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Date: August 11, 2011

Subject: Oceano Dunes SVRA - Sand Grain Size Analyses, Part 2
Microprobe Analyses of Grain Size and Mineral Composition

Since 2007, the California Geological Survey (CGS) has assisted California State Parks (CSP) with the geologic review of various projects related to the Oceano Dunes State Vehicular Recreation Area (ODSVRA) and Pismo State Beach. This report presents findings of Part 2 of the ODSVRA Sand Grain Size Analyses, in which (1) the mineral composition of various grain size fractions in selected samples was examined, and (2) the percentages of particles less than (<) 10 microns and <2.5 microns were assessed. Samples were analyzed using the electron microprobe at the University of California, Davis (UCD) Geology Department (Roeske, 2011). Details of the study are summarized below and are included in the attached Appendices.

GEOLOGIC SETTING

ODSVRA and adjacent lands managed by CSP are located within an active sequence of beach and dune sands within the Callender Dune Sheet of the Santa Maria Valley Dune Complex (Cooper, 1967; Orme and Tchakerian, 1986; Hunt, 1993; CGS, 2007). The aeolian transport of sand is ongoing and the dunes are migrating inland. Sand supplied to the coastal dunes comes from the ocean flat and banks at low tide and from dry inland margins of the beach. Approximately 115,000 cubic yards of sand are blown inland each year along the 55 mile stretch of coastline from Pismo Beach to Point Arguello (Griggs and others, 2005; Hapke and others, 2006). During seasonal winds, a thin layer of fine particles also collects on the fences and vegetation of ODSVRA, both near the ocean and farther inland.

PURPOSE OF STUDY

Part 1 of the ODSVRA Sand Grain Analyses (CGS, 2011) showed the majority of soils within areas managed by CSP are loosely consolidated sand greater than (>) 75 microns in size. The sand contains less than (<) 1.1% silt/clay size particles (<50 microns in size) and <0.5**%** clay size particles (<2 microns in size).

The purpose of Part 2 of the study was to compare the mineral composition and fine grain size distribution of sand samples collected at 11 locations within and adjacent to ODSVRA (Figure 1). Representative unsieved (whole) sand samples and representative sieved sand samples with components <45 microns in size were assessed. In addition, very fine particles in two samples collected from the seasonal fences within ODSVRA were analyzed. The mineral composition of the various size fractions on the fences are also compared with those found in the fine grain components of the sieved sand samples collected from the beach and dunes.

The findings of both Part 1 and Part 2 of the study can be used in understanding potential sources of particulate matter, both within and outside of the areas managed by CSP, and in comparing mineral composition and percentages of particulate matter (PM10 and PM2.5) found on the Nipoma Mesa.

SUMMARY OF FINDINGS

Mineral Composition of Unsieved Sand Samples (Figure 1, Table 1)

- Quartz, plagioclase, and potassium feldspar (K-feldspar) comprised between 75 and 89% of the unsieved sand minerals. Sources for these minerals are typically granitic and metamorphic rocks.
- Silica from two different sources comprised between 34 and 50% of each sand sample. Between 34 and 50% of the grains were quartz; one sample indicated 1% of the grains were silica shell fragments.
- Heavy minerals (i.e., minerals with higher densities than quartz, plagioclase and K-feldspar) comprised between 1 and 14% of the sand. Heavy (dense) minerals such as amphibole, apatite, barite, biotite, chlorite, clinopyroxene, epidote, garnet, iron (Fe) oxide, titanite, and zircon were present.

Mineral Composition of Sieved Sand Grains <45 Microns (Figure 1,Tables 2 & 3)

- Individual grains <45 microns in size (silt and clay) comprised 0.1% or less by weight of each unsieved sand sample selected for analysis.
- Quartz, plagioclase, and K-feldspar comprised between 51 and 72% of the sieved sand grains <45 microns in size.
- Silica comprised between 24 and 33% of the sieved sand grains <45 microns in size. Of these, between 11 and 26% were quartz; between 5 and 15% were silica shell fragments.
- Heavy minerals comprised between 8 and 17% of the sieved sand grains <45 microns in size.

Mineral Composition of Sieved Sand Grains <10 Microns (Figure 1, Table 4)

- When examined within the 300 micron microprobe range of view, between 18 and 46% of the <45 micron size sieved sand grains were <10 microns in size.
- Between 20 and 40% of the <10 micron fraction were <2.5 microns in size.
- Quartz, plagioclase, and K-feldspar comprised between 49 and 67% of the <10 micron size sieved sand particles.
- Silica comprised between 17 and 39% of the <10 micron particles. Between 5 and 17% were quartz; between 7 and 22% were silica shell fragments.
- Heavy minerals comprised between 10 and 19% of the <10 micron fraction of the sieved sand particles.

Mineral Composition of Fine Particles on Fences (Figure 1, Table 5)

- Between 96 and 99% of the particles on the fences were <10 microns in size.
- Quartz, plagioclase, and K-feldspar comprised between 69 and 71% of the particles on the fences.
- Silica comprised between 28 and 36% of the particles. Between 27 and 29% were quartz; between 1 and 7% were silica shell fragments.
- Heavy minerals comprised between 12 and 19% of the particles.
- The two fence samples were texturally distinct. Sample 4F (closest to the ocean) is bimodal (characterized by two main size fractions) with an ultrafine (<1 micron) component that binds the coarser grains in the sample (Figure 4).
- Clumps of ultrafine (<1 micron) particles found in Sample 4F are absent in Sample 7F (inland fence). Although <1 micron particles are present, they are more uniformly dispersed and appear to be less abundant than in Sample 4F.
- The ultrafine (<1 micron) particles are dominantly silica and aluminum, indicative of clay materials.
- Analyses of sodium and chloride content indicate that sea salt is not the binding agent in the fine materials on the fences.
- No lead was found in either fence sample. A minor amount of zinc was present in both samples.

Comparison of Sand Samples with Fine Particles on Fences (Table 6)

- 0.1% or less of the particles found in sand samples collected from the beach and dunes were <45 microns in size (Table 2). In contrast, more than 96% of the particles found on the fences were <10 microns in size (Table 5, Figure 5).
- All samples were predominantly quartz, plagioclase, and K-feldspar.
- Fine particles from the fences showed higher percentages of quartz and lower percentages of silica shell fragments than the <45 micron and <10 micron fractions of the sieved sand samples.
- Fine particles from the inland fence were texturally better sorted than those from the fence closest to the ocean. Samples within the dune sand east of the fences are better sorted and more rounded than the beach sands to the west.
- There was minimal variation in fine grain size distribution within the sieved sand samples from the seasonal restricted area, the Dune Preserve, and the ride area. However, the highest percentages of particles <10 microns, as well as the highest percentage of clay minerals, found in the sieved sand were

located within the seasonal restricted area just east of the fence closest to the ocean and in the Dune Preserve.

SAMPLE COLLECTION

Eleven (11) sand samples were collected and sieved per standards described in Part 1(CGS, 2011). One sample was from Pismo Beach (PB-1), one was from the Dune Preserve (DP-2), and nine (S1-3 through S1-11) were from ODSVRA (Figure 1). The nine S1 samples represent both beach sands (S1-3 to S1-5) and dune sands (S-6 to S1-11) from the first rise and depression in the dunes closest to the ocean. Samples S1-3 to S1-7 were collected from an area closed seasonally for Plover habitat, while Samples S1-8 through S1-11 were from the OHV ride area (Figure 1).

All S1 samples were collected between 11:40 a.m. and 1:31 p.m. on September 9, 2010, along a NW - trending transect in the prevailing wind direction surrounding the CSP S1 Windtower. During the time of sample collection, sustained wind speeds measured at the S1 Windtower ranged between 10 and 18 mph, with gusts up to 20 mph or more (Sonoma Technologies, 2010).

In addition to the 11 sand samples, two samples of very fine grain particles (Samples 4F and 7F) were collected from the fences bounding the seasonal restricted area west of the S1Windtower (Figure 1).

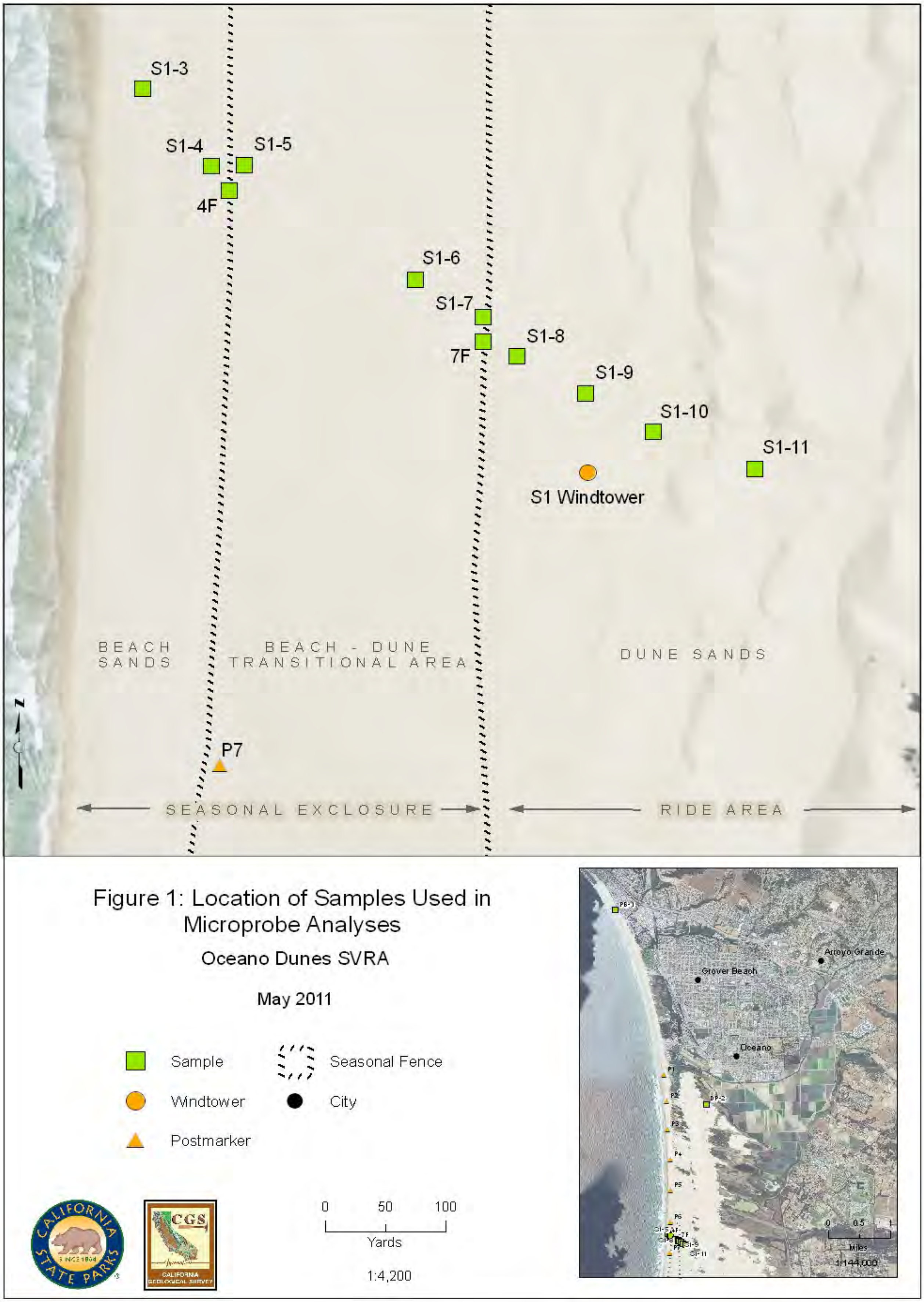


Figure 1: Location of Samples Used in Microprobe Analyses

Oceano Dunes SVRA

May 2011

MICROPROBE ANALYSES

The Cameca SX-100 5-spectrometer electron microprobe at the UCD Geology Department has imaging, energy-dispersive, and wave-length dispersive capabilities used for mineral identification (Roeske, 2011; Appendix A). Images from this machine can be made at a wide range of magnifications, including particles as small as a few microns. According to Roeske, the images used in the grain size distribution and mineral composition analyses of this report are primarily back-scattered electron (BSE) images, where the phase of mineral development controls the brightness, i.e., denser phases, such as iron oxide, are bright (Figure 2). BSE images also show whether individual grains are composed of a single phase (uniform grey scale) or multiple phases (range of grey scale) and allow observation of the morphology of different fractions of grain sizes generally too small to observe with a standard petrographic microscope. Mineral identification is done by comparing x-ray fluorescence energy-dispersive spectroscopy (EDS) from individual grains with known mineral phases (Appendix B). The percentage of each mineral and size fraction in a sample is determined using a statistical method of estimating the frequency of occurrence by counting the number of times the mineral occurs at specified intervals throughout the sample. Figure 2 provides an example of an image used for point counting grains in the <45 micron fraction of a sample.

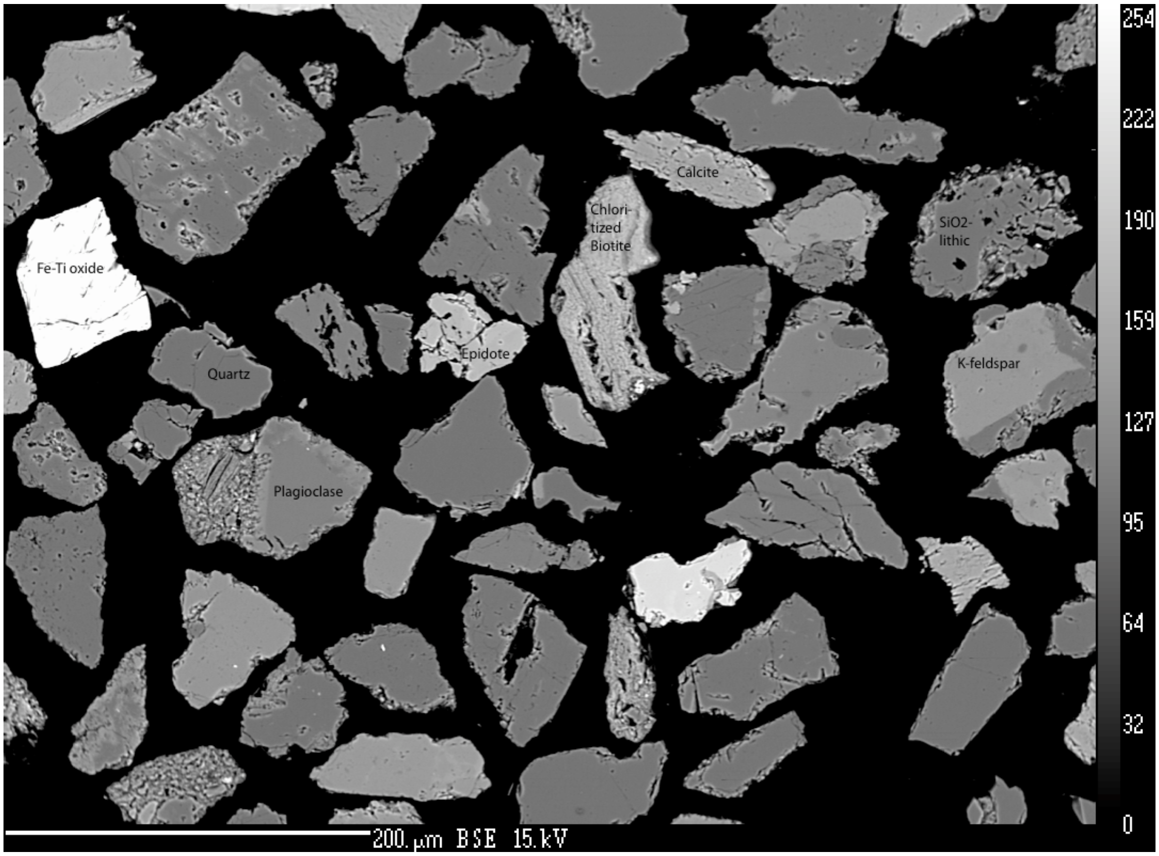


Figure 2. Example of an image used for point-counting grains. Mineral fragments have different gray scale intensities depending on total mass. Photo by S. Roeske.

MINERAL COMPOSITION OF UNSIEVED SAND SAMPLES

Eight representative unsieved sand samples were selected for mineral composition analyses (Table 1; Appendix C). The samples were collected from areas that were categorized as “undisturbed” (where no OHV riding is allowed) and “disturbed” (within the OHV ride area). Sample PB-1 represents beach sands in the tidal zone at Pismo Beach; Sample DP-2 represents “undisturbed” sands at the eastern edge of the Dune Preserve; Sample S1-3 represents beach sands in the “undisturbed” tidal zone west of the S1 Windtower; Sample S1-4 represents “undisturbed” beach sands at the western edge of the seasonal fence; Sample S1-6 represents “undisturbed” dune sands inside the seasonally fenced restricted area west of the S1 Windtower; Sample S1-7 represents dune sands at the eastern edge of the seasonal fence; Sample S1-9 represents “disturbed” dune sands in the OHV ride area just north of the S1 Windtower; and Sample S1-11 represents “disturbed” dune sands in the ride area within the depressed leeward side of the dune east of the S1 Windtower (Figure 1).

Microprobe Analyses of Eight Representative Unsieved Sand Samples

Sample Preparation: Sand from each of the eight unsieved sand samples was placed on circular templates 2.5 centimeters across, using double-stick tape, to ensure all size fractions were exposed on the surface. The samples were then coated with an approximately 200 angstrom thick coating of carbon to make them conductive under the electron beam. This allowed for imaging and quantitative analyses using the electron microprobe. Sample preparation was done by Greg Baxter, UCD Geology Department Staff Research Assistant.

Microprobe Analysis: Mineral identification was done by Dr. Sarah M. Roeske, UCD Research Geologist and Electron Microprobe Lab Manager, using the 100 point count method. To obtain a statistical sampling of the mineral composition, all grains within 20 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 (Appendix B).

Findings

Quartz, plagioclase, and K-feldspar comprised between 75 and 88% of the grains within all of the unsieved sand samples (Table 1; Appendix C). According to Roeske (2011), these minerals are common to granitic and metamorphic rocks. The total silica (quartz and silica shell fragments) in the samples ranged between 35 and 50%. In each sample examined, between 34 and 50% of the grains were quartz; only one sample (S1-9) had 1% silica shell fragments present. Heavy minerals such as biotite, chlorite, amphibole, clinopyroxene, Fe-oxide, apatite, zircon, epidote, titanite, and barite comprised between 1 and 14% of the sand. Sample S1-9, north of the S1 Windtower, had the highest percent of heavy minerals.

