Grain size analysis of U.S. Geological Survey sediment grab samples (SFB-98-1 to SFB-98-56) for the purpose of benthic habitat identification in San Francisco Bay, California

Prepared for:

Michele Jacobi
NOAA
National Ocean Services
Office of Response and Restoration
Coastal Protection & Restoration Div. Bldg 4
7600 Sand Point Way NE
Seattle, WA 98115

Prepared by:

Steve Watt
Center for Habitat Studies
Moss Landing Marine Laboratories
8272 Moss Landing Road
Moss Landing, CA 95039

Introduction

Geophysical seafloor imagery (side-scan sonar and multibeam bathymetry) within the San Francisco Bay area are being analyzed and interpreted into marine benthic habitat maps using the methodology described in Greene et al, 1999. To aid in the interpretation of these images, 56 surface sediment grab samples collected in the San Francisco Bay region by the U.S. Geological Survey (USGS) were analyzed at the USGS Marine Sediment Lab (MSL) in Menlo Park, California for grain size characteristics following USGS MSL standards. MSL standards are based on the work of Carver (1971), Folk (1974), Folk & Ward (1957), Inman (1952), Krumbein & Pettijohn (1938), and Trask (1930). The grain size analyses provided geographically located physical evidence of seafloor surface substrate, a valuable tool when displayed over the geophysical imagery and interpretations.

Methods

With the guidance of Dr. Jon Chin, Mike Torresan and Simon Barber of the MSL at the USGS, the appropriate San Francisco Bay sediment grab samples were located and organized. One sample was missing (sample ID SFB-98-09) from the expected 56 sample total and 13 samples had duplicates (Figure 1). Samples were analyzed to half phi intervals ranging from greater than –1 phi (2.00 mm) to 11 phi (0.00049 mm) and at 14 phi (0.00006). Samples were separated by wet sieving at -1 phi (2.00 mm), -0.5 phi (1.4 mm), and 0 phi (1.00 mm) grain diameters. Sample grain diameters below 0 phi (1.00 mm) were analyzed using a Beckman Coulter Light Scattering (LS) particle analyzer. The sieve data and the data produced using the Beckman Coulter LS particle analyzer were combined to produce an over all grain size distribution and descriptive statistics for each individual sample using SedSize, a USGS developed Unix based computer program. Using the Folk and Ward (1957) mean grain diameter calculated by SedSize, the samples were categorized into Wentworth size classes (Wentworth, 1922) (Table 1 and 2). For a detailed description of sediment sample preparation and grain size analysis techniques, see Appendix A and for individual grain size distributions and statistical parameters, see Appendix B.

Results

The 56 USGS sediment grab samples were mapped according to individual Wentworth size classes along with a note about whether or not the sample contained large amounts of shell debris and geographically displayed over multibeam images collected by the USGS, and other multibeam and side-scan sonar imagery supplied by NOAA NOS using GIS. The samples provide physical evidence or “ground truth” of seafloor surface substrate to aid in the interpretation of the geophysical images. An example of how the sediment data is displayed over a multibeam image is shown in Figure 2.

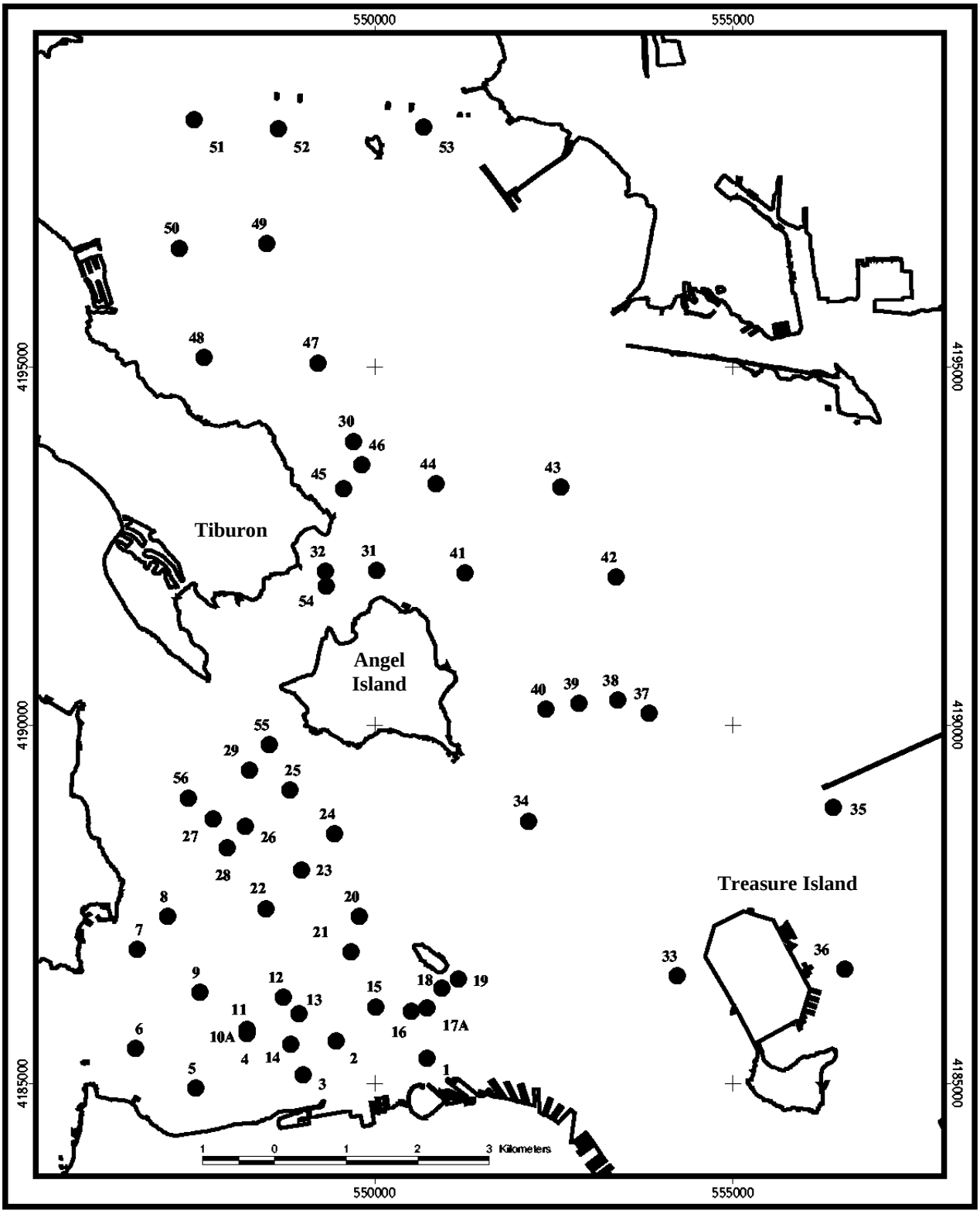

Figure 1. Location of the 56 USGS collected sediment grab samples within the San Francisco Bay

