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CALIFORNIA GEOLOGICAL SURVEY

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Date: August 17, 2011

Subject: MacKerricher State Park – Sand Grain Size and Mineral Composition Analyses, Ten Mile Dunes Road Removal and Dune Rehabilitation Project

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The California Geological Survey (CGS) has assisted California State Parks (CSP) with the geologic review and implementation of numerous restoration and rehabilitation projects within Mendocino County and other parts of the state. This report presents the findings of sand grain size and mineral composition analyses associated with the planned removal of the road and culverts within the Inglenook Fen-Ten Mile Dunes Natural Preserve of MacKerricher State Park. The mineral composition of the samples was analyzed using the electron microprobe at the University of California, Davis (UCD) Department of Geology (Roeske, 2011).

GEOLOGIC SETTING

The road and culverts to be removed within MacKerricher State Park are located within an active sequence of beach and dune sands that follow a series of marine terraces just south of the Ten Mile River (Figure 1). The dunes within the project area form three main lobes that extend south from the mouth of the river for approximately 4 miles, where they gradually become more stabilized. The dunes upon which the road was built rest on a terrace surface that slopes almost to sea level (Cooper, 1967; Barry and Schlinger, 1977; Griggs and others, 2005; Wollenberg, 2004). The dunes ascend a gentle slope directly from the beach. Emergent rocks from the surf zone indicate the original terrace surface was slightly above sea level at this location (Cooper, 1967; Kelley, 1983). Low cliffs, comprised of marine terrace deposits and underlying Franciscan sandstone bedrock, are present both north and south of the project area. Traces of the active San Andreas Fault Zone lie roughly parallel to the coast both onshore and within 0.5 to 1 mile offshore (CGS, 2010, Jennings, 1994).

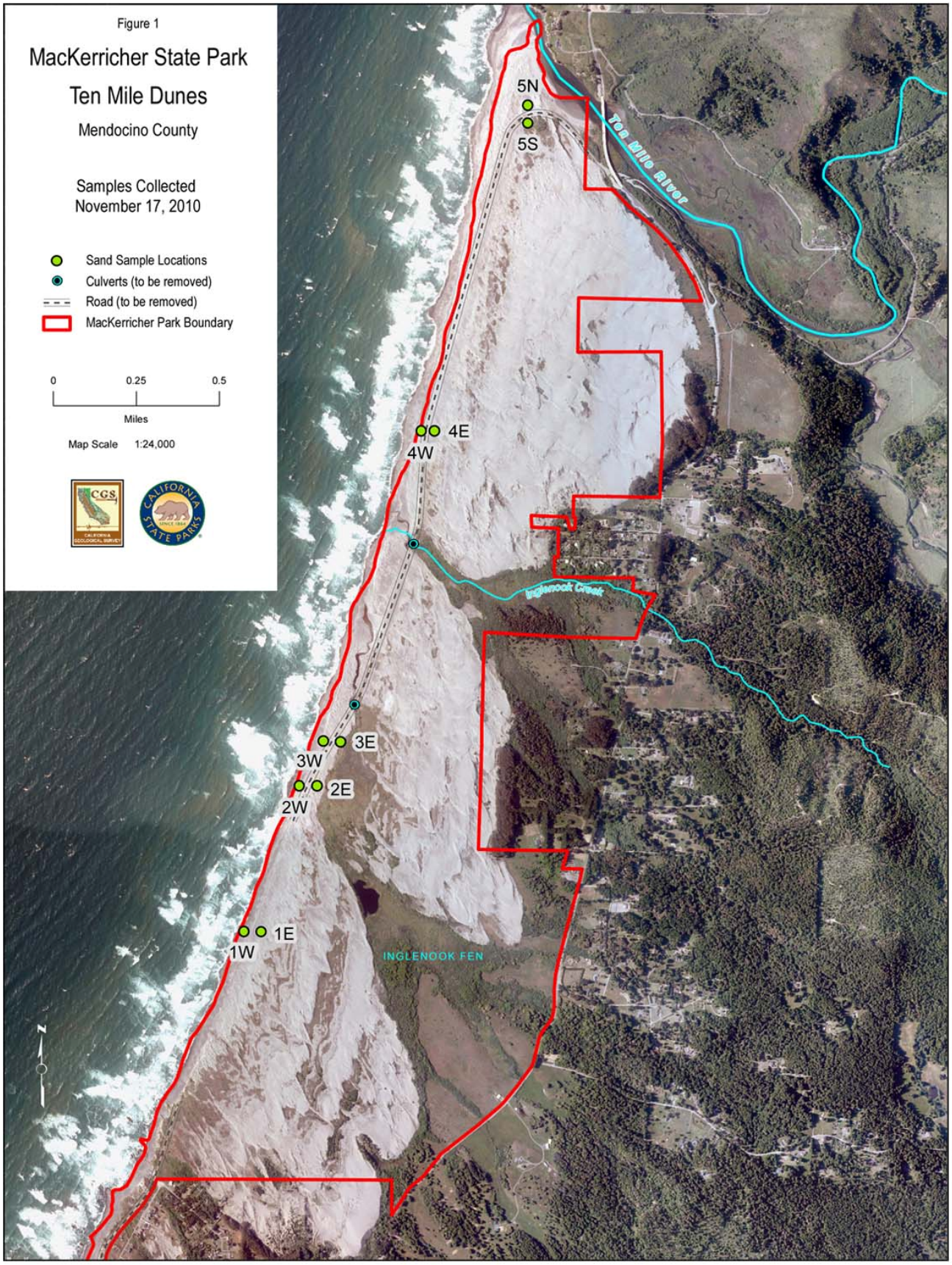


Figure 1
MacKerricher State Park
Ten Mile Dunes
Mendocino County
Samples Collected
November 17, 2010
Sand Sample Locations
Culverts (to be removed)
Road (to be removed)
MacKerricher Park Boundary
0
0.25
0.5
Miles
Map Scale 1:24,000
5N
5S
Ten Mile River
4E
4W
Inglenook Creek
3E
3W
2E
2W
1E
1W
INGLENOOK FEN
N

PURPOSE OF STUDY

The purpose of the sand analyses was: (1) to assess relative percentages of various sand grain sizes within 10 representative samples collected by CGS at different locations along the road to be removed (Figure 1); and (2) to identify the relative percent of mineral types in the10 samples. Findings of the sand sample analyses were used: (1) to compare gross similarities and differences in surface sand grain sizes as they relate to location, surface disturbance, dune type, wind direction and vegetation density along portions of the road to be removed; and (2) in conjunction with aerial photo interpretation, to identify general sand movement patterns and expected locations of future sand deposition following road removal.

SUMMARY OF FINDINGS

Sand Grain Size Analyses

- Between 61 and 99% of the grains within the samples collected were fine grained sand; i.e., between 0.125 and 0.425 millimeters (mm) in size.
- Sand samples collected in the northernmost lobe of the dunes had a larger component of fine sand, very fine sand, and silt/clay than those to the south.
- The northernmost sand samples also contained the highest percentages of coarse size particles (greater than 2 mm in size).
- Sand samples from the southern two lobes contained a greater medium sand grain fraction (between 0.425 and 2 mm) ranging between 16 and 38%.
- Samples collected from areas occupying a lower topographic position along the road had a greater medium size sand fraction than those collected at a higher elevation near the same location.

Mineral Composition Analyses

- Quartz, feldspar, and lithic (rock) fragments composed of quartz and feldspar comprised between 65 and 82% of the sand samples.
- Lithic (rock) fragments of granitoid, silicic, clastic (mudstone and sandstone), and schistose origin comprised between 43 and 62% of the samples.
- Calcite fragments, which comprised between 1 and 7% of the samples, were mostly shell material.
- Heavy minerals (i.e., minerals with higher densities than quartz and feldspar) such as epidote, amphibole, chlorite, zircon, iron and iron-titanium (Fe and Fe-Ti) oxide, and garnet comprised between 1 and 5% of most of the samples.

SAMPLE COLLECTION

A total of ten (10) representative sand samples were collected along the road and in the vicinity of the culverts to be removed (Figure 1). The samples were collected between 20 and 60 feet on each side of the road (west=W and east=E or north=N and south=S) to determine if there were any significant changes in grain size and mineral composition as sand is blown inland and/or as a result of topographical differences. All samples were collected between 12:25 p.m. and 4:30 p.m. on November 17, 2010. During this time, sustained wind speeds measured at Fort Bragg City Hall (Mendocino County, 2011) were from the northwest (271º- 311º) and ranged between 2.7 and 7.3 miles per hour (mph).

The 10 samples were collected using hand-driven 6-inch long, 2.5-inch diameter, thin-walled brass tubes, typically used in a Modified California Split Barrel Sampler. The open-ended tube ends were sealed with removable plastic caps. Upon returning to the office, sand samples were transferred to plastic bags.

While the top 6 inches of sand were sampled at all 10 locations, the sample sizes varied in weight due to the loosely consolidated nature of the sand, moisture content, and an organic and/or small shell component in some samples. In most sample areas, some degree of moisture was encountered 3 to 6 inches below the surface.

