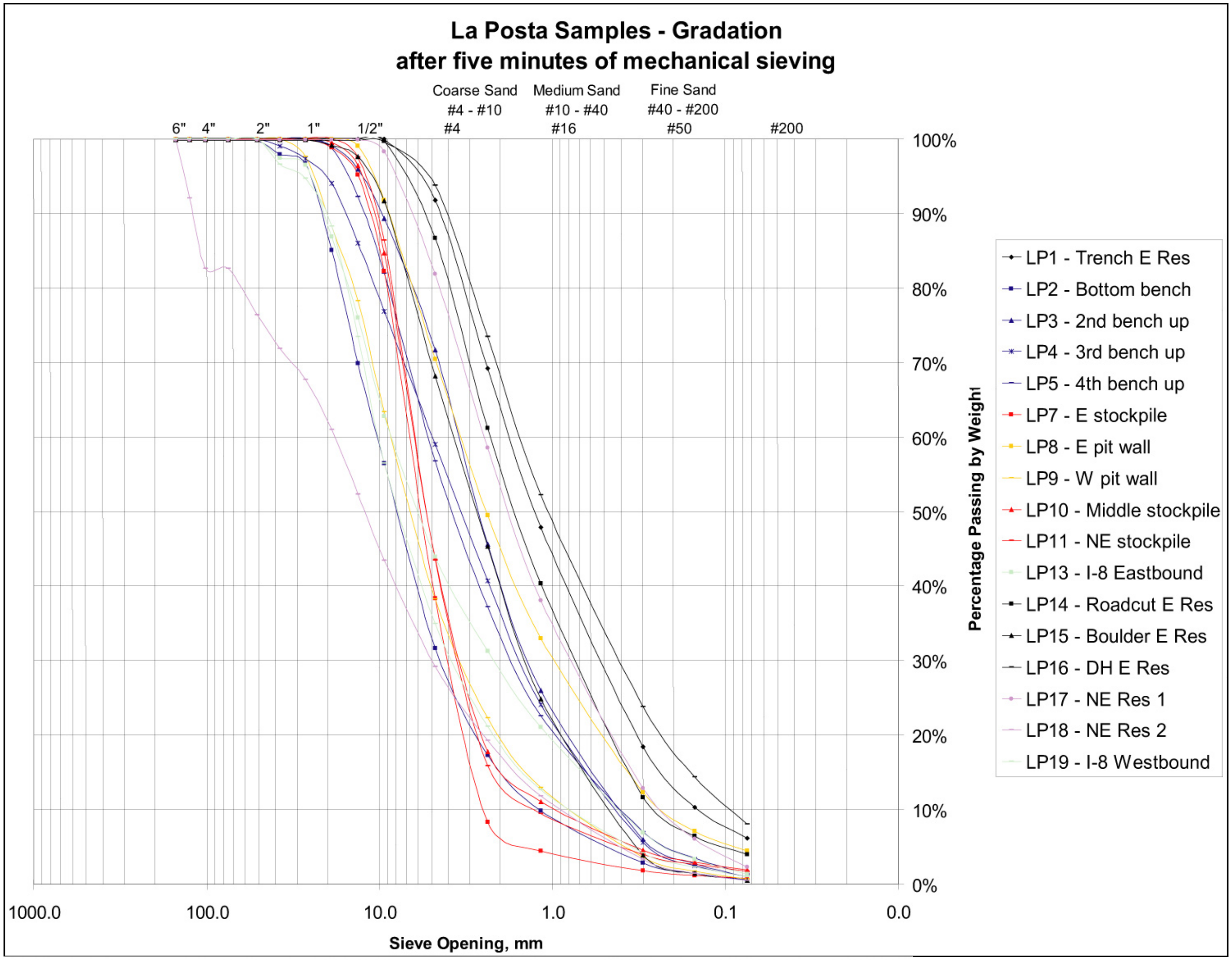

Figure 4.2: Results from surface sample gradation tests. Samples collected from similar locations are indicated with the same color line.

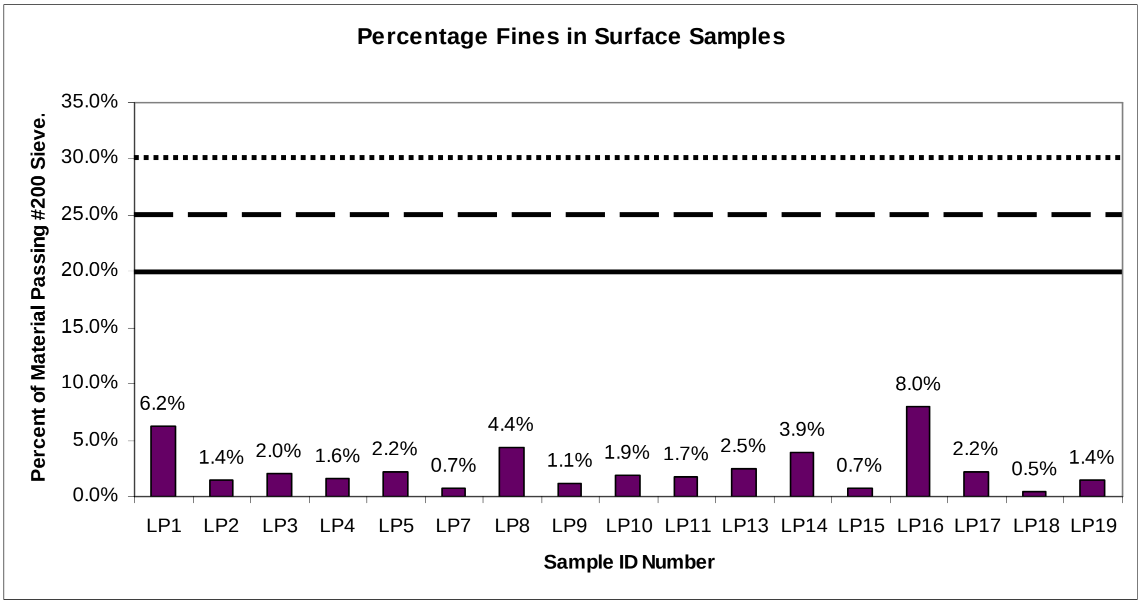

Figure 4.3: Percentage of minus #200 sieve material (fines) in surface samples with Caltrans maximum allowable percentages for class 1 subbase (solid black line), class 2 subbase (dashed black line), and class 3 subbase (dotted black line).

4.2 Seismic Refraction

Six seismic refraction survey lines were performed within the study area during February 2004. A seventh site was located just outside the study area in order to investigate conditions there for comparitive purposes. Of these seven, four were oriented roughly N-S and three W-E. They were placed across a variety of anticipated subsurface features in order to evaluate if these features could be observed and recorded through seismic refraction. Descriptions of the line locations are shown in Table 4.2, while locations and orientations are shown in Plate 2.

After completion of the field work, the data was interpreted using refraction modeling software. Results include travel-time curves based on first-arrival times from

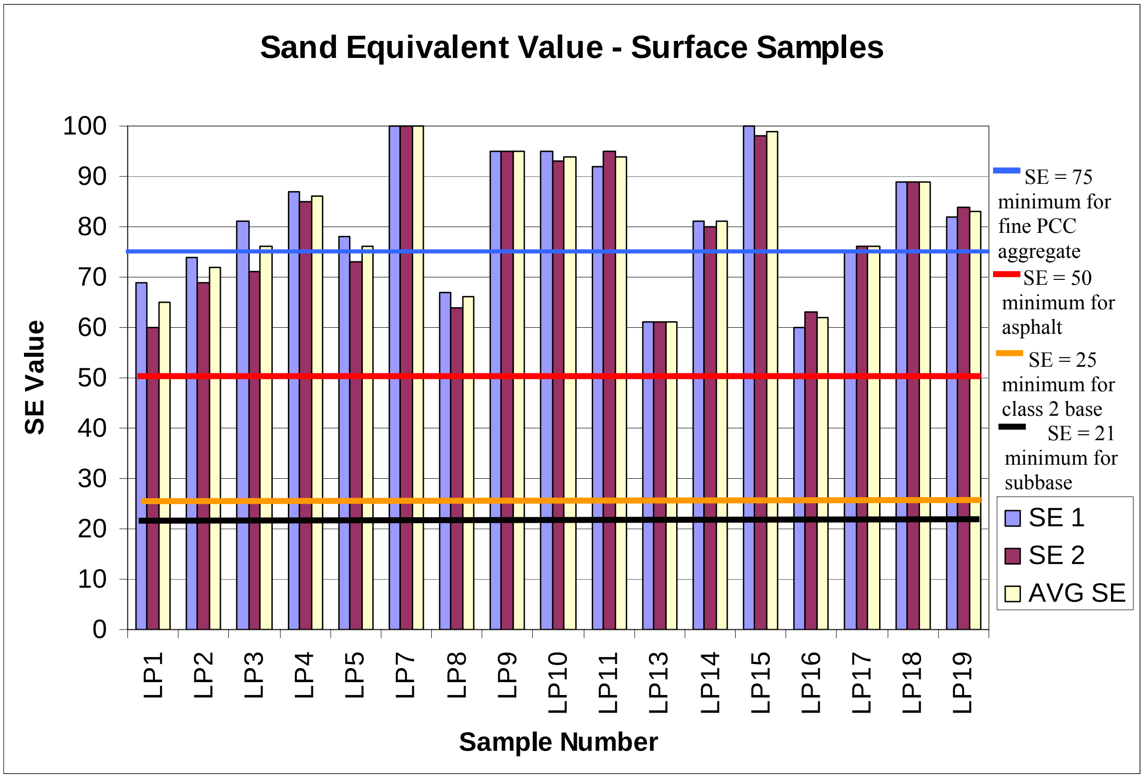

Figure 4.4: Surface sample results for Sand Equivalent (SE) test and Caltrans minimum requirements for fine PCC (Portland cement concrete) aggregate (75 = blue), asphalt concrete (50 = red), class 2 base (25 = orange), and subbase (21 = black). The SE value was an average of tests performed on two separate samples.

each shot location, cross-sections that depict generalized subsurface conditions such as layer thicknesses, and velocity profiles that indicate the wave speed through the unit. From these graphs, both the rippability of the subsurface layers and their thicknesses were evaluated. Velocity has a margin of error of a few hundred feet per second and thickness error may be up to a few feet. Included in Appendix C are digital versions of

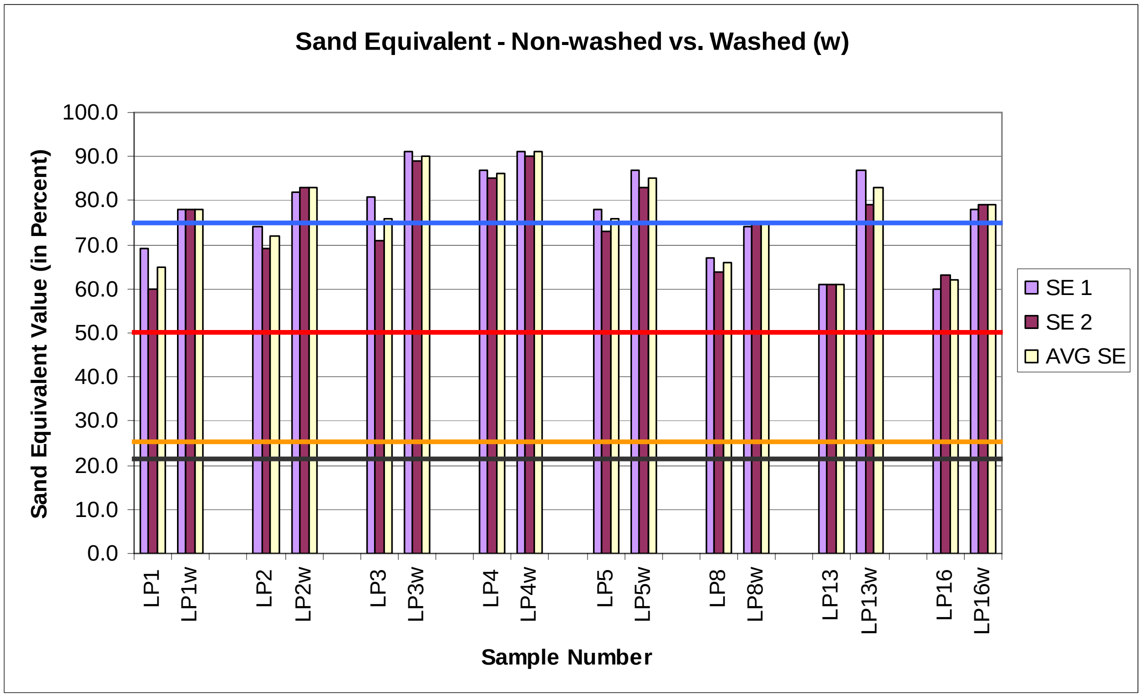

Figure 4.5: Results of selected samples for Sand Equivalent test, unwashed vs. washed (w) and Caltrans minimum requirements for fine PCC (Portland cement concrete) aggregate (75 = blue), asphalt concrete (50 = red), class 2 base (25 = orange), and subbase (21 = black). The SE value was an average of tests on two separate samples.

the three profiles associated with each refraction line. Summaries of these interpretations are provided in Table 4.3, while an example of one of these lines is shown in Figure 4.6.

For LP-S1, located near the northwestern edge of the study area along a road, two layers were observed in the interpretation of the refraction data. The boundary between these layers closely resembles the surface topography. Due to the limited length of the trigger extension reel, data could only be acquired for the first two-thirds of the line.

LP-S2 was situated along a hilltop and roughly traces a seismic line from the 2001 Christian Wheeler refraction line S6 (Plate 2). Two layers are identified, with a third

Table 4.2: Descriptions of seismic refraction lines and their locations.

Line Number	Description
LP-S1	On road, N of pit, along study area boundary, 5 m geophone spacing
LP-S2	Along hilltop, to verify 2001 line, boulders at N end, 2 m spacing
LP-S3	Perpendicular to main stream drainage, to estimate alluvium thickness, 2 m geophone spacing
LP-S4	Perpendicular to lineament, to observe influence of lineament on DG development and thickness, 2 m geophone spacing
LP-S5	Parallel to possible lineament, to verify 2001 line, 2 m spacing
LP-S6	Across hilltop and down hillside, boulders on hilltop, 2 m spacing
LP-S7	Near and roughly parallel to lineament, 2 m geophone spacing

layer suggested at depth. The interface between the first and second layers is somewhat irregular, but roughly parallels the surface topography. A possible third, deep unit is indicated by a few of the travel-time curves. Since the supposed third layer is at roughly the expected maximum depth of resolution, the validity of the speed and depth are not certain. Interpretations from the 2004 study are similar to the 2001 Christian Wheeler study of this location, indicating good correlation between the studies.

Another refraction line, LP-S3, was placed perpendicular to and across the main stream drainage in the study area to evaluate the thickness and extent of alluvium, as well as to see if refraction could detect any subsurface anomalies near the lineaments (Plate 2). The data indicates two velocity layers with the boundary generally following the surface expression, except that the low-velocity layer is thickest across the present channel.

To assess the influence that the lineaments have on the development of DG in another location, LP-S4 was located perpendicular to a N-S striking lineament just east of the Sand Pit. Two velocity zones are detected in the subsurface. The boundary between

Table 4.3: Velocity and depth results of 2004 refraction lines and two 2001 lines for comparison purposes.

		2004	2004	2001	2004	2004	2004	2001	2004	2004
		LP-S1	**LP-S2**	**S6**	**LP-S3**	**LP-S4**	**LP-S5**	**S10**	**LP-S6**	**LP-S7**
Velocity of top layer	**ft/s**	1,650	1,300	1,000-1,300	1,000-1,300	1,300-1,950	1,000-1,650	1,200-1,300	1,000-1,650	1,000-1,300
	m/s	500	400	300-400	300-400	400-600	300-500	350-400	300-500	300-400
Thickness of top layer	**ft**	10-16	13-23	8-10	23-43	23-56	10-20	10-11	16	10-20
	m	3-5	4-7	3	7-13	7-17	3-6	3	5	3-6
Velocity of second layer	**ft/s**	11,100-16,400	3,900-4,250	3,600-3,900	8,500-9,800	6,550-10,500	3,300-4,600	3,700-4,400	4,600-6,550	4,100-4,900
	m/s	3,400-5,000	1,200-1,300	1,100-1,200	2,600-3,000	2,000-3,200	1,000-1,400	1,100-1,350	1,400-2,000	1,250-1,500
Depth to third layer	**ft**	x	75	x	x	x	x	x	x	x
	m	x	23	x	x	x	x	x	x	x
Velocity of third layer	**ft/s**	x	6,000	x	x	x	x	x	x	x
	m/s	x	1,800	x	x	x	x	x	x	x
Observable Depth	**ft**	110	66	37	110	110	110	40	75	85
	m	33	20	11	33	33	33	12	23	26

x = no indication of deeper layer in refraction results layers is deepest to the west (approximately above the location of the lineament) and shallows to the east. The velocity of the deeper unit also increases to the west.