Phi diameter	mm diameter	Classification
< -8.0	> 256	boulder
-6.0 to -8.0	64 to 256	cobble
-2.0 to -6.0	4.00 to 64	pebble
-1.0 to -2.0	2.00 to 4.00	granule
0.0 to -1.0	1.00 to 2.00	very coarse sand
1.0 to 0.0	0.50 to 1.00	coarse sand
2.0 to 1.0	0.25 to 0.50	medium sand
3.0 to 2.0	0.125 to 0.25	fine sand*
4.0 to 3.0	0.0625 to 0.125	very fine sand
5.0 to 4.0	0.031 to 0.0625	coarse silt
6.0 to 5.0	0.0156 to 0.031	medium silt
7.0 to 8.0	0.0078 to 0.0156	fine silt
8.0 to 7.0	0.0039 to 0.0078	very fine silt
> 8.0	< 0.0039	clay

Table 1. Break down of Wentworth grain-size classification based on Folk and Ward (1957) mean grain diameter in phi and millimeter.

Sample ID	Folk & Ward mean (phi)	Wentworth Size Class	Northing	Easting
1	-0.26	Very Coarse Sand (w/shells)	550727.9627	4185338.014
2	1.64	Medium Sand	549457.2314	4185577.702
3	2.16	Fine Sand	549004.0928	4185106.765
4	1.78	Medium Sand	548214.655	4185682.387
5	4.71	Coarse Silt	547501.6708	4184925.974
5R	4.07	Coarse Silt	547501.6708	4184925.974
6	1.4	Medium Sand	546660.5378	4185475.926
7	-0.49	Very Coarse Sand	546685.2489	4186859.656
8	2.26	Fine Sand	547113.8246	4187322.559
9	MISSING	MISSING	547556.4237	4186265.5
10A	1.5	Medium Sand	548220.7251	4185697.957
11	0.1	Coarse Sand	548211.6308	4185747.832
12	1.08	Medium Sand	548720.3689	4186194.646
13	1.97	Medium Sand	548944.402	4185966.302
14	1.71	Medium Sand	548829.0141	4185536.224
15	6.26	Fine Silt	550010.5841	4186060.37
16	6.05	Fine Silt	550513.5409	4185996.872
17A	2.57	Fine Sand	550728.0043	4186044.793
18	1.08	Medium Sand	550934.9024	4186319.019
19	0.24	Coarse Sand	551161.1861	4186445.803
20	0.29	Coarse Sand	549782.0085	4187324.971
21	0.63	Coarse Sand	549665.3068	4186831.628
22	0.27	Coarse Sand	548476.3132	4187432.559
23	1.38	Medium Sand	548978.269	4187963.677
24	1.05	Medium Sand	549440.6928	4188473.507
25	0.23	Coarse Sand (w/shells)	548819.3657	4189086.699
26	0.42	Coarse Sand (w/shells)	548190.6154	4188581.473
27	-0.15	Very Coarse Sand	547747.4592	4188680.964
28	1.9	Medium Sand	547938.1131	4188275.982
29	0.44	Coarse Sand	548251.1625	4189358.509
30	0.6	Coarse Sand	549705.7829	4193954.063
31	1.83	Medium Sand	550025.4129	4192150.763
32	0.39	Coarse Sand (w/shells)	549309.5672	4192139.774
33	7.08	Very Fine Silt	554217.5196	4186493.127
34	5.8	Medium Silt	552144.349	4188653.324
35	6.32	Fine Silt	556396.3985	4188844.514
36	6.86	Fine Silt	556553.615	4186583.203
37	4.57	Coarse Silt	553824.7359	4190158.732
38	5.65	Medium Silt	553393.3584	4190342.321
39	5.46	Medium Silt	552847.3797	4190293.298
40	3.08	Very Fine Sand	552384.2685	4190215.991
41	4.34	Very Fine Sand	551262.1859	4192119.56
42	6.17	Fine Silt	553370.7849	4192055.332
43	4.98	Coarse Silt	552589.6219	4193314.077
44	5.61	Medium Silt	550849.9279	4193359.697
45	0.15	Coarse Sand	549569.1015	4193290.833
46	1.26	Medium Sand	549817.6933	4193625.205
47	0.8	Coarse Sand (w/shells)	549211.2147	4195046.211
48	6.41	Fine Silt	547618.5944	4195117.805
49	5.17	Medium Silt	548492.7494	4196709.592
50	6.52	Fine Silt	547269.5156	4196650.296
51	5.9	Medium Silt	547477.1502	4198437.882
52	1.09	Medium Sand	548655.5131	4198312.759
53	3.2	Very Fine Sand	550681.076	4198338.357
54	1.57	Medium Sand	549325.7317	4191937.932
54R	2.08	Fine Sand	549325.7317	4191937.932
55	1.33	Medium Sand	548529.7095	4189715.204
56	1.36	Medium Sand	547395.5756	4188975.174
56R	1.18	Medium Sand	547395.5756	4188975.174

Table 1. Grain size parameters used to aid in benthic habitat interpretations of San Francisco Bay geophysical seafloor imagery. Where shells were present in the samples, they were included with the Wentworth size class of the sediment sample.