SAND GRAIN SIZE ANALYSES

Sieve Analyses: To be consistent with sand analyses previously conducted for CSP at Oceano Dunes (CGS, 2007, 2011a, and 2011b), CGS performed sieve analyses on the 10 samples per ASTM Standard D421-85 for dry preparation of soil samples for particle-size analysis. Samples collected from the dunes were removed from the plastic bags, placed under an AirFiltronix, Inc. containment hood in the CGS laboratory, and dried at room temperature for at least 24 hours until thoroughly dried.

Samples were sieved at the UCD Department of Geology laboratory, using the UCD shaker and CGS sieves. Where present, large organic material was removed prior to shaking. The loosely consolidated nature of the sand precluded the need for further break-up of aggregated materials. Each sample was then weighed using an OHAUS Triple Beam Balance, taking into consideration the tare. Next, each sample was placed into four stacked ASTM E-11 Specification, wire mesh USA Standard Testing Sieves and a receiver, with the following dimensions:

Table 1: USA Standard Sieve Size and Equivalent Size Conversions

Sieve Size	mm opening	inches
No. 10	2.000	0.0787
No. 40	0.425	0.0165
No. 100	0.150	0.0059
No. 200	0.075	0.0029

After securing the test sieve lid, the sieves were clamped onto an electric shaker and shaken for 5-10 minutes. Sand remaining on each sieve and in the receiver was weighed and the percent weight computed into five general categories:

Coarse: Sands remaining on the No. 10 sieve, greater than 2 mm
Medium: Sands remaining on the No. 40 sieve, less than 2 mm but greater than 0.425 mm
Fine: Sands remaining on the No. 100 sieve, less than 0.425 mm but greater than 0.125 mm
Very Fine: Sands remaining on the No. 200 sieve, less than 0.125 mm but greater than 0.075 mm
Silt/Clay: Material remaining in the receiver, less than 0.075 mm

Results of Sieve Analyses: Results of the sieve grain size analysis are shown by percent (Table 2) and graphically by location (Figure 2). Between 61 and 99% of the grains within the samples collected are fine grained sand; i.e., between 0.125 and 0.425 millimeters (mm) in size. Less than 3% of the grains are very fine sand (between 0.075 and 0.125 mm) and/or silt/clay (less than 0.075 mm). Medium and coarse grains (greater than 0.425 mm) ranged between 0 and 38%.

In general, sand collected along the road in the northernmost lobe of the dunes has a larger fine sand component than to the south, where it appears to gradually coarsen. Samples 4W, 4E, 5N, and 5S have a fine sand, very fine sand, and silt/clay grain size fraction that ranges between 79 and 99%. The fine sand, very fine sand, and silt/clay fraction of samples collected along the road in the middle lobe of the dunes ranges between 61 and 83%, while the same fraction in samples collected along the road in the southern lobe ranges between 62 and 71%.

The northernmost samples also contain both the highest percentages of coarse size particles (greater than 2 mm in size) and the highest percentages of very fine (between 0.075 and 0.125 mm) and silt/clay (less than 0.075 mm) size particles. Samples collected from areas occupying a lower topographic position along the road, regardless of whether it is to the west or east, appear to have a slightly greater medium size sand fraction (between 0.425 and 2 mm) than those collected at a higher elevation at the same location.

TABLE 2: Percent Sieved Grain Size, CGS Sand Samples, Ten Mile Dunes

Sample #	+10 (Coarse)	10-40 (Medium)	40-100 (Fine)	100-200 (Very Fine)	-200 (Silt/Clay)
TMD-1W (low foredune)	0.2	37.0	62.6	0.1	0.1
TMD-1E (deflated)	Trace	28.8	71.1	0.1	0.1
TMD-2W (lower side)	0.1	36.3	63.5	0.1	Trace
TMD-2E (higher side)	0	16.6	83.1	0.2	0.1
TMD-3W (higher side)	0	30.3	69.4	0.2	0.1
TMD-3E (lower side)	0	38.1	61.6	0.2	0.1
TMD-4W (higher side)	0	5.5	94.2	0.2	0.1
TMD-4E (even with road)	3.7	16.5	78.4	0.8	0.6
TMD-5N (deflated)	7.9	2.3	86.9	1.9	1.0
TMD-5S (deflated)	0	0.8	98.7	0.4	0.1

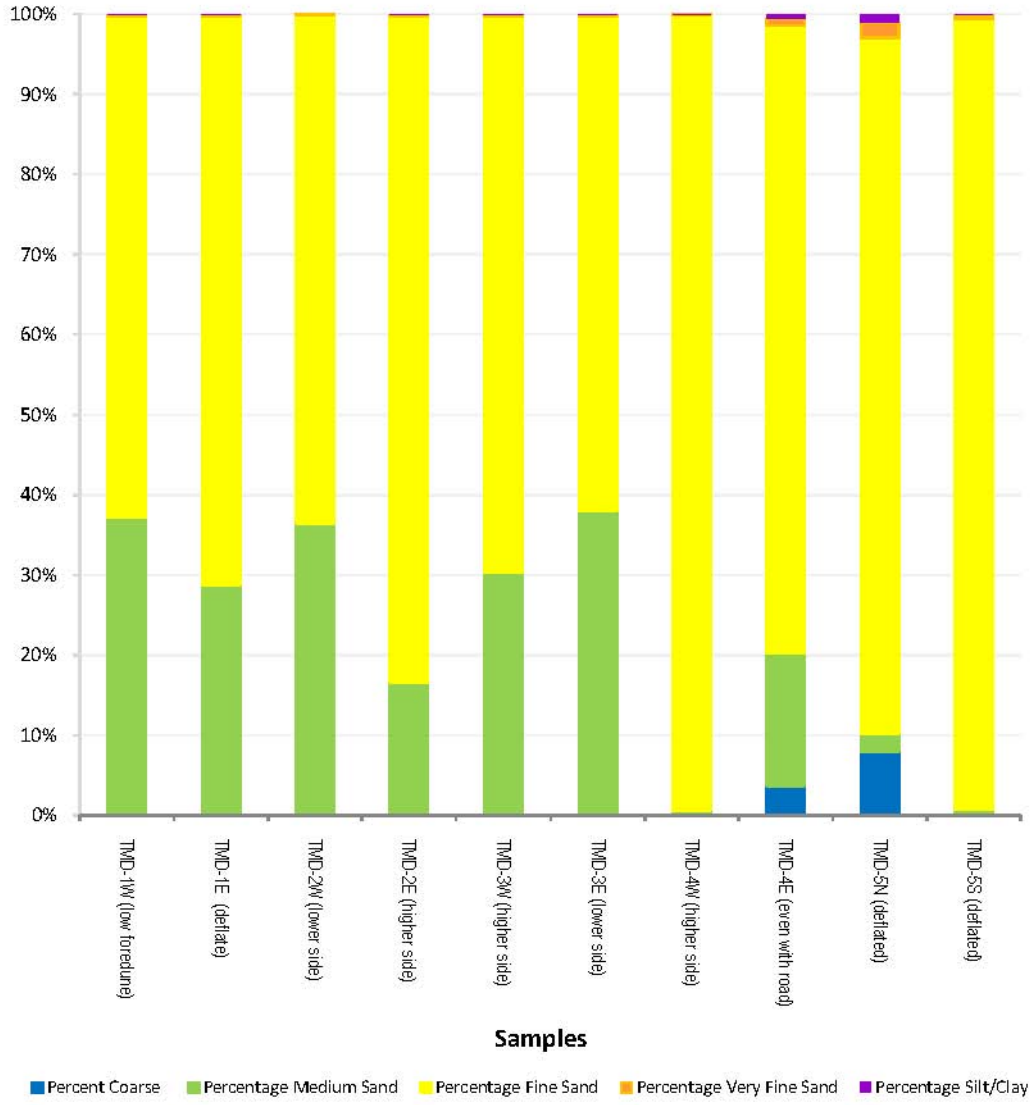


Figure 2: Percent Sieved Grain Size, CGS Sand Samples, Ten Mile Dunes

MINERAL COMPOSITION ANALYSES

Microprobe Analyses: The UCD Electron Microprobe Laboratory was used to conduct sand sample analyses using back scatter electron (BSE) imagery for percent (%) mineral composition. The BSE images show different phases of mineral development based on brightness (Figure 3). Mineral identification is done by comparing x-ray fluorescence energy-dispersive spectroscopy (EDS) from individual grains with known mineral phases (Appendix A). Unsieved sand from each of the 10 sand samples was placed on circular templates 2.5 centimeters across, using double-stick tape, to ensure all size fractions were exposed at the surface. The samples were then coated with an approximately 200 angstrom thick coating of carbon to make them conductive under the electron beam. Sample preparation was done by Greg Baxter, UCD Department of Geology Staff Research Assistant.

