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FINAL REPORT

LIBERTY DEVELOPMENT 2001 SEDIMENT QUALITY STUDY

Prepared for

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August 3, 2001

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Submittal of Sediment Quality Study 2001 Final Report
Liberty Development

Gentlemen:

BP Exploration (Alaska) Inc. (BPXA) is herein submitting the *Liberty Development 2001 Sediment Quality Study Final Report*. The work plan, field activity reports, grain size sampling report, laboratory data results, data quality summary reports and data plots are included in the appendices.

If you have any questions or require further information, please contact me at (907) 564-5517.

Sincerely,

Cash Fay

Cash Fay, Permitting Advisor
HSE-Alaska

Attachment

CEF/cef

cc: Dr. Billy Johnson, USACE

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BPXA	BP Exploration (Alaska), Inc.
Corps	U.S. Army Corps of Engineers
CVAA	Cold vapor atomic absorption
EPA	Environmental Protection Agency
EIS	Environmental Impact Study
GPS	Global Positioning System
HPAH	High Molecular Weight Polyaromatic Hydrocarbons
HSE	Heath, Safety, and Environment
LPAH	Low Molecular Weight Polyaromatic Hydrocarbons
MDL	Method Detection Limit
mg/kg	milligrams per kilogram
MMS	U.S. Minerals Management Service
MDRD	Minimum detectable relative difference
MS/DS	Matrix Spike/Duplicate Spike
NEPA	National Environmental Policy Act of 1969
NPDES	National Pollutant Discharge Elimination System
OCS	Outer Continental Shelf
PAH	Polyaromatic Hydrocarbons
ppb	parts per billion
ppm	parts per million
PSDDA	Puget Sound Dredged Disposal Analysis Program
PSEP	Puget Sound Estuary Program
QA/QC	quality assurance/quality control
QC	quality control
Rollagons	Arctic off-road vehicles
RPD	relative percent difference
SVOCs	semi-volatile organic compounds
TSS	total suspended sediments
USCS	Unified Soil Classification System
VOCs	volatile organic compounds
μg/kg	micrograms per kilogram