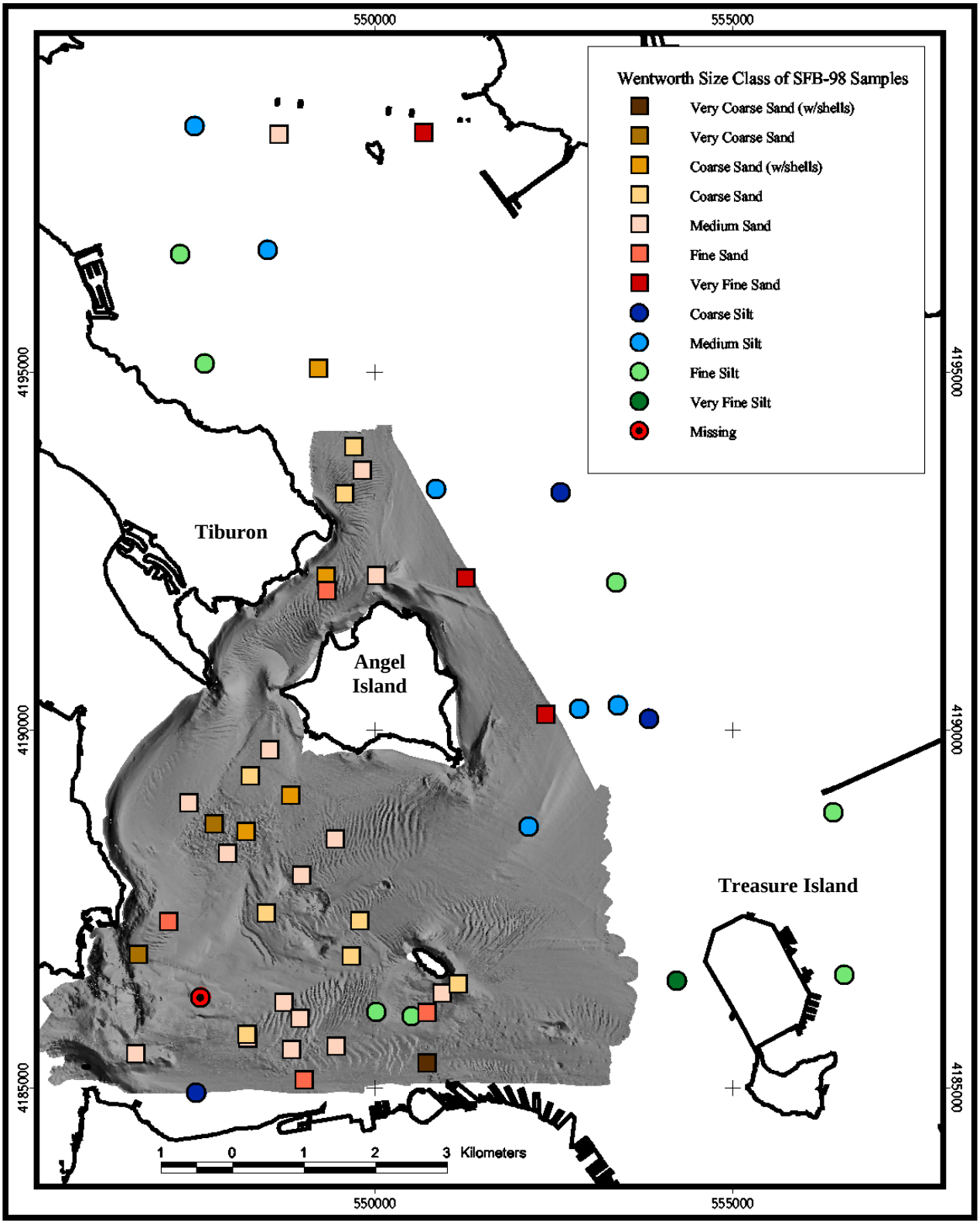

Figure 2. Example of geographically located grain size data displayed over a San Francisco Bay area multibeam image produced by the USGS.

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Appendix A.

Sediment Sample Analysis Protocol (USGS MSL)

1. Sample Preparation

- Mix each individual sample thoroughly to homogenize
- Add representative sample to a 1000 ml beaker
- Add 100-200ml of DI water and stir sample to completely disaggregate sediment grains
- Add 5-10 ml of 30% hydrogen peroxide to oxidize any organic matter, let stand over night
- Gently boil off hydrogen peroxide for 2-4 hours, adding DI water if necessary
- Wash entire sample into a pre-labeled 250 ml centrifuge bottle. Place samples in centrifuge, making sure to balance the weight across the centrifuge in pairs. Use DI water to equalize weights so that the centrifuge will not vibrate. Run centrifuge, slowly turning the speed up to 36 rpm, for 30 minutes. Removed sample and decanted water to remove excess soluble salts.
- Add DI water and mix sample repeating the centrifuge process for an 60 additional minutes. Decant excess water, removing soluble salts.

2. Wet Sieving

- Rinse sample from centrifuge tubes over a 2mm, 1.4mm and 1mm sieves and a funnel using DI water into a pre-labeled 1000ml graduated cylinder, saving the less than 1mm portion of the sample in the cylinder for analyzing by the Beckman Coulter LS Particle Size Analyzer.
- Place the sieved coarse fraction (>2mm gravels) on a pre-labeled drying dish and place in oven
- Place the sieved intermediate (2mm to 1.4 mm sands) on a pre-labeled drying dish and place in oven.
- Place sand fraction (1.4mm to 1mm sands) on a pre-labeled drying dish and place in oven.
- Weigh all sieve fractions when completely dry to apply in the SedSize grain size analysis program

3. Coulter Counter (processing the <1mm sediment sample fraction)

- Weigh and record three metal weighing tins using gloves to keep from affecting the weight
- Add 10 ml of Calgon dispersing solution to each tin.
- Dry tins, subtract from the original tin weight to find the weight of Calgon then average the three weights to subtract from the <1mm sample weight later.
- Add 10 ml of the Calgon solution to the less than 1mm sediment sample collected in the graduated cylinders. This will disperses the clays and keep them from sticking together. Bring level of cylinder to 1000ml using DI water and agitate sample to disperse Calgon uniformly throughout the sample. Let stand over night.

- The following day, use latex gloves to label and weigh 1000ml beaker and added entire dispersed sample from 1000ml-graduated cylinder. Place under mechanical agitator and mix sample.

- Running the Beckman Coulter LS Particle Analyzer

- Turn on tap water in sink connected to the Coulter Counter. It doesn't have to be on hard. Remove yellow lid where you add sample.

- From the adjacent computer, click on "Coulter Counter" desktop icon. Use 'optical module'. From the Control menu click "pump on", then "rinse". Wipe out the reservoir with a paper towel to remove any residual sediment. Then click "open drain" to clear the water then "close drain".

- Fill with deoxygenated DI water available in carboys opposite the machine. Fill reservoir between the second and third sensors. The water should be swirling in the reservoir. If not you must manually open the valve, siphon out the air lock, manually close the drain, and add more water until it is visibly swirling. If you add too much water, manually open the drain and let some out.

- From the Preferences menu choose "Preference Files" then "Load Preferences". Find the appropriate preference file from the Preference files folder. In our case, the file will run the analysis three times.

- From the "Run" menu choose "Run Cycle". Turn off the "Auto Rinse" and click "New Sample" then "Start". The computer should start by measuring background noise, etc. When the screen displays the message "low add sample" begin adding sample to the swirling water reservoir.

- Pipette sample from the still agitating sample into the water reservoir until the computer message says "O.K.", when the obscuration rate is between 8% and 12%.

- Type in the sample ID number, etc in the spaces provided and run the sample.

- After the sample is run, overlay the graphs of the three sample runs and average for the final grain size distribution. Print results and save for later use in the SedSize program.

- Drain the sample from the Coulter Counter and recombine with the sample in the 1000 ml beaker. Dry the sample completely in the oven over night and weigh for a total fine sample weight.

4. SedSize (combining fine and coarse sediment data)

- SedSize is a Unix based program that combines weights of the greater than 1mm fraction with percentages of the less than 1 mm to produce an over all grain size distribution. The program automatically calculates mean, sorting, skewness and kurtosis using a variety of methods as well as the percentages of sand, silt and clay present in the samples. The program also produces ratios of gravel, sand silt and clay as well.

Appendix B.