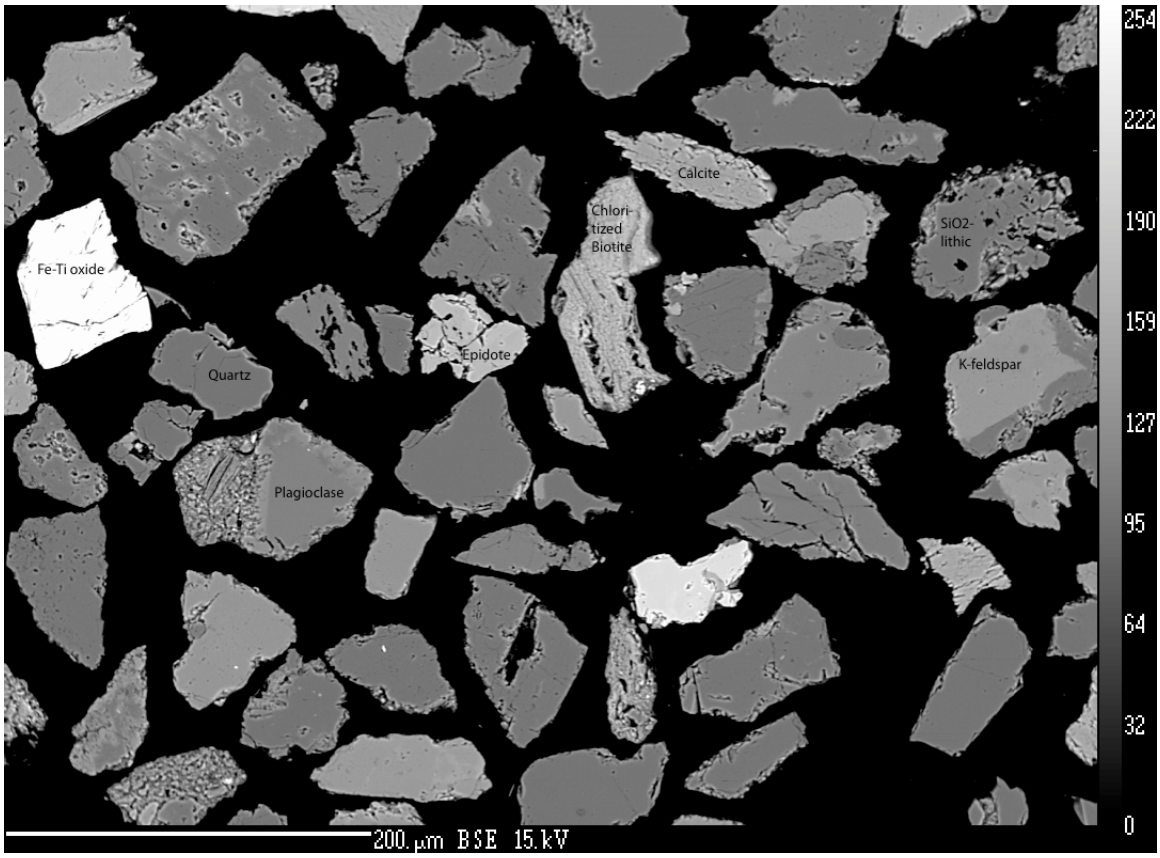


Figure 3. Example of an image used for point-counting grains. Mineral fragments have different gray scale intensities depending on total mass. Photo by S. Roeske.

Mineral Composition Identification: Mineral identification was done by Dr. Sarah M. Roeske, UCD Research Geologist and Electron Microprobe Lab Manager, using the 100 point count method (Figure 3). To obtain a statistical sampling of the mineral composition, all grains within 300 microns of a horizontal line were counted, noting composition, until 100 grains were counted. Mineral composition was determined by comparing EDS spectra from individual sand grains with known mineral phases (Appendices A, B, and C).

Results of Mineral Analyses: According to Roeske (2011, Appendix B), all of the samples are similar in mineral composition. Quartz, feldspar, and lithic (rock) fragments composed dominantly of quartz and feldspar comprised between 65 and 82% of the sand samples (Table 3, Appendix C). According to Roeske (2011, Appendix B), these minerals and lithic fragments are resistant to both physical and chemical weathering.

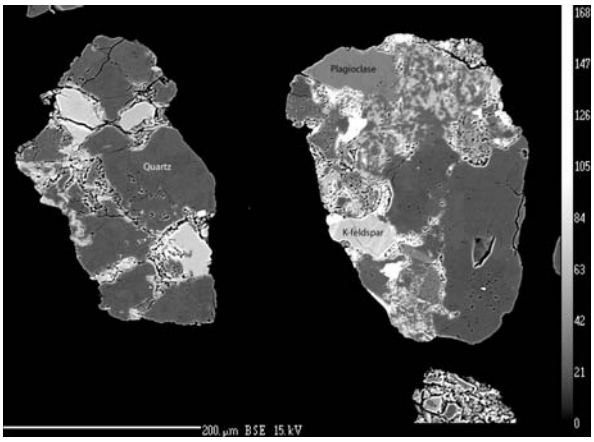
Lithic fragments comprised between 43 and 62% of the samples. These included granitoid, silicic, metabasite (volcanic), chert (silica-rich fine sediment), clastic (mudstone and sandstone), and schistose fragments (Figure 4, Appendix C). The granitoid and silicic fragments included particles of both intrusive (plutonic) and

extrusive (volcanic) origin (Roeske, 2011). Quartz and feldspar also dominated the clastic fragments, some of which were relatively coarse and angular.

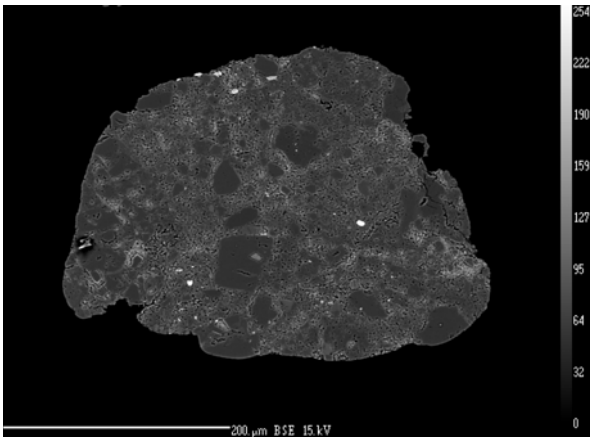
Calcite fragments, which comprised between 1 and 7% of the samples, were determined by Roeske to be, almost without exception, shell material based on their morphology. Most samples also contained between 1 and 5% heavy minerals (i.e., minerals with higher densities than quartz and feldspar) such as epidote, amphibole, chlorite, zircon, Fe and Fe-Ti oxide, and garnet.

TABLE 3: % Mineral Composition of Unsieved Sand Samples (from Roeske, 2011)

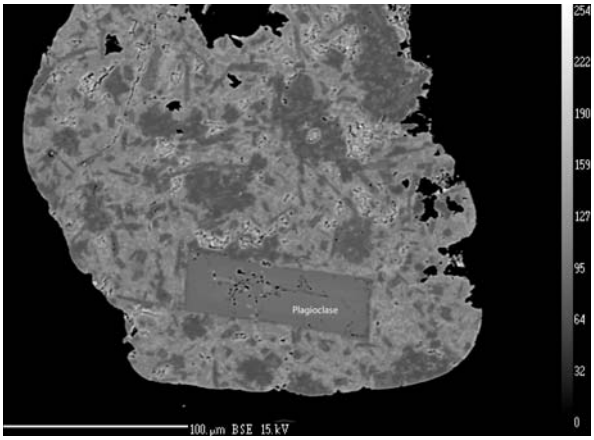
	Sample No.									
MINERAL	**1W**	**1E**	**2W**	**2E**	**3W**	**3E**	**4W**	**4E**	**5N**	**5S**
Quartz	24	30	32	35	26	27	22	25	30	25
Plagioclase (incl. albite)	10	15	13	11	12	10	6	9	5	15
Alkali feldspar	7	2	4	5	4	2	3	6	6	3
Lithic (granitoid or silicic)	36	33	29	31	24	29	34	30	29	36
Lithic (metabasite)	8	7	9	7	10	11	6	5	10	7
Lithic (chert, silicic)	8	5	3	1	2	6	7	4	1	1
Lithic (mud-sandstone)	2	2	4	4	13	12	15	15	8	11
Lithic (schist)	0	0	0	0	1	1	0	3	0	0
Calcite	4	2	4	1	5	1	7	2	6	1
Epidote	1	2	0	0	0	1	0	0	3	1
Amphibole	0	1	0	0	0	0	0	0	0	0
Chlorite	0	1	0	0	0	0	0	0	0	0
Fe- and Fe-Ti Oxide	0	0	1	1	2	0	0	0	1	0
Zircon	0	0	1	0	1	0	0	1	0	0
Garnet	0	0	0	4	0	0	0	0	1	0
Total	100	100	100	100	100	100	100	100	100	100
Composition Summary										
% quartz, feldspar, lithic silica fragments	77	80	78	82	66	68	65	70	70	79
% lithic fragments (all)	54	47	45	43	50	59	62	57	48	55



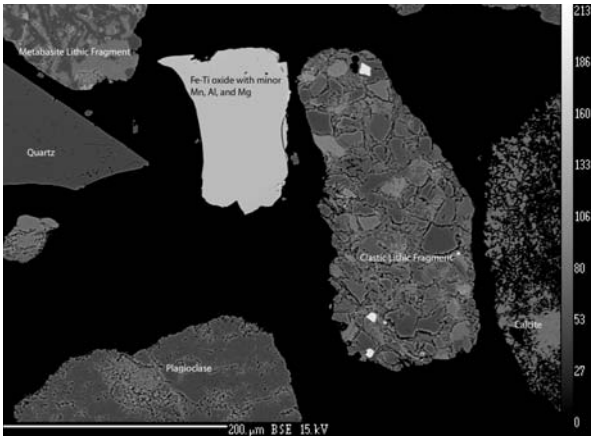
Sample 1W. Granitoid lithic fragments (silicic to intermediate composition).