Table 1: % Mineral Composition of Representative Unsieved Sand Samples (from Roeske, 2011, Whole Samples)

MINERAL	Sample PB-1	Sample DP-2	Sample S1-3	Sample S1-4	Sample S1-6	Sample S1-7	Sample S1-9	Sample S1-11
Quartz	40	44	50	44	41	36	34	34
Plagioclase (incl. albite)	27	20	20	23	16	19	20	31
K-feldspar	21	21	18	22	29	34	21	17
Silica shell	0	0	0	0	0	0	1	0
Muscovite	0	1	0	0	0	0	2	1
Biotite	0	0	1	0	3	0	0	0
Chlorite	0	3	0	1	0	0	1	3
Lithic fragment (mudstone)	2	2	0	0	2	3	3	3
Carbonate (incl. calcite, dolomite)	2	1	0	2	1	0	2	1
Amphibole	0	0	0	0	0	0	0	0
Clinopyroxene	0	0	0	0	0	0	1	0
Fe-oxide, Fe-Ti oxide	0	1	5	1	2	0	4	2
Apatite	0	1	0	0	0	0	2	0
Zircon	0	0	0	0	0	0	2	1
Epidote	1	1	0	0	0	1	4	3
Lithic fragment (granitic)	7	3	5	6	6	7	3	3
Titanite (sphene)	0	2	1	0	0	0	0	0
Serpentine	0	0	0	1	0	0	0	1
Total	100	100	100	100	100	100	100	100
Composition Summary								
Granitic minerals	95	88	93	95	92	96	80	86
Silica (quartz and shell fragments)	40	44	50	44	41	36	35	34
Heavy minerals	1	8	7	2	5	1	14	9

MINERAL COMPOSITION OF SIEVED SAND GRAINS <45 MICRONS

All 11 sand samples were sieved per American Society for Testing and Materials (ASTM) Standard D421-85 for dry preparation of soil samples for particle size analysis (Table 2; CGS, 2011). Results of the sieving showed that, in all 11 samples, 0 to 0.1% of the particles were silt and clay <45 microns in size (Table 2).

Table 2: Sieved Sand Sample Results -% Sieve Grain Size (modified from CGS, 2011, Table B-1)

Sample # and Location	2000-425 Microns (Medium)	425-150 Microns (Fine)	150-75 Microns (Very Fine)	75-45 Microns (Silt/Clay)	-45 Microns (Silt/Clay)
PB-1 (Pismo Beach, wet zone)	1.1	75.3	23.6	Trace	Trace
DP-2 (Dune Preserve, S of Silver Spur)	0.2	84.4	15.0	0.3	0.1
S1-3 (wet zone, seasonal area, W of S1)	7.9	89.9	2.2	0	0
S1-4 (seasonal area, W side of fence)	19.5	79.1	1.4	Trace	Trace
S1-5 (seasonal area, W inside fence)	10.4	86.1	3.2	0.2	0.1
S1-6 (seasonal area, M, inside fence)	28.0	64.7	7.1	0.2	Trace
S1-7 (seasonal area, E, inside fence)	41.4	56.1	2.4	0.1	Trace
S1-8 (ride area, E of Plover fence)	21.9	76.1	1.8	0.1	0.1
S1-9 (ride area, W of S1)	3.7	92.1	3.9	0.2	0.1
S1-10 (ride area E of S1, top)	29.0	65.2	5.0	0.7	0.1
S1-11 (ride area E of S1, flat)	9.4	84.6	5.5	0.4	0.1

Silt and clay-sized particles <45 microns found in nine of the sieved sand samples were used in the microprobe analyses of mineral composition and grain size summarized below (Tables 3 and 4). No particles <75 microns in size were recovered from Sample S1-3. In addition, there were so few silt and clay particles <45 microns in Sample PB-1 that samples could not be recovered for analysis.

Microprobe Analyses of Grain Size Fraction <45 Microns

Sample Preparation: Soil samples with sieved silt and clay size fractions <45 microns are typically broken down using wet sedimentation methods, such as a hydrometer, to release the finest particles. However, according to Marticorena and Bergametti (1995), such estimations are not representative of the characteristics of the size distribution of the in-place soil particles. This is because very fine clayey particles are not usually present in natural soils as loose individual particles. Therefore, in loosely consolidated natural soil samples such as the beach and dune sands evaluated in this study, dry sieving of the natural soil samples is more suited to the evaluation of grain size distribution. For this reason, the <45 micron silt and clay dry sieved fraction from each sample was placed directly within a circular template 6 millimeters across and covered with epoxy. This was allowed to harden, to prevent electrical charge build-up on the surface of the sample, and was then ground and polished for microprobe analysis. The samples were then coated with an approximately 200 angstrom thick coating of carbon to make them conductive under the electron beam.

This allowed for imaging and quantitative analyses using the electron microprobe. Samples were prepared by Greg Baxter.

Microprobe Analysis: Mineral composition and grain size distribution of particles <45 microns and particles <10 microns were analyzed by Dr. Sarah M. Roeske, using the 100 point count method. To obtain a statistical sampling of the mineral composition of particles in the <45 micron samples, all grains within 20 microns of a horizontal line (traverse) were counted, noting mineralogy, until 100 grains were counted. Mineral composition was determined by comparing EDS spectra from individual sand grains with known mineral phases (Appendix B). In order to determine the mineral composition and percent of particles <10 microns in size, images of areas 300 microns across were taken (Appendix D). The number of grains <10 microns, and their composition, were counted and compared with the total number of grains within the image.

Findings

Mineral Composition: Quartz, plagioclase, and K-feldspar comprised between 51 and 72% of the sieved grains <45 microns in size (Table 3; Appendix C). Silica (quartz and silica shell fragments) comprised between 24 and 33% of the grains. Of these, between 11 and 26% were quartz and between 5 and 15% were silica shell fragments. Heavy minerals ranged between 8 and 17% of the grains. Quartz, plagioclase, and K-feldspar in the <10 micron size fraction ranged between 49 and 67% (Table 4; Appendix D). Silica (quartz and silica shell fragments) comprised between 17 and 39% of the <10 micron samples, of which between 5 and 17% were quartz and between 7 and 22% were silica shell fragments. Heavy minerals comprised to between 10 and 19% of the <10 micron particles.

Grain Size Distribution: Individual grains <45 microns in size comprised 0.1% or less of the unsieved sand samples selected for analysis (Table 2). When examined within a 300 micron microprobe range of view, the <45 microns in size particles that were <10 microns in size ranged between 19 and 46%. Particles <2.5 microns in size ranged between 5 and 19% (Table 3). In general, between 20 and 40% of each <10 micron fraction was comprised of grains <2.5 microns in size (Table 4).

Within the ODSVRA, sieved sand Samples S1-5 and S1-6, inside the seasonal fenced area east of the fence closest to the ocean, showed the highest percentages of particles <10 microns and <2.5 microns within the <45 micron size fraction (Table 3). Sieved sand Sample DP-2 within the Dune Preserve showed the next highest percentages of particles <10 microns and <2.5 microns within the <45 micron fraction (Table 3). All of these represent a small fraction of one percent of the unsieved whole sand samples taken at each location.

Table 3: % Mineral Composition of Grains <45 Microns within the <0.1% Sieved Sand Samples (from Roeske, 2011, 45 Micron Samples)

MINERAL	Sample DP-2	Sample S1-4	Sample S1-5	Sample S1-6	Sample S1-7	Sample S1-8	Sample S1-9	Sample S1-10	Sample S1-11
Quartz	22	19	23	11	16	20	22	26	12
Plagioclase (incl. albite)	25	28	28	27	34	27	26	30	34
K-feldspar	13	16	15	13	18	19	15	18	22
Silica shell	7	7	9	15	8	7	11	5	15
Muscovite	3	1	0	2	0	1	2	2	0
Biotite	1	10	4	3	1	3	3	1	1
Chlorite	5	2	6	6	1	3	4	1	2
Lithic fragment (mudstone)	11	6	4	16	7	5	4	7	6
Lithic fragment (granitic)	2	2	0	0	4	3	0	1	1
Clay	0	1	0	0	0	0	0	1	0
Carbonate (incl. calcite, dolomite)	9	3	4	2	3	7	6	2	2
Amphibole	0	1	3	1	1	1	2	0	0
Clinopyroxene	0	1	1	0	0	0	0	0	1
Fe-oxide, Fe-Ti oxide	1	3	2	2	4	2	2	4	3
Apatite	0	0	0	0	0	0	0	0	0
Zircon	0	0	0	0	0	0	2	0	0
Epidote	1	0	0	2	0	1	0	2	1
Titanite (sphene)	0	0	0	0	0	1	0	0	0
Serpentine	0	0	1	0	2	0	0	0	0
Garnet	0	0	0	0	1	0	0	0	0
Barite (BaSO4)	0	0	0	0	0	0	1	0	0
Total	100	100	100	100	100	100	100	100	100
Composition Summary									
Granitic minerals	62	65	66	51	72	69	63	75	69
Silica (quartz and shell fragments)	29	26	32	26	24	27	33	31	27
Heavy minerals	8	17	16	14	8	11	14	8	8
<45 Micron Size Distribution									
% of 45 micron fraction <10 microns	39	27	40	46	22	33	19	29	26
% of 45 micron fraction <2.5 microns	11	7	16	19	5	7	6	6	8

Table 4: % Mineral Composition of Grains <10 Microns within the <45 Micron Fraction of Sieved Sand Samples (from Roeske, 2011, 10 Micron)

MINERAL	Sample DP-2	Sample S1-4	Sample S1-5	Sample S1-6	Sample S1-7	Sample S1-8	Sample S1-9	Sample S1-10	Sample S1-11
Quartz	9	10	11	17	15	9	17	9	5
Plagioclase (incl. albite)	27	31	22	28	35	34	22	35	29
K-feldspar	13	18	9	7	12	20	9	23	15
Silica shell	15	16	20	7	15	17	22	8	20
Muscovite	3	5	1	6	2	3	1	3	3
Biotite	7	6	7	4	4	5	4	4	7
Chlorite	2	3	7	10	10	2	8	5	8
Lithic fragment (mudstone)	2	0	0	0	2	0	2	0	0
Lithic fragment (granitic)	0	0	0	0	0	0	0	0	0
Clay	6	5	4	12	0	1	1	1	1
Carbonate (incl. calcite, dolomite)	12	2	9	4	3	5	4	8	6
Amphibole	1	2	2	0	0	1	0	1	2
Clinopyroxene	0	0	0	0	0	0	1	0	0
Fe-oxide, Fe-Ti oxide	1	1	4	4	1	2	4	2	4
Apatite	1	0	3	0	0	0	1	0	0
Zircon	0	0	0	0	0	0	0	0	0
Epidote	0	1	1	0	0	0	1	1	0
Titanite (sphene)	1	0	0	1	1	1	2	0	0
Serpentine	0	0	0	0	0	0	1	0	0
Garnet	0	0	0	0	0	0	0	0	0
Barite (BaSO4)	0	0	0	0	0	0	0	0	0
Total	100	100	100	100	100	100	100	100	100
Composition Summary									
Granitic minerals	49	59	42	52	62	63	48	67	49
Silica (quartz and shell fragments)	24	26	31	24	30	26	39	17	25
Heavy minerals	13	13	24	19	16	10	18	12	19
<10 Micron Size Distribution									
% of 10 micron fraction <2.5 microns	28	26	46	41	22	20	34	34	31

MINERAL COMPOSITION OF FINE PARTICLES ON FENCES

During seasonal winds, very fine particles are deposited on the fences of ODSVRA, both near the ocean and farther inland (Figure 3). The fine materials are typically washed off the fences during heavy rains and are also absent from the fences during the summer dry season. Two samples of very fine grain particles were collected from the fences bounding the seasonal restricted area adjacent to the ocean and OHV ride area west of the S1 Windtower (Figure 1). Sample 4F was collected from a portion of the fence approximately 1.5 meters in height closest to the ocean in the vicinity of sieved sand Sample S1-4; Sample 7F was taken from a portion of the fence approximately 1.5 meters in height on the inland (east) side of the restricted area in the vicinity of sieved sand Sample S1-7.

Figure 3. Fine particles on fence surrounding the S1 Windtower. Photo by C. Dugan

Microprobe Analyses of Fine Particles on Fences

Sample Preparation: Two sets of fine particles from the two fence samples (4F and 7F) were placed on circular templates 2.5 centimeters across, using double-stick carbon tape, to ensure all size fractions were exposed on the surface. One set was left unpolished to allow examination of any binding agents contained in the samples; the second set was covered with epoxy, allowed to harden, and polished (Appendix E). The samples were then coated with an approximately 200 angstrom thick coating of carbon to make them conductive under the electron beam. This allowed for imaging and quantitative analyses using the electron microprobe. Samples were prepared by Greg Baxter.

Microprobe Analysis: Material from the fences was examined by Dr. Sarah M. Roeske, both before and after polishing (Appendix E). After the fine material was carbon-coated, it was scanned for sodium and chloride to determine if salt was present as a binding agent. The samples were also scanned for carbon, to determine if organic particles were present, and for lead. Because the majority of the fence particles were <10 microns in size, several images of areas 300 microns across were taken in order to determine the mineral composition and grain size distribution (Appendix E). The number of grains <10 microns, and their mineral composition, were counted and compared with the total number of grains within the image.

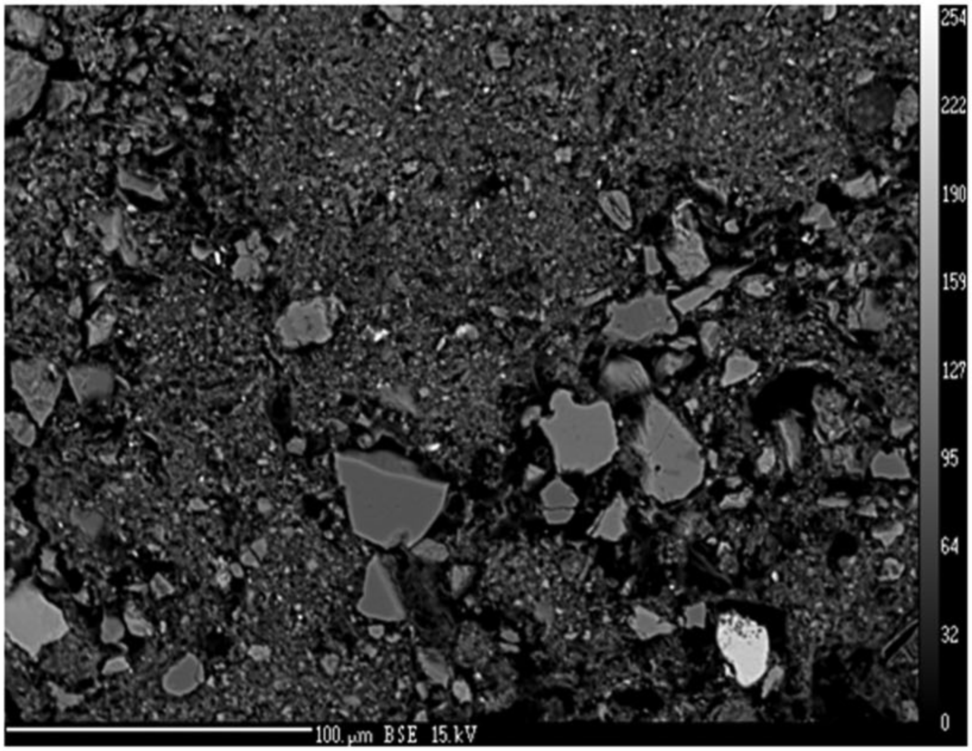
Findings

Mineral Composition: Quartz, plagioclase, and K-feldspar comprised between 69 and 71% of the particles sampled from the fences (Table 5). Silica comprised between 26 and 36% of the particles; between 27 and 29% were quartz and between 1 and 7% were silica shell fragments. Heavy minerals comprised between 12 and 19% of the particles. According to Roeske (2011), sodium and chloride x-ray mapping showed less than 1% in Sample 4F and 0.2% or less in Sample 7F, indicating that sea salt is not the binding agent in the fine materials on the fences. In addition, no lead was found in either sample. However, a minor amount of zinc was present, possibly from a zinc-based coating on the fences, or some other source.

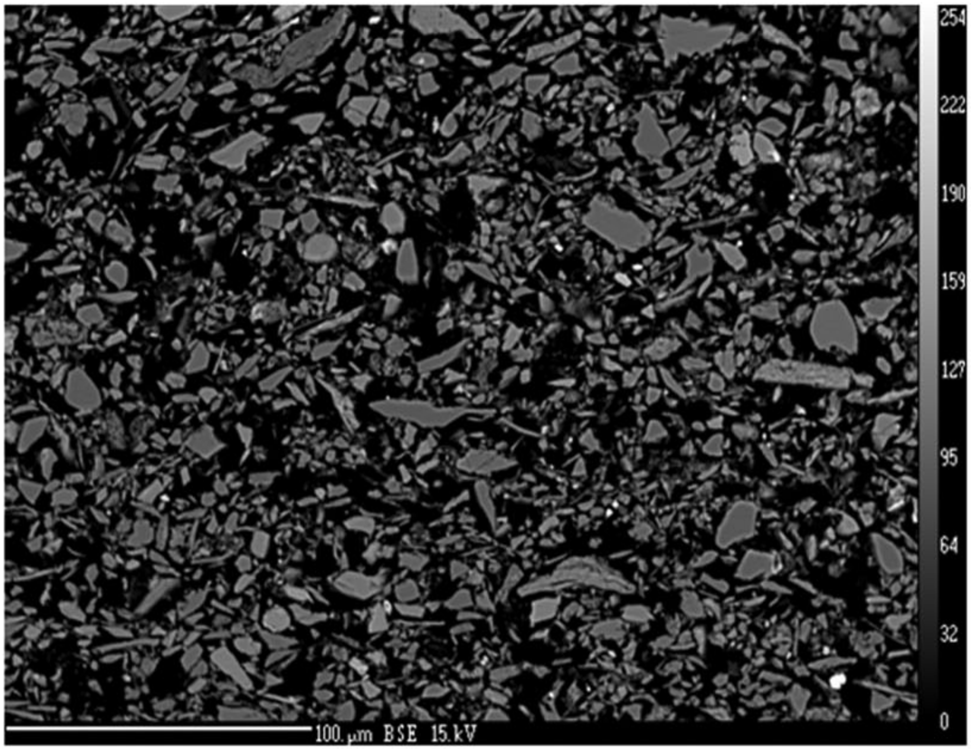
Textural Composition: Although the mineral composition of Samples 4F and 7F are similar, the two samples are texturally distinct (Figure 4, Appendix E). Sample 4F is bimodal (characterized by two main size fractions), i.e., it has an ultrafine (<1 micron) component that is flocculated (forms clumps) and binds the coarser grains in the sample. According to Roeske (2011), the ultrafine material in Sample 4F is uniform in composition and consists dominantly of silica and aluminum, which are indicative of clays of crustal origin. Lesser amounts of potassium, calcium, iron, magnesium, and zinc are also present. With the exception of zinc, all of these minerals are consistent with the elements present in the various sand grain sizes analyzed.