Grain size distributions and descriptive statistical parameters

SFBay-98 USGS grain size samples 1 - 14

	1	2	3	4	5	5R	6	7	8	10A	11	12	13	14
Phi -1	62.18	0	0	0	0	0	0	35.76	1.66	0	20.87	1.38	0	0
-0.5	1.32	0	0	0	0.18	0.11	0.11	13.52	2.65	0	8.8	0.41	0	0
0	0.53	0.18	0	0	0.29	0.23	0.26	15.15	2.56	0	11.63	0.41	0	0.1
0.5	2.46	4.18	0	0	0	0	6.97	21.64	4.43	4.1	15.79	8.27	0	3.61
1	2.43	7.7	0.03	1.52	0.01	0.01	14.84	10.69	8.7	11.4	17.85	31.43	0.32	4.46
1.5	10.22	28.75	7.61	24.88	1.11	1.65	36.46	2.06	15.37	33.9	15.15	41.56	13.28	25.1
2	10.36	36.54	32.16	44.5	8.23	11.99	27.4	0.64	15.37	35.4	4.93	14.96	39.4	37.86
2.5	5.65	18.07	39.8	23.3	18.51	24.81	8.87	0.28	16.48	13.4	1.88	0.98	34.7	22.68
3	1.4	2.89	14.5	2.8	13.64	16.74	2.09	0.11	11.45	1.5	0.76	0.59	8.3	4.2
3.5	0.29	0.5	1.5	0.5	5.47	5.48	0.6	0.04	3.63	0.3	0.29	0	0.9	0.5
4	0.18	0.3	0.7	0.4	4.58	3.89	0.2	0	1.77	0	0.18	0	0.4	0.3
4.5	0.18	0.1	0.3	0.2	4.68	3.79	0.2	0.04	1.68	0	0.23	0	0.3	0.1
5	0.22	0.1	0.3	0.2	4.08	3.09	0.2	0	1.49	0	0.23	0	0.3	0.1
5.5	0.22	0.1	0.3	0.2	3.38	2.49	0.1	0	1.3	0	0.18	0	0.2	0.1
6	0.18	0	0.2	0.1	3.38	2.39	0.2	0.04	1.21	0	0.18	0	0.2	0.1
6.5	0.25	0.1	0.3	0.2	3.38	2.39	0.2	0	1.21	0	0.12	0	0.2	0.1
7	0.25	0.1	0.3	0.1	3.58	2.59	0.1	0	1.21	0	0.18	0	0.2	0.1
7.5	0.29	0.1	0.3	0.2	3.98	2.79	0.2	0.02	1.21	0	0.12	0	0.2	0.1
8	0.32	0.1	0.3	0.2	4.18	2.99	0.2	0.01	1.3	0	0.12	0	0.2	0.1
8.5	0.29	0.1	0.3	0.2	4.08	2.89	0.2	0	1.3	0	0.18	0	0.2	0.2
9	0.25	0	0.3	0.2	3.48	2.59	0.2	0	1.12	0	0.12	0	0.2	0.1
9.5	0.22	0.07	0.3	0.2	2.89	2.29	0.2	0	1.02	0	0.12	0	0.2	0
10	0.14	0.03	0.2	0.06	2.69	1.99	0.1	0	0.84	0	0.06	0	0.2	0.09
10.5	0.11	0	0.2	0.03	2.19	1.49	0.08	0	0.56	0	0.05	0	0.08	0.01
11	0.06	0	0.08	0.01	1.59	1	0.02	0	0.37	0	0.01	0	0.02	0
14	0.01	0	0.02	0	0.4	0.3	0	0	0.09	0	0	0	0	0
% Gravel	62.18	0	0	0	0	0	0	35.76	1.66	0	20.87	1.38	0	0
% Sand	34.83	99.1	96.3	97.9	52.02	64.92	97.81	64.13	82.41	100	77.25	98.62	97.3	98.8
% Silt	1.91	0.7	2.3	1.4	30.66	22.52	1.39	0.1	10.62	0	1.35	0	1.8	0.8
% Clay	1.08	0.2	1.4	0.7	17.32	12.56	0.8	0	5.31	0	0.53	0	0.9	0.4
% Mud	2.99	0.9	3.7	2.1	47.98	35.08	2.19	0.11	15.92	0	1.88	0	2.7	1.2
Gravel/ Sand	1.79	0	0	0	0	0	0	0.56	0.02	0	0.27	0.01	0	0
Sand/ Silt	18.27	141.82	41.87	69.93	1.7	2.88	70.12	621.8	7.76	0	57.21	0	54.06	123.63
Silt/ Clay	1.77	3.5	1.64	2	1.77	1.79	1.75	28.95	2	0	2.56	0	2	2
Sand/ Clay	32.28	496.41	68.79	139.86	3	5.17	122.71	n/a	15.53	0	146.21	0	108.11	247.25
Sand/ Mud	11.67	110.31	26.03	46.62	1.08	1.85	44.62	601.04	5.18	0	41.12	0	36.04	82.42
Gravel/ Mud	20.83	0	0	0	0	0	0	335.13	0.1	0	11.11	0	0	0
1st moment	-0.06	1.64	2.3	1.88	4.74	4.08	1.5	-0.4	2.48	1.49	0.3	1.05	2.1	1.75
Variance	3.59	0.57	1.28	0.81	7.56	6.67	1.12	0.68	5.42	0.28	1.89	0.3	0.94	0.67
Std. deviation	1.89	0.76	1.13	0.9	2.75	2.58	1.06	0.82	2.33	0.53	1.37	0.54	0.97	0.82
3rd moment	2.18	3.27	4.43	5.1	0.66	1.1	4.21	0.98	1.56	-0.13	2.23	-0.97	4.82	3.77
4th moment	9.55	29.67	26.65	37.24	2.21	3.03	28.81	6.73	5.42	3.14	13.7	6.72	33.06	32.07
F&W median	-1.1	1.6	2.07	1.76	3.77	2.74	1.42	-0.47	1.98	1.5	0.29	1.05	1.99	1.71
F&W mean	-0.26	1.64	2.16	1.78	4.71	4.07	1.4	-0.49	2.26	1.5	0.1	1.08	1.97	1.71
F&W sorting	1.36	0.55	0.51	0.49	2.72	2.49	0.6	0.8	2.07	0.47	1.13	0.47	0.45	0.47
F&W skewness	0.82	0.01	0.26	0.09	0.48	0.76	-0.02	0.06	0.36	-0.14	-0.13	0.03	-0.04	-0.04
F&W kurtosis	0.59	1.31	1.66	1.05	0.72	0.91	1.39	0.61	2.23	1.03	0.8	1.47	1.43	1.08
I. median	-1.1	1.6	2.07	1.76	3.77	2.74	1.42	-0.47	1.98	1.5	0.29	1.05	1.99	1.71
I. mean	0.17	1.66	2.21	1.79	5.18	4.73	1.39	-0.49	2.4	1.5	0	1.09	1.97	1.71
I. sorting	1.54	0.52	0.45	0.5	2.98	2.69	0.54	0.93	1.58	0.48	1.2	0.42	0.42	0.34
I. skewness 1	0.82	0.11	0.3	0.05	0.47	0.74	-0.05	-0.02	0.27	-0.01	-0.24	0.1	-0.05	-0.01
I. skewness 2	1.04	-0.18	0.48	0.2	0.67	1.09	0.01	0.17	1.2	-0.4	-0.02	-0.06	-0.07	-0.19
I. kurtosis	0.28	0.82	1.15	0.59	0.37	0.41	1.02	0.19	1.68	0.53	0.44	1.03	0.87	1.95
T. median	2.14	0.33	0.24	0.3	0.07	0.15	0.37	1.39	0.25	0.35	0.82	0.48	0.25	0.3
T. mean	1.41	0.32	0.22	0.3	0.1	0.12	0.4	1.64	0.29	0.36	1.1	0.47	0.26	0.32
T. sorting	2.6	1.23	1.18	1.24	4.97	3.25	1.25	1.68	1.71	1.23	1.85	1.18	1.17	1.3
T. skewness	0.2	0.92	0.87	0.97	0.26	0.19	1.06	1.08	1.01	0.99	1.28	0.92	1.07	1.01
T. kurtosis	0.43	0.22	0.19	0.28	0.36	0.34	0.21	0.36	0.19	0.21	0.27	0.18	0.18	0.31