Sample 1W. Mafic volcanic lithic fragment (metabasite lithic).



Sample 3W. Metabasite lithic.



Sample 5W. Clastic lithic fragment, metabasite lithic fragment, and grains composed of single minerals.

Figure 4. Examples of lithic (rock) fragments collected in sand from Ten Mile Dunes. Photos by S. Roeske.

DISCUSSION

The deposition of sand along the Ten Miles Dunes is largely a result of sand supply, shoreline topography, moisture content, wind currents, and sand grain size.

Sand Supply: Results of the microprobe analyses indicate all of the sand samples collected along the road within the Ten Mile Dunes are predominantly quartz, granitoid (igneous) or silica-rich lithic (rock) fragments, and feldspar. Quartz and feldspar also dominate the clastic (mudstone and fine sandstone) fragments, some of which were relatively coarse and angular. According to Roeske (2011), this suggests that some of the particles may have not been reworked extensively and may have been derived from nearby volcanic and/or plutonic sources (Roeske, 2011). However, the relatively low percentages of zircon and relatively high percentages of mudstones and other lithic fragments found within the sands also indicate the grains may have

been reworked from nearby marine terrace deposits and/or surrounding sandstones typical of Franciscan coastal belt rocks east of the dunes.

Recent studies have confirmed that high rates of sedimentation occur immediately north of the dunes at the mouth of the Ten Mile River (Griggs and others, 2005; Hapke and others, 2006; Matthews, 2000). Other sources of sediment are eroded soils and rock from the smaller drainages within the dunes, including Inglenook Creek and Fen Creek (Figure 1), as well as offshore sands carried in from the north and south during large storm events.

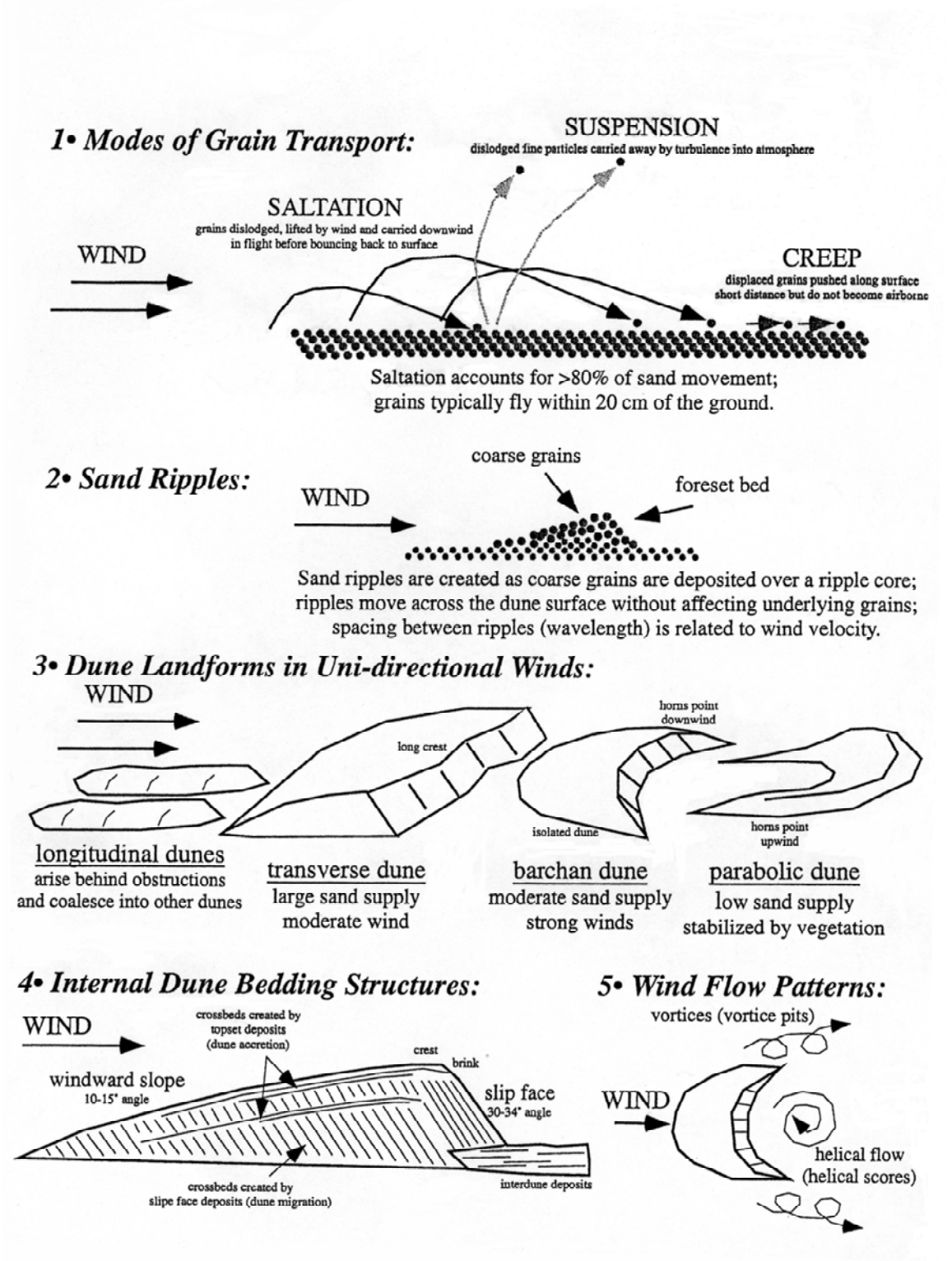
According to Hapke and others (2006), the average long-term (200 yr) and short-term (50 yr) rates of change (accretion and erosion) in the shoreline in this area have been much lower than in other areas along the coast. The average long-term rate of shoreline change in California was accretion at 0.2 m/yr; while the average short-term rate of change in California was erosion at -0.2 m/yr. In the vicinity of Ten Mile Dunes, the net shoreline change was accretion that averaged 0.1 m/yr; i.e., the average accretion rate was 0.6 m/yr, while the average erosion rate was -0.5 m/yr (measured at DeHaven Creek Beach, north of Westport). The long-term maximum accretion rate of 0.7 m/yr was measured along Ten Mile Beach just south of the Ten Mile River, while the short-term maximum accretion rate of 3.3 m/yr occurred just north of the mouth of the Ten Mile River. These numbers are likely related to the large volumes of sand discharged by the Ten Mile River and are consistent with the geomorphological findings of Wollenberg (2004), i.e., that more sand is accreting at the northernmost lobe of the Ten Mile Dunes than along the southernmost lobes.

Topography and Coastal Dune Formation: The shoreline near the mouth of the Ten Mile River shifts from its general northwest-southeast trend to a general northeast-southwest direction at the northern end of the Ten Mile Dunes (Figure 1). This change allows for the deposition of sand and, combined with the low gently sloping terraced terrain adjacent to the shoreline, provides a surface over which wind-propelled sand can move to form dunes (Barry and Schlinger, 1977; Cooper, 1976).

During the natural process of coastal dune formation (Figure 5), longitudinal-shaped foredunes will form perpendicular to the coastline, usually around small clumps of vegetation (Bagnold, 1941; Cooper, 1967; Gallant, 1997). The small dunes will collect more sand and continue to grow until some threshold size, dependent upon local physical conditions, is reached (Bagnold, 1941). The foredunes will grow in height as the vegetation expands.

East of the foredunes, a series of predominantly unvegetated transverse dunes will form nearly parallel to the coastline. The transverse dunes tend to migrate downwind (eastward) as sand is eroded from the windward (west) side of the dunes and deposited on the leeward (east) side. The transverse dunes may form several steep (60-62%), sometimes crescent-shaped (barchanoid), slip faces up to 100 feet or more in height. In general the windward side of the transverse dunes is less steep (generally 15-20%) than the leeward slip face. Smaller, more rapidly advancing dunes gradually encroach in an en echelon fashion onto the more gentle windward sides of the older dunes with higher slip faces, eventually adding height to the older dunes.

Figure 5. Dune Processes and Landforms. Excerpted from Parsons, 2002.



Moisture Content and Vegetation: As noted during sample collection, considerable moisture is found close below the surface of the Ten Mile Dunes. Bagnold (1941) attributes this subsurface moisture to periodic storms and the uniformity of temperature in the dunes below a depth of about 8 inches; i.e., because sand is a poor conductor of heat, most diurnal temperature changes are inappreciable at a depth of 8 inches below the surface. Therefore, as long as the saturated air between sand grains remains unchanged, appreciable quantities of water are not lost.