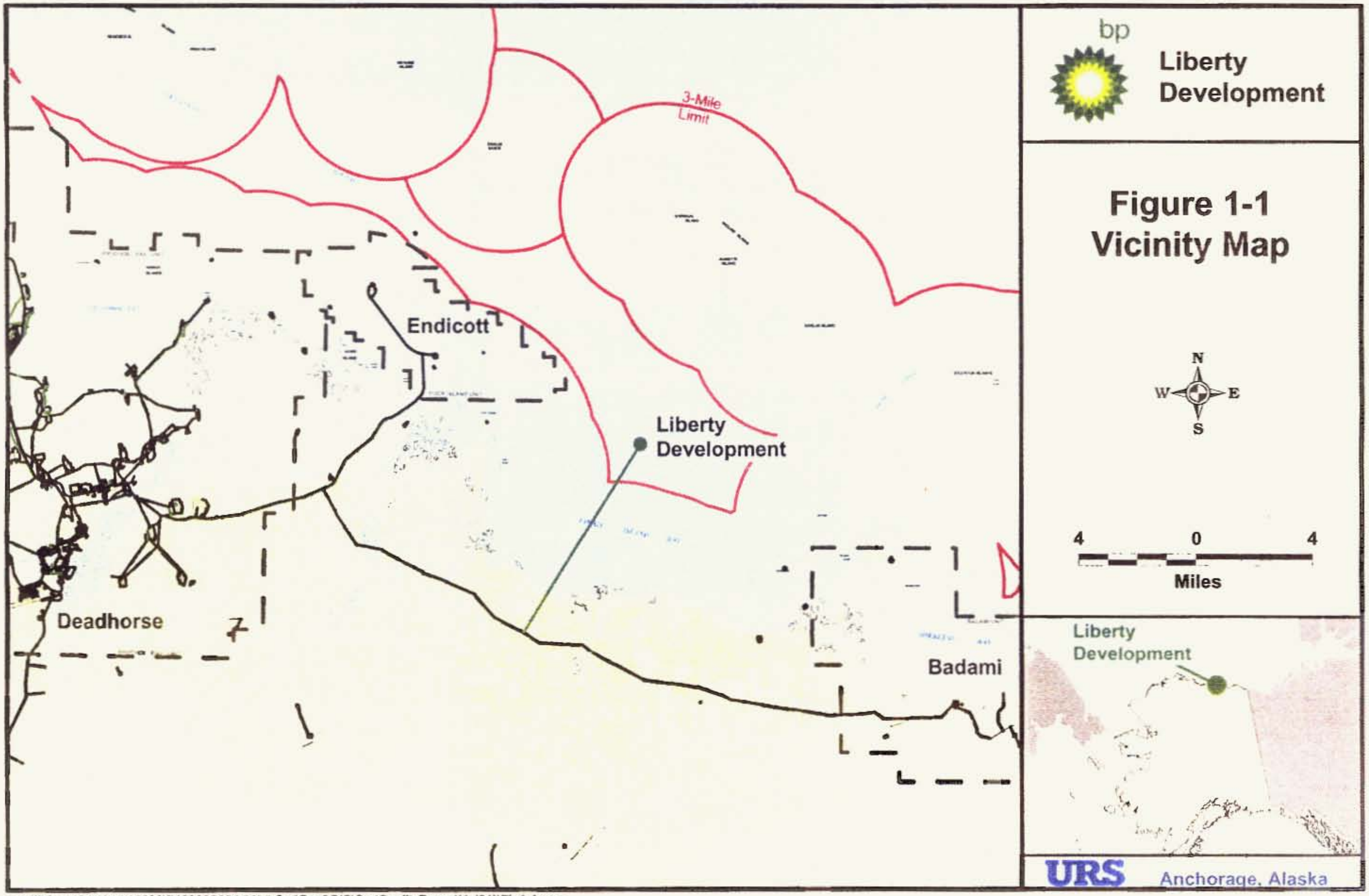
BP Exploration (Alaska) Inc, (BPXA) plans to develop the Liberty oil field in the Beaufort Sea for production and transport of sales-quality oil to the Trans-Alaska Pipeline System. The field will be developed from a gravel island to be constructed in Federal Outer Continental Shelf (OCS) waters within Foggy Island Bay (Figure 1-1). The Liberty oil field development will include construction of a subsea pipeline from the proposed island (Liberty Island) to a land-based connection with the Badami Sales Oil Pipeline.

The U.S. Minerals Management Service (MMS) is currently conducting an environmental evaluation of the Liberty Development based on the National Environmental Policy Act of 1969 (NEPA). The evaluation is presented in the *Liberty Development and Production Plan Draft Environmental Impact Statement* (MMS 2001), and includes evaluations of multiple pipeline routes and production island locations, including the applicant's proposed Liberty Island route (Figure 1-2).

The pipeline system is anticipated to be constructed during the winter. Ice roads will be built to allow equipment access to the construction area. The proposed pipeline construction activity sequence is: 1) ice cutting and slotting, 2) trenching, 3) pipeline assembly and installation, 4) trench backfilling, and 5) pipeline pressure testing. During construction, some dredged material will be stored temporarily at sites away from the trench due to loading capacity and deflection characteristics of the ice. If necessary, the storage sites also will serve as disposal sites. Although the majority of dredged material is intended to be backfilled into the trench, as much as 110,000 cubic yards (yd^3) (76,500 cubic meters [m^3]) of dredged material from the applicant's preferred trench could be disposed of in Foggy Island Bay. Also, a contingency plan for disposal of temporarily stored spoil is required in the event that weather or ice conditions necessitate abandonment of operations prior to completion of construction activities.

The U.S. Environmental Protection Agency (EPA) and the U.S. Army Corps of Engineers, Alaska District (Corps) are cooperative agencies with the MMS on the Liberty Development EIS. Construction permits administered by the Corps and EPA require that physical properties (e.g., grain-size distribution) and chemical characteristics of sediment be collected for the evaluation of potential impacts to the surrounding environment related to trench excavation and fill activities and possible ocean disposal of spoils. Because there are no existing sediment analyses for one of the alternative pipeline routes, the EPA and Corps requested sampling be conducted.