Table 5: % Mineral Composition of Fine Particles on Fence (from Roeske, 2011, Fines from Fence)

MINERAL	Sample 4F	Sample 7F
Quartz	29	27
Plagioclase (incl. albite)	18	18
K-feldspar	24	24
Silica shell	7	1
Muscovite	3	4
Biotite	3	4
Chlorite	1	4
Lithic fragment (mudstone)	0	4
Clay	2	2
Carbonate (incl. calcite, dolomite)	3	0
Amphibole	1	1
Clinopyroxene	0	0
Fe-oxide, Fe-Ti oxide	5	7
Apatite	1	2
Zircon	1	0
Epidote	0	1
Titanite (sphene)	0	0
Serpentine	1	1
FeS	1	0
Total	100	100
Composition Summary		
Granitic minerals	71	69
Silica (quartz and shell fragments)	36	28
Heavy minerals	12	19
<10 Micron Size Distribution Summary		
% of total fence sample <10 microns	96%	99%
% of 10 micron fraction <2.5 microns	53%	67%
% of total fence sample <2.5 microns	51%	66%



Sample 4F: West side of seasonal fence (closest to ocean).



Sample7F: East side of seasonal fence (inland).

Figure 4: Comparison of fine materials from fences, 300 micron field of view. Note the bimodal nature of Sample 4F in which ultrafine (<1 micron) materials bind the coarser grains. Sample 7F is better sorted and contains a higher proportion of <10 and <2.5 micron particles than Sample 4F. Photos by S. Roeske.

The clumps of ultrafine (<1 micron) particles found in Sample 4F are absent in Sample 7F. According to Roeske (2011), the fine particles from Sample 7F are texturally better sorted and more distinguishable as individual grains than those from Sample 4F (Figure 4). While the number of ultrafine grains (<1 micron) in Sample 4F appear to be greater than in Sample 7F, the total number of individual particles <10 microns and <2.5 microns was higher in Sample 7F (Table 5). Based on image analysis, Roeske (2011) was able to determine that approximately 96% of the particles in Sample 4F and 99% of the particles in Sample 7F were <10 microns in size (Table 5). Of the 10 micron fraction, 53% of Sample 4F and 67% of Sample 7F were <2.5 microns in size. CGS and UCD are in the process of conducting additional areal analyses of the fine grains in an attempt to quantify the ultrafine (<1micron) particles found in each sample.

DISCUSSION

Mineral Composition

Results of the microprobe analyses (Roeske, 2011) indicate that all of the sand samples, including their <45 micron and <10 micron size fractions, are predominantly quartz, plagioclase, and K-feldspar of granitic origin (Tables 1, 3, 4, and 6). The finer grained fractions of the sand samples have consistently less quartz than the coarser fractions of the sand, possibly because quartz is more resistant to physical weathering than the feldspars. The proportion of silica shell fragments and heavy minerals rises in the finer fractions.

The fine particles from the fences are similar in composition to the coarser grained sand particles in that both are dominated by quartz and feldspar (Tables 5 and 6). The overall mineral composition and percentages of fragments of granitic origin and heavy minerals found in the fine particles on the fence are generally consistent with the <45 micron fraction of the sand (Table 6). However, the fine particles on the fence generally showed higher percentages of quartz and lower percentages of silica shell fragments than the <45 micron and <10 micron fractions of the sand samples (Table 6).

Table 6. Comparison of Grain Size and Mineral Composition

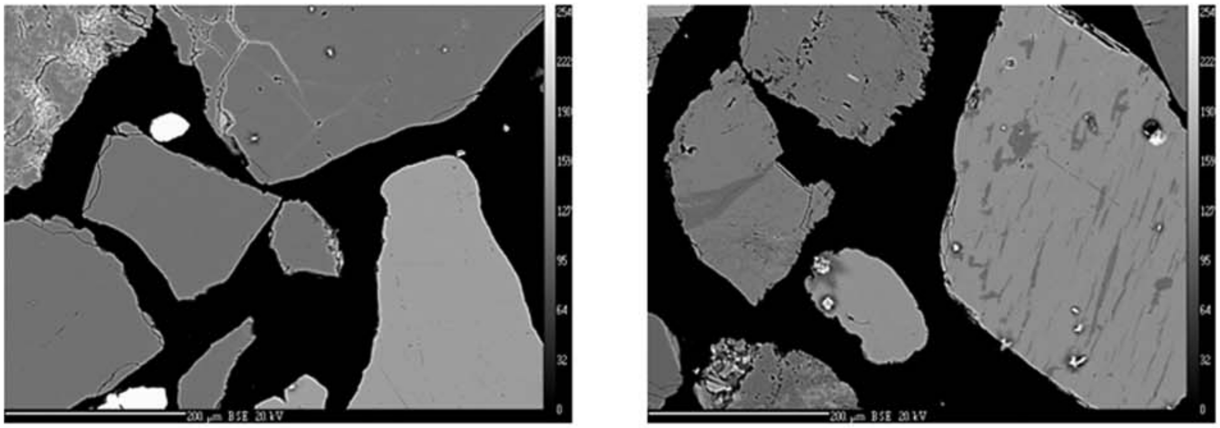
Sample Type and % Minerals	Granitic Origin	Total Silica (Quartz & Shell)	Quartz	Silica Shell Fragments	Heavy Minerals
Unsieved (whole) sand samples	80-96	35-50	34-50	1	1-14
< 45 micron fraction of sieved sand	51-72	24-33	11-26	5-15	8-17
< 10 micron fraction of sieved sand	49-67	17-39	5-17	2-22	10-19
Fine particles on fence (<10 microns)	69-71	28-36	27-29	1-7	12-19

Grain Size Distribution of Particles <45 Microns in Size

Results of the microprobe analyses indicate that fine materials collected from the fences bounding the seasonal restricted area contain a significantly higher percentage of particles <10 microns in size than sand collected from the beach and dunes (Figure 5). Between 96 and 99% of the particles found on the fences were <10 microns in size (Table 5). Other than wind and wave action, there was no activity west of the fences at the time the samples were collected that would result in the short-term weathering and break-down of such fine quartz and clay size particles found on the fences. This suggests they were deposited on the fences prior to being deposited on the ground. The presence of flocculated (clumped) ultrafine (<1 micron) particles on the fence closest to the ocean also suggests the fine materials may have been deposited directly onto the fence as an aerosol rather than as a result of sand saltation west of the fence. The more dispersed and sorted nature of the fine materials on the fence farther inland indicates the ultrafine particles (<1 micron) are removed by wind action as it moves eastward.

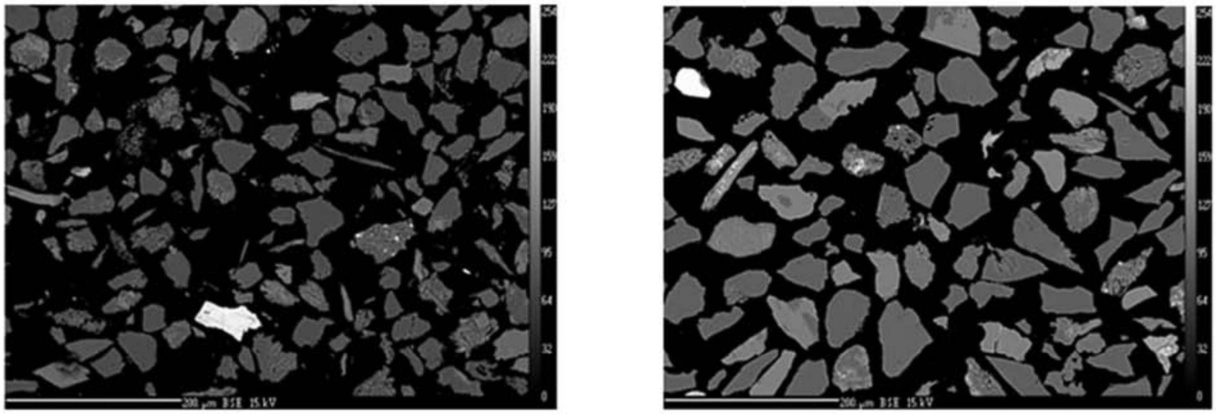
In contrast, 0.1% or less of the particles found in samples collected from the beach and dune sands are <45 microns in size (Table 2). In general, there was minimal variation in fine grain size distribution within the sieved sand samples from the seasonal restricted area, the Dune Preserve, and the OHV ride area. Although the sand samples contained a significantly smaller fraction of particles <10 microns in size than that found on the fences, it is notable that the highest percentages of particles <10 microns found in the sieved sand are from Samples S1-5 and S1-6, located just east of the fence closest to the ocean (Tables 3 and 4). Samples within the dune sand east of the fence (S1-7 through S1-11, DP-2) also appear to be better sorted and more rounded than beach sands to the west (Roeske, 2011; Appendices C and D). This indicates there is selective sorting whereby finer grains are removed by wind action leaving the coarser grains behind. Variations in the actual percentages of the fine grain sizes in Samples S1-7 to S1-11 (Tables 3 and 4) are also consistent with studies of sand movement on inclined dune surfaces by White and Tsoar (1998). These studies showed that, as wind speed and sand flux 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. The relatively larger percentage of particles <10 microns in Sample DP-2 in the Dune Preserve (Table 3) also suggests there is a continued transfer of fine particles to the east.

The findings of the microprobe analyses reconfirm conclusions in Part 1 of this study (CGS, 2011) that the beach and dune sands in ODSVRA contain only a small fraction of particles <10 microns in size. This suggests there may be other sources of PM10 and PM2.5 recorded at monitoring stations on the Nipoma Mesa. For example, in addition to the fine materials on the fences, high percentages of silt and clay size particles are present in the fluvial soils and older dunes adjacent to ODSVRA and on the Nipoma Mesa (NRCS, 2008; Orme, 1992). NRCS (2008) showed some of these soils contain more than 30% clay (<2 microns in size) and as much as 80% silt/clay, while Orme (1992) found fluvial deposits interbedded with older dune deposits, exposed in the canyon of Mussel Rock Ravine south of the Nipoma Mesa, contain 5% sand, 67% silt, and 28% clay or a total of 95% silt/clay.



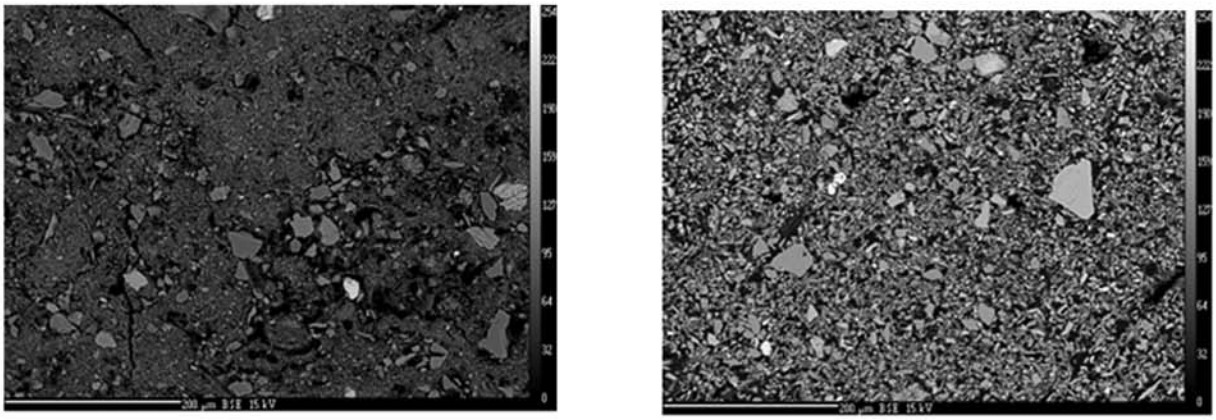
Sample S1-4: Unsieved (whole) sand sample.

Sample S1-7: Unsieved (whole) sand sample.



Sample S1-4: Sieved sand, <45 micron fraction.

Sample S1-7: Sieved sand, <45 micron fraction.



Sample 4F: Fine material on fence (near ocean).

Sample 7F: Fine material on fence (inland).

Figure 5: Comparison of different sand size fractions with fine materials on the fences, 600 micron field of view. Photos by S. Roeske.

CONCLUSIONS

Microprobe analyses performed in Part 2 of this study demonstrate that fine materials found in samples collected from the fences in the seasonal restricted area of ODSVRA contain a significantly higher percentage of particles <10 microns and <2.5 microns than the sand samples collected from beach and dune sands of ODSRVA.

Between 96 and 99% of the particles on the fences were found to be <10 microns in size. For this reason, they should be considered a potential natural source of PM10 and PM2.5 in the vicinity of the Nipoma Mesa, along with other areas previously identified by NRCS (2008) and Orme (1992) as having high silt and clay content.

Based on the findings of both Part 1 and Part 2 of this study, it is unlikely that sand from ODSVRA is the only source of PM10 and PM2.5 collected in air quality monitoring stations on the Nipoma Mesa.

ACKNOWLEDGEMENTS

During the course of this study, the author consulted Dr. Sarah Roeske of UCD, and Dr. Ronald Churchill and John Clinkenbeard of CGS's Mineral Hazards Program, regarding the mineral composition of the materials examined and implications of the microprobe analyses. In addition, coastal processes and the nature of the windblown sands at Pismo Beach and Oceano Dunes were discussed with Dr. Antony Orme, retired Professor of Geography at UCLA; Dr. Gary Griggs, Professor of Earth & Planetary Studies at UC Santa Cruz; and Will Harris of CGS. The author also wishes to thank Christopher Dugan of TRA Environmental Sciences, Inc. and Ronnie Glick of CSP for their assistance with the collection of sand samples and wind data and Anita Carney of CGS for assistance with preparation of the figures for this report.

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Attachments:

Appendix A: UC Davis Microprobe Analyses Report
Appendix B: BSE and EDS Examples
Appendix C: Comparison of Unsieved Sand Samples
Appendix D: Comparison of Sieved Sand Grains <45 Microns
Appendix E: Comparison of Fine Particles on Fences

Cc: Phil Jenkins, Chief, CSP, Off-highway Motor Vehicle Recreation Division
Will Harris, Senior Engineering Geologist, Supervisor, CGS

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Appendix A: UC Davis Microprobe Analyses Report

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Size fraction analysis and mineral identification of sand samples from Oceano Dunes and vicinity for California Geological Survey

Introduction and General Methods

This report summarizes observations and data from sand samples collected and sieved by Trinda Bedrossian, California Geological Survey. Part of the goal of the project is to identify mineral compositions in the various size fractions and to determine the percent of fractions less than 10 microns and less than 2.5 microns in the finest portion of the sieved materials and from material collected along fences. For both of these goals an electron microprobe with imaging, energy-dispersive and wave-length dispersive capabilities is an ideal tool. 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 primarily 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. BSE images also allow observation of the morphology of different fractions on grain sizes generally too small to observe with a standard petrographic microscope.

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. Less than 1% of the EDS spectra are non-unique; the most common example is actinolite, a common amphibole, and clinopyroxene. They have essentially identical EDS spectra, in which case the operator made a judgement call on the mineral based on morphology, because actinolite and clinopyroxene have different crystal habits.

The operator noted also that many of the phases that have spectra showing only silica and oxygen (SiO_2) also had a small white circle on the surface after the focused beam was removed. This phenomenon is known as "beam damage" and is distinctive of certain phases that are burned by the focused electron beam. Quartz is slightly beam-sensitive, but shelly material made of SiO_2 which has not converted to the mineral species quartz is highly beam sensitive. These beam-sensitive silica-dioxide phases include the minerals opal-A and opal-CT, as well as silica-rich lithic fragments composed of opal-A and opal-CT such as porcellanite and diatomite. The mineral composition tables break these two types of SiO_2 into separate categories, quartz vs. silica lithics and shell fragments because they reflect different origins for these two types of silica.

Sample Preparation

All samples were prepared by Greg Baxter (Geology Department Staff Research Associate). He received the dry-sieved samples, fence fines, and the whole samples from Trinda Bedrossian and did not do further sieving. He placed the <325 mesh sieved fraction samples within a circular template 6 mm across and poured epoxy over them, allowed it to harden and then polished them. For the non-sieved samples and fence fines he first put 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.The remainder of the sample preparation was similar to the sieved fractions.

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 on the various size fractions on the non-sieved samples and on the less than 325 mesh fractions, I moved the stage in a straight line such that the scanning image moved across the sample. I counted any grain that was within ~ 20 microns of this horizontal line, noting its composition, until 100 grains were counted. In order to determine the percent of very fines (< 10 microns and <2.5 microns) and their compositions I took images of areas 300 microns across and counted the numbers and noted the composition of all phases less than 10 microns in that image, then counted how many total grains were in the image.

For the fence fines, much of the material is less than 10 microns and a significant fraction is less than 2.5 microns. The above methods do not work as well, because much of the material is clumped and too fine to resolve the number of grains. Thus estimates for the percents of the very fine fractions from the fence are more approximate than for the sieved samples.

Summary of Data

Sieved Sands and Whole (non-sieved) Sands

Compositions

All samples have >75% of the grains composed of quartz, plagioclase, and K-feldspar, the common minerals of intermediate to siliceous intrusive rocks and very high grade metamorphic rock. The finer fractions have consistently less quartz in them than the coarser fractions (see table "comparison by sample"); this is likely due to quartz being more resistant to physical weathering compared to feldspar. In contrast, the shelly material, both the silica and carbonate types, rise proportionally in the finest fractions, probably reflecting that they are more susceptible to physical breakdown than quartz.

The main compositional changes noted across the transect from samples 3 through 11 varies depending on what size fraction one examines. In the non-sieved material (total sample), there is a significant drop in the percentage of quartz moving inland. Although not a trend, it is interesting to note that the two samples in the non-sieved fraction with the most heavy minerals (densest phases, often finer-grained than other minerals) are in the 2 most inboard sites, nos. 9 and 11.

The material in the sieved fraction (less than 325 mesh) varies considerably in terms of composition, but overall the most pronounced change across the transect is a drop in the percent of sheet silicates, including muscovite, biotite, and clay (see table "all in fines"). This compositional shift also is seen texturally; compare images from sites 4 and 6 with sites 7 and any sites further east, and note that the latter have generally more equant grains (see Texture comparison fine fraction for examples from samples 6 and 9).

Size Fractions

The finest material (<325 mesh) was examined in detail for sieved samples 2, 4, 5, 6, 7, 8, 9, 10 and 11. They show a wide range of percent that is less than 10 microns and less than 2.5 microns. Sample nos. 5 and 6 are outliers in comparison to samples 4 and 7-11. Samples 5 and 6 have a significantly higher percentage of fine (<10 microns) and very fine (<2.5 microns) materials in comparison to the other samples in the transect (see table "10 micron from fines").