Moisture is also more common where vegetation is present. The depressed areas on the leeward side of the dunes are often moist and may be favorable places for vegetation. Both vegetated areas and those under which moisture is present consist of soft sand, whereas naturally barren areas are more firm underfoot.

In addition, deposits of windblown sand consist of thin stratified layers or laminae (Figure 5), a few millimeters thick, in which the grading varies slightly as result of the proportion of fine materials present (Bagnold, 1941). Coarser grains rise to the top while finer grains sink through material to the bottom of each depositional sequence. Firmness occurs when the relatively angular sand grains fit together. In some dune sands, this layering may be undetected or may collapse rapidly when disturbed. Studies by Bagnold (1941) showed that both vegetated and moist areas were built up of steeply encroaching laminae, while barren areas were underlain by accretion laminae that run nearly parallel to the surface (Figure 5). This is because, in the encroachment laminae, the water runs down the old shear planes of the laminae and almost immediately reaches a depth where subsequent evaporation is negligible. In contrast, in areas underlain by accretion laminae, water runs rapidly sideways along the surface layers that contain fine material, and is prevented from sinking downward by the relatively non-conducting layers from which finer sand material is absent. The moisture in these deposits remains close to the surface and soon evaporates.

Wind Speed and Sand Movement: Within the Ten Mile Dunes project area, the three lobes of transverse dunes have formed perpendicular to the coastline. This indicates that sand within the dunes moves in the direction of the prevailing winds, which are generally from the north-northwest during the summer and from south-southeast during winter (Barry and Schlinger, 1977; Cooper, 1967; Mendocino County, 2011; Wallenberg, 2004). However, irregular sand ripple patterns along the tops of the dunes and at the bottoms of the steep advancing slip faces represent localized pockets of changing wind velocities, wind eddies, and wind reversals.

Records collected from Fort Bragg between July 2009 and July 2011 (Mendocino County, 2011) indicate there were several periods between March and early June of 2010 where winds blew from the north-northwest for 8 to 12 consecutive days, and for up to 54 hours, with gusts of more than 10 mph. Wind speeds of 16.3 and 19.1 mph were recorded on April 2 and April 30, respectively. Two periods of 8 or more days of wind with gusts over 10 mph occurred in early November of 2009 and 2010, from both the northwest and southeast. Winds of over 10 mph and up to 20.5 mph also occurred from north-northwest for a duration of 45 hours between April 1 and 3, 2011. The highest wind speeds recorded were 25.6 mph on April 21, 2010 from the north-northwest and 25.6 mph on December 17, 2010 from the south-southeast.

Bagnold (1941) determined that the wind speed needed to start grains moving depends upon the size of the sand grains. He found that a minimum wind speed of 10 mph is needed to move very fine grained desert sands between 0.08 and 0.150 mm in size (Bagnold, 1941; Welland, 2009). This sand grain size range is finer than the predominant grain size at Ten Mile Dunes, which is between 0.125 and 0.425 mm in size. Additional field studies by Bagnold predicted a grain of sand 0.4 mm should require an initial wind speed of 31 mph to be lifted from the ground. Based on these findings, threshold wind speeds in the Ten Mile Dunes are expected to be between 10 and 20 mph. Actual variations in threshold wind speed as related to grain size would need to be verified. Although threshold velocity of natural sediment cannot be represented by a single value (Nickling, 1988), erosion thresholds observed in both natural and wind tunnel experiments were found to be higher on rough surfaces than on smooth surfaces (Musick and Gillete, 1990; Gillette and others, 1982); i.e., sand will move more slowly over rougher surfaces.

Sand Grain Size and Sand Movement: Sand grain size analyses within Ten Mile Dunes indicate between 61 and 99% of the grains within the samples collected are fine grained sand between 0.125 and 0.425 mm in size (Table 2 and Figure 2). In general, sand collected along the road in the northernmost lobe of the dunes has a larger fine sand component than to the south, where it contains a greater percentage of medium size sand grains. The larger component of fine sand collected in samples from the northernmost lobe of dunes may be related to their proximity to the floodplain of Ten Mile River and/or to the northward sorting of finer sand materials over the less well-vegetated surfaces of the dunes at the northern end of the Ten Mile Dunes. The coarser, more bimodal nature of the samples collected in the southernmost lobes may also be related to the deflated, more well-vegetated areas in which they were collected and/or their proximity to the less well-sorted nature of sediments deposited at the mouths of Inglenook Creek and Fen Creek.

According to Bagnold (1941), most sand movement is by the process of saltation, where grains skip along the ground surface as they are dislodged, lifted by the wind, and carried downwind before bouncing back to the surface (Figure 5). Sand grains normally move only a short horizontal distance while in the air, generally on the order of a few inches to a few feet, and to a height of several inches to approximately 2 feet above the ground (Bagnold, 1941; Welland, 2009; Zheng, 2009). Although extremely strong winds can raise smaller sized sand particles higher than 6 feet, the wind will not keep sand particles suspended in the air for long periods of time such as it may do with silt-sized and smaller particles (Bagnold, 1941). As a result of continued bombardment of the surface, a slow forward creep of the surface grains takes place.

Studies by Bagnold (1941) indicate there will be more mass movement if the sand is composed of different grain sizes (poorly sorted) than if it is more uniform in size. Bagnold also showed that smaller, or shrinking dunes, will move more quickly than those with higher slip faces, or that are growing in size. This is likely to affect the rate of dune advancement. For example, more poorly sorted sands deposited on the beach, and within unvegetated, lower-lying dunes closest to the shoreline, will migrate more quickly downwind as sand is eroded from the windward side of the dunes and is deposited on the leeward side of the dunes (Bagnold, 1941; Welland, 2009; Zheng,

2009). As they move inland, sands in the smaller encroaching dunes travel up and over the higher slip faces, eventually adding height to the larger dunes and slowing them down. Sand movement along the slip face will also generally slow down where vegetation is present. Sand within the unimpeded portions of the encroaching dune will, however, continue to move faster, often forming longitudinal or lobate ridges that wrap around the vegetation (Figure 5). The side ridges commonly enclose small flat valleys, hollows, or dune swales.

Grain size is also responsible for dune shapes; i.e., transverse dunes are generally composed of well sorted fine sand while interdune and/or flat areas in the dunes tend to be more bimodal in size composition (White and Tsoar, 1998). In addition, studies of sand movement on inclined dunes surfaces show that, as wind speed increases with the height of the dune, sand grains left at the base of the slope are generally coarser than those near the dune crest (White and Tsoar, 1998). Seasonal variations in grain size distribution may also occur as a result of heating and cooling, which alter turbulence and control sand transport at each location on the surface of the dune.

General Observations: The presence of the road (including the Ten Mile Railroad) and culverts within the project area has prevented the natural formation of foredunes along Ten Mile Dunes for more than 100 years. As documented in detail by Maslach (2004) and Wollenberg (2004), sand has continued to build up along the majority of the west side of the road. This, in effect, has created one long transverse dune on the windward side of the road, and an equally long deflated area east of the road, except where disrupted by the drainages of Inglenook Creek and Fen Creek.

A review of aerial photographs taken between 1981 and 2010 (CDF, 1981; WAC, 1996 and 2000; USDA, 2010) indicates relatively minor changes have occurred in vegetation cover and drainage patterns along the road during the past 30 years. Vegetation appears to be more well-established farther inland within the northernmost dune lobe than it was in 1981. However, there appears to be less vegetation immediately adjacent to the road than in 1996, both in the northern and southern lobes of the dunes. This may be related to: (1) the accretion of sand and/or the recent removal of non-native vegetation on the west side of road in the northern lobe of the dunes, and (2) the partial removal of the road itself due to wave action in the two southernmost lobes, particularly during the 1998 El Nino storm events (Lewis, 1998). Minor changes in drainage patterns west of the road near the culvert outlets at Inglenook Creek and Fen Creek may be related to the over- topping of wood debris from storm-generated waves and high tides as documented by Wallenberg (2004).

The removal of the road and culverts will restore natural sand movement within the dunes. The removal of non-native vegetation will also continue to increase sand movement inland until new vegetation is re-established. Heavy seasonal storms will also continue to modify the coastal topography once the road and culverts are removed. High tides and large storm surges could result in localized erosion and modification of the beach and dunes, particularly any foredunes that develop. The re-establishment of natural hydrological conditions near the mouths of Inglenook Creek and Fen Creek is also likely to alter drainage patterns, both along the watercourses and within the wetlands of the adjacent dunes.

CONCLUSIONS

- Removal of the road and culverts, in conjunction with the removal of non-native vegetation on the windward side of the road, will eliminate the barriers to natural sand movement within the Ten Mile Dunes.

- Natural coastal dune formation processes are likely to be re-established, including the formation of foredunes perpendicular to the shoreline along the west side of the three main dune lobes.

- As a result of these natural processes, more sand is likely to blow inland (nearshore) over the short-term, especially in the northern lobe.

- The addition of sand will change the configuration of the dunes as they migrate to the east (i.e., additional transverse dunes could develop and/or grow in height farther inland), the nature of the vegetation, and the drainage patterns throughout the dunes.