Seismic line LP-S5 was located in the northern portion of the study area to verify another 2001 Christian Wheeler refraction line (Plate 2). Two velocity layers are identified (Figure 4.6). As in most of the preceding lines, the layer boundary roughly follows surface topography, except a slight rise is recognized about 82 ft (25 m) from the southern end. This corresponds to a slight velocity decrease in the underlying unit. Data from the 2004 survey corresponds to the interpretations of the 2001 survey of line S10.

LP-S6 was placed partly on the side of a hill and continued across the top of a ridge with prominent outcropping boulders (Plate 2). The interface between units approximates the surface expression, although the velocity of the eastern portion of the line is lower than the velocity of the western two-thirds of the survey.

The last seismic line, LP-S7, traversed through the eastern portion of the study area and roughly paralleled a lineament. Two layers were observed, with the boundary between layers generally following the topographic expression, and the velocity of the underlying unit decreasing slightly beneath local topographic highs.

4.3 Drilling

A total of 995 ft of sonic and wireline core drilling from 12 boreholes was recovered during August and September 2004. Holes were drilled to test refraction interpretations, collect subsurface samples, and to gather depth information in new areas to construct cross-sections. Plate 2 provides the locations of these boreholes in relation to seismic lines and lineaments.

4.3.1 Sonic Drilling

Using sonic drilling methods, 599 ft was drilled and sampled in seven vertical holes. The recovered samples consisted of silty sand due to the vibrations of the drilling

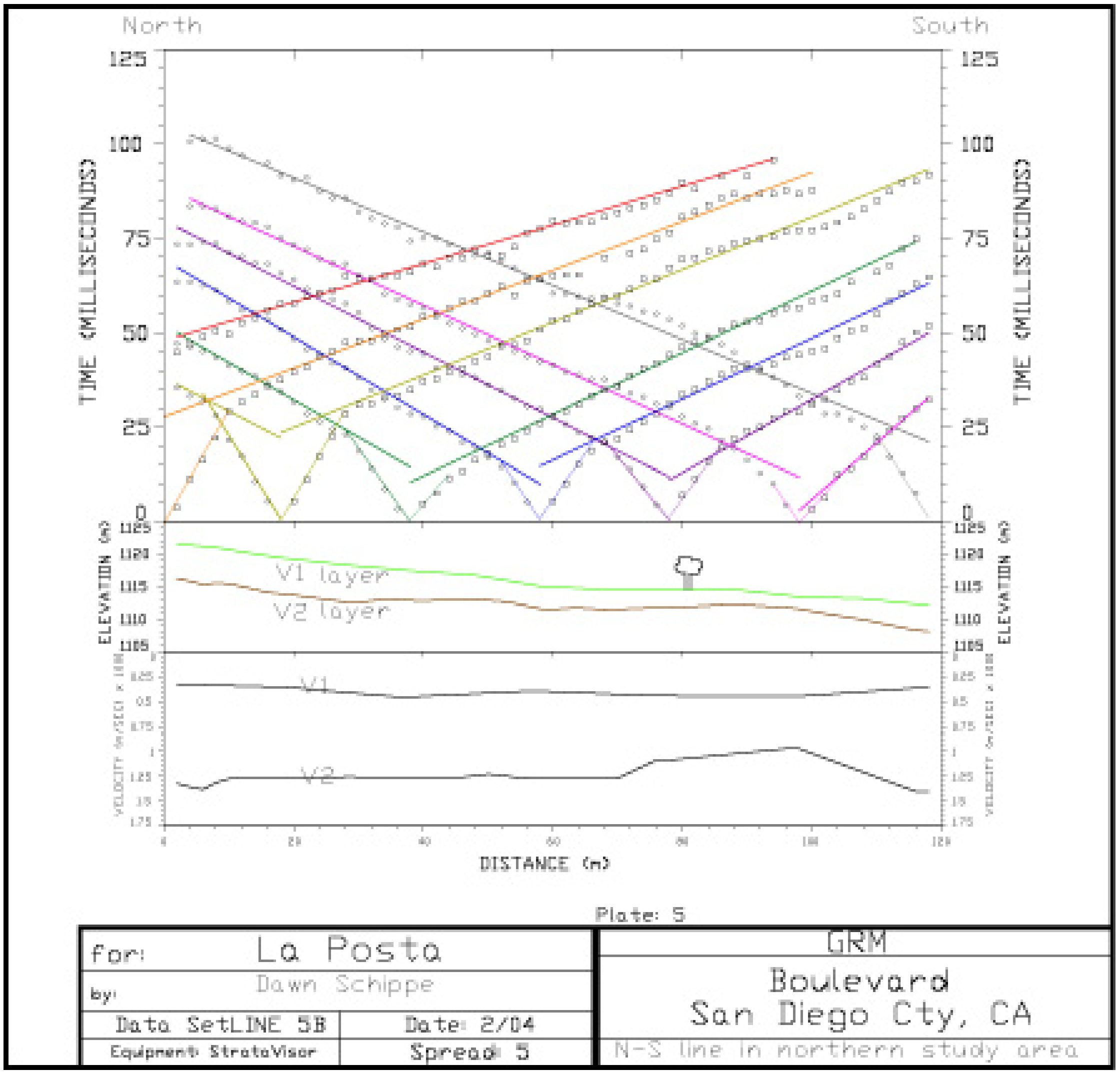

Figure 4.6: Travel-time curves (top), cross-section (center, ground surface in green and indicated by tree, boundary between velocity layers in brown), and velocity profiles (bottom) for LP-S5.

method (Figure 4.7), while the surface and stockpile material was coarser grained. However, when solid rock was drilled, core samples were recovered (Figure 4.8).

Figure 4.7: Four foot sample interval of DG obtained through sonic drilling.

Figure 4.8: Sample of sonic drilling through competent rock.

4.3.2 Wireline Core Drilling

From core drilling at six locations (two holes which twinned sonic holes, a hole that was started by sonic and finished using core, and three additional holes), 396 ft of core samples were collected from the study area. DH-A was 175 ft in length and oriented 45 degrees from vertical toward the east in order to investigate subsurface conditions near a N-S trending lineament, while the other holes were vertical. DH-H was used to verify a 2004 seismic line (Plate 2).

Compared to sonic drilling, the recovered core samples are much more informative of subsurface conditions, since fracture spacings and orientations were preserved, the fabric of the rock was not destroyed, and degree of weathering and how it changed, both with depth and with distance from fractures, could be recorded. An example of the difference in sample quality between the two drilling methods is shown by comparing Figures 4.7 and 4.9, since they both show material collected from roughly the same depth and location, but were drilled using different techniques.

4.4 Core Logging

Core logs are in Appendix D, with generalized visual logs provided in Figure 4.10. Photographs of each box of core are included in Appendix E.

Material recovered from the drilling is a medium-grained hornblende-biotite tonalite based on hand sample identification. The rock is moderately to intensely weathered near the surface, grading into slightly weathered or fresh rock at depth. Biotite is partly altered to chlorite and shows evidence of weathering rims up to 2 mm around crystals. Plagioclase is partly altered to clay as well.

From the core drilling, several prominent features were also recorded. Clay seams were sampled in several boreholes, with additional alteration to the sides present in some locations. Fractures are sometimes associated with additional weathering or alteration. Several fractures are also filled and/or healed with chlorite or other minerals.

Figure 4.9: Four foot interval of DG drilled by wireline core; note this sample is collected from a twinned hole from approximately the same depth as Figure 4.7.

Veins of white or pink material roughly ¼" wide were also observed, with identification made later through thin section analysis. Hornblende and biotite-rich xenoliths of the Julian Schist were also recovered.

4.5 Rock Quality Designation

Results of the RQD calculations are provided in the core logs in Appendix D. RQD was not performed on DG. Both the biotite and plagioclase crystals are more weathered near the discontinuities, which helped differentiate between natural and mechanical breaks in the rock. RQD values were calculated from the more competent

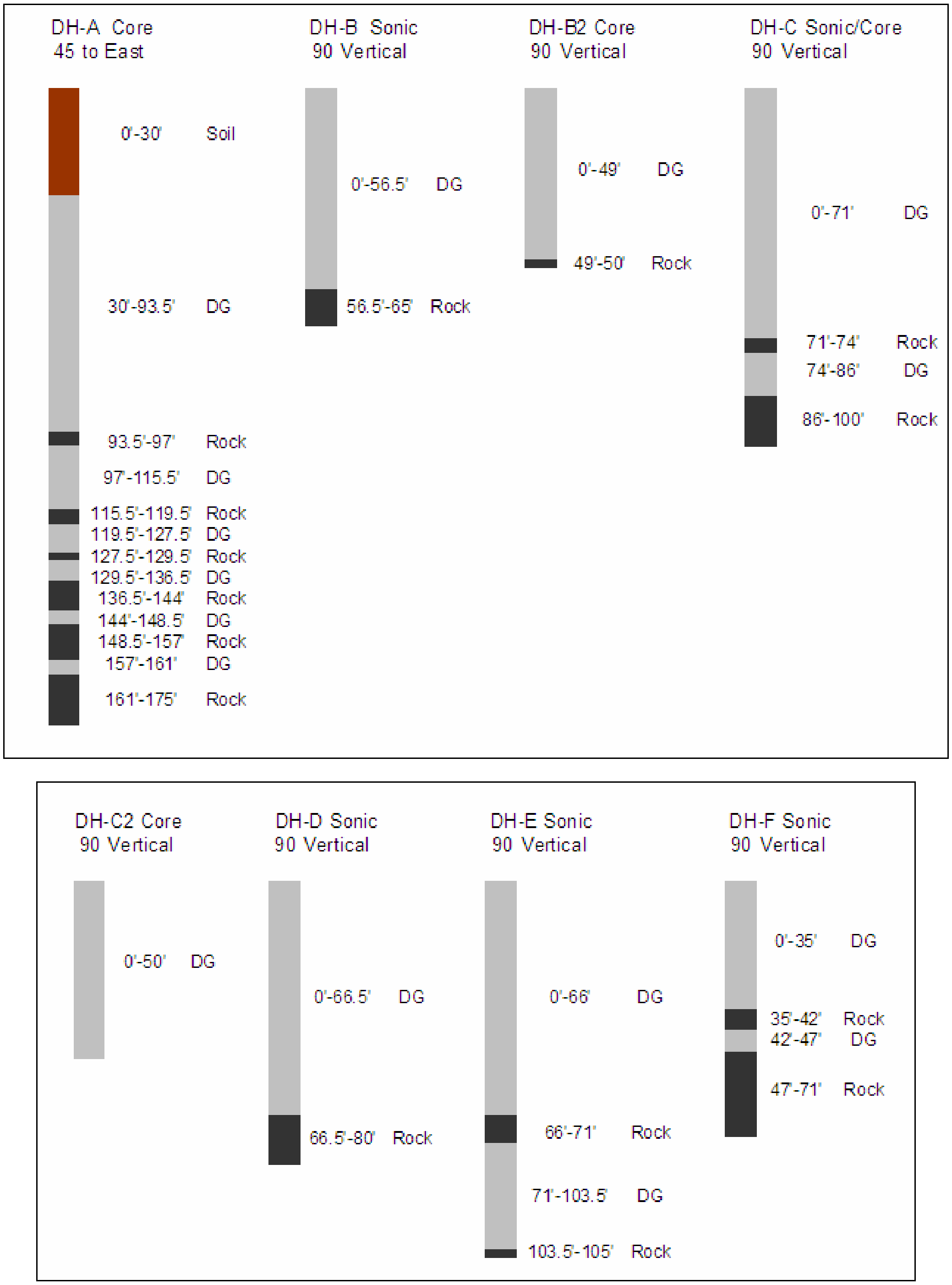

Figure 4.10: Generalized core logs from the drilling program on the La Posta Band of Mission Indians Reservation showing relative amounts of soil, decomposed granite (DG), and rock in each hole.

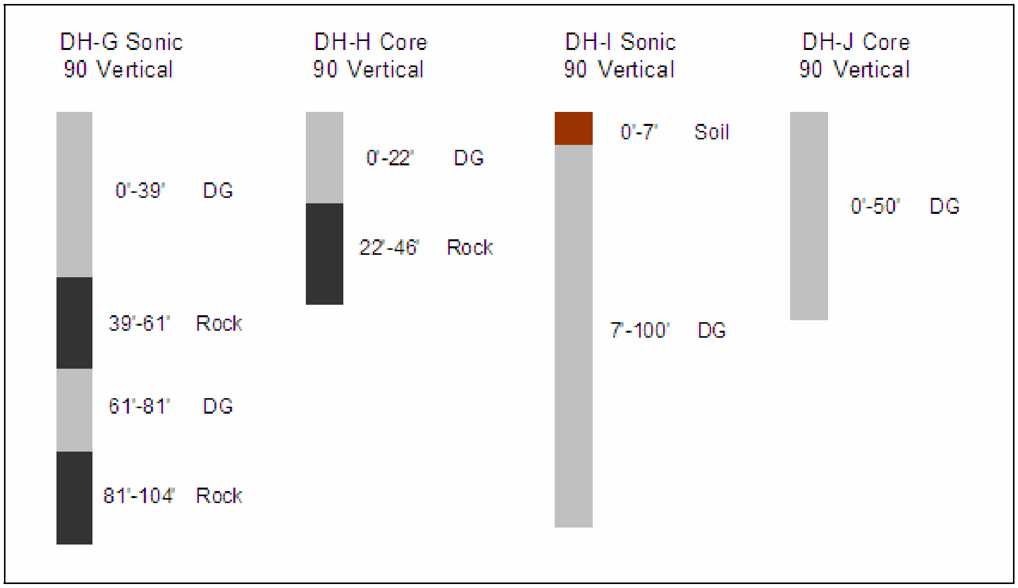

Figure 4.10: (continued).

rock sampled during the drilling program from DH-A, B, C, D, F, G, H, and J. These values ranged from 53 in DH-F to 85 in DH-B, with an average RQD of 70.

4.6 Physical Testing and Standards for Decomposed Granite

Samples of DG were collected from the drilling program and stockpiles created during the previous mining operation. Testing results are contained in Appendix F. Since the sonic drilling provided samples that were not representative of the DG, these results are not presented in this chapter after the first part of the gradation section, although they are included in Appendix F along with graphs comparing sonic and core results from the twinned holes.

4.6.1 Gradation

The gradation analyses confirmed the observation that subsurface samples obtained through sonic drilling were broken down into smaller grain sizes than those acquired by core drilling. Figures 4.11 (sonic samples), 4.12 (core samples), 4.13 (twinned samples), and 4.14 (stockpile samples) show the percentage of fines in each sample. The sonic holes averaged 20% fines, core holes were 6% fines, and stockpiles were the lowest with 3% fines.