Summary of all Sands

The compositional, textural and size fraction percent changes noted in the fine fraction of samples 5 and 6 in comparison to 7-11 are consistent with the latter being physically better sorted. The higher percentages of sheet silicate material in samples 5 and 6 indicate less physical reworking, which is consistent also with the higher percent of very fine material in these samples.

Fence Fines

Material collected by Trinda Bedrossian from the fences at sites 4 and 7 were examined both before and after polishing. Sample preparation for the former consisted of pressing the weakly cemented material on to double-stick carbon tape that was on a alumina round.

Composition and Texture

The fence fine material was carbon coated and scanned for Na, Cl, C, and Pb. No Pb was found in either sample. Na and Cl xray maps indicate ~ 1% at most in sample 4, .2% at most for sample 7. This indicates that sea salt is not the binding agent in these fence fines. Compositionally samples no. 4 and 7 are similar, and as with the sands dominated by quartz and feldspar. Texturally samples no. 4 and 7 are quite distinct, with the former having an ultrafine material (<1 micron) that binds the coarser grains. The ultrafine material is uniform in composition, containing dominantly Si and Al with lesser amounts of K, Ca, and Fe, and varying but always present Mg and Zn (see EDS figures 1 and 2). All of these elements are consistent with an "average" of all of the elements present in the various sand grains, with the exception of the Zn. The amount of Zn varies between trace and minor (possibly as high as several wt. percent). Any paint or other coating on the fence should be examined if the origin of the Zn is important. (see EDS images from fence fines).

Texturally the fence fines from sample no. 7(fence) are better sorted than those from no. 4, in that the proportion of fine (<10 microns) and very fine (<2.5 microns) material is higher in sample no. 7 fence (see images in document "Fence Fines images"). The very fine material in sample no. 7 is coarser than in no. 4, and visually resolvable as individual grains, thus they were included in the point count data for that sample, In contrast, the very fine material in sample no. 4 was too fine to resolve individual grains and was not included in the point count data.

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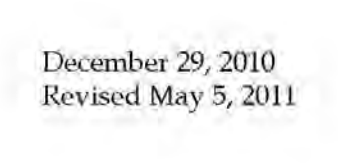
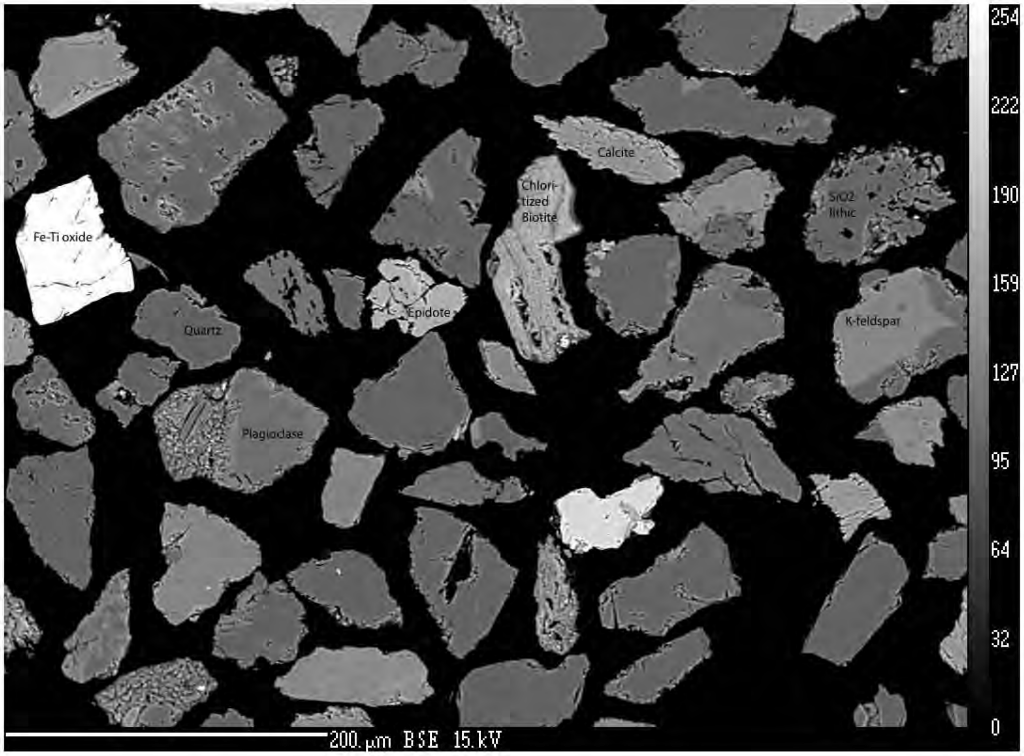


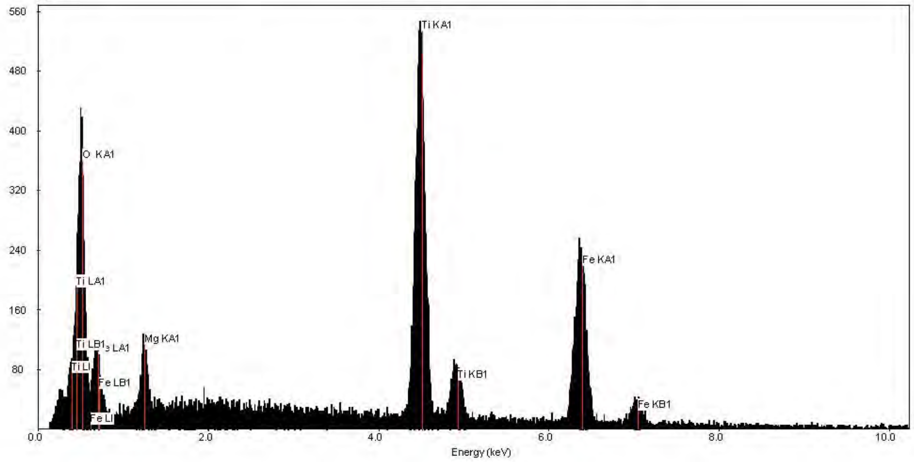
December 29, 2010
Revised May 5, 2011

Appendix B: BSE and EDS Examples

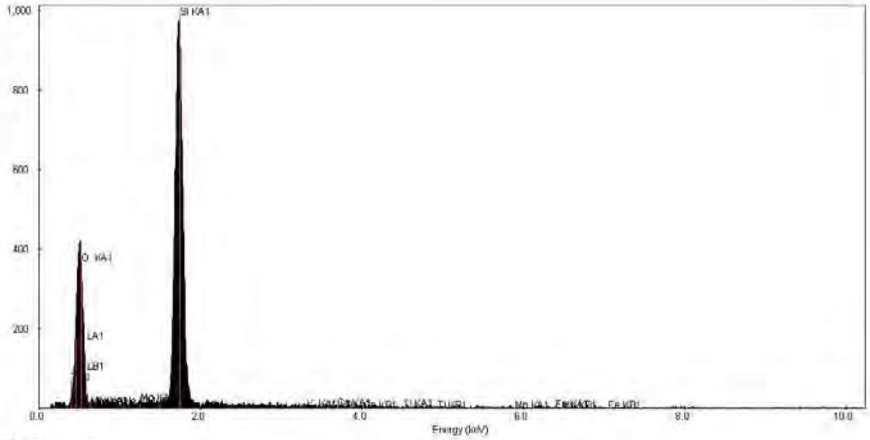


Example of an image used for point-counting grains in the less than 325 micron fraction. Mineral fragments have different gray scale intensity depending on their total mass.

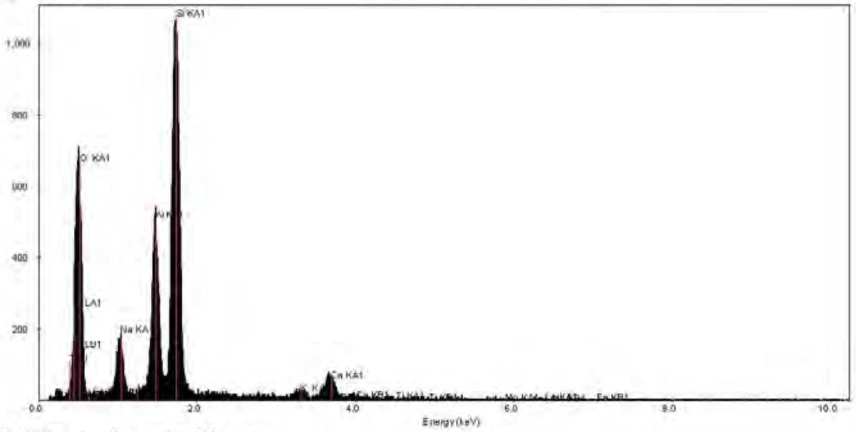
Below are EDS (energy-dispersive spectrometry files) generated from the above image.



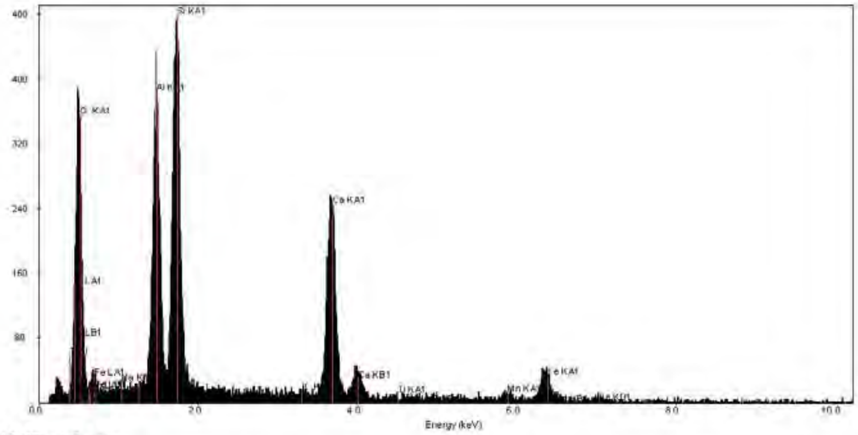
1) Fe-Ti oxide with some magnesium (typical of solid solution in the Fe-Ti oxides).



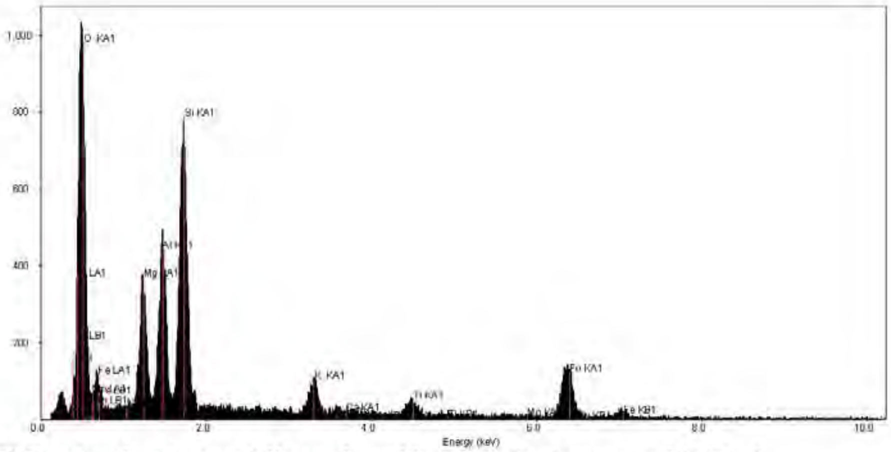
2) Quartz



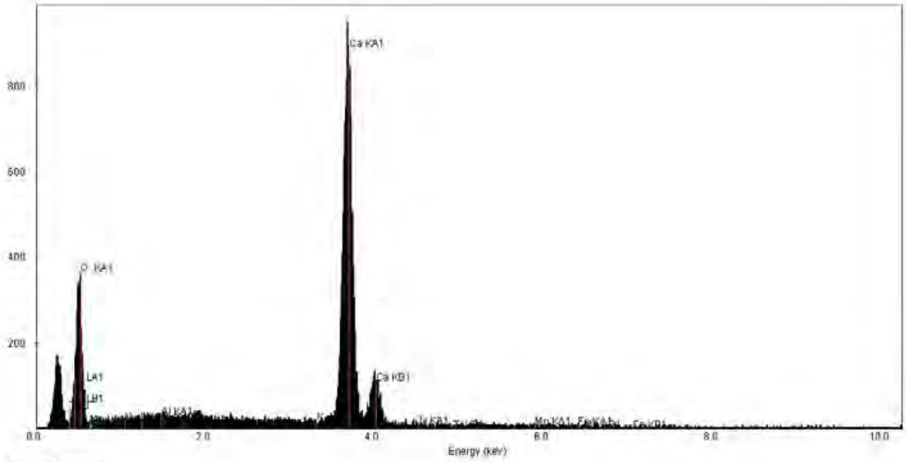
3) Plagioclase Feldspar



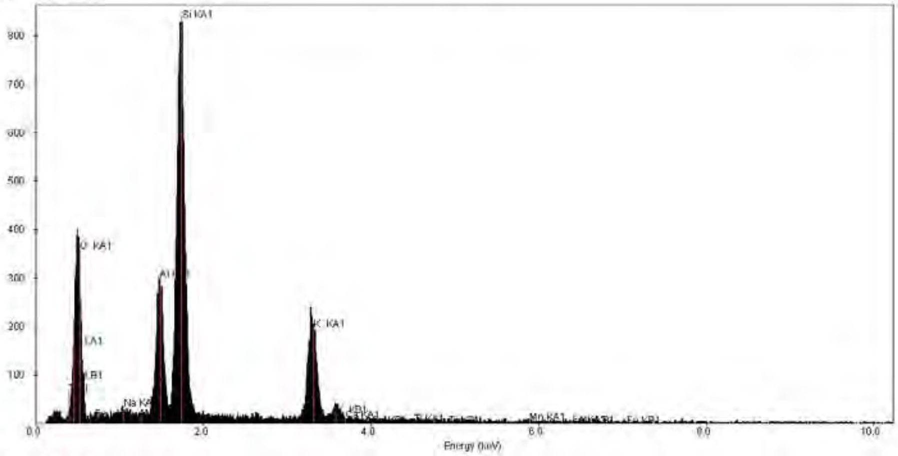
4) Epidote



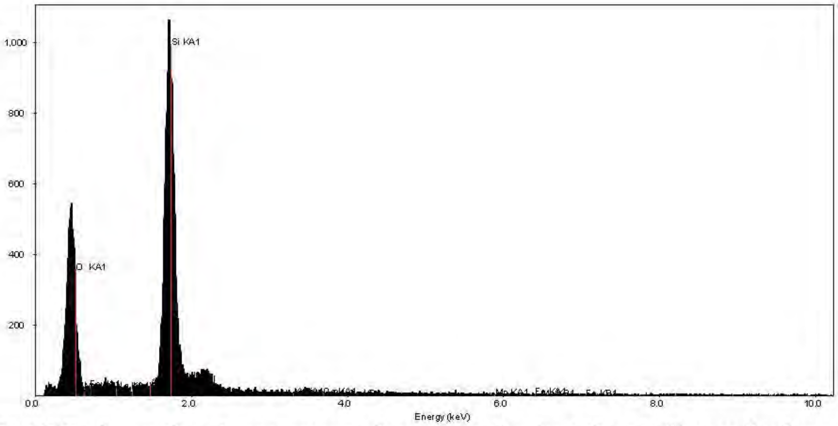
5) Biotite that is partially replaced by chlorite (count as bioitite).



6) Calcite



7) K-feldspar



8) SiO2 phase that is not quartz based on the fact that it "burns" when the electron beam sits on it for 10 seconds (see image below). Texturally it does not appear to be an individual shell fragment, so it falls under the category of Si-rich mudstone.

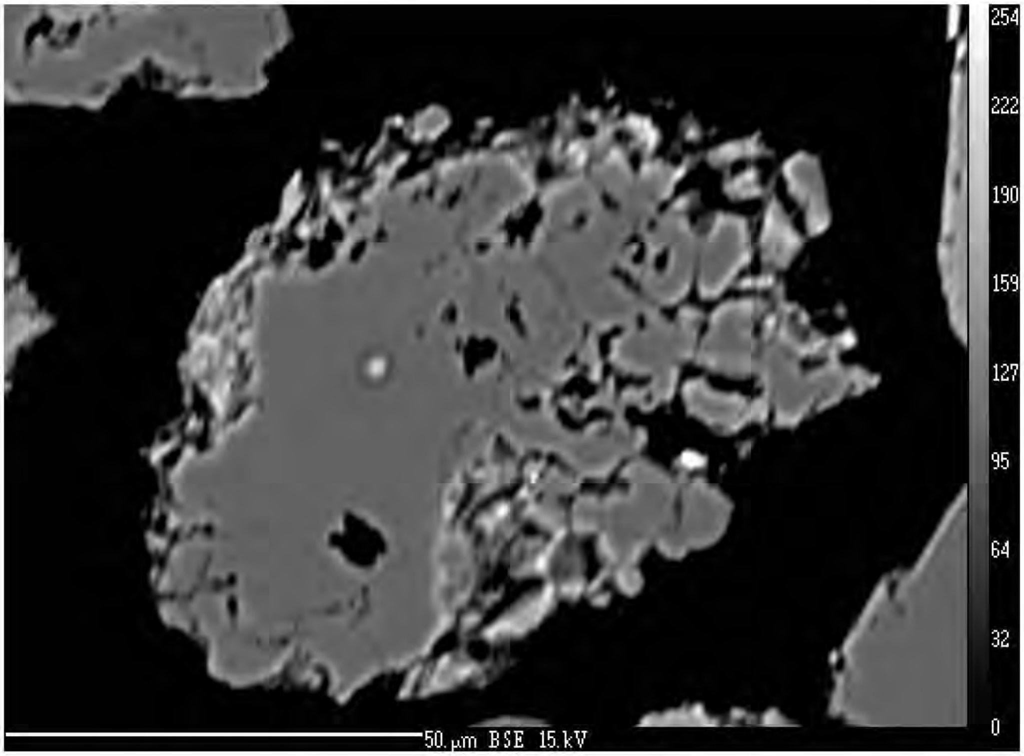
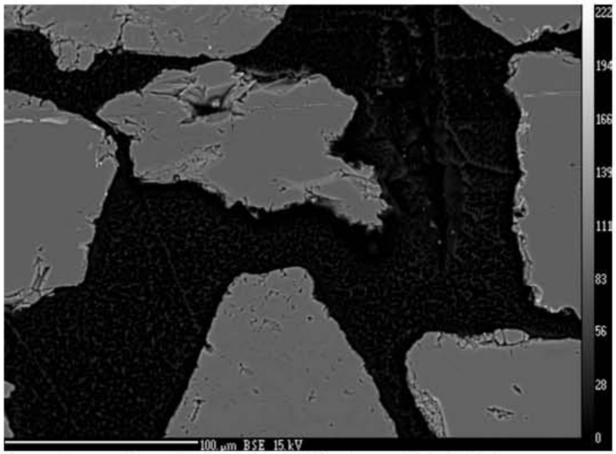


Image of "burn" mark (white circle) on the SiO2-rich phase (compare to back-scattered electron image at beginning of file, which does not show any white circle).