Respecfully submitted:

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Attachments:

Appendix A. BSE and EDS Examples
Appendix B: UC Davis Microprobe Analyses Report
Appendix C: Comparison of Sand Samples

Cc: Syd Brown, California State Parks
Adam Hutchinson, California State Parks
Michael Huyette, California Geological Survey

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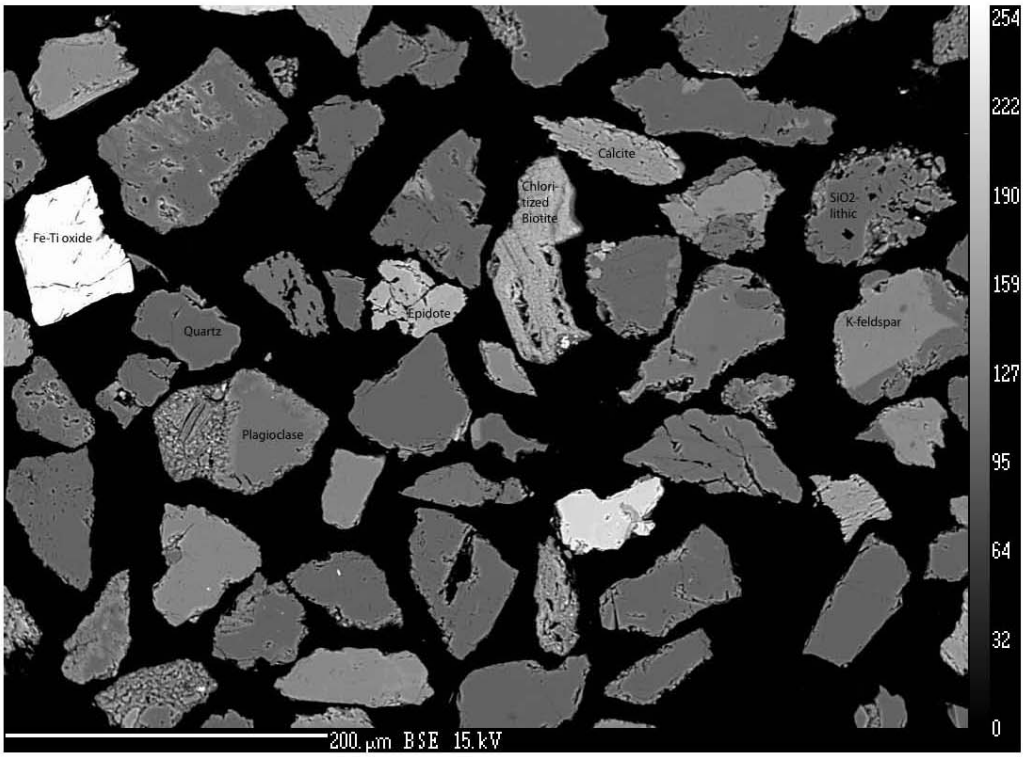
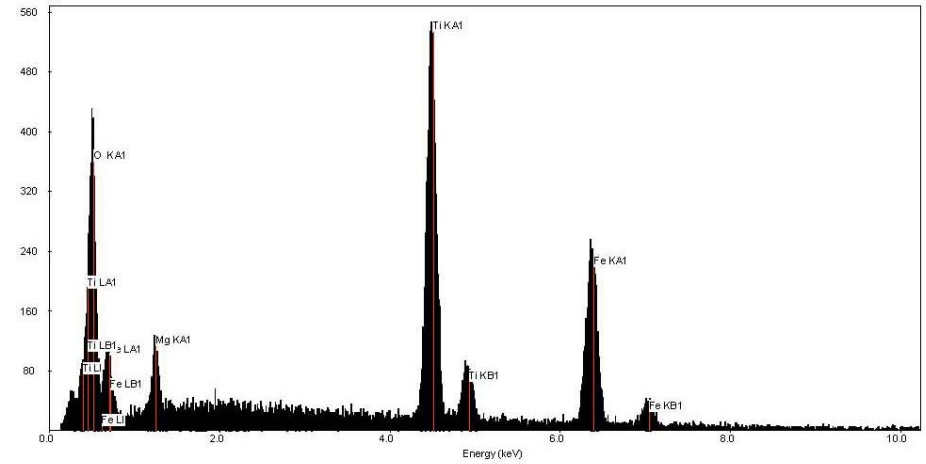
APPENDIX A: BSE AND EDS EXAMPLES

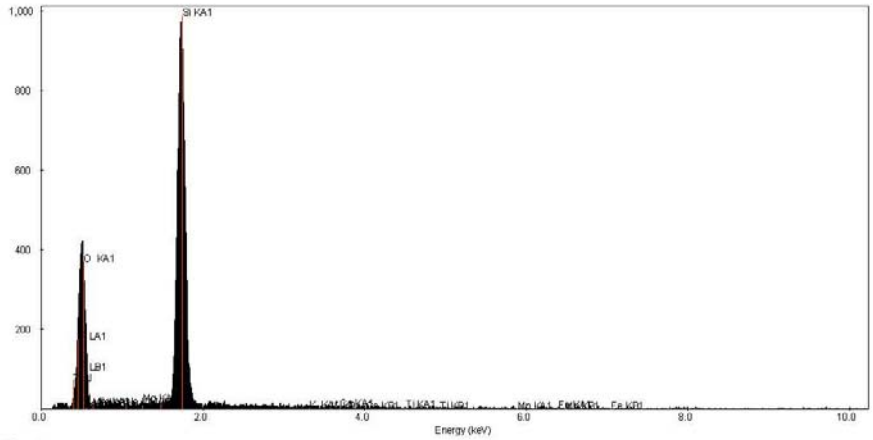


Example of an image used for point-counting grains in the less than 325 micron fraction. Mineral fragments have different gray scale intensity depending on their total mass.

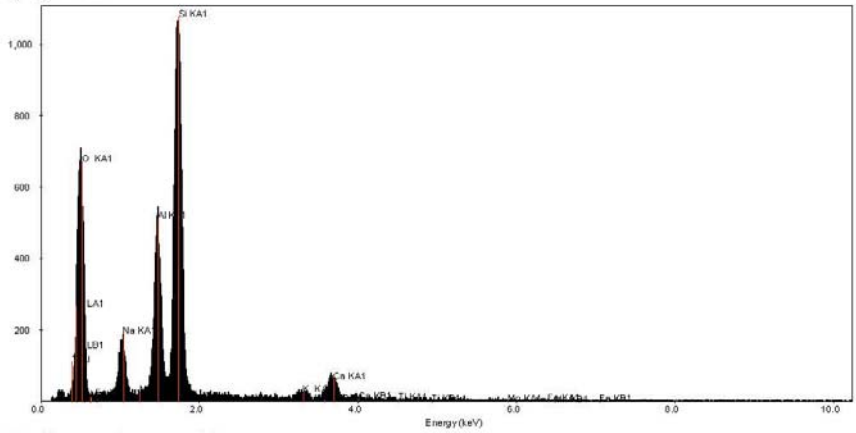
Below are EDS (energy-dispersive spectrometry files) generated from the above image.



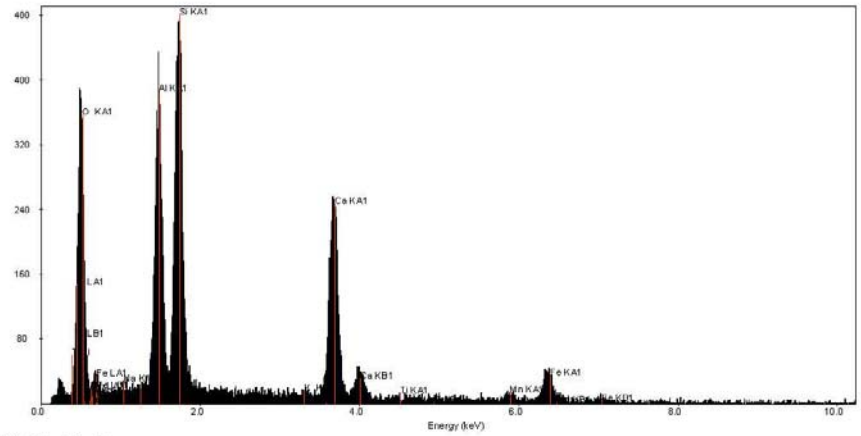
1) Fe-Ti oxide with some magnesium (typical of solid solution in the Fe-Ti oxides).