This document presents the results of the sediment sampling project completed in May 2001. These results provide baseline information about those sediments anticipated to be excavated and used as fill or disposed via ocean dumping for the three routes evaluated in the EIS. The Work Plan, Heath Safety and Environment (HSE) Interface Document, field activity reports, grain size sampling report, laboratory data results, data quality summary reports, and data plots are contained in the Appendices.



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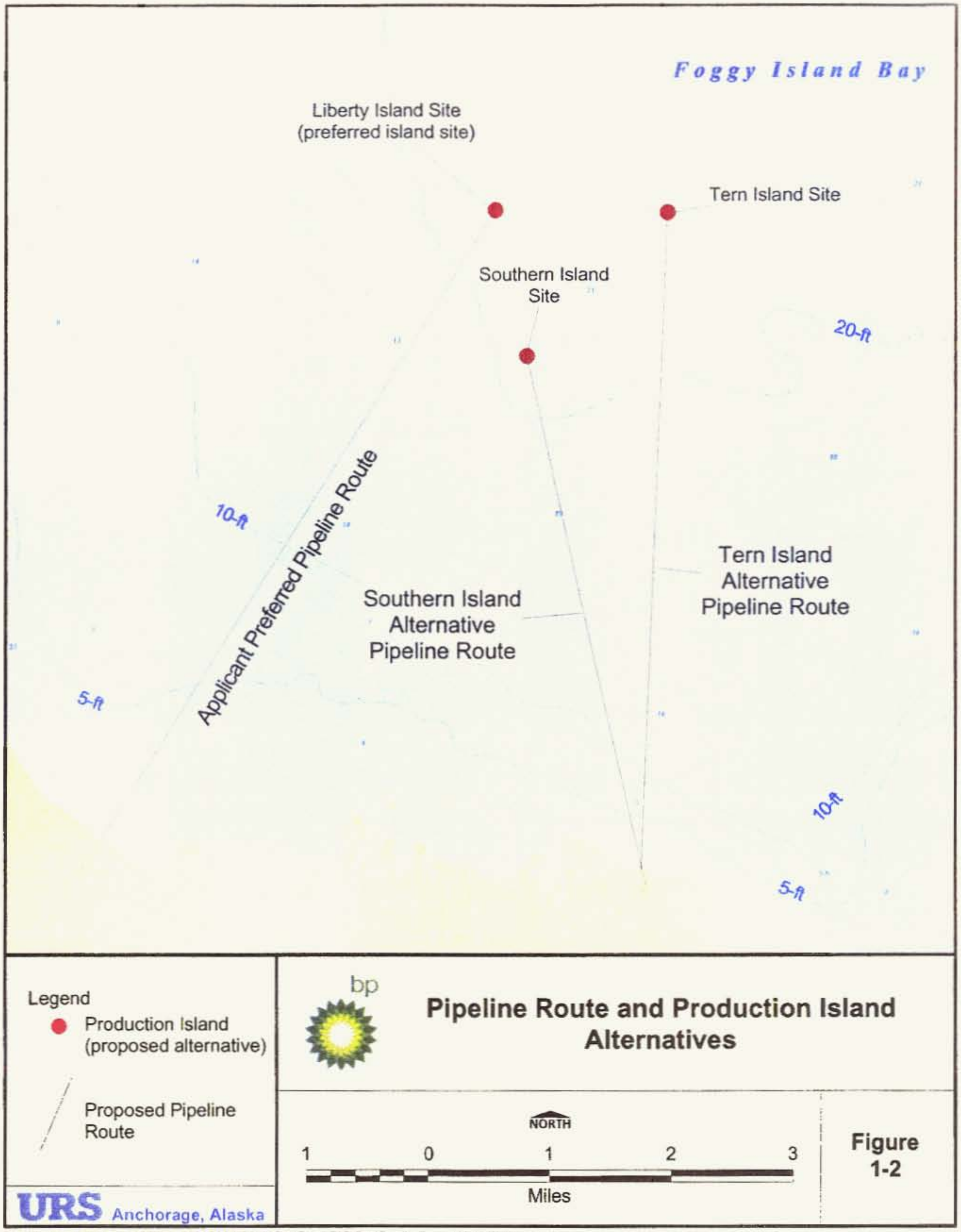