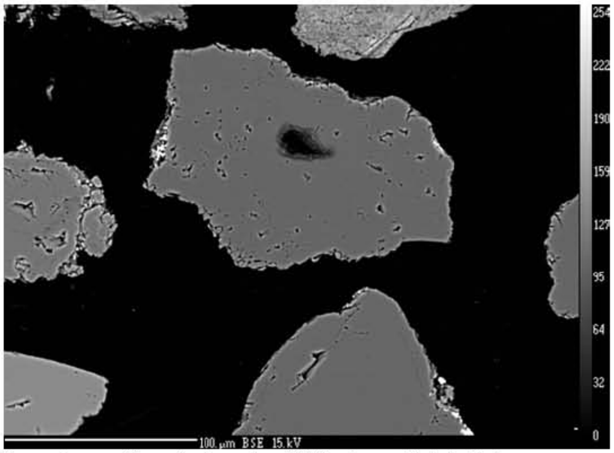
Appendix C: Comparison of Unsieved Sand Samples

MINERAL COMPOSITION OF UNSIEVED SAND SAMPLES (Roeske, 2011)

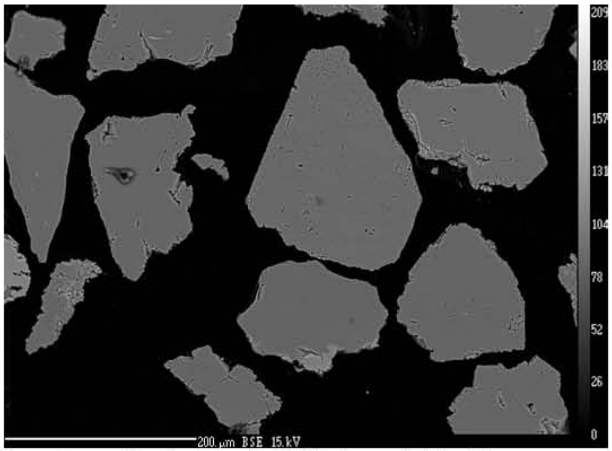
Mineral	**Sample no.**							
	1	**2**	**3**	**4**	**6**	**7**	**9**	**11**
Quartz	40	44	50	44	41	36	34	34
Plagioclase (includes albite)	27	20	20	23	16	19	20	31
K-feldspar	21	21	18	22	29	34	21	17
Silica shell	0	0	0	0	0	0	1	0
Muscovite	0	1	0	0	0	0	2	1
Biotite	0	0	1	0	3	0	0	0
Chlorite	0	3	0	1	0	0	1	3
Lithic fragment (mudstone)	2	2	0	0	2	3	3	3
Carbonate (includes calcite and dolomite)	2	1	0	2	1	0	2	1
Amphibole	0	0	0	0	0	0	0	0
Clinopyroxene	0	0	0	0	0	0	1	0
Fe-oxide and Fe-Ti oxide	0	1	5	1	2	0	4	2
Apatite	0	1	0	0	0	0	2	0
Zircon	0	0	0	0	0	0	2	1
Epidote	1	1	0	0	0	1	4	3
Lithic fragment (granitoid)	7	3	5	6	6	7	3	3
Titanite (sphene)	0	2	1	0	0	0	0	0
Serpentine	0	0	0	1	0	0	0	1
Total	100	100	100	100	100	100	100	100
Summary of compositions:								
Minerals and rock fragments that most likely are from intermediate to Silicic Granitoid	95.00%	88.00%	93.00%	95.00%	92.00%	96.00%	80.00%	86.00%
Total SiO2 (quartz and SiO2 - shell fragments)	40.00%	44.00%	50.00%	44.00%	41.00%	36.00%	35.00%	34.00%
Heavy minerals (biotite, chlorite, amphibole, clinopyroxene, Fe-oxide, apatite, zircon, epidote, titanite)	1	8	7	2	5	1	14	9



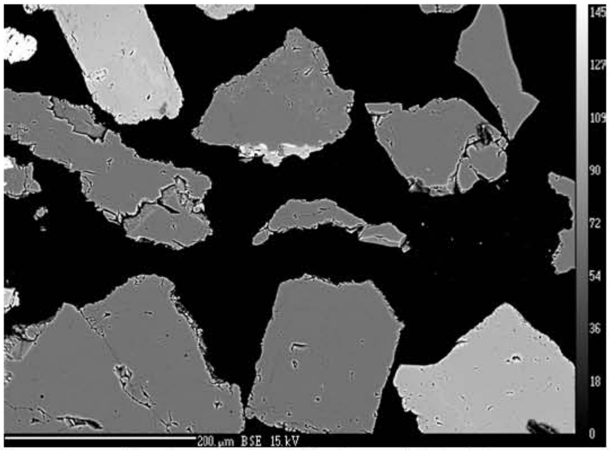
Sample no. 1 not sieved 300 micron field of view.



Sample no. 2 not sieved 300 micron field of view.



Sample no. 1 not sieved 600 micron field of view.



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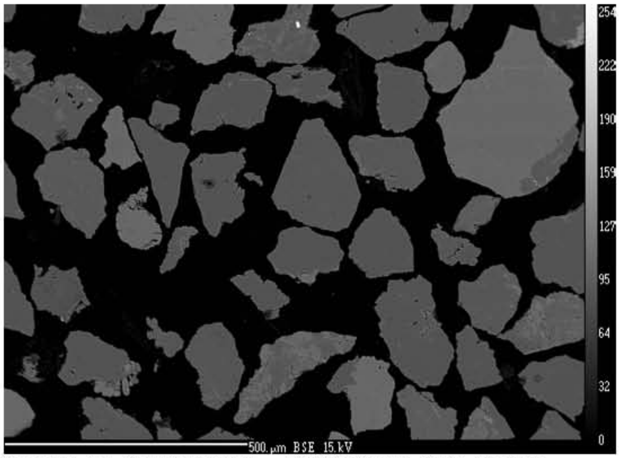
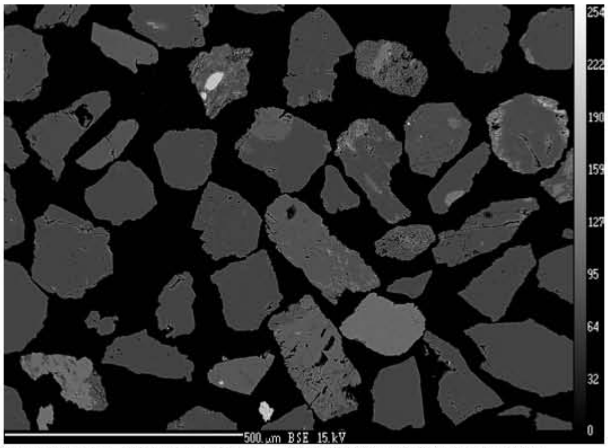


Sample no. 1 not sieved 1200 micron field of view.



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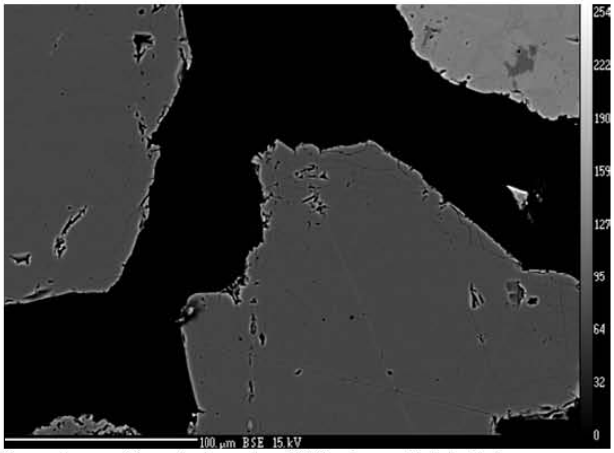
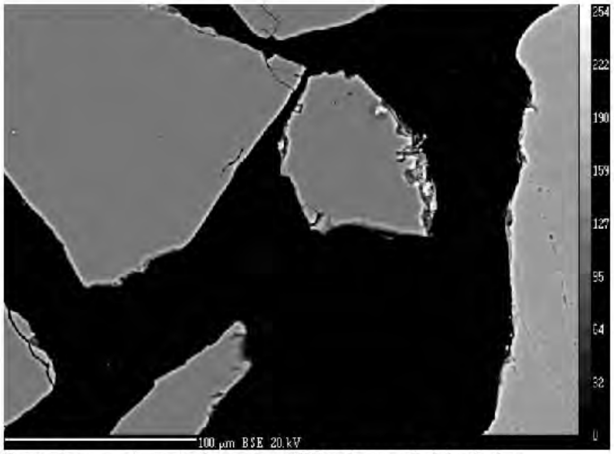
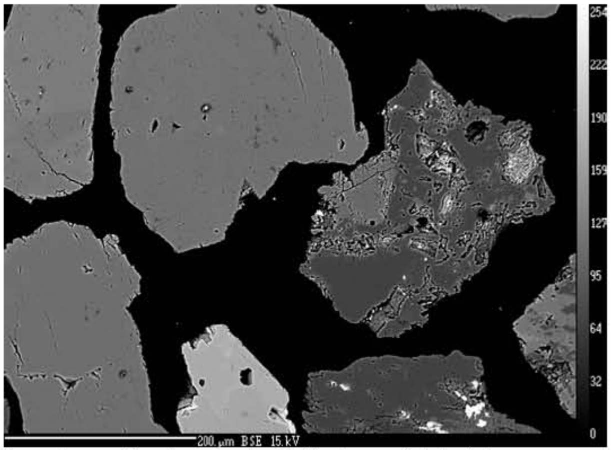


Sample no. 3 not sieved 300 micron field of view.

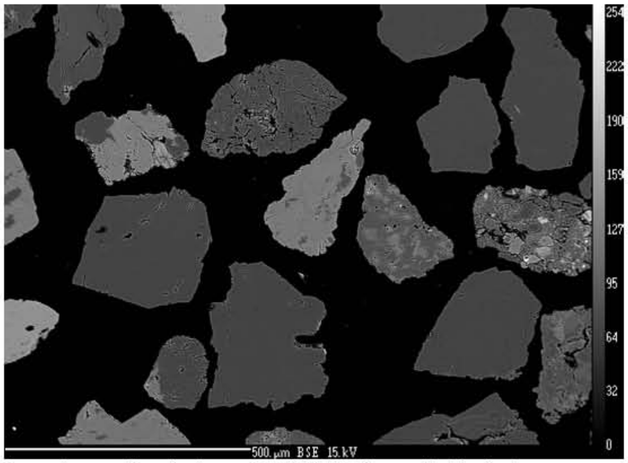


Sample no. 4 not sieved 300 micron field of view.

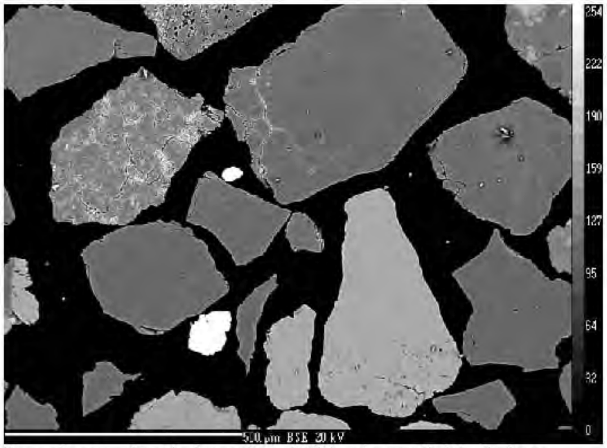


Sample no. 3 not sieved 600 micron field of view.

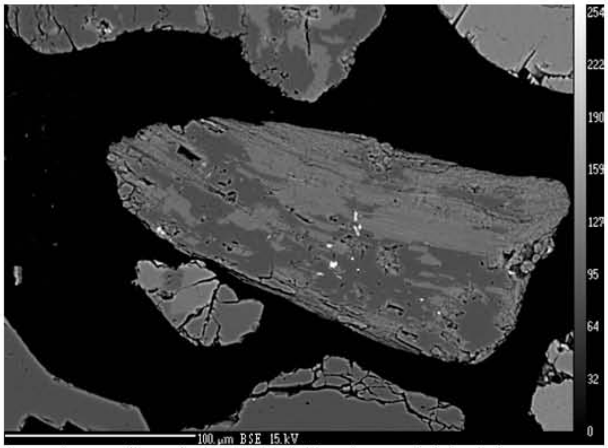
Sample no. 4 not sieved 600 micron field of view.



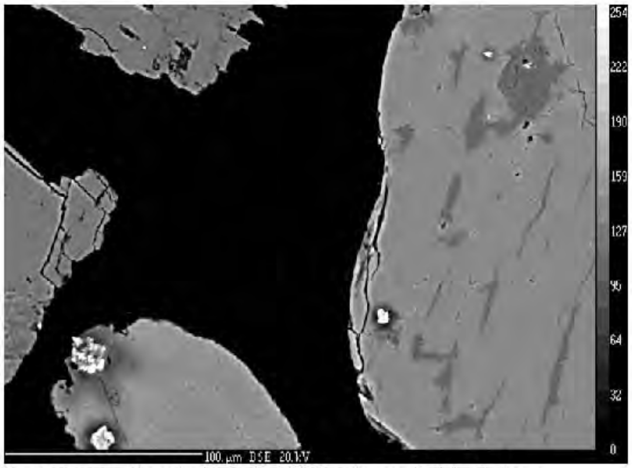
Sample no. 3 not sieved 1200 micron field of view.



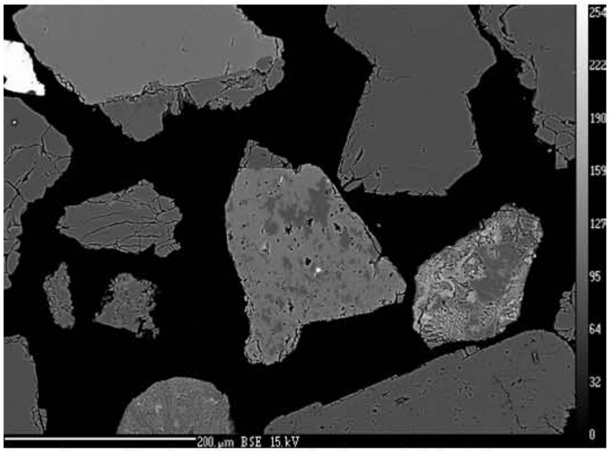
Sample no. 4 not sieved 1200 micron field of view.



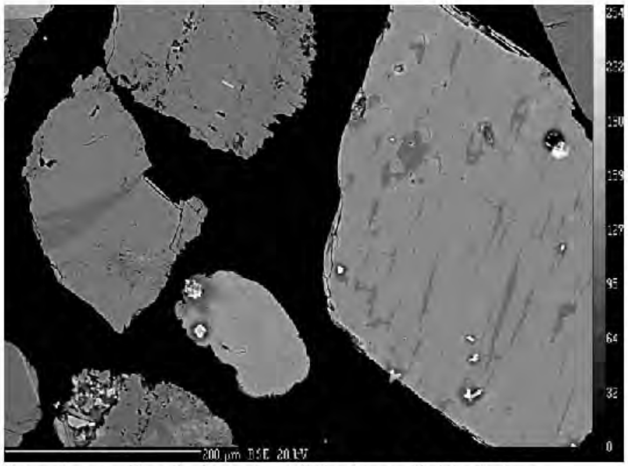
Sample no. 6 not sieved 300 micron field of view.



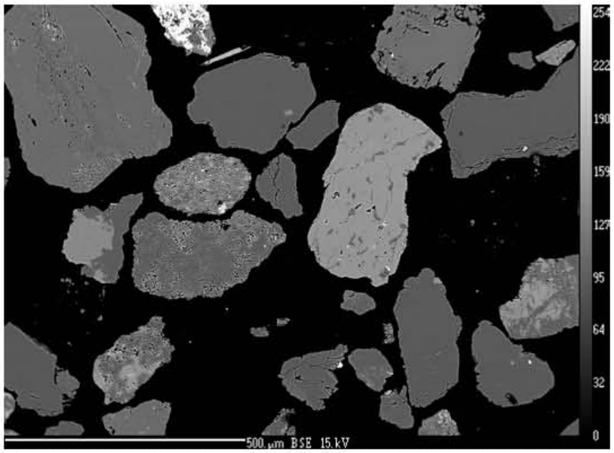
Sample no. 7 not sieved 300 micron field of view.



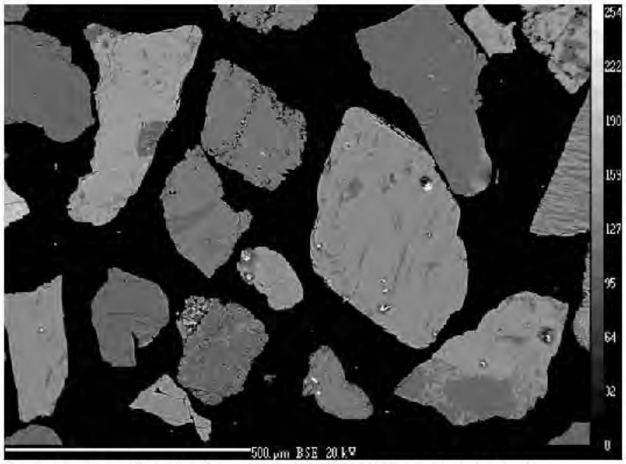
Sample no. 6 not sieved 600 micron field of view.



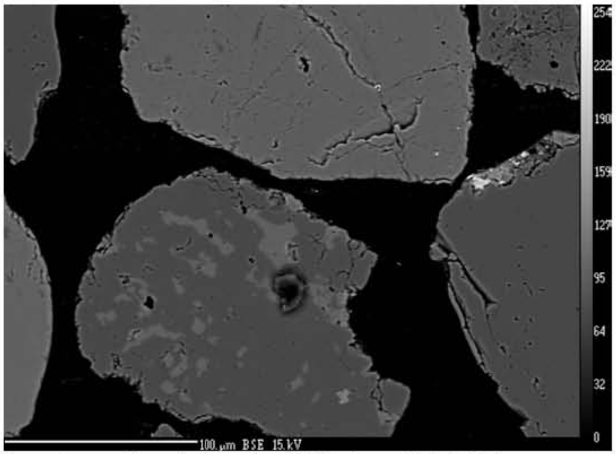
Sample no. 7 not sieved 600 micron field of view.