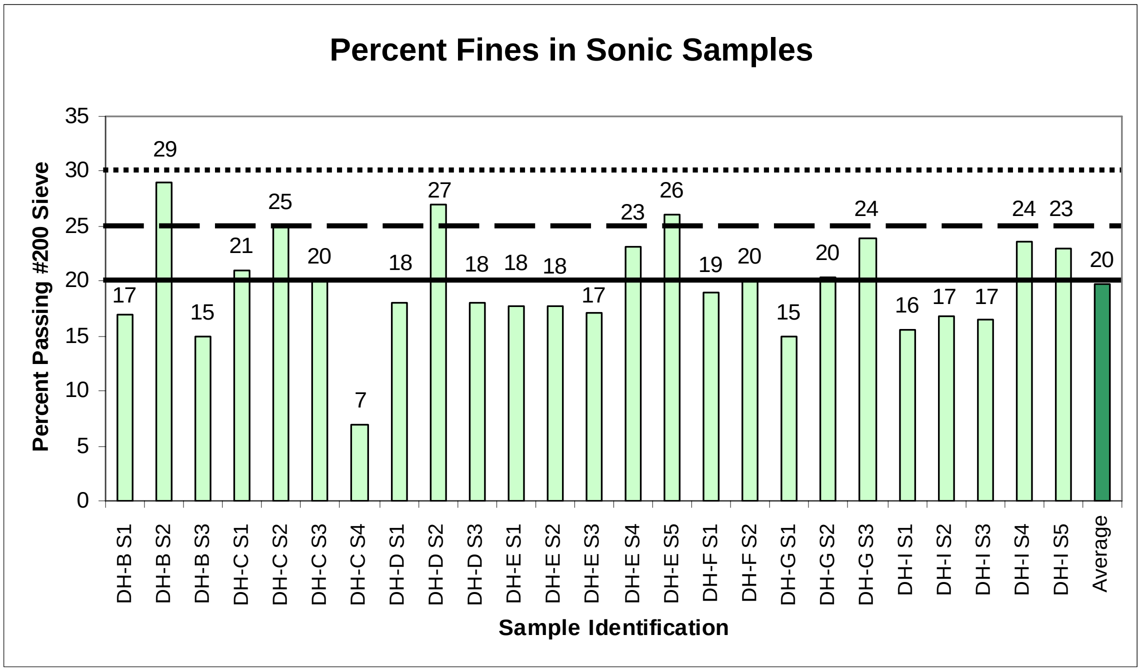

Figure 4.11: Percentage of fines (silt and clay) in each sonic sample with Caltrans standard maximum allowable values for different quality materials represented as horizontal lines (30 = dotted line = class 3 subbase, 25 = dashed line = class 2 subbase, and 20 = solid line = class 1 subbase).

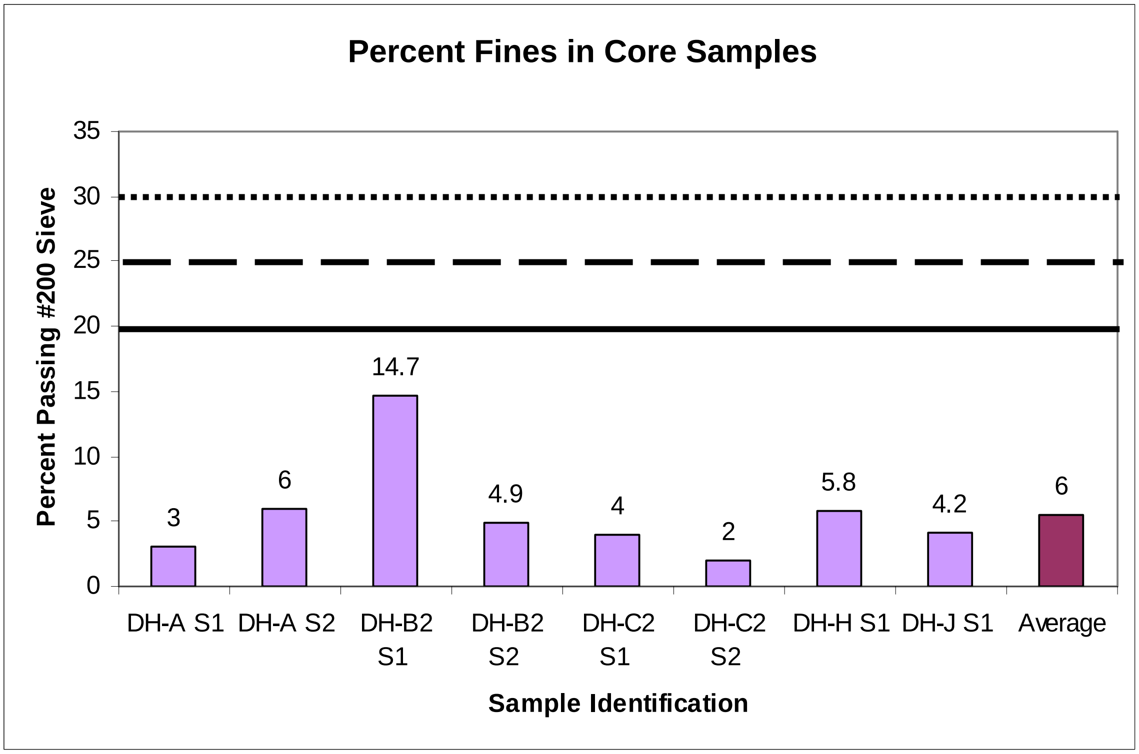

Figure 4.12: Percentage of fines (silt and clay) in each core sample with Caltrans standard maximum allowable values for different quality materials represented as horizontal lines (30 = dotted line = class 3 subbase, 25 = dashed line = class 2 subbase, and 20 = solid line = class 1 subbase).

The core samples were primarily well-graded sands with silt and/or gravel, while stockpile samples ranged from sandy gravels to gravelly sands. Figure 4.15 provides the grain size distributions for these two types of samples.

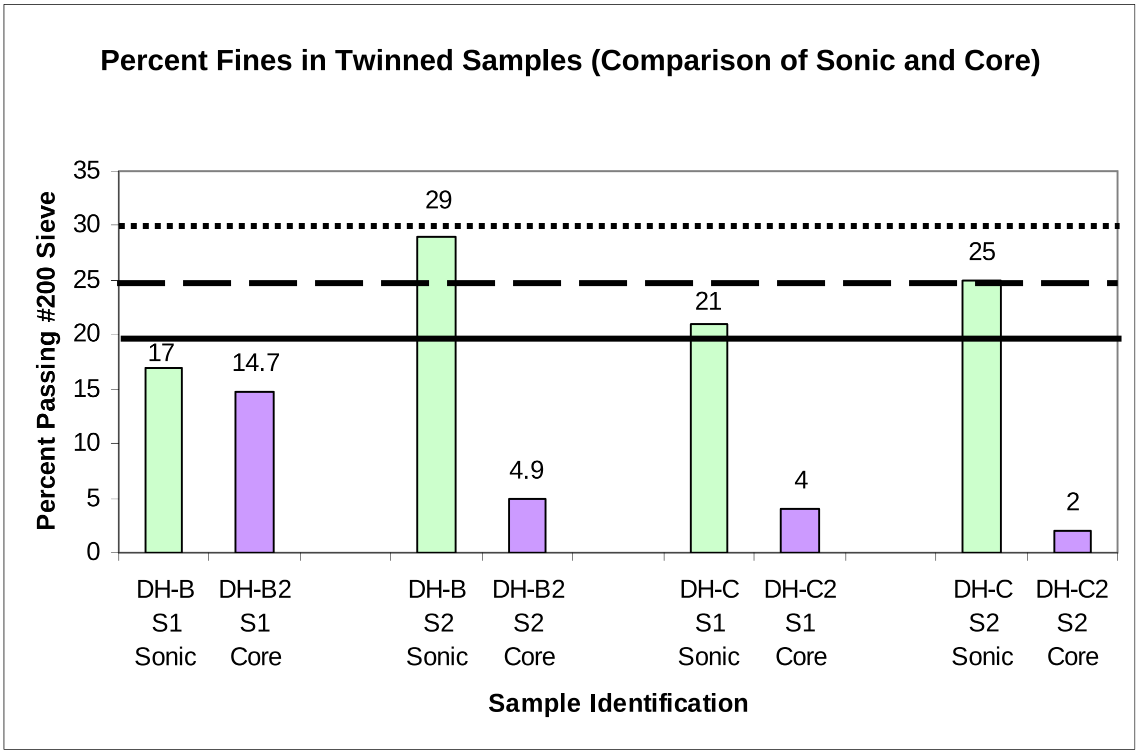

Figure 4.13: Percentage of fines (silt and clay) for each twinned sample (sonic and core) with Caltrans standard maximum allowable values for different quality materials represented as horizontal lines (30 = dotted line = class 3 subbase, 25 = dashed line = class 2 subbase, and 20 = solid line = class 1 subbase).

4.6.2 Sand Equivalent

Results of the sand equivalent test are shown in Figures 4.16 (core samples) and 4.17 (stockpile samples). Results ranged from 32 to 95, with an average core value of 53 and stockpile value of 79. Caltrans standards are shown on the figures.

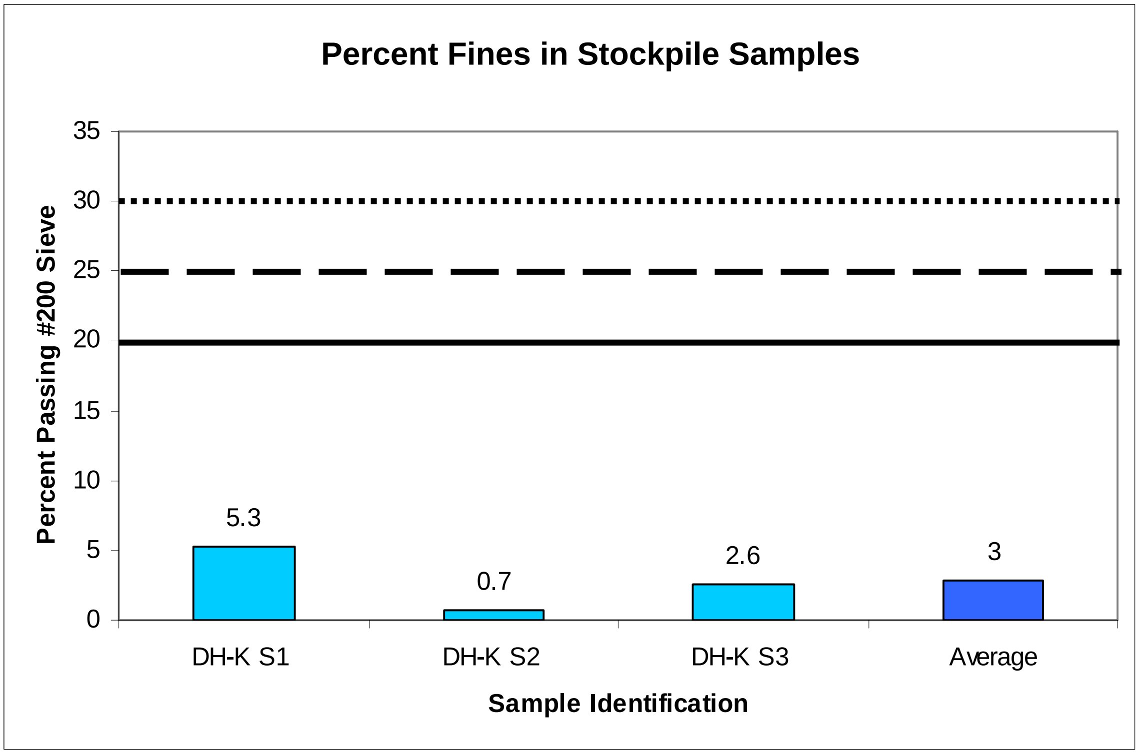

Figure 4.14: Percentage of fines (silt and clay) in each stockpile sample with Caltrans standard maximum allowable values for different quality materials represented as horizontal lines (30 = dotted line = class 3 subbase, 25 = dashed line = class 2 subbase, and 20 = solid line = class 1 subbase).

4.6.3 Durability Index

Results from the durability index tests are provided in Figure 4.18 (core samples) and 4.19 (stockpile samples). The overall durability index is the lower value of the coarse and fine tests. Using the overall durability index, the average value is 37 for core and 55 for the stockpiles. Also on the graphs are Caltrans minimum standards for various uses.

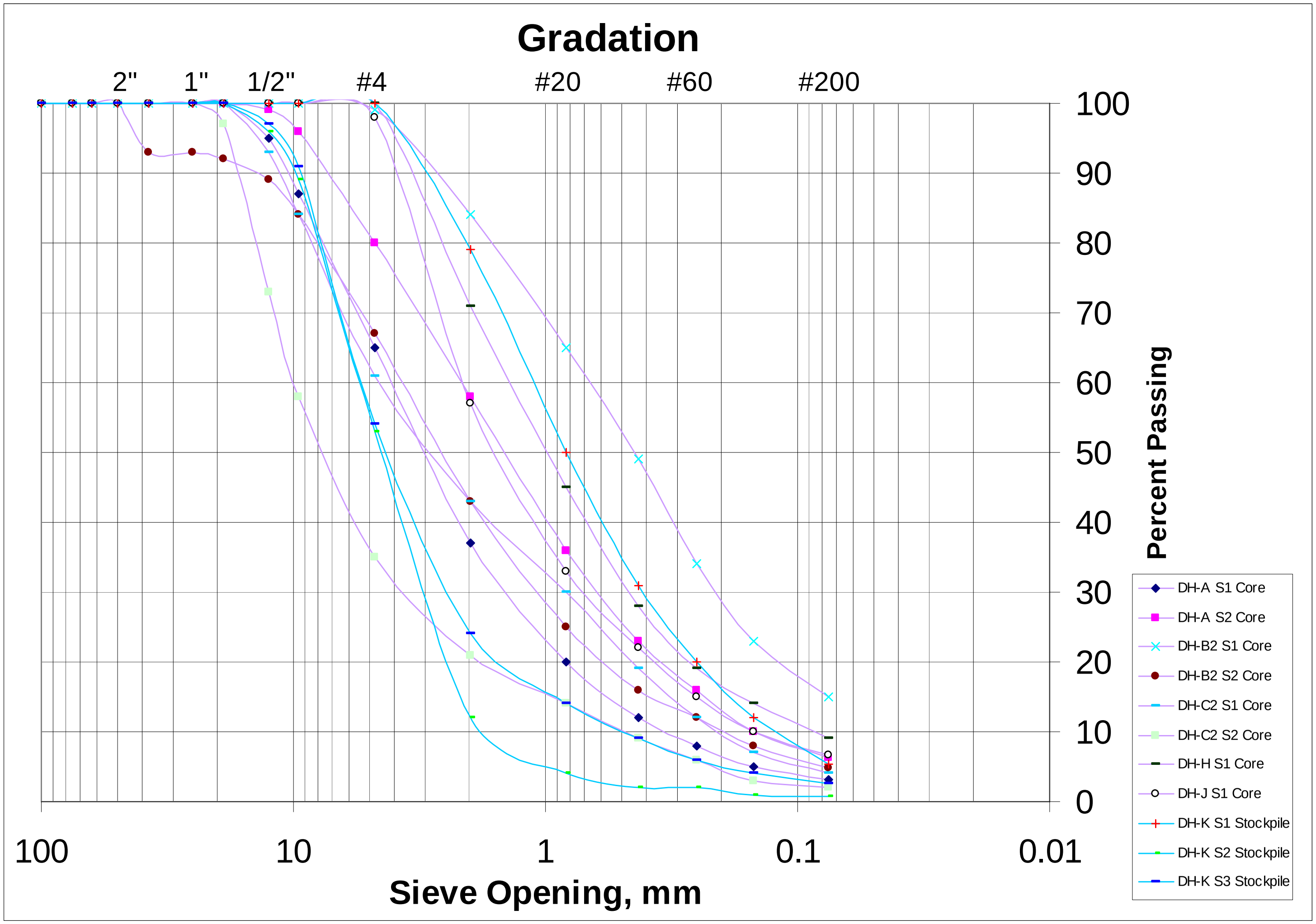

Figure 4.15: Grain size distributions for core (purple) and stockpile samples (blue).