Pipeline Route and Production Island Alternatives

Figure 1-2

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The sediment sampling program is part of a baseline data collection survey to support permit activities associated with the Liberty Development. The goal of the sediment sampling plan is to describe the natural concentrations and variability of selected physical and chemical parameters of sediment anticipated to be excavated and used as fill or disposed via ocean dumping.

This sampling program has three objectives based on the Corps and EPA requirements:

- Collect sediment quality samples from the seafloor (i.e., surficial samples) to determine whether a larger group of chemicals-of-concern (CoCs) identified by the EPA exceeds regulatory screening levels as presented in *Dredged Material Evaluation Framework, Lower Columbia River Management Area* (November 1998);

- Collect representative sediment quality samples of the proposed excavated material to determine if any of the CoCs identified by the EPA exceed regulatory screening levels as presented in the *Dredged Material Evaluation Framework, Lower Columbia River Management Area* (November 1998); and

- Collect representative samples of the proposed excavated material to ascertain the grain-size distribution, including silt and clay sized particles. This information will support the Corps' SSFATE modeling effort to predict suspended sediment transport associated with pipeline construction.

3.1 DEVELOPMENT ALTERNATIVES

The Liberty Development oil and gas production facilities will be placed on an artificial gravel island located in Federal OCS waters within Foggy Island Bay (Figure 1-1). A subsurface (buried) sales quality oil pipeline will connect to an onshore segment to transport oil to the Badami Sales Oil Pipeline. The applicant preferred island site – Liberty Production Island – is in approximately 22 feet of water. The offshore pipeline segment will follow a nearly straight route from the island to a landfall located about 6.1 miles to the southwest. The alternative Southern Island is in 18 feet of water located approximately 1.5 miles south-southeast of the proposed Liberty Island. The marine pipeline segment for the South Island alternative would extend toward the southeast approximately 4.2 miles until landfall. The alternative Tern Island is located in 23 feet of water, 5.5 miles offshore in Foggy Island Bay. Tern Island is approximately 1.5 miles east of the proposed Liberty Island location. The Tern Island alternative pipeline length is 8.6 miles with the offshore portion approximately 5.5 miles. The Southern Island and Tern Island offshore pipeline routes would reach landfall at the same location.

3.2 PHYSICAL PROCESSES AFFECTING FOGGY ISLAND BAY

Within Foggy Island Bay, the local input of fresh water from the Sagavanirktok River strongly influences water quality. The Sagavanirktok River delta forms the western shore of Foggy Island Bay and its eastern distributary discharges directly into the embayment. In Foggy Island Bay, as elsewhere along the entire Beaufort Sea coast, water column movements are due almost entirely to the frictional stress of wind on the water surface. Under prevailing east winds, the fresh water discharge typically flows along shore, around Point Brower and toward the west. For west wind conditions, the fresh water discharge flows directly into Foggy Island Bay.

Suspended sediment is introduced naturally to the marine environment through river runoff and coastal erosion (MMS 1996), which is resuspended during summer by wind and wave action. Satellite imagery and suspended particulate matter data suggest that turbid water generally is confined to depths less than 16 feet. In mid-June through early July, the shallow nearshore waters generally carry more suspended sediment as a result of increased sediment loads discharged from the Sagavanirktok, Kadleroshilik and Shaviovik Rivers. Storms and their associated winds and coastal erosion periodically increase turbidity in shallow waters during the open water season.