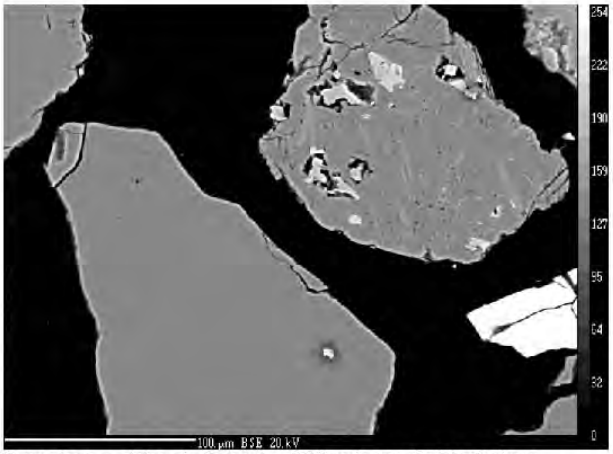
Sample no. 6 not sieved 1200 micron field of view.



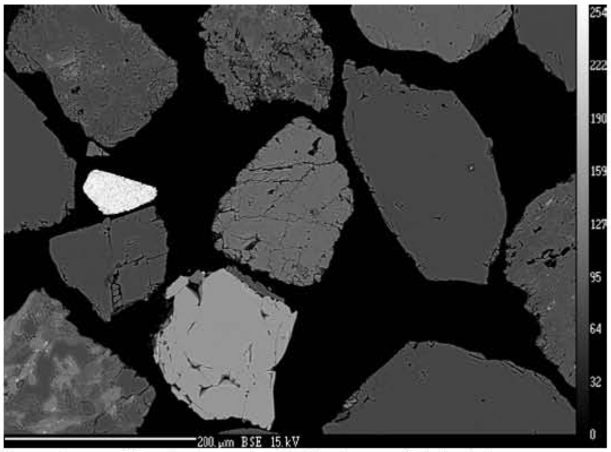
Sample no. 7 not sieved 1200 micron field of view.



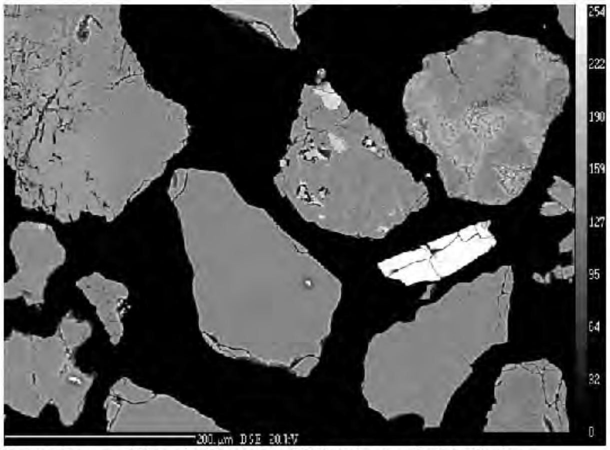
Sample no. 9 not sieved 300 micron field of view.



Sample no. 11 not sieved 300 micron field of view.



Sample no. 9 not sieved 600 micron field of view.



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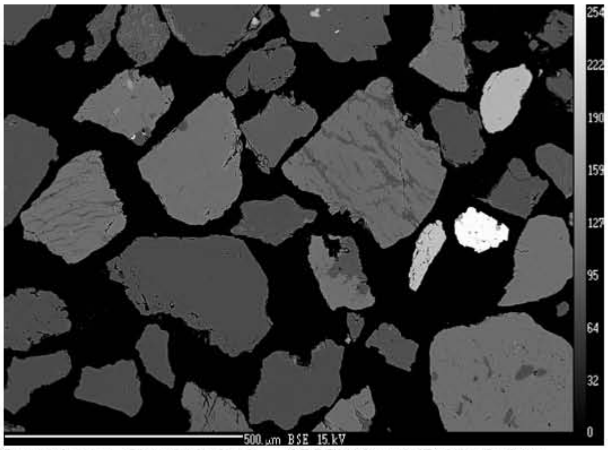
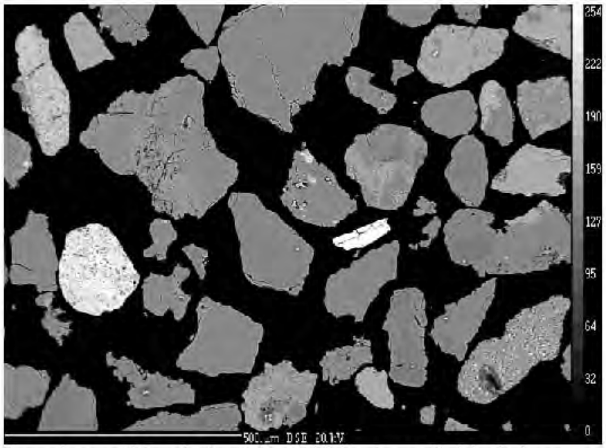


Sample no. 9 not sieved 1200 micron field of view.



Sample no. 11 not sieved 1200 micron field of view.

Appendix D: Comparison of Sieved Sand Grains <45 Microns

MINERAL COMPOSITION OF SIEVED SAND GRAINS <45 MICRONS (Roeske, 2011)

Point counts of <325 mesh fraction (all grain sizes)

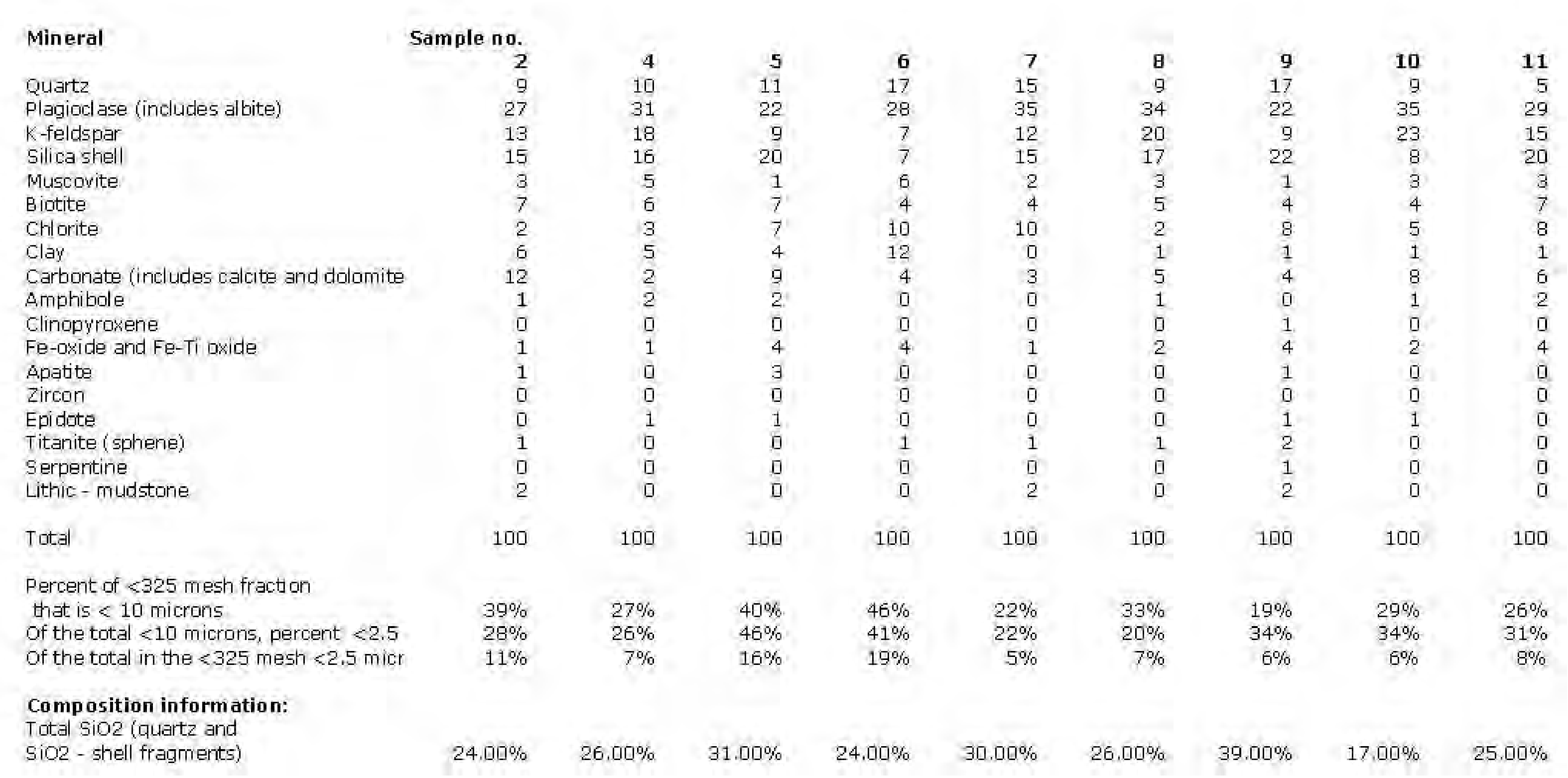
Mineral	**sample no 2**	**sample no 4**	**sample no 5**	**sample no 6**	**sample no 7**	**sample no 8**	**sample no 9**	**sample no 10**	**sample no 11**
Quartz	22	19	23	11	16	20	22	26	12
Plagioclase (includes albite)	25	28	28	27	34	27	26	30	34
K-feldspar	13	16	15	13	18	19	15	18	22
Silica shell	7	7	9	15	8	7	11	5	15
Muscovite	3	1	0	2	0	1	2	2	0
Biotite	1	10	4	3	1	3	3	1	1
Chlorite	5	2	6	6	1	3	4	1	2
Clay	0	1	0	0	0	0	0	1	0
Carbonate (includes calcite and dolomite)	9	3	4	2	3	7	6	2	2
Amphibole	0	1	3	1	1	1	2	0	0
Clinopyroxene	0	1	1	0	0	0	0	0	1
Fe-oxide and Fe-Ti oxide	1	3	2	2	4	2	2	4	3
Apatite	0	0	0	0	0	0	0	0	0
Zircon	0	0	0	0	0	0	2	0	0
Epidote	1	0	0	2	0	1	0	2	1
Titanite (sphene)	0	0	0	0	0	1	0	0	0
Serpentine	0	0	1	0	2	0	0	0	0
Lithic - mudstone	11	6	4	16	7	5	4	7	6
Lithic - granitoid	2	2	0	0	4	3	0	1	1
Garnet	0	0	0	0	1	0	0	0	0
Barite (BaSO4)	0	0	0	0	0	0	1	0	0
Total	100	100	100	100	100	100	100	100	100

MINERAL COMPOSITION OF SIEVED SAND GRAINS <45 MICRONS (Roeske, 2011) cont’d.

Composition information:

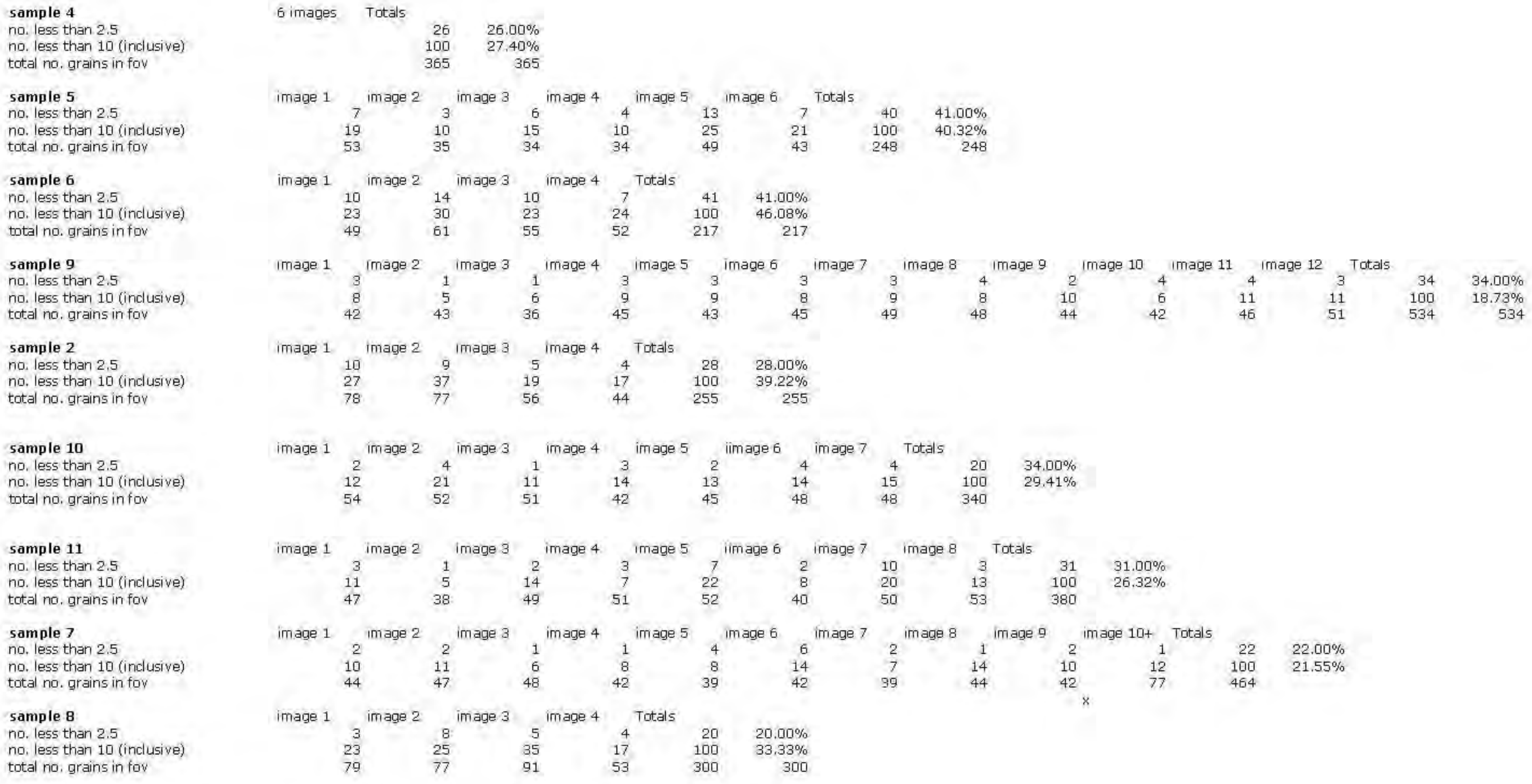
Total SiO2 (quartz and SiO2 - shell or siliceous mudstone fragments)	29.00%	26.00%	32.00%	26.00%	24.00%	27.00%	33.00%	31.00%	27.00%
Heavies (biotite, chlorite, amphibole, clinopyroxen, Fe-oxide, apatite, zircon, epidote, titanite, garnet, BaSO4)	8	17	16	14	8	11	14	8	8
Sheet silicate phaes (muscovite, biotite, chlorite, and clay)	9	14	10	11	2	7	9	5	3

MINERAL COMPOSITION OF SIEVED SAND GRAINS <10 MICRONS (Roeske, 2011)



Mineral	**Sample no.**								
	2	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Quartz	9	10	11	17	15	9	17	9	5
Plagioclase (includes albite)	27	31	22	28	35	34	22	35	29
K-feldspar	13	18	9	7	12	20	9	23	15
Silica shell	15	16	20	7	15	17	22	8	20
Muscovite	3	5	1	6	2	3	1	3	3
Biotite	7	6	7	4	4	5	4	4	7
Chlorite	2	3	7	10	10	2	8	5	8
Clay	6	5	4	12	0	1	1	1	1
Carbonate (includes calcite and dolomite	12	2	9	4	3	5	4	8	6
Amphibole	1	2	2	0	0	1	0	1	2
Clinopyroxene	0	0	0	0	0	0	1	0	0
Fe-oxide and Fe-Ti oxide	1	1	4	4	1	2	4	2	4
Apatite	1	0	3	0	0	0	1	0	0
Zircon	0	0	0	0	0	0	0	0	0
Epidote	0	1	1	0	0	0	1	1	0
Titanite (sphene)	1	0	0	1	1	1	2	0	0
Serpentine	0	0	0	0	0	0	1	0	0
Lithic - mudstone	2	0	0	0	2	0	2	0	0
Total	100	100	100	100	100	100	100	100	100
Percent of <325 mesh fraction that is < 10 microns	39%	27%	40%	46%	22%	33%	19%	29%	26%
Of the total <10 microns, percent <2.5	28%	26%	46%	41%	22%	20%	34%	34%	31%
Of the total in the <325 mesh <2.5 micr	11%	7%	16%	19%	5%	7%	6%	6%	8%
Composition information:									
Total SiO2 (quartz and SiO2 - shell fragments)	24.00%	26.00%	31.00%	24.00%	30.00%	26.00%	39.00%	17.00%	25.00%

MINERAL COMPOSITION OF SIEVED SAND GRAINS <10 MICRONS (Roeske, 2011) cont'd.



sample 4	6 images	Totals	
no. less than 2.5		26	26.00%
no. less than 10 (inclusive)		100	27.40%
total no. grains in fov		365	365

sample 5	image 1	image 2	image 3	image 4	image 5	image 6	Totals	
no. less than 2.5	7	3	6	4	13	7	40	41.00%
no. less than 10 (inclusive)	19	10	15	10	25	21	100	40.32%
total no. grains in fov	53	35	34	34	49	43	248	248

sample 6	image 1	image 2	image 3	image 4	Totals	
no. less than 2.5	10	14	10	7	41	41.00%
no. less than 10 (inclusive)	23	30	23	24	100	46.08%
total no. grains in fov	49	61	55	52	217	217

sample 9	image 1	image 2	image 3	image 4	image 5	image 6	image 7	image 8	image 9	image 10	image 11	image 12	Totals	
no. less than 2.5	3	1	1	3	3	3	3	4	2	4	4	3	34	34.00%
no. less than 10 (inclusive)	8	5	6	9	9	8	9	8	10	6	11	11	100	18.73%
total no. grains in fov	42	43	36	45	43	45	49	48	44	42	46	51	534	534

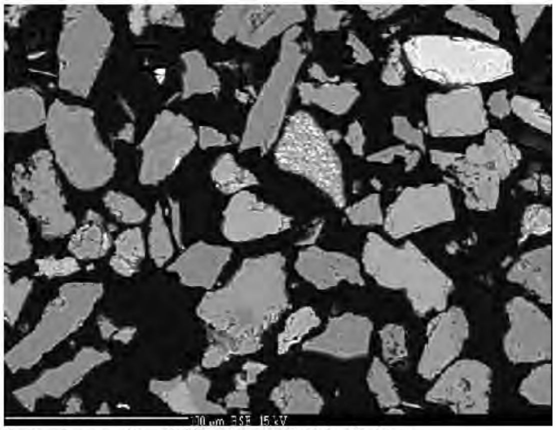
sample 2	image 1	image 2	image 3	image 4	Totals	
no. less than 2.5	10	9	5	4	28	28.00%
no. less than 10 (inclusive)	27	37	19	17	100	39.22%
total no. grains in fov	78	77	56	44	255	255

sample 10	image 1	image 2	image 3	image 4	image 5	iimage 6	image 7	Totals	
no. less than 2.5	2	4	1	3	2	4	4	20	34.00%
no. less than 10 (inclusive)	12	21	11	14	13	14	15	100	29.41%
total no. grains in fov	54	52	51	42	45	48	48	340	