SFBay-98 USGS grain size samples 15 - 27

	15	16	17A	18	19	20	21	22	23	24	25	26	27
Phi -1	3.1	2.36	31.77	24.83	0	34.83	3.01	35.07	0.4	1.61	48.45	35.17	24.12
-0.5	0.24	0.7	2.12	1.83	18.2	5.48	4.24	0	0.4	2.17	0.24	3.3	11.67
0	0.16	0.91	1.24	0	22.52	3.54	8.2	0.51	1.08	4.28	0.21	2.55	16.04
0.5	0	0	1.76	3.59	22.35	7.92	27.82	10.37	7.39	17.83	10.53	6.31	20.28
1	0	0	3.35	0.89	18.73	9.38	28.24	18.36	14.39	22.89	6.29	6.67	15.46
1.5	0.01	0.26	8.19	8.58	10.31	15.27	18.85	21.26	33.07	25.37	7.15	15.93	8.33
2	1.66	5.14	8.04	18.99	4.56	14.26	7.36	10.76	30.32	16.27	11.7	19.94	2.99
2.5	4.79	5.17	5.25	23.54	2.31	6.91	1.69	2.58	10.2	6.8	10.53	9.02	0.67
3	2.33	1.25	2.34	9.39	0.71	1.74	0.34	0.58	1.47	2.02	3.58	0.94	0.29
3.5	4.54	2.5	1.17	1.54	0.12	0.28	0.08	0.19	0.49	0.28	0.51	0.18	0.05
4	5.79	3.94	1.23	0.59	0.06	0.06	0.08	0	0.2	0.09	0.26	0	0
4.5	6.47	5.95	1.69	0.51	0	0.06	0	0.06	0	0.09	0.1	0	0.05
5	6.56	6.82	2.21	0.51	0.06	0.06	0	0	0.1	0	0.1	0	0
5.5	5.5	6.15	2.47	0.51	0	0	0	0.06	0.1	0.09	0.05	0	0
6	5.11	5.86	2.72	0.44	0	0	0	0	0	0	0.05	0	0.02
6.5	5.31	5.86	2.98	0.44	0.04	0.06	0.06	0.06	0.1	0	0.05	0	0.02
7	5.79	6.24	3.05	0.51	0.01	0	0.02	0.06	0	0.09	0.05	0	0
7.5	6.66	6.91	3.24	0.51	0.01	0.06	0.01	0	0.1	0	0.05	0	0
8	7.14	7.3	3.31	0.51	0	0	0	0	0.1	0	0	0	0
8.5	6.95	6.72	3.05	0.51	0	0.06	0	0.04	0	0.06	0.05	0	0
9	5.98	5.67	2.59	0.51	0	0	0	0.01	0.05	0.02	0.03	0	0
9.5	5.02	4.61	2.08	0.44	0	0.04	0	0.01	0.03	0.01	0.02	0	0
10	4.25	3.84	1.75	0.37	0	0.01	0	0.01	0.02	0.01	0.01	0	0
10.5	3.57	3.17	1.36	0.22	0	0	0	0	0	0	0	0	0
11	2.41	2.11	0.78	0.15	0	0	0	0	0	0	0	0	0
14	0.68	0.58	0.26	0.07	0	0	0	0	0	0	0	0	0
% Gravel	3.1	2.36	31.77	24.83	0	34.83	3.01	35.07	0.4	1.61	48.45	35.17	24.12
% Sand	19.51	19.86	34.69	68.94	99.88	64.83	96.91	64.61	99.01	98.02	50.99	64.83	75.78
% Silt	48.54	51.09	21.67	3.96	0.12	0.22	0.08	0.26	0.49	0.28	0.46	0	0.1
% Clay	28.85	26.7	11.87	2.27	0	0.11	0	0.06	0.1	0.09	0.1	0	0
% Mud	77.39	77.78	33.54	6.23	0.12	0.34	0.08	0.32	0.59	0.37	0.56	0	0.1
Gravel/ Sand	0.16	0.12	0.92	0.36	0	0.54	0.03	0.54	0	0.02	0.95	0.54	0.32
Sand/ Silt	0.4	0.39	1.6	17.41	850.94	288.64	1146.3	250.72	201.81	355.42	110.87	0	786.5
Silt/ Clay	1.68	1.91	1.83	1.74	98.62	2	n/a	4	5	3	4.5	0	n/a
Sand/ Clay	0.68	0.74	2.92	30.32	n/a	577.37	n/a	1002.9	1009.1	1066.1	499.01	n/a	n/a
Sand/ Mud	0.25	0.26	1.03	11.06	842.39	192.44	1146.2	200.58	168.18	266.55	90.71	n/a	786.56
Gravel/ Mud	0.04	0.03	0.95	3.98	0	103.39	35.56	108.87	0.68	4.38	86.19	n/a	250.39
1st moment	6.14	6	2.57	1.44	0.3	0.28	0.61	0.28	1.39	1.01	0.16	0.38	-0.08
Variance	7.74	7.93	13.92	4.66	0.68	1.91	0.56	1.57	0.59	0.74	2.36	1.87	0.86
Std. deviation	2.78	2.82	3.73	2.16	0.82	1.38	0.75	1.25	0.77	0.86	1.54	1.37	0.92
3rd moment	-0.42	-0.44	0.6	1.14	0.96	0.48	0.25	0.23	2.16	0.88	0.69	-0.07	0.46
4th moment	2.93	2.8	2.04	6.13	5.46	3.63	6.43	3.68	23	10.79	3.12	1.38	3.34
F&W median	6.36	6.26	1.58	1.83	0.2	0.43	0.61	0.63	1.43	1.02	0.05	0.71	-0.05
F&W mean	6.26	6.05	2.57	1.08	0.24	0.29	0.63	0.27	1.38	1.05	0.23	0.42	-0.15
F&W sorting	2.64	2.74	3.78	1.94	0.8	1.29	0.67	1.13	0.58	0.72	1.43	1.34	0.96
F&W skewness	-0.06	-0.1	0.39	-0.29	0.13	-0.09	-0.04	-0.28	-0.2	0	0.2	-0.22	-0.06
F&W kurtosis	0.83	0.91	0.63	0.85	0.95	0.57	1.27	0.52	1.17	1	0.57	0.56	0.77
I. median	6.36	6.26	1.58	1.83	0.2	0.43	0.61	0.63	1.43	1.02	0.05	0.71	-0.05
I. mean	6.21	5.95	3.06	0.71	0.25	0.22	0.64	0.09	1.35	1.06	0.32	0.27	-0.2
I. sorting	2.78	2.89	4.31	1.89	0.81	1.49	0.62	1.36	0.57	0.67	1.66	1.54	1.05
I. skewness 1	-0.05	-0.11	0.34	-0.59	0.07	-0.14	0.05	-0.4	-0.15	0.06	0.16	-0.28	-0.14
I. skewness 2	-0.1	-0.14	0.54	0.04	0.32	-0.04	-0.25	-0.19	-0.44	-0.1	0.28	-0.18	0.03
I. kurtosis	0.49	0.48	0.24	0.75	0.62	0.2	0.92	0.09	0.72	0.88	0.19	0.2	0.36
T. median	0.01	0.01	0.33	0.28	0.87	0.74	0.66	0.64	0.37	0.49	0.96	0.61	1.03
T. mean	0.03	0.03	1.09	1.03	0.92	1.28	0.66	1.32	0.4	0.54	1.35	1.27	1.31
T. sorting	4.12	3.81	11.36	3.02	1.48	2.46	1.31	2.27	1.27	1.43	2.68	2.58	1.7
T. skewness	1.19	1.1	0.32	4.76	0.97	1.45	0.93	2.29	1.09	1.04	0.84	1.97	1.23
T. kurtosis	0.15	0.1	0.42	0.36	0.27	0.4	0.2	0.4	0.2	0.28	0.42	0.41	0.3