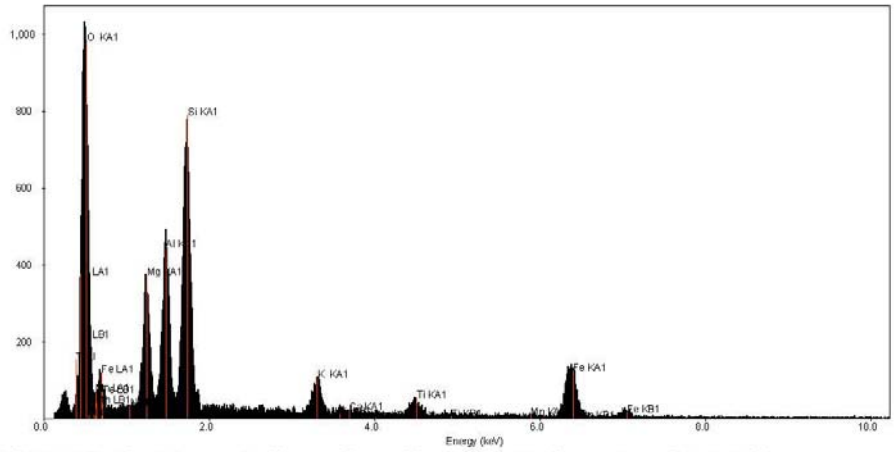
2) Quartz



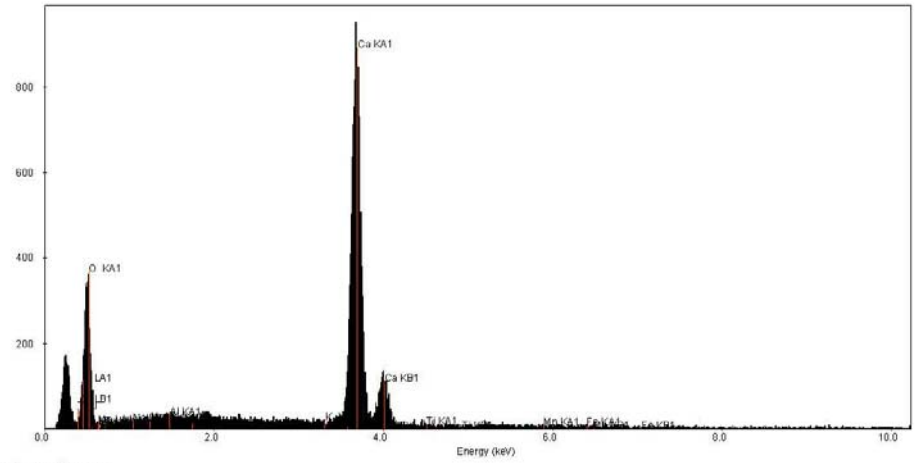
3) Plagioclase Feldspar



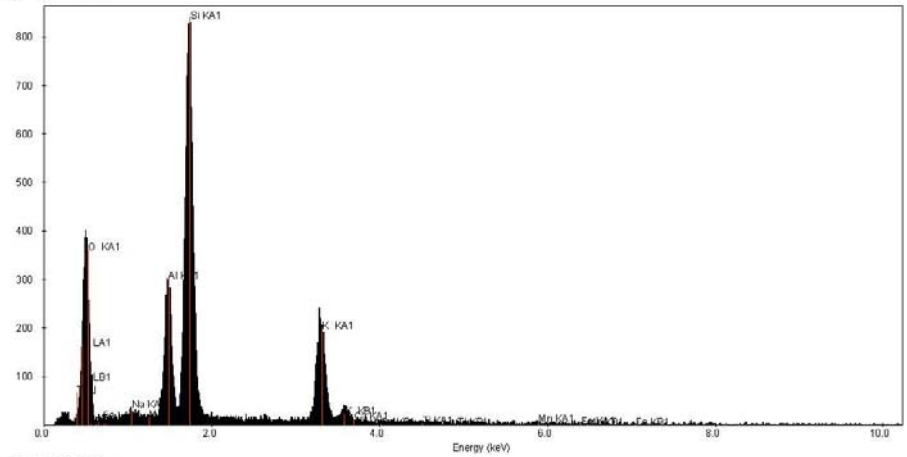
4) Epidote



5) Biotite that is partially replaced by chlorite (count as bioitite).



6) Calcite



7) K-feldspar

APPENDIX B: UCD MICROPROBE ANALYSES REPORT

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Mineral identification of sand samples from 10 Mile Dunes

Introduction and General Methods

This report summarizes observations and data from sand samples collected by Trinda Bedrossian, California Geological Survey. The goal of this report is to identify mineral compositions in the whole sand material collected from different sites. The electron microprobe is an ideal tool for such analyses because it has imaging, energy-dispersive, and wavelength dispersive capabilities. The latter two methods yield quantitative analyses of 1-micron size regions, which allow for identification of what minerals are present. The Geology Department at University of California, Davis has a Cameca SX-100 5-spectrometer electron microprobe. Images obtained from this machine can be made at a wide range of magnifications, resolving items as small as a few microns. The images presented here are back-scattered electron images (BSE). The density of a phase controls the brightness in a BSE image, such that denser phases (Fe-oxide, for instance) are bright. BSE images also show whether individual grains are composed of a single phase (uniform grey scale) vs. multiple phases (range of grey scales). The latter are described as lithic fragments in the data table.

Mineral identification is done by the operator comparing energy-dispersive spectra (EDS) from individual grains with known mineral phases. Analytical conditions for the energy-dispersive spectrometer were accelerating voltage of 15 Kev, 20 nampere beam current, and a beam size of 1 micron. The beam was on each point for ~ 5-10 seconds minimum, to allow for peak and background separation to become clear. In almost all cases the relative heights of the various elemental peaks, which indicates abundance of an element in the phase, allows for unique mineral identification.

Sample Preparation

All samples were prepared by Greg Baxter (Geology Department Staff Research Associate). He received the dried whole samples from Trinda Bedrossian and did not do any sieving or other methods of separation. He placed the grains on double-stick tape, to ensure that all size fractions would be exposed on the surface, in a circular template 2.5 cm across, then poured epoxy over them, allowed it to harden and polished them.

All samples were coated with an approximately 200 angstrom thick coating of carbon to make them conductive under the electron beam. This allows for imaging and quantitative analysis.

Point Count Methods

To obtain a statistical sampling of the composition, I moved the stage in a straight line such that the scanning image moved across the sample. I counted any grain that was within ~300 microns of this horizontal line, noting its composition, until 100 grains were counted.

The type of lithic fragment can be a slightly subjective decision, because rocks display a continuum of compositions and the categories used in this report are end members. For instance, the distinction between an intermediate and mafic (metabasite) composition igneous rock is not precisely defined. For the purposes of this point count I labeled lithic fragments as mafic if the fragment contained a substantial (~>20%) amount of Mg and Fe bearing phases and contained little or no quartz. Textural distinctions also display a continuum, such that the difference between a chert (SiO2-rich very fine grained sediment) and a mudstone is a qualitative assessment. For lithic fragments that display distinct rounded clasts within a finer matrix, I categorized the rock as clastic. For those that were uniformly very fine grained quartz, I categorized the rock as chert.

Images of the samples were taken at a constant scale (2 mm field of view) such that variation in average grain size can be seen easily. Some images were taken at closer view to emphasize the fine-grained textures visible in the back-scattered electron images.

Summary of Data

The samples are overall very similar in composition. Minerals and lithic fragments that are resistant to both physical and chemical weathering dominate them: quartz, feldspar, and rock fragments that are composed of dominantly these minerals. The silicic to intermediate composition igneous rock fragments include both intrusive (plutonic) and extrusive (volcanic) types. Quartz and feldspar grains also dominate the clastic sediment lithic fragments. Some of these clastic sediments are relatively coarse and angular, suggesting they have not been reworked extensively and were derived from proximal volcanic and/or plutonic sources.

The calcite fragments are almost without exception shell material, based on their morphology. Rare calcite that was angular may be derived from calcite veins.

All of the samples had only a few "heavy" (dense) minerals, which include epidote, amphibole, chlorite, zircon, Fe-Ti oxide, and garnet. The sample that contained 4% garnet stands out from the others and suggests some "lag" deposit was sampled here.

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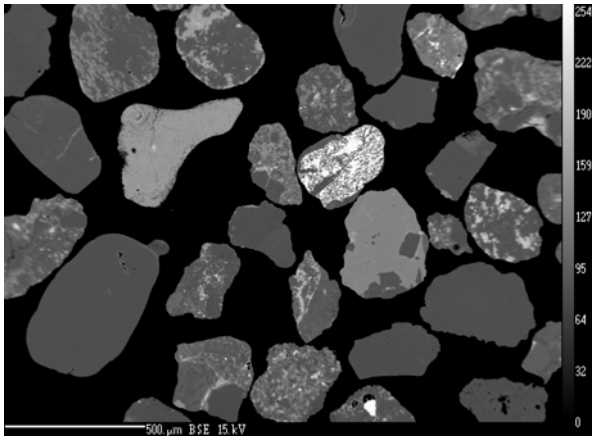
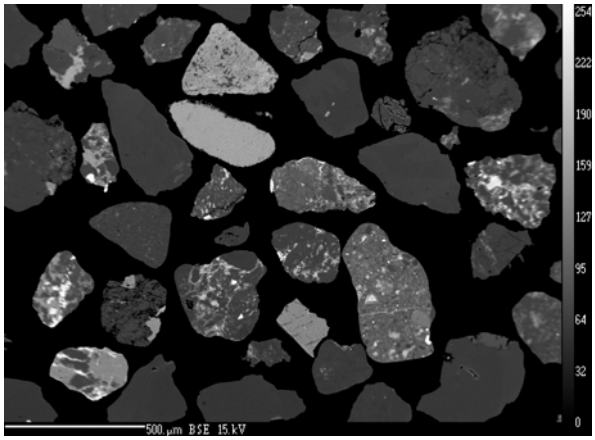
July 28, 2011