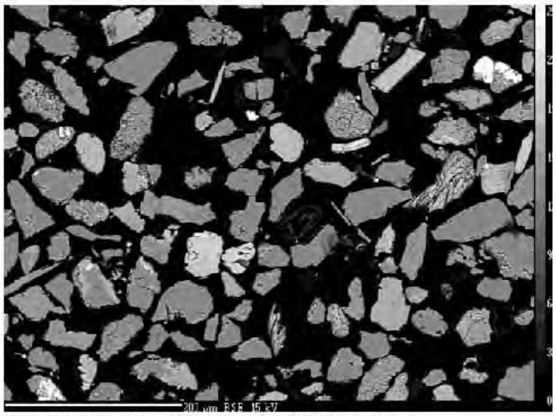
sample 11	image 1	image 2	image 3	image 4	image 5	iimage 6	image 7	image 8	Totals	
no. less than 2.5	3	1	2	3	7	2	10	3	31	31.00%
no. less than 10 (inclusive)	11	5	14	7	22	8	20	13	100	26.32%
total no. grains in fov	47	38	49	51	52	40	50	53	380	

sample 7	image 1	image 2	image 3	image 4	image 5	image 6	image 7	image 8	image 9	image 10+	Totals	
no. less than 2.5	2	2	1	1	4	6	2	1	2	1	22	22.00%
no. less than 10 (inclusive)	10	11	6	8	8	14	7	14	10	12	100	21.55%
total no. grains in fov	44	47	48	42	39	42	39	44	42	77	464	
										x		

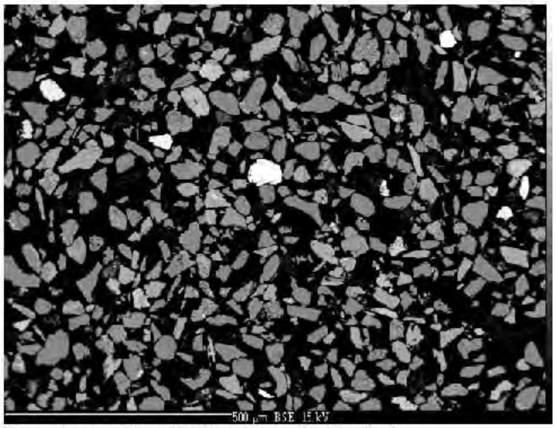
sample 8	image 1	image 2	image 3	image 4	Totals	
no. less than 2.5	3	8	5	4	20	20.00%
no. less than 10 (inclusive)	23	25	35	17	100	33.33%
total no. grains in fov	79	77	91	53	300	300



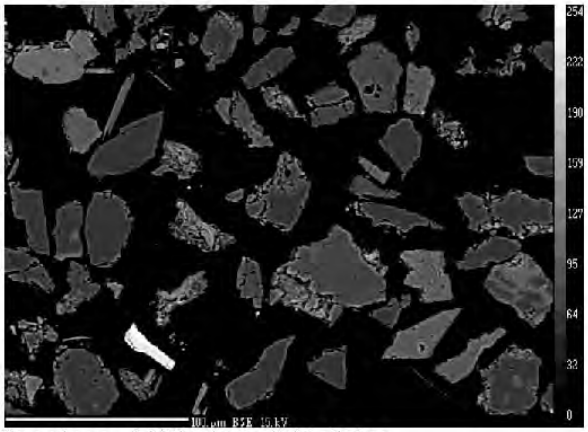
Sample no. 2 300 micron field of view.



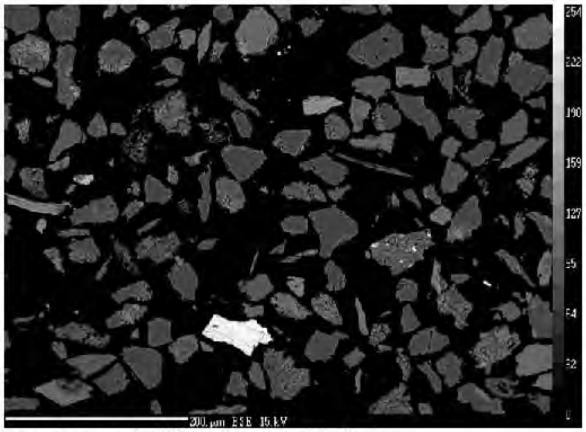
Sample no. 2 600 micron field of view.



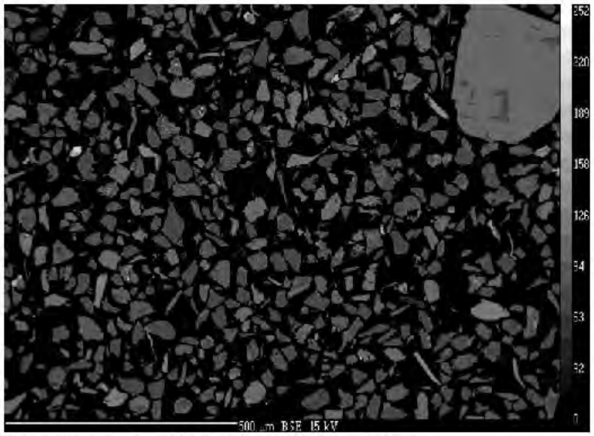
Sample no. 2 1200 micron field of view.



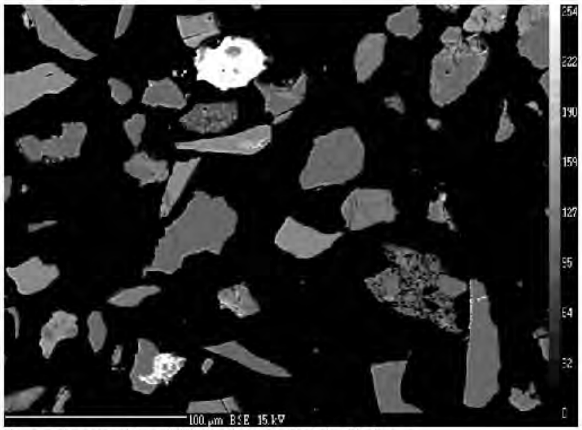
Sample no. 4 300 micron field of view.



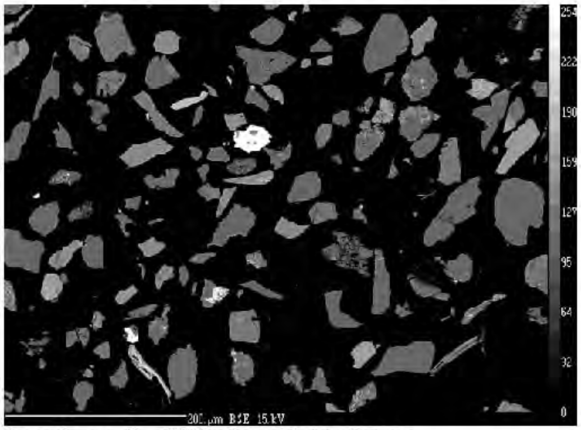
Sample no. 4 600 micron field of view.



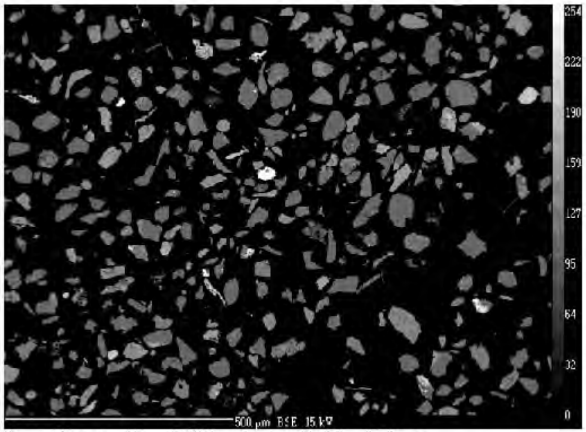
Sample no. 4 1200 micron field of view.



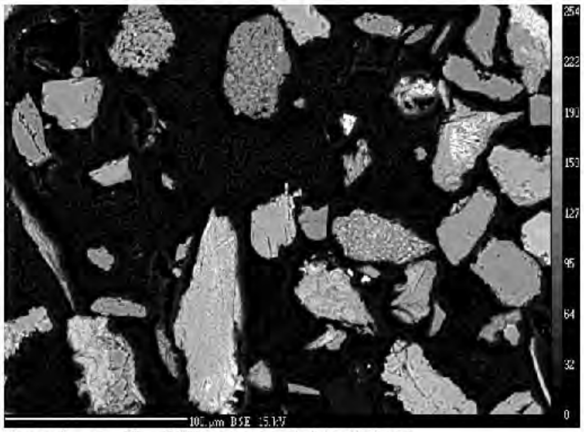
Sample no. 5 300 micron field of view.



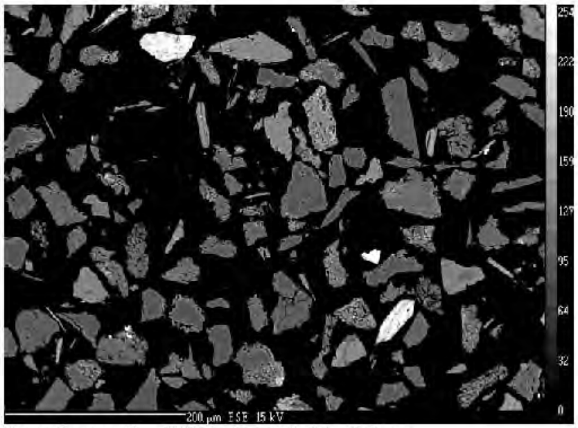
Sample no. 5 600 micron field of view.



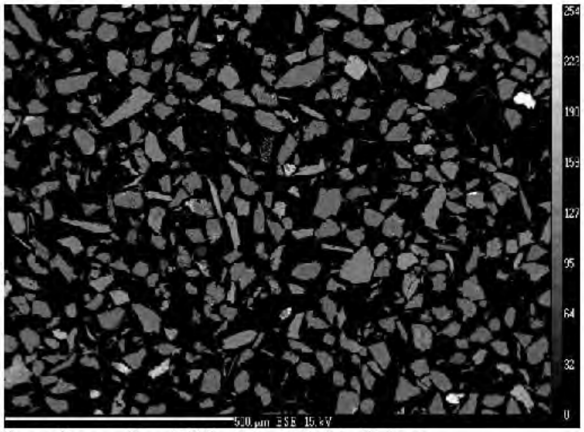
Sample no. 5 1200 micron field of view.



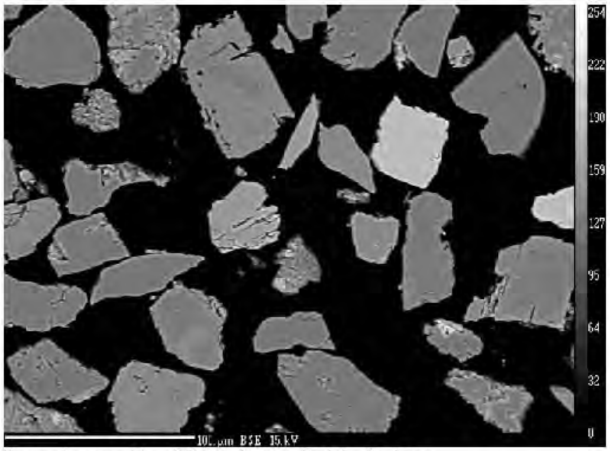
Sample no. 6 300 micron field of view.



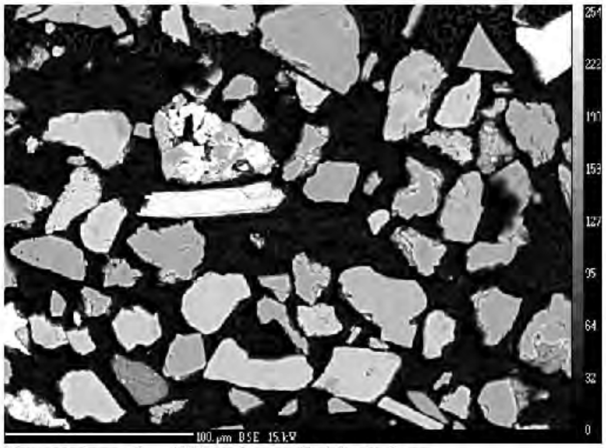
Sample no. 6 600 micron field of view.



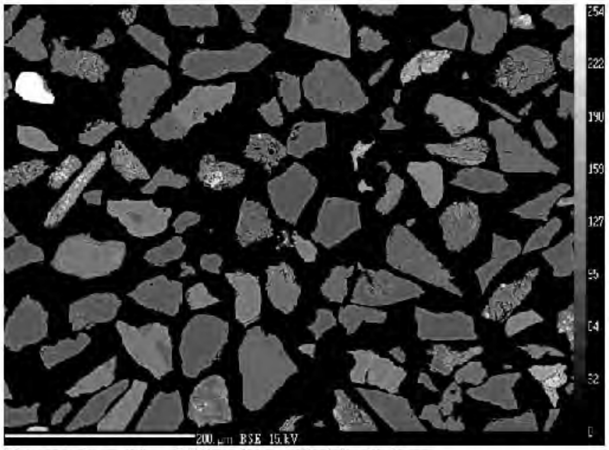
Sample no. 6 1200 micron field of view.



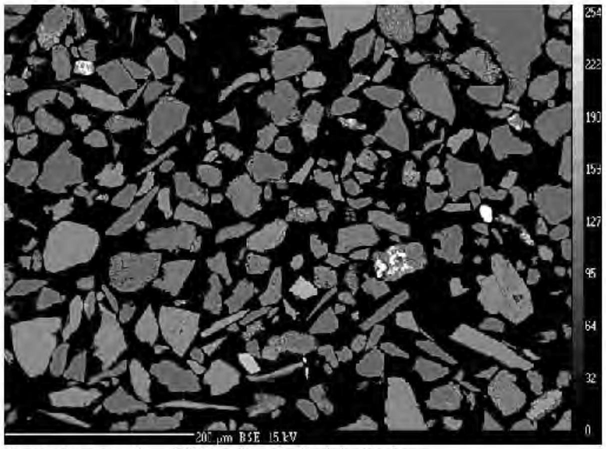
Sample no. 7 300 micron field of view.



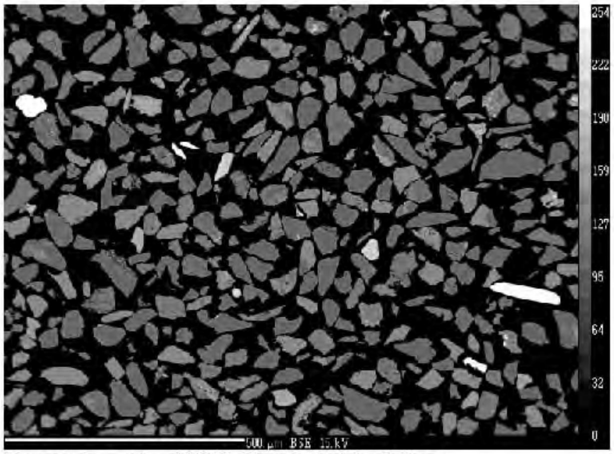
Sample no. 8 300 micron field of view.



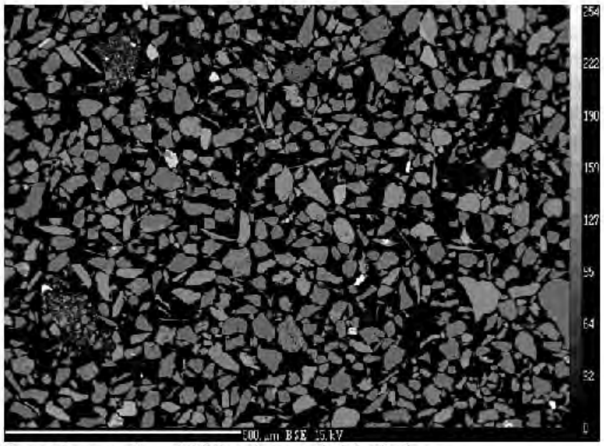
Sample no. 7 600 micron field of view.



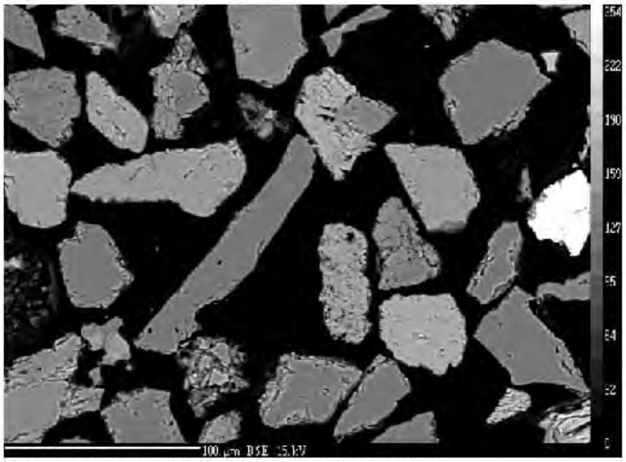
Sample no. 8 600 micron field of view.



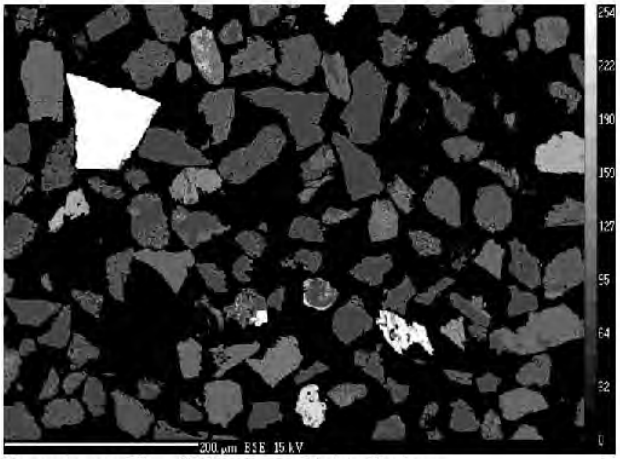
Sample no. 7 1200 micron field of view.



Sample no. 8 1200 micron field of view.



Sample no. 9 300 micron field of view.