SFBay-98 USGS grain size samples 28 - 42

Phi -1	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42
-1	2.07	6.83	8.46	0	46.25	0	0	0	0	0	0	0	0	0.5	0
-0.5	0.94	4.13	3.76	0	0.96	0	0	0	0	0	0	0	0	0.04	0
0	1.48	9.96	4.03	0	0.9	0	0	0	0	0	0	0	0	0.03	0
0.5	6.15	32.9	24.96	0	5.86	0	0	0	0	0	0	0	0.57	0	0
1	3.59	27.83	30.24	0.56	6.28	0	0	0	0	0.09	0	0.11	0.01	0.16	0
1.5	9.17	13.36	20.02	19.34	10.12	0	0	0	0	1.31	0.01	0.95	5.01	1.8	0.02
2	25.59	3.56	5.7	42.5	11	0	0.13	0.65	0	2.73	0.74	2.4	26.71	9.48	1.02
2.5	33.43	0.87	1.68	29.1	9.81	0	5.1	4.88	0	7.08	2.98	8.24	36	20.78	2.39
3	14.71	0.4	0.92	6	3.42	0.01	10.27	7.17	0.54	15.3	6.37	9.5	9.7	14.02	3.59
3.5	1.53	0	0.08	0.6	0.88	1.02	7.5	5.5	3.21	18.1	11	7.6	1.7	5.77	6.88
4	0.48	0.08	0	0.3	0.57	4.78	7.7	4.9	6.45	13.8	11.9	7.8	1.3	4.57	9
4.5	0.1	0	0.08	0.2	0.57	6.99	7.1	5.5	7.1	8.7	9.9	7.5	1.2	4.57	9
5	0.19	0	0	0.1	0.42	7.2	6.1	5.6	7.3	4.9	6.9	6	1.3	4.47	7.2
5.5	0	0	0	0.1	0.31	6.5	5	4.9	6.2	3	4.8	4.6	1.3	3.78	5.6
6	0.1	0	0	0.1	0.26	6.4	4.8	4.9	6	2.4	4.3	4.2	1.2	3.28	5.2
6.5	0.1	0.05	0.07	0.1	0.26	6.8	4.9	5.3	6.3	2.3	4.3	4.1	1.4	3.08	5.1
7	0	0.02	0.02	0.2	0.31	7.3	5.2	6	7	2.5	4.5	4.4	1.4	3.18	5.6
7.5	0.1	0.01	0	0.1	0.26	8.1	5.8	6.8	8	2.6	5	4.9	1.7	3.38	6.3
8	0.1	0	0	0.2	0.31	8.8	6.1	7.4	8.6	2.8	5.2	5.2	1.8	3.48	6.7
8.5	0.1	0	0	0.1	0.31	8.4	5.8	7.1	8.1	2.7	5	5	1.8	3.18	6.3
9	0	0	0	0.2	0.31	7.4	5	6.1	7	2.4	4.4	4.3	1.5	2.68	5.5
9.5	0.07	0	0	0.1	0.21	6.2	4.2	5.2	5.7	2.2	3.8	3.8	1.4	2.39	4.5
10	0.02	0	0	0.09	0.21	5.5	3.6	4.6	4.9	2	3.5	3.5	1.2	2.09	4
10.5	0	0	0	0.01	0.1	4.6	3.1	4	4.1	1.7	2.9	3.1	1	1.79	3.3
11	0	0	0	0	0.09	3.1	2	2.7	2.7	1.1	1.9	2.2	0.6	1.19	2.2
14	0	0	0	0	0.02	0.9	0.6	0.8	0.8	0.3	0.6	0.6	0.2	0.3	0.6
% Gravel	2.07	6.83	8.46	0	46.25	0	0	0	0	0	0	0	0	0.5	0
% Sand	97.07	93.09	91.38	98.4	49.81	5.81	30.7	23.1	10.2	58.4	33	36.6	81	56.65	22.9
% Silt	0.67	0.08	0.17	1.1	2.7	58.09	45	46.4	56.5	29.2	44.9	40.9	11.3	29.23	50.7
% Clay	0.19	0	0	0.5	1.25	36.1	24.3	30.5	33.3	12.4	22.1	22.5	7.7	13.62	26.4
% Mud	0.86	0.08	0.17	1.6	3.94	94.19	69.3	76.9	89.8	41.6	67	63.4	19	42.85	77.1
Gravel/ Sand	0.02	0.07	0.09	0	0.93	0	0	0	0	0	0	0	0	0.01	0
Sand/ Silt	145.19	1177.4	545.47	89.45	18.46	0.1	0.68	0.5	0.18	2	0.73	0.89	7.17	1.94	0.45
Silt/ Clay	3.5	3454.3	n/a	2.2	2.17	1.61	1.85	1.52	1.7	2.35	2.03	1.82	1.47	2.15	1.92
Sand/ Clay	508.23	n/a	n/a	196.8	39.99	0.16	1.26	0.76	0.31	4.71	1.49	1.63	10.52	4.16	0.87
Sand/ Mud	112.93	1177	545.49	61.5	12.63	0.06	0.44	0.3	0.11	1.4	0.49	0.58	4.26	1.32	0.3
Gravel/ Mud	2.41	86.41	50.48	0	11.73	0	0	0	0	0	0	0	0	0.01	0
1st moment	1.85	0.42	0.57	1.95	0.43	7.12	5.88	6.37	6.89	4.53	5.71	5.55	3.13	4.38	6.18
Variance	0.99	0.58	0.72	0.66	4	4.21	6.31	6.43	4.56	5.34	5.97	7	5.24	6.95	5.73
Std. deviation	1	0.76	0.85	0.81	2	2.05	2.51	2.54	2.13	2.31	2.44	2.65	2.29	2.64	2.39
3rd moment	0.18	0.18	-0.12	5.12	1.61	0.09	0.3	0.01	0.08	1.17	0.51	0.39	1.9	0.83	0.22
4th moment	10.95	6.89	5.26	40.81	7.12	2.17	1.98	1.97	2.14	3.44	2.16	2.03	5.53	2.63	2.05
F&W median	2.01	0.48	0.64	1.88	0.42	7.19	5.61	6.56	6.99	3.67	5.02	4.99	2.12	3.26	6.01
F&W mean	1.9	0.44	0.6	1.83	0.39	7.08	5.8	6.32	6.86	4.57	5.65	5.46	3.08	4.34	6.17
F&W sorting	0.75	0.7	0.76	0.46	1.55	2.13	2.58	2.65	2.2	2.29	2.45	2.69	1.93	2.56	2.43
F&W skewness	-0.36	-0.18	-0.19	-0.05	0.08	-0.04	0.14	-0.09	-0.05	0.58	0.36	0.26	0.84	0.61	0.1
F&W kurtosis	1.32	1.49	2.13	1.57	0.65	0.8	0.72	0.76	0.79	1.2	0.75	0.72	3.97	0.81	0.76
I. median	2.01	0.48	0.64	1.88	0.42	7.19	5.61	6.56	6.99	3.67	5.02	4.99	2.12	3.26	6.01
I. mean	1.85	0.41	0.58	1.81	0.37	7.03	5.89	6.2	6.8	5.03	5.96	5.69	3.55	4.89	6.24
I. sorting	0.7	0.59	0.61	0.41	1.7	2.31	2.85	2.91	2.39	2.32	2.66	2.97	1.64	2.77	2.62
I. skewness 1	-0.23	-0.12	-0.09	-0.19	-0.03	-0.07	0.1	-0.12	-0.08	0.58	0.35	0.24	0.87	0.59	0.09
I. skewness 2	-0.9	-0.55	-0.73	0.17	0.27	-0.02	0.24	-0.07	-0.01	0.92	0.5	0.39	1.83	0.88	0.17
I. kurtosis	0.85	1.27	1.46	1.06	0.37	0.4	0.33	0.35	0.4	0.6	0.39	0.34	1.25	0.4	0.41