During the summer open-water season, the timing and rate of discharge from the Sagavanirktok, Kadleroshilik, and Shaviovik rivers determine the amount of freshwater available for distribution in the marine environment of Foggy Island Bay. Sea ice breakup typically occurs in late June to early July. As warming continues into summer, the sea ice melts, resulting in about 75-90 days of open water. After sea ice breakup, wind speed and direction become the key factor in determining the fate of freshwater advected along the coast. Wind speed and direction also influence water level variations, which in turn play a key role in the exchange rates between brackish nearshore and offshore marine waters. Other agents controlling currents include the small tides and occasionally large storm surges, and more locally, river discharge adjacent to river deltas.

During winter, the Beaufort Sea is covered by sea ice that begins to form in late September. Freezeup of the waters is completed by the end of October, with ice growing to a maximum thickness by April. Ice cover persists on average for 290 days until spring warming results in river breakup, and subsequent sea ice melting near the river and stream deltas. Under ice observations in the Beaufort Sea indicate that very low-speed currents are aligned with bathymetry, which result in an easterly or westerly flow.

Ice gouging and scouring are other mechanisms by which seafloor sediments are affected. Moving ice interacts with the seafloor to form gouges that displace or rework the soils. Ice gouging occurs when the bottoms of ice floes (i.e., keels) contact the seafloor. Ice motion is directed by wind, current, and pack ice pressures. Hydraulic scour occurs before the melting and breakup of the land fast sea ice, when the Sagavanirktok River waters flood the surface of coastal sea ice. The fresh water overflow drains through holes or cracks in the ice, creating a subsurface whirlpool that erodes the seafloor into roughly circular depressions–strudel scours (Watson Company 1998).

3.3 SITE HISTORY

In the winter of 1982, Shell Oil Company constructed Tern Island at the mouth of Foggy Island Bay to support exploratory drilling. Wastewater discharge permits under the National Pollutant Discharge Elimination System (NPDES) allowed for the discharge of potassium chloride drilling muds, cuttings, and fluids onto the surrounding sea ice during winter and direct discharge into Beaufort Sea waters during the summer open-water season. A total of 2,800 barrels (bbl) of drilling effluents were discharged between June and August 1982 on the northwest side of Tern Island, approximately 50 feet (ft) (15 meters [m]) from the island shoreline (NORTEC 1983). During the winter, approximately 700 bbl of drilling effluents were transported to a sea ice disposal area approximately 500 feet (150 m) northwest of the island. Well cuttings were transported by heavy equipment and placed on the island slope immediately adjacent to the drilling effluent outfall during periods of open water. The island slope was sufficient for the well cuttings to move down slope, resulting in deposition on the submerged island slope.

In the winter of 1997, BPXA drilled an exploration well (Liberty #1) on Tern Island. Drilling muds and cuttings, deck drainage, sanitary and domestic wastewater, and miscellaneous wastes including excess cement slurry, and desalination unit wastes were discharged into Foggy Island Bay under the NPDES permit. Approximately 16,200 bbl of muds and cuttings were transported to a sea ice disposal site located approximately 7,000 feet (2,100 m) southeast of Tern Island in 18 to 20 feet of water. Sanitary and domestic wastewater discharges were placed at the muds and cuttings disposal site, or discharged through a line with an outfall on the southeast side of Tern Island. Bioassays indicated that the drilling fluid was nontoxic (AMBAR Technical Labs 1997).

It is unlikely that the sediments along or near the applicant's preferred or alternative pipeline routes have been disturbed by past activities. Past activities occurred east and north of the pipeline route, were of limited duration, and resulted in minimal discharge of drilling muds and cuttings. Geophysical surveys conducted throughout the Liberty Development Project area did not identify any anthropogenic (i.e., man-made) structures or observable effects from human-use activities. With the exception of drillings muds and cuttings discharged immediately adjacent to

Tern Island during exploration drilling in the early 1980s and 1997, there are no other known potential sources of contamination. Prevailing currents produce a net westward drift, placing the Prudhoe Bay coastal oil production facilities down current of Foggy Island Bay.