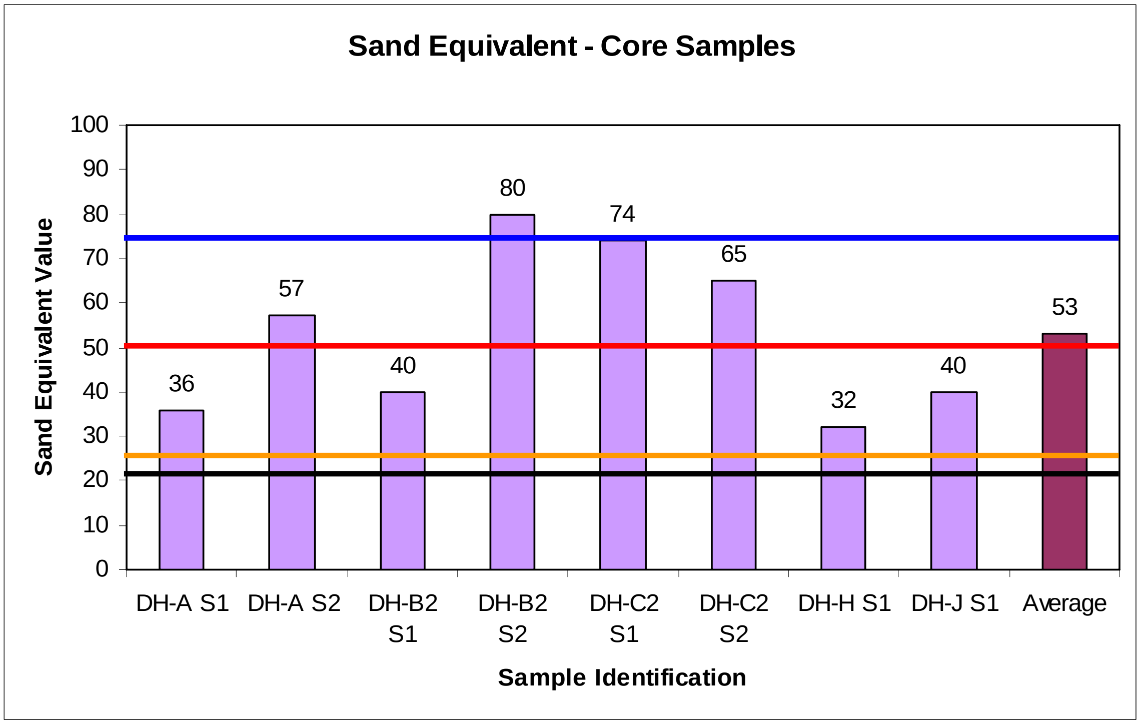

Figure 4.16: Sand Equivalent values for core samples with Caltrans standard minimum values for different materials represented as horizontal lines (75 = blue = Portland cement concrete fine aggregate, 50 = red = asphalt, 25 = orange = class 2 base, 21 = black = subbase).

4.6.4 Specific Gravity and Absorption

Table 4.4 contains the testing results for specific gravity and absorption for both the coarse- and fine-grained fractions. Two samples, DH-B2 S1 (core) and DH-K S1 (stockpile), did not contain enough coarse material to run the coarse specific gravity and absorption.

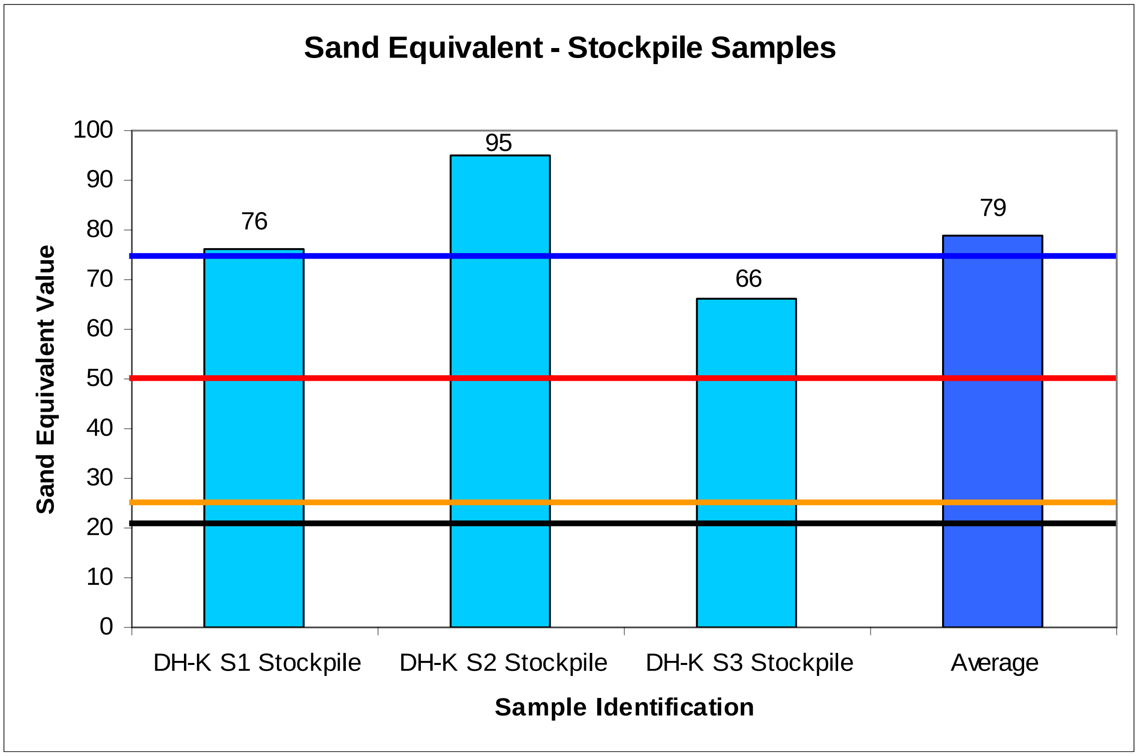

Figure 4.17: Sand Equivalent values for stockpile samples with Caltrans standard minimum values for different materials represented as horizontal lines (75 = blue = Portland cement concrete fine aggregate, 50 = red = asphalt, 25 = orange = class 2 base, 21 = black = subbase).

The average specific gravity is 2.61 and 2.60 for core and 2.53 and 2.62 for stockpile samples, listed respectively for coarse and fine gradations. Testing results indicate an average absorption value of 2.31 (coarse) and 1.74 (fine) for core samples and 2.16 (coarse) and 0.80 (fine) for the stockpiles.

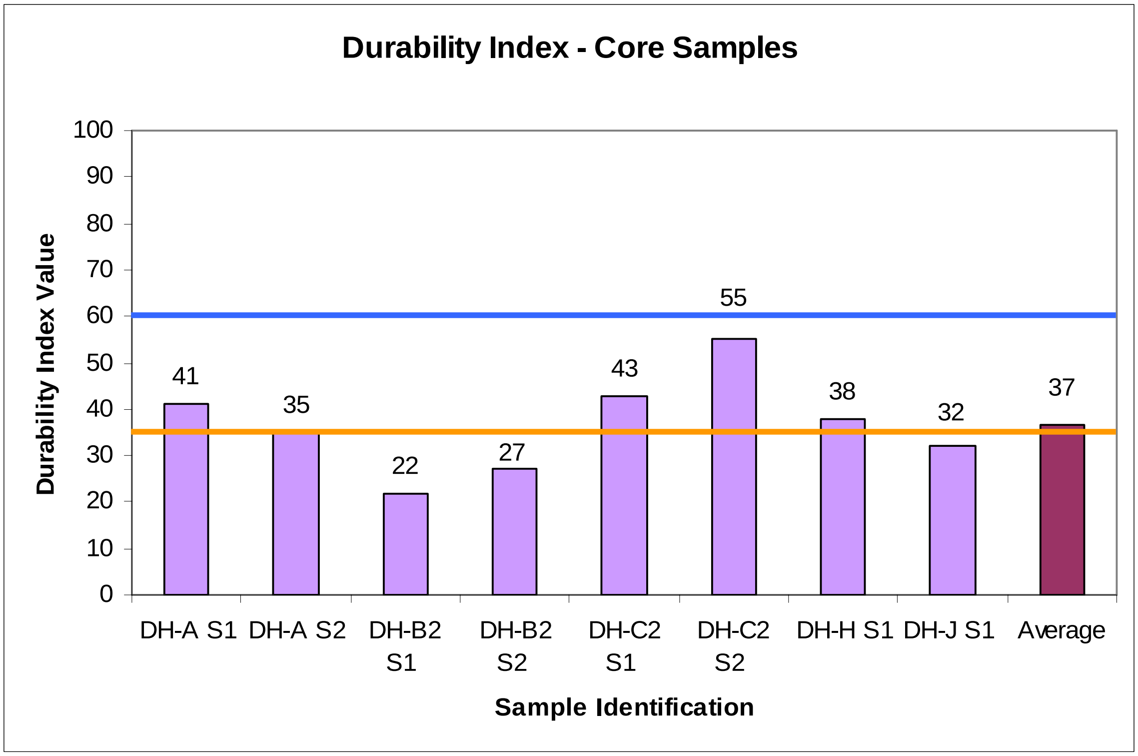

Figure 4.18: Results of the durability index test for core samples and Caltrans standards for minimal acceptable values for Portland cement concrete fine aggregate (60 = blue line) and class 2 base (35 = orange line).

4.6.5 R-Value

Results from the R-Value test are shown in Figure 4.20 for core samples and 4.21 for stockpile samples. This test was performed on all samples, with the numerical value interpolated at an exudation pressure of 300 psi. Caltrans standards are overlaid onto the graph to depict the minimum acceptable values for class 2 base (orange) and subbase (black). The average R-value for core is 81 and 79 for the stockpiles.

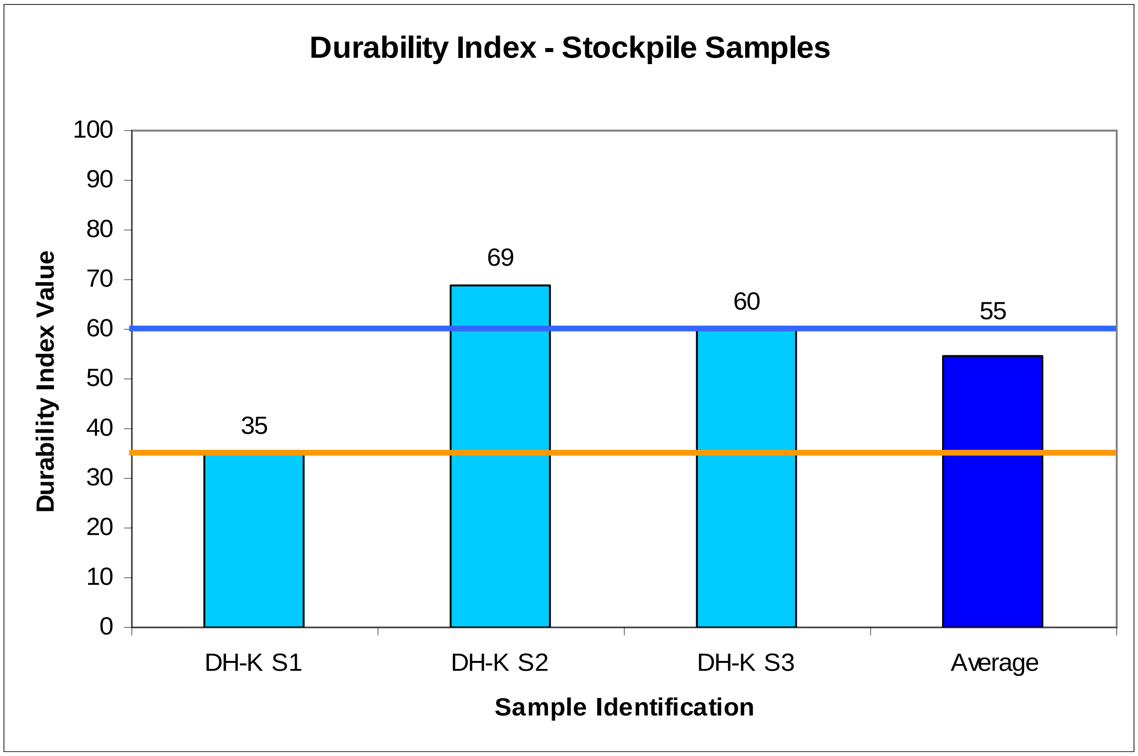

Figure 4.19: Results of the durability index test for stockpile samples and Caltrans standards for minimal acceptable values for Portland cement concrete fine aggregate (60 = blue line) and class 2 base (35 = orange line).

4.6.6 Organic Impurities

The organic impurities test was only performed on samples that underwent the full suite of engineering tests. Results of the core and stockpile samples are displayed in Table 4.5.

Only two samples of the samples showed any indication of the presence of organics, with both of these indicating only small amounts of organics. All of the other samples were free of organic impurities.

Table 4.4: Results of coarse and fine specific gravity and absorption tests.

	Sample ID	Specific Gravity-Coarse	Specific Gravity-Fine	Absorption-Coarse	Absorption-Fine
Core Samples	**DH-A S1**	2.59	2.617	2.17	1.7
	DH-A S2	2.593	2.593	2.1	1.9
	DH-B2 S1	*	2.503	*	2.9
	DH-B2 S2	2.72	2.541	1.78	2.2
	DH-C2 S1	2.608	2.647	2.4	0.96
	DH-C2 S2	2.573	2.628	2.7	1
	DH-H S1	2.592	2.585	2.13	1.91
	DH-J S1	2.565	2.644	2.9	1.35
	Average	2.606	2.595	2.31	1.74
Stockpile Samples					
	DH-K S1	*	2.634	*	0.87
	DH-K S2	2.52	2.622	2.16	0.7
	DH-K S3	2.54	2.611	2.16	0.84
	Average	2.53	2.622	2.16	0.80

* = not enough coarse material to run test

4.7 Physical Testing and Standards for Crushed Rock

For the competent rock sampled in the drilling program from either isolated boulders within the DG or bedrock underlying the DG, two physical tests were conducted including LA abrasion and sodium sulfate soundness. A brief description of each of these samples is provided in Table 4.6. Only eight samples were submitted for testing due to the limited amount of crushed rock material recovered during the drilling program.

4.7.1 Los Angeles (LA) Abrasion

Results from the LA abrasion test are provided in Figure 4.22 for both 100 and 500 rotations, in addition to the uniform hardness values of each sample which is represented by a point. Also included in the figure are Caltrans standards for maximum percent loss for various kinds of end-products.

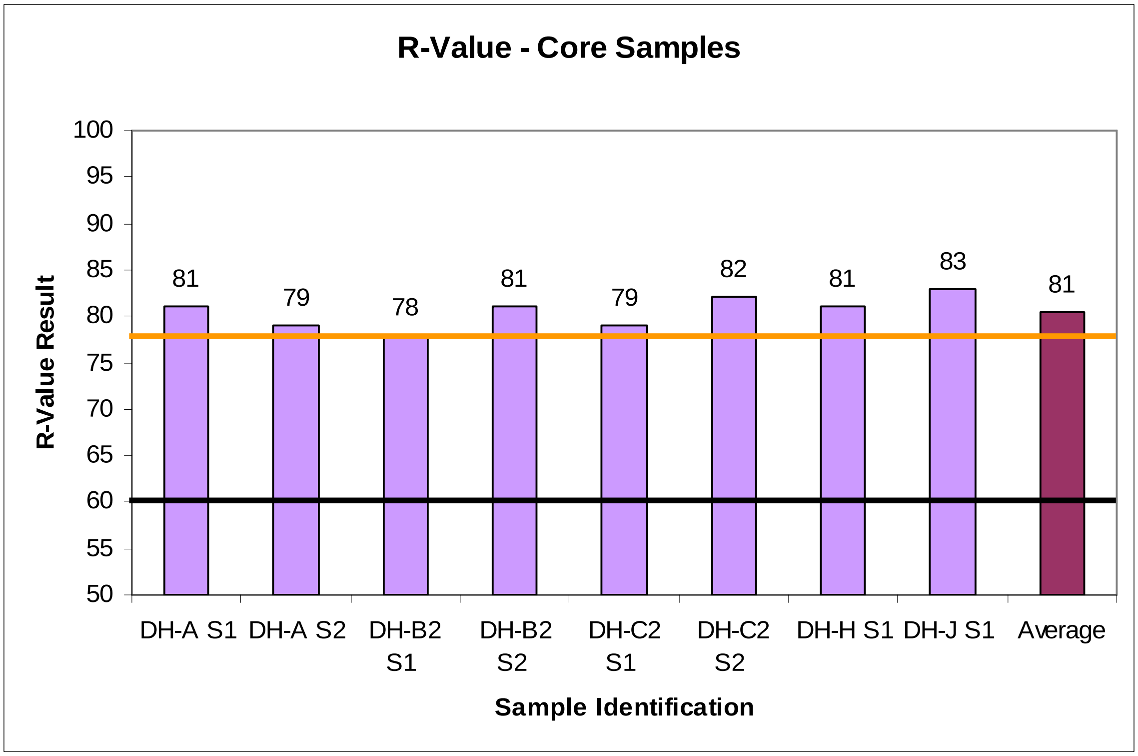

Figure 4.20: Results of the R-Value test for core samples and Caltrans standards for minimal acceptable values for class 2 base (78 = orange line) and subbase (60 = black line).