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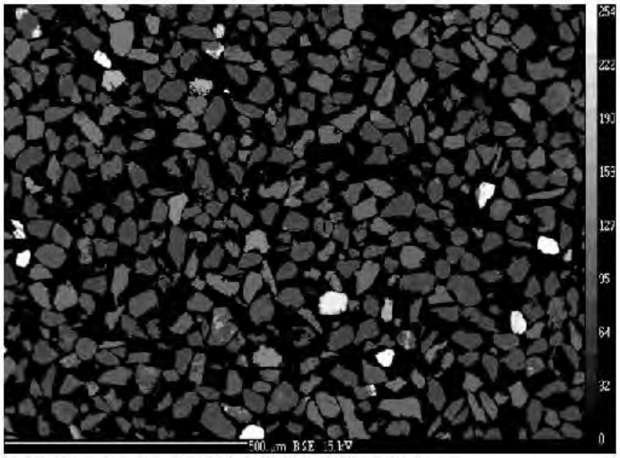
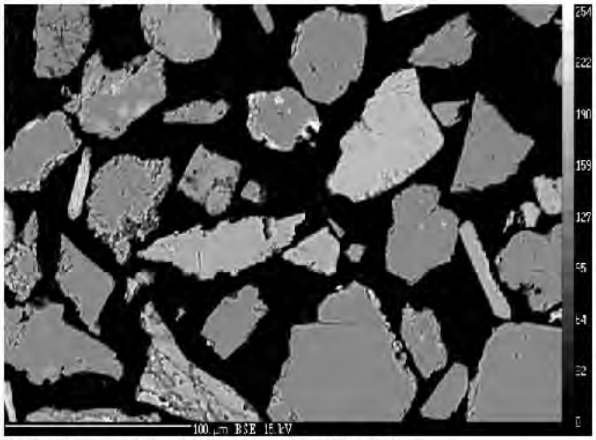


Sample no. 9 1200 micron field of view.



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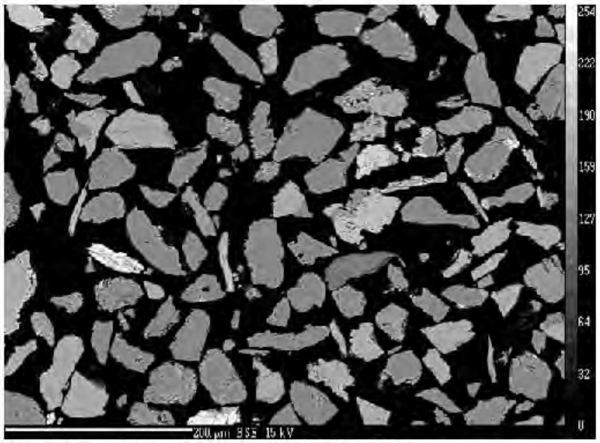
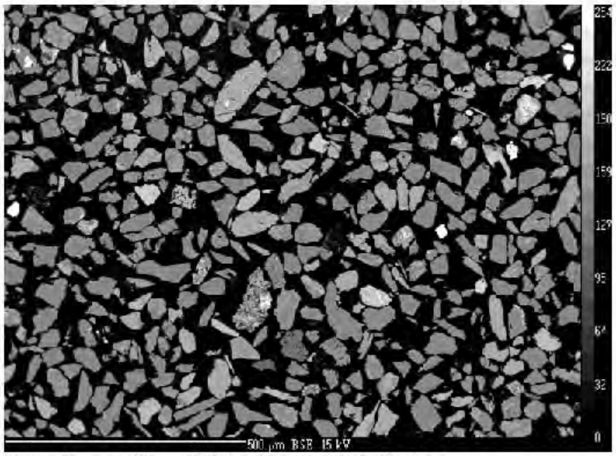
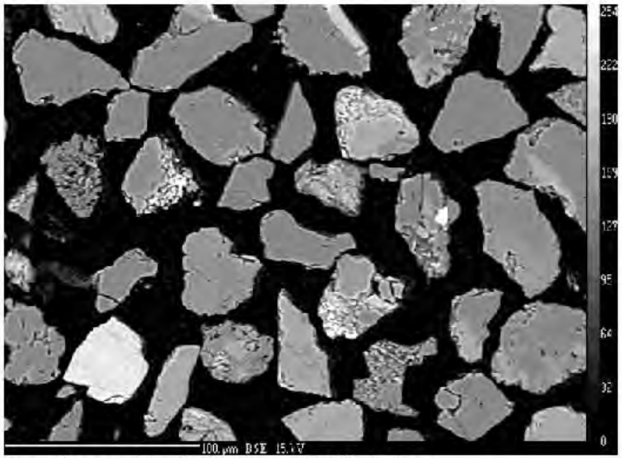


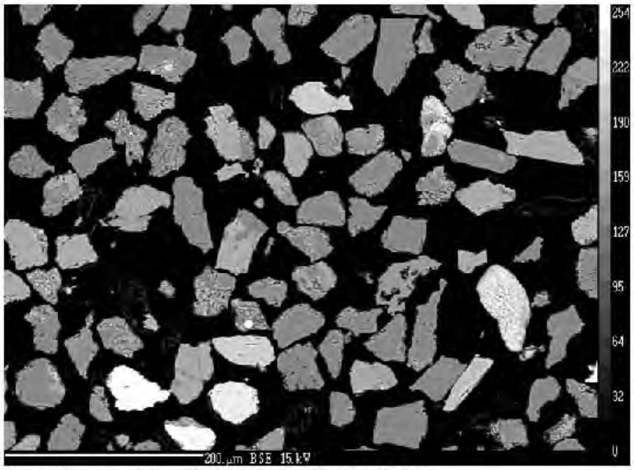
Sample no. 10 600 micron field of view.



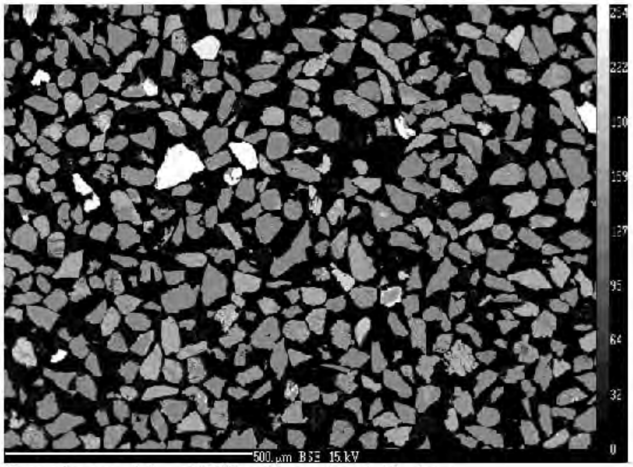
Sample no. 10 1200 micron field of view.



Sample no. 11 300 micron field of view.



Sample no. 11 600 micron field of view.



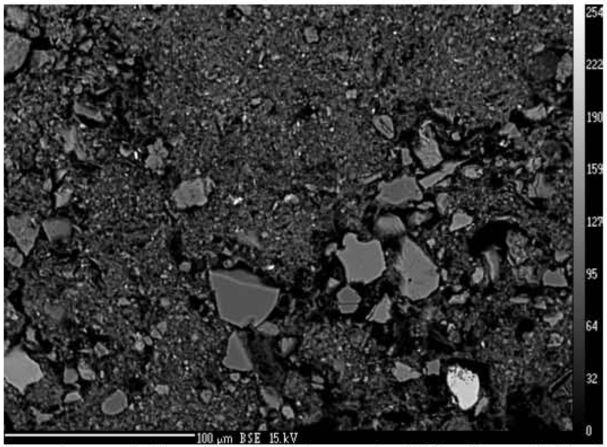
Sample no. 11 1200 micron field of view.

Appendix E: Comparison of Fine Particles on Fences

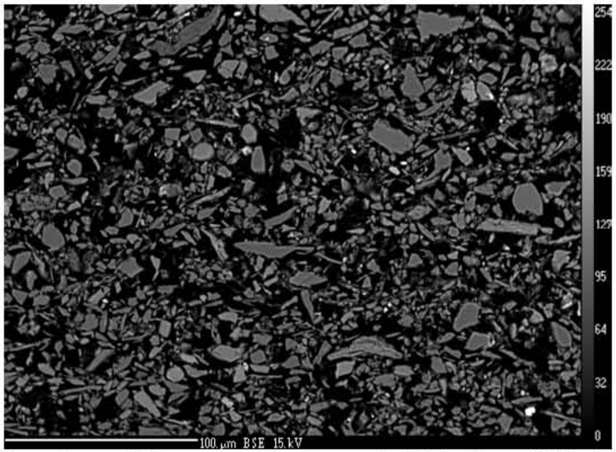
MINERAL COMPOSITION OF FINE MATERIALS ON FENCES (Roeske, 2011)

Mineral	Fence fine no. 4	fence fine no. 7
Quartz	29	27
Plagioclase (includes albite)	18	18
K-feldspar	24	24
Silica shell	7	1
Muscovite	3	4
Biotite	3	4
Chlorite	1	4
Clay	2	2
Carbonate (includes calcite and dolomite)	3	0
Amphibole	1	1
Clinopyroxene	0	0
Fe-oxide and Fe-Ti oxide	5	7
Apatite	1	2
Zircon	1	0
Epidote	0	1
Titanite (sphene)	0	0
Serpentine	1	1
Lithic - mudstone	0	4
FeS	1	0
Total	100	100

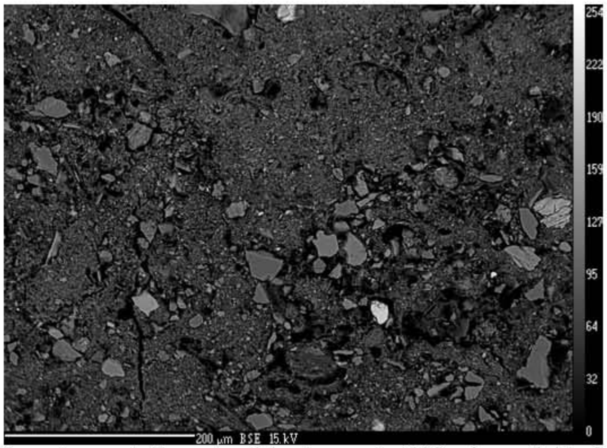
Composition information:		
Total SiO2 (quartz and SiO2 - shell fragments)	36.00%	28.00%



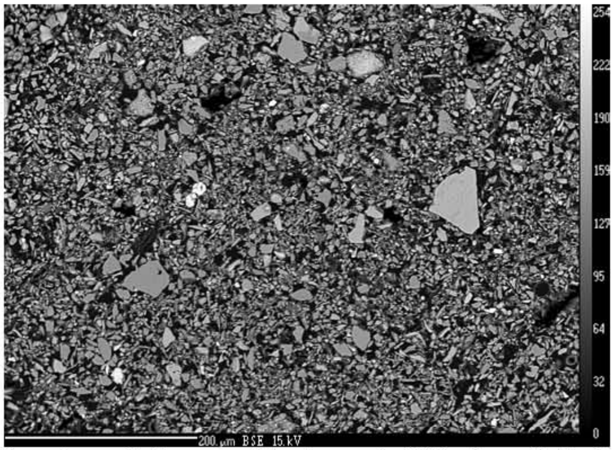
Sample no. 4 Fence polished sample 300 micron field of view.



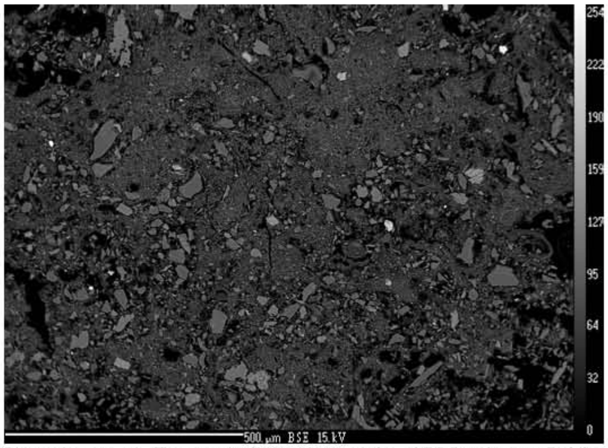
Sample no. 7 Fence polished sample 300 micron field of view.



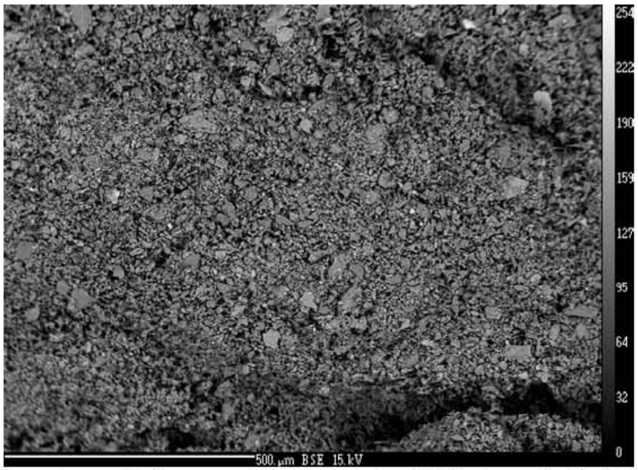
Sample no. 4 Fence polished sample 600 micron field of view.



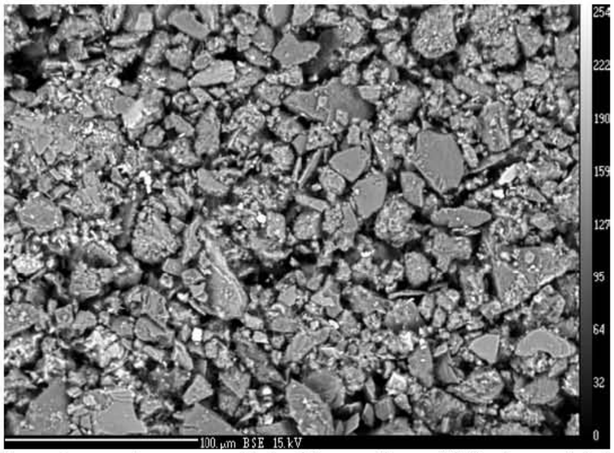
Sample no. 7 Fence polished sample 600 micron field of view.



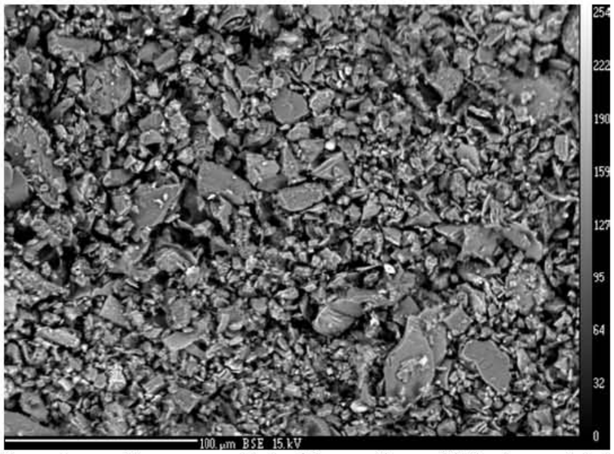
Sample no. 4 Fence polished sample 1200 micron field of view.



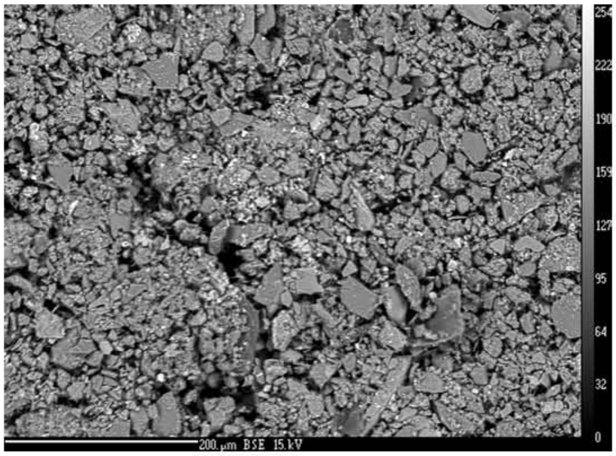
Sample no. 7 Fence polished sample 1200 micron field of view.



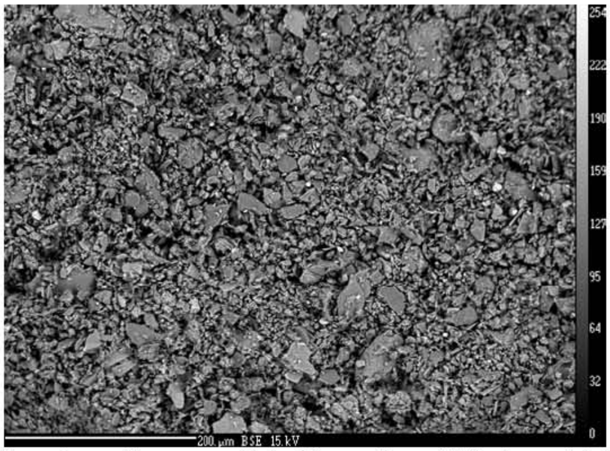
Sample no. 4 non-polished fence fines 300 micron field of view



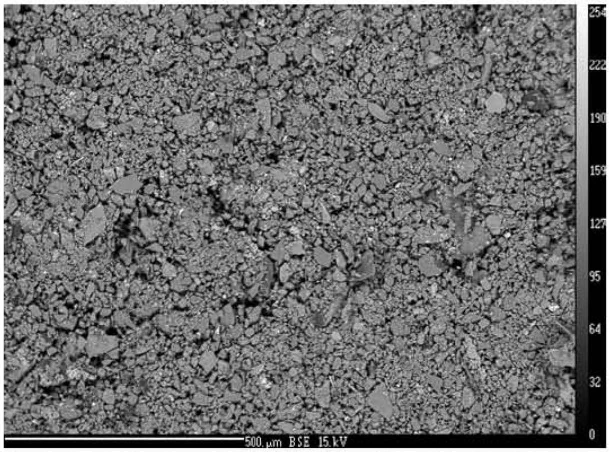
Sample no. 7 non-polished fence fines 300 micron field of view



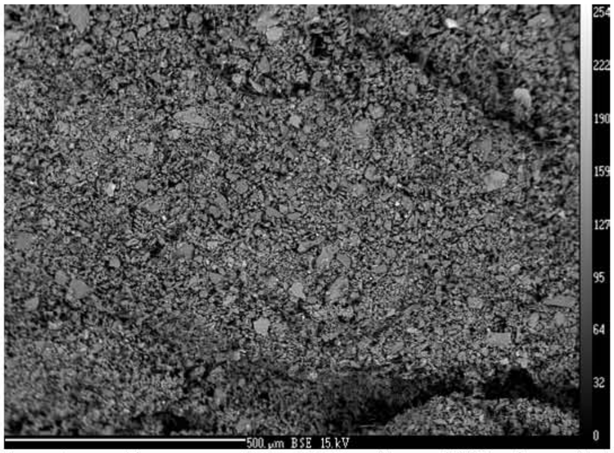
Sample no. 4 non-polished fence fines 600 micron field of view



Sample no. 7 non-polished fence fines 600 micron field of view



Sample no. 4 non-polished fence fines 1200 micron field of view



Sample no. 7 non-polished fence fines 1200 micron field of view