T. median	0.25	0.71	0.64	0.27	0.75	0.01	0.02	0.01	0.01	0.08	0.03	0.03	0.23	0.1	0.02
T. mean	0.27	0.74	0.62	0.29	1.33	0.01	0.04	0.03	0.02	0.07	0.04	0.06	0.22	0.1	0.03
T. sorting	1.32	1.29	1.22	1.16	2.77	3.13	4.46	4.3	3.34	2.4	4.09	4.78	1.3	3.92	3.99
T. skewness	1.08	1.01	0.89	1.13	1.29	1.25	0.79	1.48	1.36	0.46	0.39	0.49	0.85	0.23	0.87
T. kurtosis	0.13	0.17	0.09	0.19	0.42	0.22	0.26	0.19	0.23	0.3	0.3	0.28	0.19	0.35	0.26

SFBay-98 USGS grain size samples 43 - 56

Phi -1	43	44	45	46	47	48	49	50	51	52	53	54	54R	55	56	56R
-1	0	0	2.82	16.25	23.06	0	0	0	0	17.46	14.42	0	0	2.06	4.86	7.22
-0.5	0	0	9.86	2.98	0	0	0	0	0	0.61	1.17	0	0	1.67	3.58	3.61
0	0	0	21.92	4.34	0	0	0	0	0	0.75	0.95	0	0	3.38	6.4	6.54
0.5	0	0	43.29	6.24	8.46	0	0	0	0	2.3	0.77	5.54	0.57	11.61	6.24	9.5
1	0.14	0.11	18.05	6.76	7.08	0	0.3	0	0	0.55	0.23	8.16	5.07	13.56	6.02	9.75
1.5	3.47	1.2	2.48	9.17	19.62	0	2.41	0	0	13.79	3.58	29.4	8.46	24.34	14.56	15.7
2	11.89	1.96	1.11	13.91	20.23	0.05	4.94	0.13	0.86	27.2	10.03	32.9	28.9	23.6	24.44	21.15
2.5	14.5	5.48	0.33	14.83	9.23	1.52	9.55	0.75	3.24	19.89	13.19	16.6	32.4	13.1	23.42	18.67
3	7.5	8.55	0.07	8.26	2.92	3.33	10.7	1.96	5.08	6.17	9.51	3.8	16.7	2.69	7.15	5.54
3.5	4.6	8.7	0.07	3.21	1.15	5.2	8.6	5.91	9.12	1.7	6.34	0.7	4	0.46	0.77	0.58
4	4.4	8.1	0	1.68	0.69	7.8	6.9	7.95	10.5	0.89	4.59	0.4	0.7	0.28	0.34	0.25
4.5	4.2	7.1	0	1.15	0.54	8.9	5.7	8.1	9.3	0.65	3.76	0.2	0.3	0.28	0.17	0.08
5	3.9	5.8	0	0.99	0.62	8.1	4.8	7.2	7.1	0.73	3.42	0.2	0.2	0.28	0.17	0.17
5.5	3.4	4.8	0	0.99	0.62	6.5	3.8	5.9	5.2	0.73	2.92	0.2	0.3	0.28	0.26	0.08
6	3.4	4.4	0	0.92	0.62	6	3.7	5.6	4.5	0.65	3	0.1	0.2	0.28	0.17	0.17
6.5	3.7	4.6	0	0.92	0.62	5.8	3.8	5.7	4.5	0.65	2.75	0.2	0.2	0.37	0.17	0.08
7	4.1	5	0	0.99	0.69	6	4.2	6.2	4.7	0.65	2.67	0.2	0.2	0.28	0.09	0.17
7.5	4.6	5.7	0	1.07	0.62	6.2	4.8	7.2	5.4	0.73	2.84	0.3	0.3	0.28	0.26	0.08
8	5.1	6	0	1.15	0.77	6.4	5.2	7.6	5.7	0.81	2.84	0.2	0.2	0.28	0.17	0.17
8.5	4.9	5.7	0	0.99	0.69	6	4.9	7.3	5.4	0.73	2.59	0.2	0.3	0.19	0.17	0.17
9	4.3	4.8	0	0.99	0.54	5.2	4.3	6.2	4.8	0.65	2.34	0.3	0.3	0.28	0.17	0.17
9.5	3.6	3.8	0	0.76	0.46	4.8	3.5	5.1	4.2	0.57	1.92	0.2	0.2	0.19	0.17	0.08
10	3.2	3.2	0	0.69	0.38	4.5	3.1	4.3	3.9	0.49	1.67	0.1	0.2	0.19	0.17	0.07
10.5	2.7	2.7	0	0.46	0.23	4.1	2.6	3.7	3.5	0.32	1.34	0.08	0.2	0.07	0.07	0.01
11	1.9	1.8	0	0.23	0.12	2.8	1.7	2.5	2.3	0.24	0.92	0.02	0.08	0.02	0.02	0
14	0.5	0.5	0	0.08	0.03	0.8	0.5	0.7	0.7	0.08	0.25	0	0.02	0	0	0
% Gravel	0	0	2.82	16.25	23.06	0	0	0	0	17.46	14.42	0	0	2.06	4.86	7.22
% Sand	46.5	34.1	97.18	71.37	69.4	17.9	43.4	16.7	28.8	73.85	50.36	97.5	96.8	94.69	92.92	91.29
% Silt	32.4	43.4	0	8.18	5.08	53.9	36	53.5	46.4	5.6	24.2	1.6	1.9	2.32	1.45	0.99