The average LA abrasion value after 100 rotations is 16.8%, and after 500 rotations it is 54.1%. The average uniform hardness is 0.30.

4.7.2 Sodium Sulfate Soundness

Figure 4.23 illustrates the results of the sodium sulfate soundness test for coarse aggregate after five cycles of immersion and drying. Maximum loss allowed by Caltrans is also included in the figure.

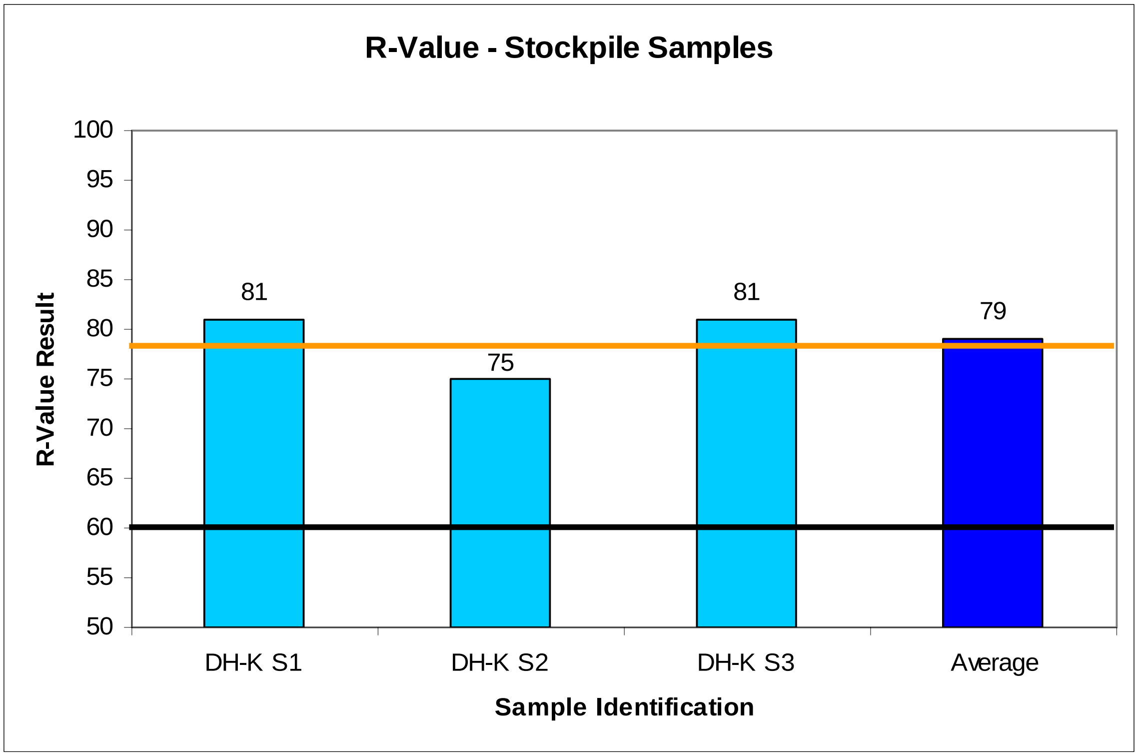

Figure 4.21: Results of the R-Value test for stockpile samples and Caltrans standards for minimal acceptable values for class 2 base (78 = orange line) and subbase (60 = black line).

For this test, the average amount of loss was 3%. Individual testing results ranged from less than 1% (DH-C) to 9% (DH-F). Weighted percent loss was based on an ASTM C 33 No. 57 aggregate, which has a nominal maximum grain size of one inch. The lab report from CTL Thompson, Inc., is located in Appendix G.

4.8 Geochemical Analysis

Twenty-seven samples were sent to ALS Chemex for both 34 element and whole rock analyses. A brief description of each sample is provided in Table 4.7. The results of

Table 4.5: Results of the organic impurities test on core and stockpile samples.

Sample ID	Organic Impurities
DH-A S1 Core	0 clear
DH-A S2 Core	0 clear
DH-B2 S1 Core	0 clear
DH-B2 S2 Core	0 clear
DH-C2 S1 Core	0 clear
DH-C2 S2 Core	0 clear
DH-H S1 Core	2 yellow
DH-J S1 Core	0 clear
DH-K S1 Stockpile	1 yellowish
DH-K S2 Stockpile	0 clear
DH-K S3 Stockpile	0 clear

Table 4.6: Generalized description of each hard rock sample tested.

Sample Identification	Depth interval used and degree of weathering
DH-B	61'-65', fresh, unweathered tonalite
DH-C	87'-95', from bedrock, biotite weathering rims 0-1 mm
DH-D	68'-74', slight biotite weathering rims up to 2 mm wide
DH-F	49'-54.5', significant biotite weathering rims 2 mm wide
DH-G-1	54'-61', from corestone, biotite weathering rims up to 1 mm
DH-G-2	88'-93', from bedrock, biotite weathering rims usually less than 1 mm
DH-H	39'-45', from bedrock, biotite weathering rims up to 1 mm
DH-J	36'-42', biotite weathering rims 2 mm wide

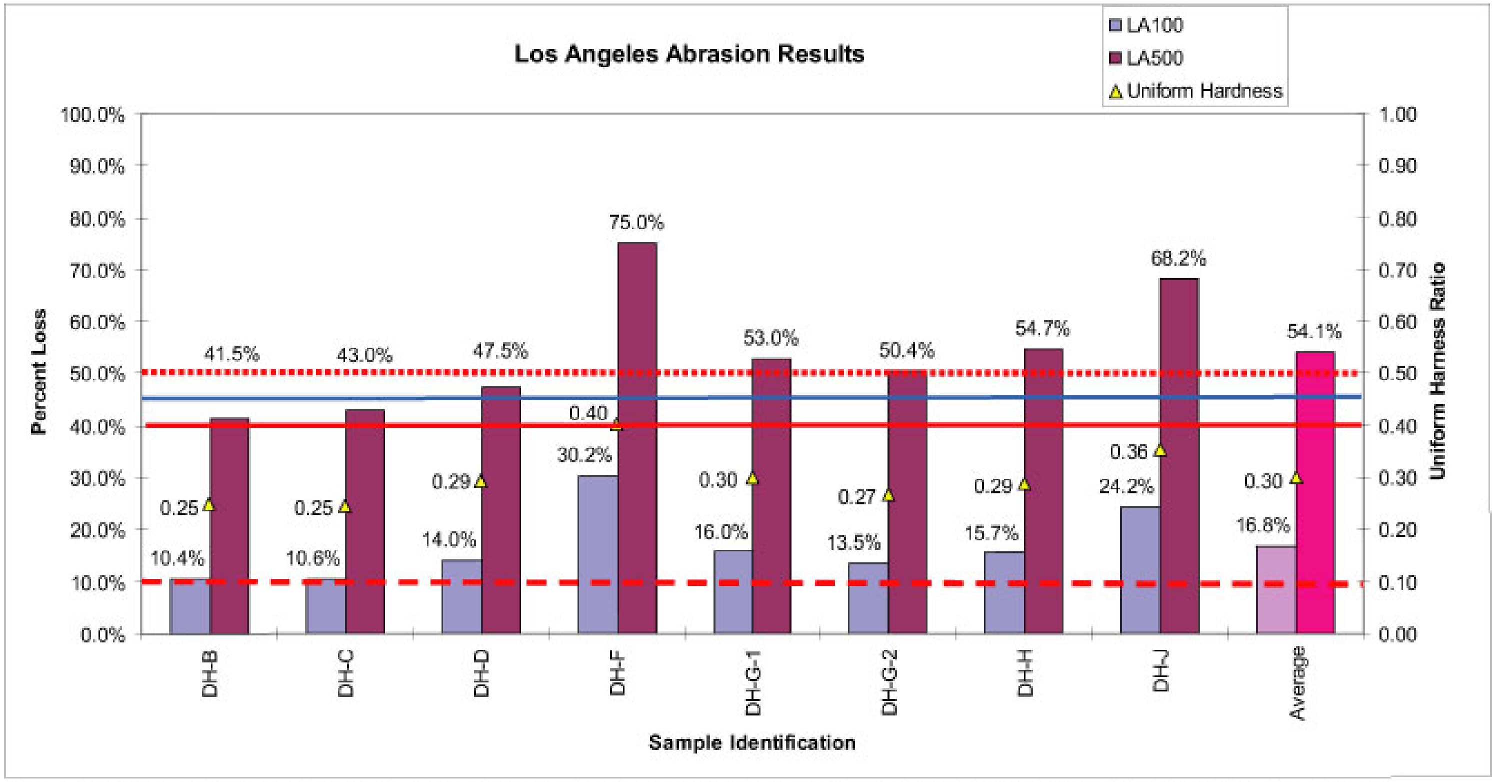

Figure 4.22: Subsurface sample results of the LA abrasion test after both 100 (LA100) and 500 (LA500) rotations of the drum. Uniform hardness ratio is represented as a point. Also shown are Caltrans maximum allowable percentage loss for both 100 (LA100) and 500 (LA500) rotations of the drum. For LA100, less than 10% loss is necessary for open graded asphalt concrete, asphalt concrete Type A, and asphalt concrete base Type A (LA100 = 10% = red dashed line). For LA500, less than 40% loss is required for open graded asphalt concrete (LA500 = 40% = red solid line), 45% loss for asphalt concrete Type A, asphalt concrete base Type A, and PCC coarse aggregate (LA500 = 45% = blue solid line), and 50% maximum loss for asphalt concrete Type B and asphalt concrete base Type B (LA500 = 50% = red dotted line).

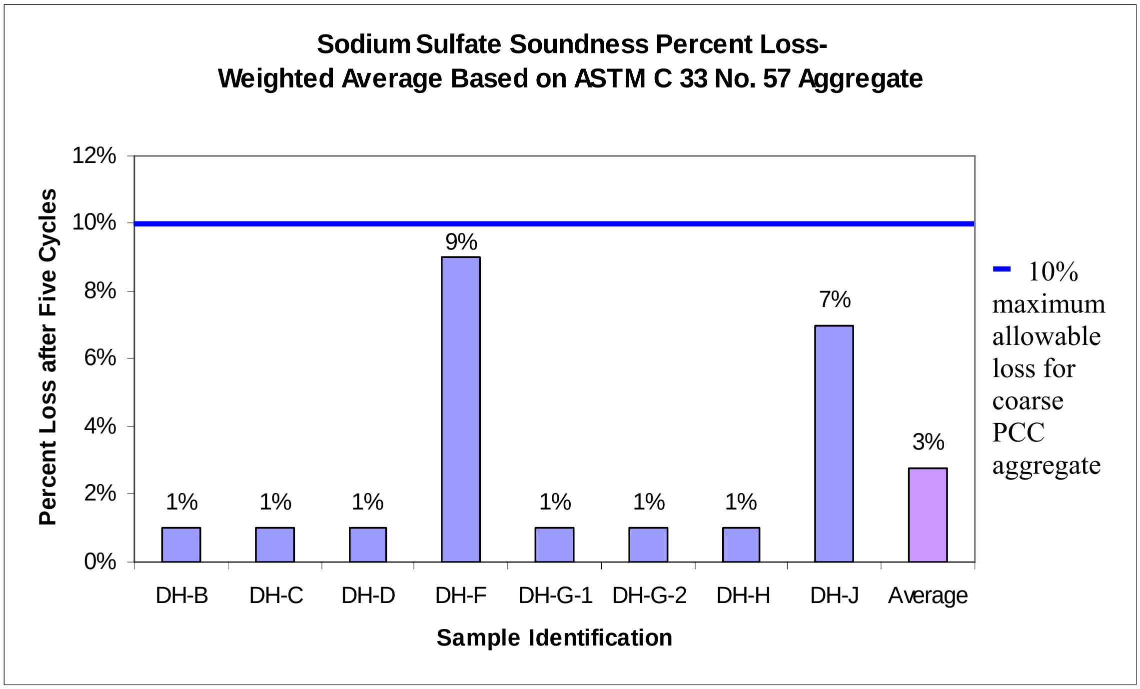

Figure 4.23: Sodium sulfate soundness test results for crushed rock samples with Caltrans standards for maximum allowable loss for coarse PCC aggregate (10%) illustrated as a blue line.

the duplicate sample were generally consistent with the sample it copied for both types of analyses.

4.8.1 34 Element Analysis

Results from the 34 element analysis tests are provided in Appendix H and are expressed in either percent or parts per million (ppm) depending on concentration. Of the elements assessed, 16 were only partially digested by the aqua regia solution, while the reported concentrations of elements easily digested and the volatile trace elements are more accurate. Concentrations of fully digested elements are shown in Table 4.8.

Table 4.7: Brief description of geochemical samples sent for testing; notation made if thin section (TS) exists.

Sample Number	TS	Description
DH-A 30-55’	No	DG gravel
DH-A 78’	No	DG gravel covered with iron-rich clay
DH-A 112’	No	Braided fractures in semi-competent rock
DH-A 150’	Yes	Fresh tonalite with sphene visible
DH-B 20-40’	No	Silty sand with gravel of grey and pinkish-red material
DH-B 58’	Yes	Tonalite with vein of pink, weathered plagioclase
DH-B2 0-25’	No	DG gravel with pieces of pink, weathered plagioclase
DH-B2 49’	Yes	Typically weathered tonalite around fractures
DH-C 20-40’	No	Grey silty sand
DH-C 73’	Yes	Mafic inclusion in tonalite, mostly hornblende, some biotite
DH-C2 3-20’	No	DG gravel
DH-C2 38’	Yes	Fracture zone in tonalite
DH-D 20-40’	No	Grey silty sand with some gravel
DH-D 80’	Yes	Typical weathered tonalite with open fracture
DH-E 20-40’	No	Grey silty sand with gravel
DH-E 97-102’	Yes	Shear zone/clay seam? 2-3 mm quartz grains
DH-F 0-20’	No	Light brown silty sand with numerous gravel pieces
DH-F 50’	Yes	Typical weathered tonalite, ¼” plagioclase vein, small biotite
DH-G 27-40’	No	Light brown to grey silty sand with gravel
DH-G 47’	No	Healed fracture with chlorite infill, unknown mineral in open fracture, all in tonalite
DH-G 58’	Yes	Three parallel pink weathered plagioclase veins 3/8” wide, rusty non-biotite minerals
DH-H 0-21’	No	DG gravel
DH-H 32.5’	Yes	Typically weathered tonalite
DH-I 20-40’	No	Light brown silty sand with gravel
DH-I 48’	Yes	Grey silty sand with gravel, some kaolinite in fractures
DH-J 46’	Yes	Typically weathered tonalite
DH-L 56’	No	Duplicate of DH-G 58’

Table 4.8: Concentrations of fully digested elements in parts per million (ppm) or percent from the 34 element analysis.

Element	ppm
Ag	0.2
As	3
Bi	<2
Cd	<0.5
Co	4
Cu	4
Hg	1
Mn	281
Mo	1
Ni	3

Element	Ppm
P	653
Pb	3
Sb	<2
U	<10
V	30
Zn	66

Element	Percent
Fe	1.86
S	0.02

4.8.2 Whole Rock Analysis

Appendix H-2 contains the results of the whole rock analyses. These results indicate that all 27 samples were fairly consistent in composition, with SiO_2 ranging from 65.50-68.76%, Al_2O_3 varying from 15.50-16.24%, Na_2O values from 3.58-4.45%, CaO and Fe_2O_3 ranging from 2-4%, K_2O from 1.5-2.5%, MgO averaging about 1%, TiO_2 averaging around 0.66%, and traces of Cr_2O_3, MnO, P_2O_5, SrO, and BaO. Loss on ignition ranged from 0.39-3.83%.