APPENDIX C: COMPARISON OF SAND SAMPLES

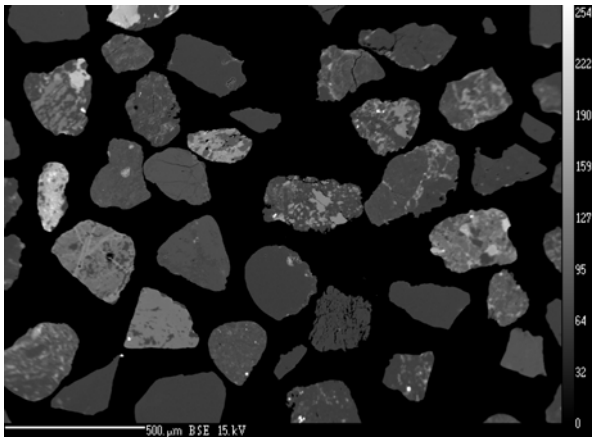
Mineral	Sample no. 1W	1E	2W	2E	3W	3E	4W	4E	5N	5S
Quartz	24	30	32	35	26	27	22	25	30	25
Plagioclase (includes albite)	10	15	13	11	12	10	6	9	5	15
Alkali feldspar	7	2	4	5	4	2	3	6	6	3
Lithic fragment (granitoid or silicic to intermediate volcanic)	36	33	29	31	24	29	34	30	29	36
Lithic fragment (metabasite)	8	7	9	7	10	11	6	5	10	7
Lithic fragment (chert or silicic sediment)	8	5	3	1	2	6	7	4	1	1
Lithic fragment (clastic sed - mudstone to sandstone)	2	2	4	4	13	12	15	15	8	11
Lithic fragment (schist)					1	1		3		
Calcite	4	2	4	1	5	1	7	2	6	1
Epidote	1	2				1			3	1
Amphitoble		1								
Chlorite		1								
Fe-oxide and Fe-Ti oxide			1	1	2				1	
Zircon			1		1			1		
Garnet				4					1	
Total	100	100	100	100	100	100	100	100	100	100
Summary of compositions:										
Percent quartz, feldspar, and lithic fragments from silicic to intermediate composition	77	80	78	82	66	68	65	70	70	79
Percent lithic fragments (all lithics)	54	47	45	43	50	59	62	57	48	55



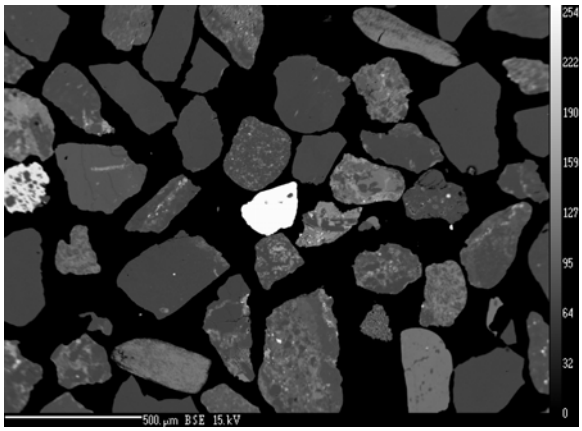
Sample 1W. 500 micron field of view.



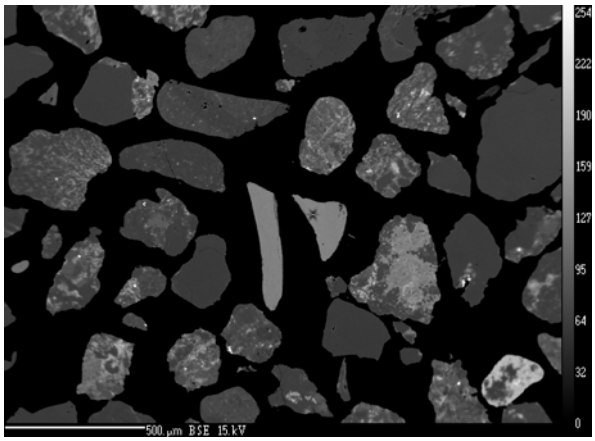
Sample 1E. 500 micron field of view.



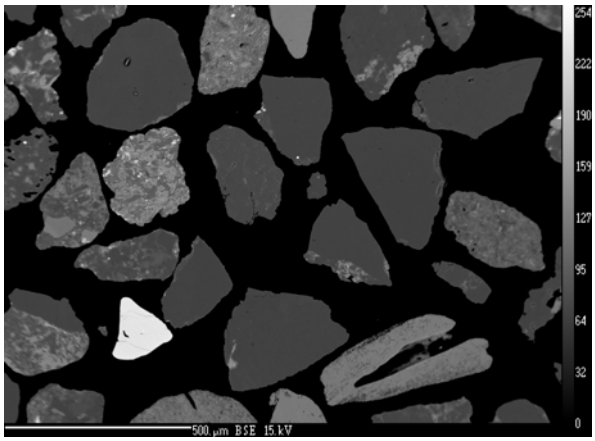
Sample 2W. 500 micron field of view.



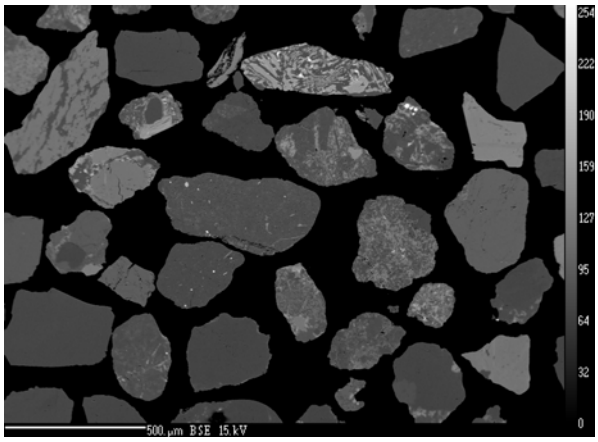
Sample 2E. 500 micron field of view.



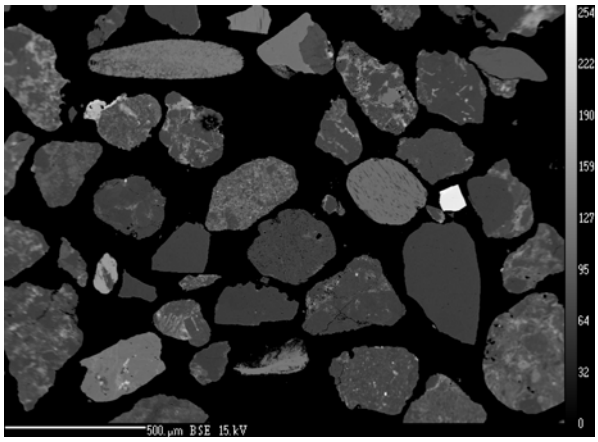
Sample 3W. 500 micron field of view.



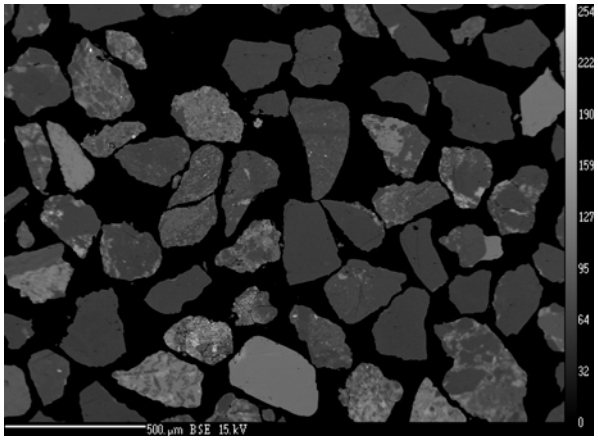
Sample 3E. 500 micron field of view.



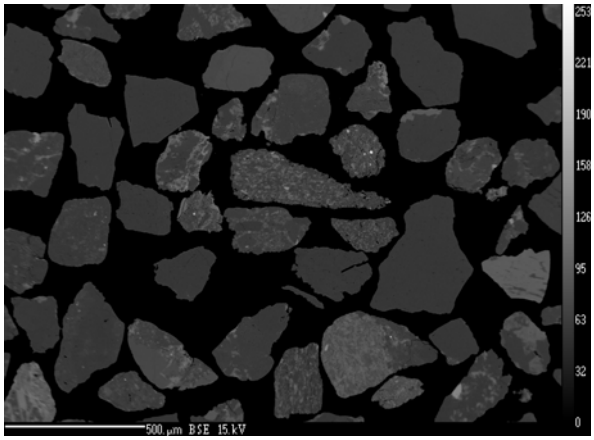
Sample 4W. 500 micron field of view.



Sample 4E. 500 micron field of view.



Sample 5N. 500 micron field of view.



Sample 5S. 500 micron field of view.