% Clay	21.1	22.5	0	4.2	2.46	28.2	20.6	29.8	24.8	3.08	11.02	0.9	1.3	0.93	0.77	0.5
% Mud	53.5	65.9	0	12.38	7.54	82.1	56.6	83.3	71.2	8.69	35.22	2.5	3.2	3.25	2.21	1.49
Gravel/ Sand	0	0	0.03	0.23	0.33	0	0	0	0	0.24	0.29	0	0	0.02	0.05	0.08
Sand/ Silt	1.44	0.79	0	8.73	13.67	0.33	1.21	0.31	0.62	13.18	2.08	60.94	50.95	40.77	64.18	92.08
Silt/ Clay	1.54	1.93	0	1.95	2.06	1.91	1.75	1.8	1.87	1.82	2.2	1.78	1.46	2.5	1.89	2
Sand/ Clay	2.2	1.52	n/a	16.98	28.19	0.63	2.11	0.56	1.16	23.94	4.57	108.33	74.46	101.93	121.24	184.16
Sand/ Mud	0.87	0.52	n/a	5.76	9.2	0.22	0.77	0.2	0.4	8.5	1.43	39	30.25	29.12	41.97	61.38
Gravel/ Mud	0	0	n/a	1.31	3.06	0	0	0	0	2.01	0.41	0	0	0.63	2.2	4.85
1st moment	5.04	5.67	0.14	1.8	1.27	6.4	5.24	6.54	5.94	1.76	3.42	1.71	2.23	1.42	1.49	1.23
Variance	8.45	6.54	0.32	6.29	4.65	5.52	7.39	5.19	6.16	4.81	9.97	1.2	1.33	1.81	1.95	1.8
Std. deviation	2.91	2.56	0.57	2.51	2.16	2.35	2.72	2.28	2.48	2.19	3.16	1.09	1.15	1.35	1.4	1.34
3rd moment	0.42	0.3	0.13	1.27	1.57	0.25	0.43	0.15	0.38	1.36	0.41	3.91	3.8	2.55	1.32	0.97
4th moment	1.86	2.02	4.46	4.93	6.87	2.09	2.01	2.06	2.06	6.57	2.55	25.29	23.68	15.29	10.78	8.95
F&W median	4.41	5.31	0.16	1.67	1.37	6.22	4.59	6.57	5.46	1.79	2.77	1.58	2.08	1.39	1.69	1.44
F&W mean	4.98	5.61	0.15	1.26	0.8	6.41	5.17	6.52	5.9	1.09	3.2	1.57	2.08	1.33	1.36	1.18
F&W sorting	2.9	2.59	0.53	2.41	1.98	2.41	2.74	2.32	2.51	2.11	3.46	0.57	0.59	0.85	1.09	1.16
F&W skewness	0.3	0.18	-0.1	0.02	-0.12	0.11	0.3	0.01	0.25	-0.19	0.2	-0.04	-0.03	-0.13	-0.48	-0.35
F&W kurtosis	0.65	0.73	1.18	1.55	1.69	0.78	0.71	0.75	0.75	3.06	1.16	1.33	1.32	1.04	1.15	1.02
I. median	4.41	5.31	0.16	1.67	1.37	6.22	4.59	6.57	5.46	1.79	2.77	1.58	2.08	1.39	1.69	1.44
I. mean	5.27	5.76	0.14	1.06	0.52	6.5	5.46	6.49	6.12	0.74	3.41	1.57	2.07	1.31	1.2	1.04

I. sorting	3.25	2.82	0.53	2.09	1.67	2.6	3.01	2.53	2.72	1.78	3.71	0.49	0.51	0.84	1.11	1.12
I. skewness 1	0.26	0.16	-0.04	-0.29	-0.51	0.11	0.29	-0.03	0.24	-0.59	0.17	-0.03	-0.02	-0.1	-0.45	-0.35
I. skewness 2	0.43	0.29	-0.27	0.71	0.6	0.17	0.43	0.07	0.35	0.5	0.32	-0.14	-0.07	-0.28	-0.83	-0.6
I. kurtosis	0.29	0.38	0.68	1.15	1.25	0.4	0.36	0.37	0.39	1.27	0.43	1.2	1.16	0.69	0.59	0.77
T. median	0.05	0.03	0.9	0.31	0.39	0.01	0.04	0.01	0.02	0.29	0.15	0.33	0.24	0.38	0.31	0.37
T. mean	0.1	0.05	0.92	0.55	0.61	0.03	0.07	0.02	0.04	0.34	0.16	0.33	0.23	0.43	0.4	0.5
T. sorting	6.32	4.52	1.24	2.28	1.88	3.81	5.13	3.74	4.23	1.46	3.66	1.26	1.27	1.47	1.54	1.74
T. skewness	0.47	0.65	1.01	1.63	1.73	0.86	0.42	1.23	0.54	1.2	0.3	0.91	0.92	1.12	1.38	1.38
T. kurtosis	0.37	0.26	0.23	0.16	0.15	0.25	0.3	0.25	0.28	0.05	0.06	0.2	0.2	0.25	0.15	0.19