4.9 Petrographic Analysis

Summary sheets of each of the 12 thin sections examined are located in Appendix I. All of the thin sections include quartz, plagioclase, and biotite, with most of the others including all or some combination of potassium feldspar, hornblende, and sphene. Trace minerals include apatite and zircons, which are encased in other minerals (generally quartz and plagioclase, but also potassium feldspar, biotite, hornblende, and sphene). A minor occurrence of muscovite was also observed in one slide. In general, descriptions are consistent with those from Clinkenbeard (1987). Lithologically, the rocks collected from the study area on the LPBMIR range from a granodiorite to a granite, as indicated in Figure 4.24, with the majority of samples classified as a granodiorite by thin section analysis. This also concurs with analyses performed by Clinkenbeard (1987). A hornblende- and biotite- rich xenolith from sample DH-C 73' was classified separately from the host rock and is considered a quartz-rich granitoid.

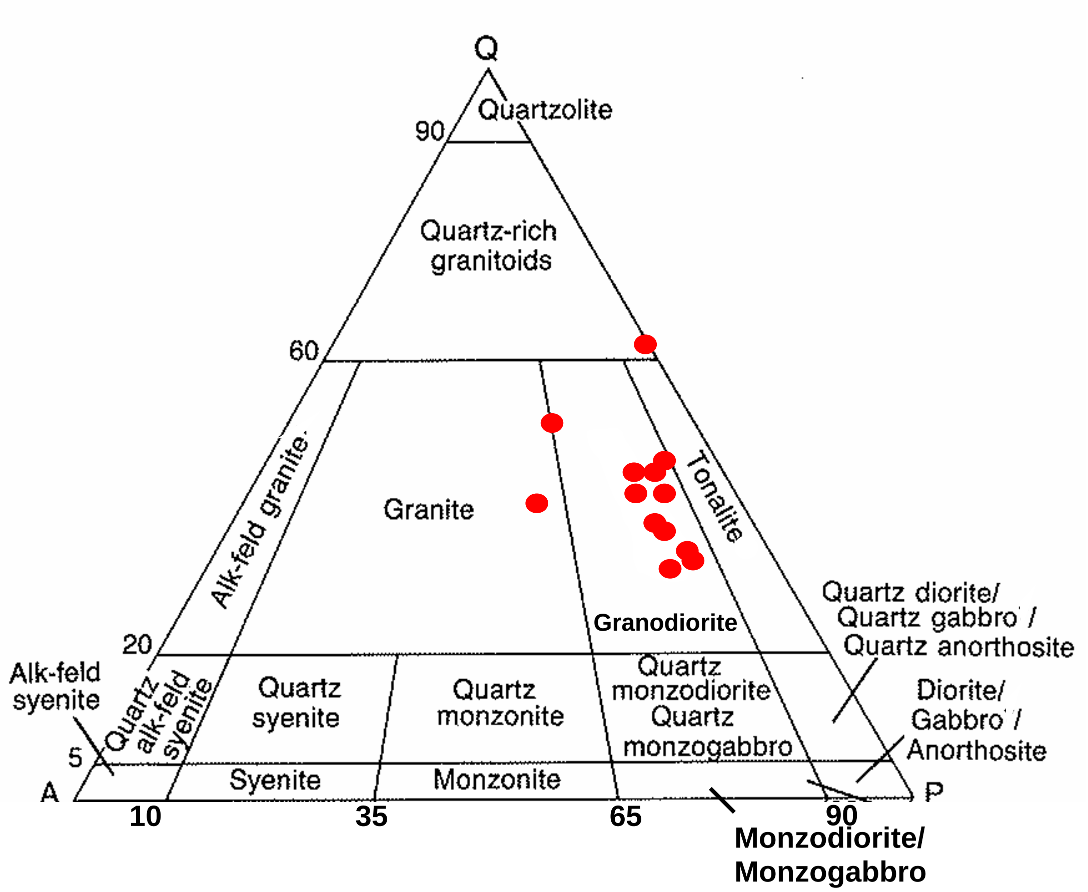

Figure 4.24: Q+P+A ternary diagram with normalized mineral percentages.

Observations indicate that weathering has occurred to some extent in all 12 samples as shown in Figure 4.25, including DH-A 150’ which was originally thought to be a sample of fresh rock. This signifies that clay minerals are also present in the samples, which can negatively affect results of engineering tests. Biotite was frequently altered to chlorite (about 5-20%), as was hornblende in some cases. Centers of plagioclase crystals frequently contained about 20% clay minerals, most likely interlayered illite and smectite, commonly located along fractures (Harrison, 2005). Quartz and potassium feldspar grains showed little to no evidence of weathering.

Other items worth noting include textures and the actual compositions of what were previously identified as veins. Both poikilitic and myrmekitic textures were observed in the thin sections, with potassium feldspar oikocrysts enclosing the other minerals. Plagioclase crystals showed both Carlsbad and albite twinning, and hornblende crystals were twinned as well. Some plagioclase grains also displayed concentric zonation. Kinked biotite crystals were also noted, indicating slight movement within the magma chamber prior to complete solidification. Both pink and white veins were noted in some of the samples. Examination under the microscope revealed that these were actually zones of more intensely weathered plagioclase and biotite crystals, caused by the intrusion of potassium feldspar veinlets.

Thin sections of DH-E 100’ and DH-I 48’ were both made from suspected clay seams or shear zones, but identification was difficult since the samples were collected via sonic drilling. Both showed significant amounts of clay development within plagioclase grains, with DH-E 100’ also showing clay minerals between grains.

Several minerals or features were not observed in thin section. Soluble sulfates, unstable sulfides, and minerals which are alkali-silica reactive were not seen. In the hand sample of DH-G 58’, rusty-looking non-biotite minerals were noted, but were not captured in thin section. The biotite weathering rims, although a prominent feature in hand sample, were also not observed in thin section.

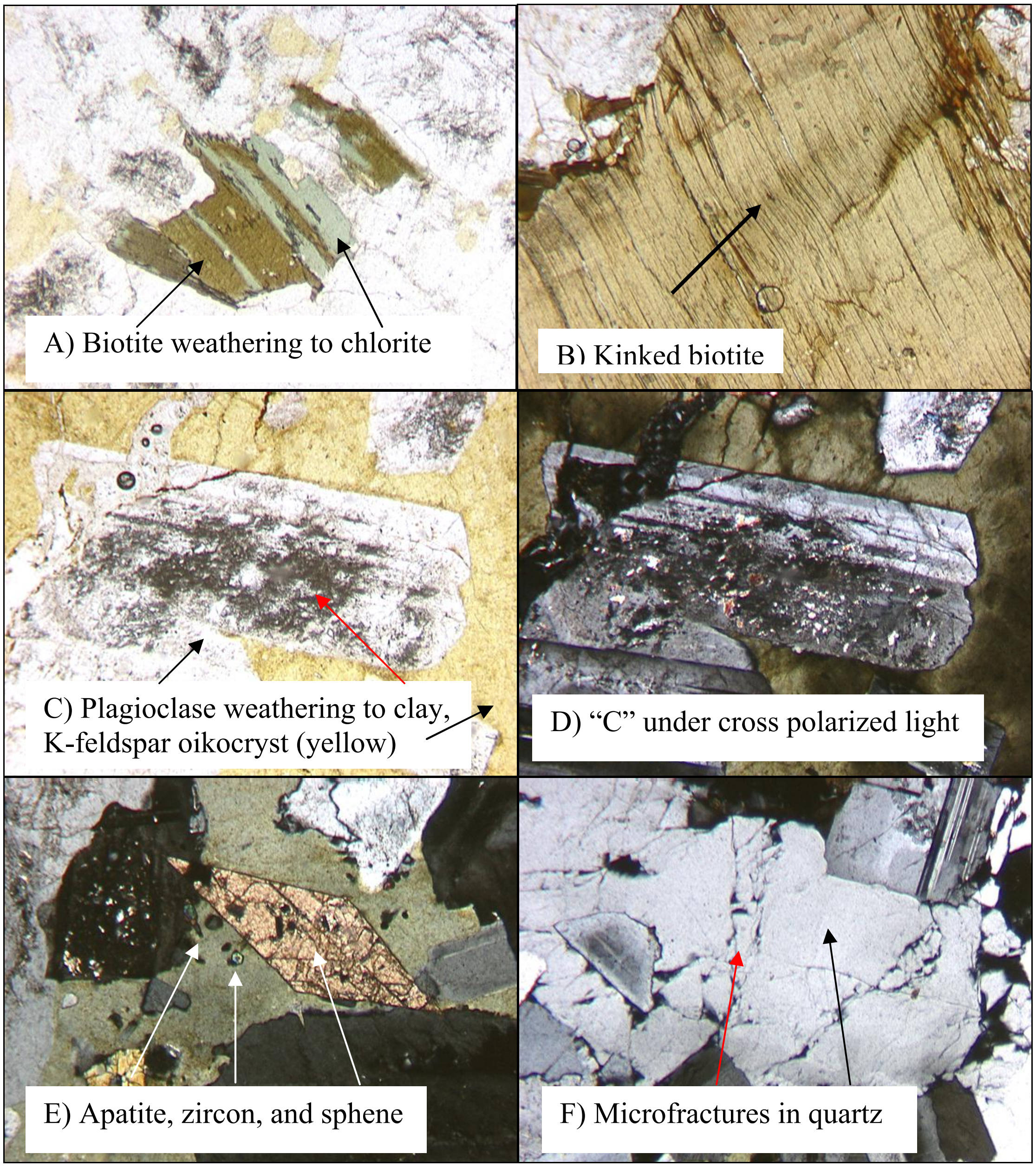

Figure 4.25: Photomicrographs of thin sections of subsurface samples, sample number and length of photomicrograph (for scale) indicated below:
A) DH-A 150', 2.47 mm; B) DH-J 46', 2.47 mm; C) and D) DH-C2 38', 1.55 mm; E) DH-B 58', 1.55 mm; F) DH-H 32.5', 2.47 mm.

4.10 Modeling

From Vulcan modeling, quantity estimates for the study area are approximately 31.6 million tons of DG resources, which can be broken into 24.7 million tons in the southern portion of the study area and 6.9 million tons in the northern region. This was calculated from the volume estimate and a density of 2.60 g/cm^3 from the laboratory testing results. An oblique view of the volume modeled is provided in Figure 4.26. Only DG resources were modeled since the majority of depth information focused on the amount of DG present in the study area. After the change in focus of the drilling program, the quantity of non-rippable rock became a lower priority than the quality of the rippable rock, since the rippable material will be mined first. Some approximations were made as to the exact depth at which the rock becomes non-rippable because this boundary is gradational in places as interpreted in both the refraction surveys and the drilling program.

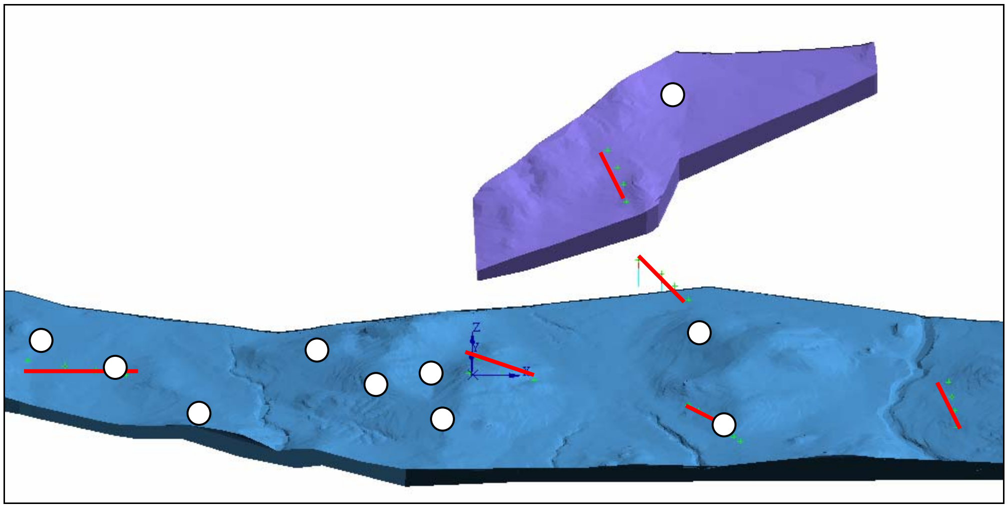

Figure 4.26: Volume of study area modeled using Vulcan; red lines and white dots indicate areas of depth information including seismic lines and boreholes, respectively.

CHAPTER 5

DISCUSSION OF RESULTS

5.1 Surface Sampling

Results of the surface sampling indicate multiple uses based on Caltrans standards, including subbase, class 2 base, and PCC fine aggregate. Although the DG passes gradation and SE tests for some types of asphalt concrete, the amount lost from the LA abrasion test exceeds Caltrans specifications for all products. Therefore use as asphalt concrete is unlikely unless the durability can be increased. Gradation tests indicate a well-graded material, with an even distribution of grain sizes between ¾ inch and the #50 sieve and less than 3% passing the #200 sieve for the majority of samples collected. Testing results of the DG collected from the pit were compared to the Caltrans required gradations for various end-products. These samples pass several Caltrans specifications as shown in Table 5.1 with no additional processing or blending of certain grain sizes to rectify non-uniform grading. All samples pass the Caltrans allowable percentage of fines for all subbase classes.

Surface samples collected from the eastern side of the Reservation were finer than those from the western side. This is most likely attributed to the smaller crystal size, since the eastern Reservation is closer to the center of the pluton and samples would be from the fine grained small biotite facies, see Figure 2.2. Three of the four eastern samples also show higher percentages of fines (roughly 4-8% compared to less than 3% for the majority of the other samples). Samples from the I-8 roadcuts and from within the Sand Pit are some of the coarsest collected because they are closer to the margins of the pluton and part of the large biotite facies, where crystals are medium to coarse grained.

Table 5.1: Overview of products for which each surface sample collected from the pit passes Caltrans specifications.

Product		LP2	LP3	LP4	LP5	LP8	LP9
Subbase	class 1	c	f	**x**	**x**	**x**	**x**
	class 2	c	**x**	**x**	**x**	**x**	c
	class 3	c	**x**	**x**	**x**	**x**	c
Class 2 Base	1.5" max	**x**	f	f	f	f	**x**
	0.75" max	**x**	f	**x**	**x**	f	**x**
Asphalt Base Type A and B		**x**	f	f	f	f	**x**
Asphalt	0.75" max coarse	c	f	f	f	f	**x**
	0.75" max medium	c	f	**x**	**x**	f	c
	0.5" max coarse	c	f	c	**x**	f	c
	0.5" max medium	c	**x**	c	**x**	**x**	c
	0.375" maximum	c	c	c	c	**x**	c
	#4 maximum	c	c	c	c	c	c
Open Graded Asphalt	0.5" maximum	c	f	c	f	f	c
	0.375" maximum	c	f	c	f	f	c

x	sample fulfills Caltrans specifications for that product
f	sample is too fine to fulfill Caltrans specifications for that product
c	sample is too coarse to fulfill Caltrans specifications for that product

Grain size also generally increases with depth due to the diminished effects of surface weathering, which is supported by the Sand Pit samples. The sample from the bottom bench face was coarser and less weathered than the samples of the three upper benches. Other support for decreased weathering at depth includes the height and angle of the bench faces, since the bottom face is about 30 ft tall and still retains a vertical face. Comparatively, the upper benches range from 12-15 ft tall with faces that appeared to have been cut vertically but have raveled enough to now stand at 45 degree angles. This suggests that higher, steeper benches may be cut when excavating less weathered material.

Another variation within the pit is the discrepancy between the gradations of samples collected from the east and west pit walls when compared to the bench samples. The west wall gradation is comparable to that of the bottom bench face sample. However, the east wall sample has a finer gradation than the samples from the upper benches, even though it was collected from the deepest part of the pit. This gradation is attributed to the abundance of clay seams. In general, the presence of the clay seams causes a decrease in grain size and, therefore, quality of material due to the intensity of weathering and higher fines content. In this case, the east wall sample contains over 4% fines rather than about or less than 2% for the other samples collected from the pit.

The three stockpile samples exhibited grain sizes between ½ inch and ¼ inch, with less than 15% under ¼ inch. The minus ¼ inch portion was most likely a result of the sieve analysis conducted at the Colorado School of Mines rather than part of the original stockpile (since stockpiles were of previously sieved material), indicating that additional handling of the DG may cause further breakdown of grain sizes. Therefore, material handling should be minimized to prevent any reduction in size.

The results of the sand equivalent tests run on unprocessed DG indicate that all surface samples pass the Caltrans specifications for asphalt concrete and class 2 base, with nine samples also passing for PCC. Since not all of the samples initially passed for PCC, eight were selected to be washed and retested. These include the four bench samples, the east wall clay seam sample, two from the eastern Reservation, and one from the I-8 roadcut. Once washed, all samples pass the specifications for PCC. This indicates that even the lower quality DG can be processed to create high quality material.

All of the stockpile samples pass the sand equivalent test for PCC because the material had been washed and sieved prior to stockpiling. This processing, which was part of the previous mining operation, broke down the more weathered material and removed most of the fines from the DG. Because the processed stockpile samples passed Caltrans PCC criteria for SE during this preliminary quality investigation, subsurface samples were tested for a wider range of PCC tests to evaluate the possibility of this as a possible end-product.

5.2 Seismic Refraction

The Caterpillar Performance Handbook (2002) suggests that granitic material can be ripped by a D9R ripper if the seismic velocity is under 7,000 ft/s. However, rippability reports from Christian Wheeler indicate that a D9 can only rip material up to about 4,500 to 5,500 ft/s. Based on the appearance and competency of cored material obtained through the drilling program where refraction data was available, the Christian Wheeler estimate is more realistic for the site. The estimate provided by Caterpillar would be economically rippable only if certain geologic conditions existed, such as competent material with closely spaced fractures.

From the 2004 seismic refraction data, both rippable and non-rippable layers were interpreted. Across the study area, the uppermost 10-30 feet has a seismic velocity ranging from 1,000 to 1,650 ft/s, suggesting rippable material for this depth interval. At the locations of seismic line LP-S2, LP-S5, and LP-S7, all of which are on the eastern half of the study area (Plate 2), this upper low-velocity layer is underlain by at least 50-100 feet of material with a seismic velocity of 4,000-5,000 ft/s. Even though this is a significant increase in velocity, this material is still considered rippable by a D9 or equivalent caliber equipment based on practice (Christian Wheeler Engineering, 2001b). A possible third deeper layer is also interpretable from the refraction data gathered from LP-S2 at about 75 ft in depth, which suggests a non-rippable, 6,000 ft/s layer. For LP-S6 in the south-central study area (Plate 2), the low velocity upper layer is above about 50 feet of material with a velocity of just over 5,000 ft/s, which is considered marginally rippable. At the remaining 2004 refraction line sites, a non-rippable layer of over 8,000 ft/s was interpreted for the 80 to 100 ft below the upper low-velocity layer.

Overall, these results indicate a rippable layer from 15 to over 100 feet thick across the entire study area. Places with thinner layers of rippable DG are located to the sides of drainages where most of the weathered material has already been removed by erosion or along hilltops where prominent boulders suggest shallow depth to bedrock. Areas with thicker layers of DG tend to be located along or near the major joint sets, since the material has been exposed to additional weathering caused by ground water flow concentrated along the breaks in the rock. If movement occurred along these joint sets, then the material has been exposed to some mechanical breakdown as well.

Two of the 2004 refraction lines were located along 2001 refraction lines in an attempt to verify the Christian Wheeler Engineering rippability studies. LP-S2 was selected to confirm S6 from the 2001 study, and LP-S5 was placed along the 2001 S10 seismic line. In the 2001 surveys, geophones were spaced every 10 feet, whereas six foot spacings were used in the 2004 study. Since closer geophone spacing can provide more control in the interpretations (especially in the shallow subsurface, as in this case), the 2004 study provides more detail. Overall, the 2004 surveys utilized more geophones (60 versus from nine to 16), had a longer survey length (usually 390 feet compared to 80 to 150 feet), and used more shotpoints (data was interpreted for seven or eight shot locations rather than two) than the earlier study. This implies that the 2004 surveys can support more in-depth conclusions because more data was collected regarding the subsurface.

Despite the differences in set-up, the results of the two pairs of refraction surveys are comparable within a margin of error of a few feet for depth and a few hundred feet per second for velocity. In the 2001 S6 seismic line, the top 8-10 ft produced a velocity of 1,000 to 1,300 ft/s and overlies a 3,600 to 3,900 ft/s layer to at least 37 ft in depth. LP-S2 was located very close to the S6 site and showed velocities of 1,300 ft/s in the top 13-23 ft and 3,900 to 4,250 ft/s to a depth of about 75 feet. The 2004 LP-S2 data also suggests a third deep layer, but the 2001 studies were not detailed enough to either support or refute this layer. The interpreted velocities were very similar for each respective area and layer since all were within about 300 ft/s of each other, indicating agreement in interpretations between the two studies. The discrepancy in upper layer thickness is most likely due to the variations in how each seismic line was set-up and the fact that the locations did not match exactly.

The 2001 S10 seismic line and LP-S5 were located in the same place as shown on Plate 2. S10 indicated an upper layer velocity of 1,250 to 1,300 ft/s for the top 10-11 feet of material, with a 3,700 to 4,400 ft/s layer underneath to a depth of at least 40 ft. The 2004 seismic line indicated a velocity of 1,000 to 1,650 ft/s for the upper 10-20 ft of material, underlain by material with a velocity of 3,300 to 4,600 ft/s to a depth of at least 110 ft. These values also support agreement in interpretations, with slight variations due to the differences in set-up and accuracy.

5.3 Core Logging

Although sonic and wireline core samples were logged as two inherently different materials, such as silty sand with gravel versus DG, the subsurface is composed of DG except along existing stream drainages and at depth, where solid rock was located. This is shown in Appendix D in the core logs of boreholes DH-B, B2, C, and C2, which were twinned holes and show that the sonic sand samples are the same as core DG samples. This assumption was used during cross-section construction and the subsurface modeling.

Two seismic lines were compared with drilling results: seismic line LP-S2 by borehole DH-G, and LP-S4 by DH-A and H. In general, the two seismic studies and the drilling methods produced the same results, signifying that the 2004 seismic refraction data and their interpretations are valid. At the location of borehole DH-G, LP-S2 indicated a low velocity zone of 1,300 ft/s in the upper 12 feet, underlain by material with a velocity of 4,000 ft/s down to a depth of about 75 feet, with 6,000 ft/s rock suggested below. Drilling at this location showed DG for the top 39 feet, a weathered corestone from 39-61 feet, DG from 61-81 feet, and weathered bedrock from 81 to 104 ft (Figure 5.1). The weathered corestone is what remains of rock between joint sets, where the material closest to the fractures is weathered into DG by ground water and the material between fractures is still somewhat competent. The lowest-velocity layer is attributable to the most highly weathered, near surface DG. However, since this hole was drilled with sonic methods, samples from this interval were not differentiable from deeper DG samples. Although no velocity changes indicate the corestone, the recovered core shows broken down pieces less than four inches long and suggests the corestone might not be one solid mass, but weathered and broken into smaller pieces. If so, a seismic velocity change would not be as evident, because the energy waves are not traveling through solid rock but through a mix of somewhat competent rock and DG. The third and deepest layer interpreted from the seismic data was estimated at 75 ft in the seismic analysis, with DH-G intercepting suspected bedrock at 81 ft. This rock was more competent than the corestone since the bedrock produced longer, less weathered samples of core. The change in competency also reflects the difference in velocities interpreted through the seismic data.

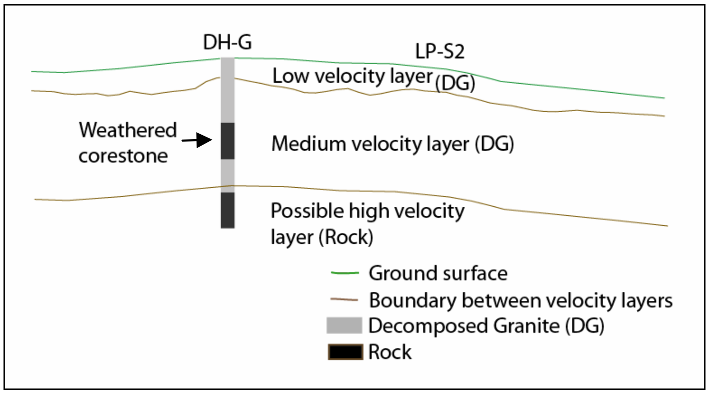

Figure 5.1: Cross-section along seismic line LP-S2 with drilling data from borehole DH-G.

Seismic data from LP-S4 at the location of DH-H indicates about 23 feet of material with a velocity of 1,600 ft/s, underlain by 8,500 ft/s velocity material to a minimum depth of 110 feet. DH-H confirmed this interpretation, with DG in the upper 22 feet of the hole and more competent rock below as shown in Figure 5.2.

About 150 feet north of LP-S4 is DH-A, the angled core hole intended to assess weathering near the joint set. Projecting drilling data onto the seismic line showed that the rippable/non-rippable boundary indicated by seismic refraction roughly coincides with the first interval of solid rock recovered from the hole. Even though the interval was only 3.5 ft long, recovered pieces of core ranged from eight to 22 inches in length, indicating solid rock with minimal fracturing. This further supports the interpretation and is illustrated in Figure 5.2. For mining purposes, however, rippable material was still located beneath this layer if the non-rippable rock can be removed economically.

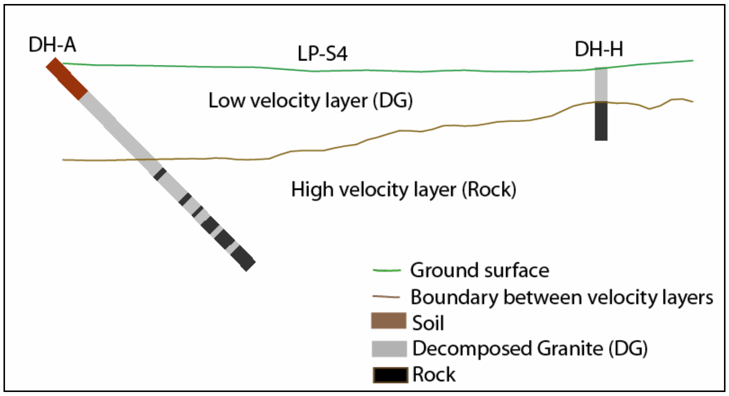

Figure 5.2: Cross-section along seismic line LP-S4 with drilling data projected onto it from borehole DH-A and DH-H.

5.4 Rock Quality Designation

An average RQD of the boreholes that sampled competent rock is 70, which correlates to rock of fair quality (Table 3.3). DH-B averaged the highest RQD value of 85, which indicates good quality rock, while DH-F averaged the lowest RQD of 53, suggesting fair quality rock. The presence of fractures, clay seams, and zones of DG all caused breaks in the rock, with higher proportions of these features lowering the RQD.

Overall, RQD is relevant because rock with more closely spaced fractures can be excavated and crushed more easily than large boulders or bedrock blocks. Therefore, areas with lower RQD can be excavated deeper using the same equipment used for DG. Areas with high RQD may need to be blasted in order to mine the rock. Variations in RQD may also indicate potential for different end-products.

5.5 Physical Testing and Standards for Decomposed Granite

The vibrations of the sonic drilling method affected the testing results by creating fine-grained, broken-up material for testing as opposed to the coarser DG that would be sold for use in construction projects. Therefore, discrepancies exist between the testing results for material sampled depending on the drilling method used for collection.

The DG fulfills the Caltrans specifications for class 2 base and all classes of subbase. Although the DG may pass for asphalt concrete based on the SE test results, the LA abrasion test results on the stockpile sample and subsurface rock samples do not indicate aggregate of asphalt concrete quality. It does not meet the criteria for PCC fine aggregate based on the SE and durability index tests. The broken down nature of the sonic samples is better described as “disturbed”. Because of this, sonic testing results were not considered for quality evaluation. The stockpile results provided an indication of how the processed DG would test, especially since it had been excavated by a mining technique utilized by the previous DG mining operation.

5.5.1 Gradation

Gradation tests were performed on 36 DG samples. Only core samples were evaluated for fulfillment of Caltrans specifications for all classes of subbase, class 2 base, asphalt base, and asphalt, as shown in Table 5.2. Stockpile samples were not evaluated because grain size distributions do not reflect the *in situ* DG, but rather whichever grain size distributions the DG was previously processed to achieve.

Table 5.2: Overview of products for which each cored DG sample passes Caltrans specifications.

Product		**DH-A S1**	**DH-A S2**	**DH-B2 S1**	**DH-B2 S2**	**DH-C2 S1**	**DH-C2 S2**	**DH-H S1**	**DH-J S1**
Subbase	class 1	x	f	f	x	x	x	f	f
	class 2	x	x	f	x	x	c	f	f
	class 3	x	x	x	x	x	c	x	x
Class 2 Base	1.5" max	f	f	f	f	f	c	f	f
	0.75" max	x	f	f	f	x	x	f	f
Asphalt Base Type A and B		f	f	f	f	f	x	f	f
Asphalt	0.75" max coarse	f	f	f	f	f	c	f	f
	0.75" max medium	f	f	f	f	f	c	f	f
	0.5" max coarse	x	f	f	f	x	c	f	f
	0.5" max medium	x	f	f	x	x	c	f	f
	0.375" max	c	x	f	c	c	c	f	f
	#4 max	c	c	f	c	c	c	x	x
Open Graded Asphalt	0.5" max	f	f	f	f	f	f	f	f
	0.375"	f	f	f	f	f	f	f	f

x	sample fulfills Caltrans specifications for that product
f	sample is too fine to fulfill Caltrans specifications for that product
c	sample is too coarse to fulfill Caltrans specifications for that product

All of the cored DG samples meet the Caltrans specifications for at least one product, with most of them qualifying for several. The DG samples are too fine-grained (large portion of less than 1/8 inch material) to pass for most of the products other than subbase. This deficit of coarse material can be compensated for by several methods: 1) washing the DG prior to sale to remove the finer-grained particles, 2) screening the DG to separate out a portion of the finer grain sizes, which will increase the relative proportion of the coarser grain sizes, with the screened out material sold as other products, or 3) crushing boulders, corestones, or bedrock which may be encountered during mining to increase the percentages of the coarser grain sizes. These three options would also increase the overall strength of the material, either by removing the finer-grained, more weathered material or by adding fresher rock to the DG. Combinations of these methods can also be employed to increase the number of products that can be made from the DG. Blending can also be used if different sections of the mine are producing materials which naturally break into different grain sizes to ensure a more homogenous product.

5.5.2 Sand Equivalent

All samples were tested for sand equivalent. Based on the average core sample SE value of 53, the DG passes the Caltrans specifications for asphalt concrete, with all eight passing for class 2 base and all classes of subbase. The quality of the DG from the upper 25 feet of the DG is generally lower than that of the material collected from deeper in the holes. Only one of the five upper-hole samples passed for asphalt; however, all three of the lower holes samples passed for asphalt with one passing for PCC fine aggregate as well. This indicates that the SE value generally increases with depth. This occurs because surface water infiltrates the ground, leading to increased erosion and weathering and therefore an increased fines content in the near-surface DG. These upper-hole samples (DH-A S1, DH-B2 S1, DH-H S1, and DH-J S1) were generally characterized by a higher percentage of sand or DG that did not retain its cored shape upon removal from the core barrel, and/or an increased amount of alteration, such as biotite to chlorite.

The average stockpile sample SE result is 79, which passes Caltrans specifications for PCC fine aggregate, asphalt concrete, class 2 base, and all classes of subbase. This value is 26 percentage points higher than the values obtained from core samples. Therefore, if the DG is washed and screened prior to sale, it could potentially be used for a wider range of products. The values obtained from stockpile samples are similar to those from the washed surface sample results, indicating that the surface sample values may be a better representation of the material than the cored samples. This also implies that the core drilling also broke down the DG, though not as much as the sonic.

5.5.3 Durability Index

From the samples collected, the processed stockpiles yielded durability index values with an average of 55 with the core samples averaged a 37. None of these averages passes Caltrans specifications for PCC fine aggregate, although the majority of samples pass for class 2 base.

The core sample average for durability index passes for class 2 base by a slight margin (2%). This is most likely due to the weathered nature of the DG, indicating that it is subject to considerable breakdown when abraded. However, since the stockpile sample average was above the minimum value for class 2 base, processing the DG removes the more weathered pieces and thereby increases product quality.

5.5.4 Specific Gravity and Absorption

Results of the specific gravity test indicate an average specific gravity of 2.60. Therefore, a density of 2.60 g/cm^3 was used to convert the modeled volume of the deposit into tonnage. Concrete aggregate from the San Diego area generally has a minimum coarse specific gravity of 2.62 (Chapman, 2005), so the density of the material is too low for PCC.

Absorption values average 2.31 (coarse) and 1.74 (fine) for core and 2.16 (coarse) and 0.80 (fine) for stockpiles. The core value was higher due to the decomposing nature of the DG, which allows for small fractures and holes in the individual grains. The fine-grained stockpile absorption value is low, indicating that most of the highly weathered DG had been removed during the washing and screening process. Therefore, the stockpile samples preferentially included only the higher quality DG. In general, processing is suggested for all of the material mined in order to remove the more weathered DG.

5.5.5 R-Value

Samples tested for R-Value produced similar testing results, with core averaging 81 and stockpiles averaging 79. All of these samples passed Caltrans criteria for both class 2 base and all classes of subbase. Since the averages are similar, processing does not increase the R-Value testing results.

5.5.6 Organic Impurities

Only two of the samples tested showed any presence of organic material. Since all of the samples produced values of less than three, the DG passes Caltrans standards for PCC for this test. One of the two samples that showed organics, DH-H S1, is the uppermost sampled interval from DH-H and possibly included leaf or root matter from soil mixed in with the DG, although this was not noted during logging. The other sample is DH-K S1, which is a stockpile sample. Organic material was observed in this stockpile in the form of bushes growing on and around this sample location. Removal of vegetation and topsoil from the area prior to mining will decrease the chances of organics contaminating the material.

5.5.7 Comparison of Seismic Velocity with DG Testing Results

Only two holes were drilled and four samples were collected along seismic refraction lines, making any correlations drawn between seismic velocities and anticipated testing results uncertain. This is true because one of the holes was drilled using sonic methods (DH-G produced three DG samples), while the other hole was cored (only one DG sample was collected from DH-H). Since the sonic results were not representative, no comparisons were made along LP-S2. DH-H, a core hole, was drilled near the eastern end of LP-S4 (Plate 2). Seismic velocities of about 1,300 ft/s were recorded in the upper 23 feet near the borehole location, which was typical for near-surface DG in the study area. Physical testing results from this sample (DH-H S1) indicate class 2 base and subbase quality material. It is a possibility that the rippable DG with seismic velocities of about 4,000 ft/s would produce better testing results and higher quality product since the rock is less weathered, although this could not be tested. However, correlations between rock mass properties, such as testing results, and "intact" sample properties, such as seismic velocity, are not always valid.

5.5.8 Influence of Major Joint Sets on DG

Quality of DG with regard to testing results does not appear to be influenced by proximity to the major joint sets, except where clay seams are present. Boreholes DH-B, B2, H, and I were near suspected joint sets and DH-A was drilled at a 45 degree angle near a joint set. Testing results from the majority of these samples were not consistent when compared with other samples collected with the same drilling method.

The only samples which seemed to have a consistent outcome were the ones where clay seams were identified in the core logs. The presence of clay seams increased the fines percentage in the gradation analyses and lowered sand equivalent values. Joint sets influencing the clay seam density is based on several observations: 1) clay seam density in the pit increased to the east, which is close to a N-S trending joint set, 2) boreholes DH-B, B2, and I all sampled numerous clay seams, and these three holes were the closest to joint sets with the exception of DH-A, explained below, and 3) clay seams in this area are associated with hydrothermal fluids (Riley, 1978), and because fluids flow more easily along joint sets than rock, clay seams would be more likely to develop near joint sets. Overall, the areas near the joint sets seem to have higher densities of clay seams, indicating lower quality DG near these features. However, the correlation between joint sets and clay seams cannot be definitively proved or disproved using this data.

DH-A, which is located near a joint set, did show some evidence of clay seam development, but not as much as anticipated. It is suspected that DH-A did not show more clay seam development because the uppermost 30 feet of the angle hole contained soil from an ephemeral stream bed, meaning that the DG nearest the joint set had been eroded away because the rock was less resistant near the joint set. Therefore, the clay seams that were sampled in DH-A were from areas further from the joint set.

Quantity of DG tended to increase near the joint sets. This is most likely due to the increased ease of water flowing along joint sets, which increases the weathering rates and breaks competent rock into DG. Stream drainages tend to form along joint sets found in the area, leading to more erosion, but also increasing the development of soil (the soil was 21 feet thick at DH-A, and seven feet of soil were found at DH-I). In general, there is more DG at depth near joint sets, but at the surface, it is replaced by residual soil.

The increased amount of DG is observed in the seismic data, specifically LP-S4, 5, and 7, and also seen in DH-I. LP-S4 is located with one end at a joint set and perpendicular to it (Plate 2). Along the joint set, rippable material is estimated to be 56 feet thick, gradually thinning to 23 feet further from the joint set and confirmed with DH-A and H. Seismic lines LP-5 and 7 are located roughly parallel to joint sets, with no evidence of non-rippable material at depth. The estimated interpretable depth was 110 feet for LP-S5 and 85 feet for LP-S7. DH-I was located adjacent to a joint set and no hard rock was sampled through the 100 ft length of the hole.

5.6 Physical Testing and Standards for Crushed Rock

From the results of the two tests performed on the more competent rock collected during the drilling program, the potential for asphalt concrete and coarse PCC-grade crushed rock resources is low. The rock generally does not pass Caltrans specifications for these products based on LA abrasion results. Although the material passes for sodium sulfate soundness for all eight samples, this test is not as critical in the San Diego aggregate market area as the temperatures rarely drop below freezing for extended periods of time. However, in order to permit a new aggregate pit for these products, sodium sulfate soundness results are required.

5.6.1 Los Angeles (LA) Abrasion

Overall, the crushed rock from the study area on the LPBMIR does not meet the Caltrans standards of percent loss for LA abrasion (Figure 4.22), indicating low to moderate resistance to mechanical breakdown. None of the tested samples passed the specifications for open graded asphalt concrete, asphalt concrete Type A, or asphalt concrete base Type A, since all eight samples lost over 10% total sample weight after 100 rotations. After 500 rotations, no samples met the Caltrans criteria for open graded asphalt concrete. The only samples which pass Caltrans criteria for any product for this test are the samples from boreholes DH-B, DH-C, and DH-D, which pass for asphalt concrete Type B and asphalt concrete base Type B.

Because the average values do not pass criteria for any product, crushed rock is not recommended for use in PCC coarse aggregate, asphalt concrete, or asphalt concrete base. In general, less weathering leads to lower percentage lost, since borehole DH-B yielded the highest quality (Figure 4.22) and showed no evidence of biotite weathering rims and overall least amount of weathering. The lowest quality came from DH-F and DH-J, which are samples of rock with weathering rims up to two millimeters wide and significant development of hairline fractures in the rock.

The average uniform hardness coefficients of these samples is 0.30, indicating that the samples do not break down evenly when abraded, but rather the breakdown is more severe initially. This is due to the weathered nature of the rock, since weathered portions will break off first, leaving only the fresher portions of the rock to be broken down later.

5.6.2 Sodium Sulfate Soundness

All of the test results pass Caltrans specifications for PCC coarse aggregate. Samples with minimal amounts of weathering (DH-B, C, D, G-1, G-2, and H) produced about 1% loss, which is below the 10% loss allowed by Caltrans. Samples DH-F and DH-J were significantly more weathered (biotite weathering rims up to 2 mm), which explains the higher percent losses (9% and 7%, respectively). Samples DH-F and DH-J also contain a higher amount of hairline fractures due to the weathered nature of the rock than the other samples. This allows more sodium sulfate solution to infiltrate the rock and ultimately cause the material to break during the simulated freeze-thaw effect. Although they both pass the specifications for PCC coarse aggregate, this more weathered material should not be used if fresher rock is available and PCC-grade coarse aggregate is a desired product. Mixing weathered and unweathered material is also a possibility as long as all the testing results meet Caltrans standards for the other tests.

5.6.3 Comparison of Seismic Velocity with Crushed Rock Testing Results

Three samples were collected from seismic line locations that were tested for crushed rock quality. Since the competent rock was not adversely affected by either sonic or core drilling methods, all three of these samples were used in the comparison. From seismic line LP-S2, samples include DH-G-1 (weathered corestone) and DH-G-2 (weathered bedrock), and from LP-S4, sample DH-H was collected (weathered bedrock). DH-G-1 produced a seismic velocity of about 4,000 ft/s, DH-G-2 showed a velocity of

6,000 ft/s, and sample DH-H was collected from a 8,500 ft/s layer. Higher velocity does not necessarily imply that a sample will pass for LA abrasion and sodium sulfate soundness. For example, although sample DH-H showed the highest velocity, DH-G-2 produced the lowest percentage loss in the LA abrasion test, and all three samples showed similar losses in the sodium sulfate soundness test. From this limited amount of data, it is not possible to correlate seismic velocity with crushed rock testing results. Also, correlations between a rock mass property and an "intact" sample property, such as seismic velocity, are not necessarily valid.

5.7 Geochemical Analysis

From the geochemical analyses, the samples all contained roughly uniform concentrations of the analyzed elements. Samples that included atypical coatings along fracture surfaces or other anomalous features sometimes produced results with subtle distinctions. For example, in sample DH-A 78', the DG is coated in a rusty orange clay suspected to be iron-rich, which was confirmed by a higher iron concentration in the analyses. Clay seams in samples DH-E 97-102' and DH-I 48' had similar results. These two samples produced higher than average concentrations of aluminum, calcium, lead, low concentrations of potassium, and high LOI. The unknown, crystalline, fracture-filling mineral from DH-G 47' is the most likely cause of a strontium spike in the analytical results. Overall, none of the samples submitted for geochemical analysis produced any results that would inhibit the reopening of the Sand Pit.

5.7.1 34 Element Analysis

No potentially hazardous elements included in the analysis were found in high concentrations based on comparison with standard rock elemental concentrations (Peterman, 2005). This is advantageous to the Tribe as it decreases the environmental risk involved with reopening the Sand Pit.

5.7.2 Whole Rock Analysis

The whole rock analyses are consistent throughout all of the samples and indicate a uniform rock geochemistry. The most significant variations are found in the LOI values, with this most likely being caused by the increased percentage of clay in some samples due to the clay seams.

5.8 Petrographic Analysis

Based on petrographic analysis, the lithology of the rock within the study area is primarily a granodiorite. This is due to the presence of approximately 10% potassium feldspar that is nearly indistinguishable from plagioclase in hand sample. According to the geologic map of the area just north of the Reservation (Todd, 1995), the rock is called the Tonalite of La Posta. This is a misnomer based on thin section analysis, but the classification is correct if only hand samples are examined.

The extent of weathering observed in thin section analysis is a key factor in the types of products made from the DG and crushed rock. The results of the physical engineering tests that indicated low quality were likely the result of the weathering of the plagioclase and biotite grains, especially since these weathered minerals constitute about half of the rock.

Weathering is fairly uniform throughout the study area. Rock from greater depths is generally less altered than rock from the shallow subsurface. Clay seams and zones of more weathered plagioclase crystals have higher amounts of clay than the typical samples of DG and rock, and these samples produced testing results indicating lower quality.

The only mineral observed in thin section deleterious to the manufacture of concrete is the interlayered illite/smectite which developed from the weathering of the plagioclase crystals. Smectite swells when mixed with water, and volume changing minerals are undesirable in concrete since they facilitate physical breakdown. Although there is a relatively small percentage of smectite with the majority encased within grains of plagioclase, this could be a concern in some of the more highly weathered areas if concrete aggregate is ever produced from the site. However, since the material generally does not pass Caltrans standards for PCC, this should not be an issue.

5.9 Modeling

Average testing results from the area just east of the Sand Pit where wireline core samples were collected pass Caltrans criteria for class 2 base and all classes of subbase. In general, deeper samples produced lower amounts of fines and higher SE, durability index, and R-Value results. The only test where not all of the samples passed for both of these products is durability index, so maintaining material quality with regard to this test will be the most critical.

Wireline core boreholes cover about 1/3 of the southern portion of the study area modeled. Using this approximation and the estimated 24.7 million tons of resources in the south, about eight million tons of DG resources are indicated to pass Caltrans criteria for class 2 base and all classes of subbase.

CHAPTER 6

CONCLUSIONS

DG from the study area on the LPBMIR passes Caltrans specifications for class 2 base and all classes of subbase based on results of gradation, SE, durability index, and R-Value tests. Individual samples which did not pass were generally characterized by higher percentages of fines, the presence of clay seams, or intense weathering and alteration of minerals. These lower quality samples primarily came from areas near surface lineaments, indicating a relationship between joint sets and material quality. Samples that had been processed either through washing or a combination of washing and sieving during the previous mining operation showed an increase in quality in both the SE and durability index tests.

Crushed rock generally does not pass for any asphaltic concrete product or PCC coarse aggregate. Although all eight samples passed the sulfate soundness test, only three samples passed for any product based on LA abrasion results, with average losses not passing for any product.

Based on both seismic refraction and drilling data, the thickness of the rippable layer varies throughout the study area. Around the Sand Pit, depth to competent bedrock is roughly 15 to 25 feet thick, whereas areas in the central and eastern parts of the study area showed thicknesses from 70 to 100 ft. DG thickness usually increases with proximity to joint sets as well, as non-rippable bedrock was not found either through refraction surveys or boreholes at several of these locations. Corestones are located within the DG and will be found during future mining operations if the Sand Pit is reopened. They are generally not weathered enough to be ripped and will need to be excavated separately or blasted for removal.

Modeling indicates 31.6 million tons of DG resources within the study area, which can be separated into 24.7 million tons in the southern portion and 6.9 million tons in the north. Testing results were not modeled due to the discrepancies between the sonic and wireline core samples and the overall lack of core samples. However, roughly eight million tons of DG resources just east of the pit pass the Caltrans criteria for class 2 base and all classes of subbase.

CHAPTER 7

RECOMMENDATIONS

In order to increase the quality of DG and the number of commodities produced, washing and sieving the material is recommended. Washing will increase quality by removing the fines and the intensely weathered DG. Sieving benefits the quality of the DG in two ways: 1) it also removes finer grained particles and the more heavily weathered material from the coarser, more durable DG, and 2) DG can be separated into stockpiles of different grain sizes, which can then be sold either directly as different products or recombined to obtain mixes for distribution as various end-uses. Blending the material from different areas within the pit can also help to increase the homogeneity of the products. However, the amount of handling, either through processing or moving DG, should be minimized to prevent excessive reduction of grain size.

Crushed rock may be blended with the DG to increase the quality and grain size distributions of the DG products. For example, some samples of DG produced testing results which either did not meet Caltrans standards for class 2 base or passed them by only a small margin. If this lower quality DG is mixed with either higher quality DG or crushed rock, these values, and therefore product quality, should increase. Rock for crushing may be obtained from either bedrock or corestones. Otherwise, DG which does not meet aggregate specifications can be sold as other products (decorative rock for trails, landscaping, etc.) that are not required to pass Caltrans criteria.

DG can be mined near lineaments as long as there is a low density of clay seams. The chances of finding clay seams and more intensely weathered DG are higher near the lineaments due to the joint sets. Higher clay seam density would necessitate a greater amount of processing to maintain product quality. Instead, hills between lineaments are recommended as better quality DG targets.

Trenching should also be completed perpendicular to the lineaments in order to evaluate if there is actually a relationship between the joint sets and clay seams. If there is a connection, trenching would also help evaluate how far clay seams are present from the joint sets based on aerial extent.

Based on the information currently known about the study area, a small scale operation is recommended. However, additional subsurface samples are necessary to develop a mine plan for either a larger mining operation or one that would extend beyond the area where wireline core samples were collected. Ideally, samples should be collected using trenching methods since this is similar to practices used for mining the rippable DG. Therefore, testing results will more accurately reflect the material without additional breakdown due to vibrations or fluids used in drilling. Since this will only provide samples from the uppermost 15 feet, rippable DG below this depth would not be sampled. Since near-surface material is generally more susceptible to weathering, these samples would be more of a worst-case scenario for the entire area, excluding areas with clay seams.

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