Access to Foggy Island Bay is limited to marine vessels during the brief summer open-water season and tundra travel vehicles during the winter. During autumn freeze-up and spring ice breakup there is virtually no surface accessibility. Foggy Island Bay is occasionally used by the local native population for subsistence hunting and fishing. There are no industrial or military activities operating within the bay, with the exception of occasional geophysical exploration surveys.

3.4 RESULTS OF PREVIOUS INVESTIGATIONS

Two geotechnical investigations (Duane Miller & Associates 1997, 1998), two sediment quality studies (Montgomery Watson 1997, 1998), and two geophysical hazard surveys (Watson Co. 1998a, 1998b, 1998c) provide a comprehensive understanding of the sediments encountered along the applicant's proposed pipeline route and production island location. No evidence of any anthropogenic features or disturbance was found by these studies. Following is a summary of the current understanding of the site.

3.4.1 Geophysical Hazard Surveys

High-resolution geophysical data were collected in the summer of 1997 to identify geological hazards and man-made materials that could affect or alter the design of the proposed Liberty Development (Watson Company 1998a). This was a comprehensive survey, which included geophysical data from high-resolution multi-channel seismic systems, digital side-scan sonar, and a sub-bottom profiler. No man-made structures or evidence of human-use activities were identified.

Watson described the seafloor as gently undulating, although a northwest-southeast ridge with 3 to 6 feet (1 to 2 m) of relief was delineated west of the applicant's preferred gravel island. Interpretations of side-scan sonar records indicated seafloor sediments with greater than 25 percent boulders and cobbles are situated west and northwest of the proposed gravel island. Watson noted that the seafloor areas, characterized by boulders and cobbles, are considered to be lag deposits of Pleistocene origin and were formed by the erosion of the Flaxman marine units of the Gubik Formation. These lag deposits are exposed on the seafloor where Holocene (recent) sediments are absent (Watson Company 1998a).

Analysis of geophysical records determined that approximately 75 percent of the 1997 survey area consists of Holocene fine-grained materials characterized by low reflectivity with few boulders (Watson Company 1998a). Watson states that the Holocene sediments are relatively thin, less than 8.5 feet (2.6 m), with distributions characterized as small patchy accumulations of soft mud. While the deposits are considered to be marine sediments, the source may be fine-grained silts and clays discharged from the Sagavanirktok River (Watson Company 1998a).

3.4.2 Geotechnical Investigations

Duane Miller & Associates conducted geotechnical exploration surveys in 1997 and 1998 along possible pipeline alignments, including the selected route. The 1998 survey, which included 18 borings along the applicant's preferred pipeline route, yielded the following information.

Seafloor sediments at the island location can be divided into three primary horizons: the upper Holocene non-plastic silt; the intermediate Pleistocene clayey silt; and the underlying granular sand and gravel (Duane Miller & Associates 1998). No frozen soils were encountered at any location along the offshore pipeline route. Soft silts were documented from the seafloor (0 feet) to a depth of 4 to 6 feet. The underlying stiff clayey silt horizon reached depths between 18 to 21.5 feet. This stratigraphy corresponds with the relatively flat seafloor with depths averaging 22 feet (Figure 3-1).

The seafloor rises gently from the 22-ft isobath to the 15-ft isobath where the sediments typically consists of sand, silty sand with some soft silt, and many pockets and layers of peaty soil. One 4.5-ft thick shoal consisting of uniform fine-grained, clean sand was identified in 15 feet (4.6 m) of water.

The sediments found in water depths between the 15-ft and 7-ft isobaths are silty sands interbedded with medium stiff silt to a depth of 10 feet. Stiff silt underlain by sandy gravel are found below the silty sands.

Between the 7-ft and 4-ft isobaths, the dominant material is silty sand with thin interbeds of silt and thin organic rich layers. The underlying gravelly sand is shallower than the pipeline depth at Boring D-16 (Figure 3-2).

Sediments from water depths less than 4 feet and extending to the shoreline consist of thin surface layers of sand and soft silt with the underlying sand and gravel at shallow depths 5 to 6 feet. Frozen ice bound sediments were observed up to 230 feet north of the shoreline.

Figure 3.1 Offshore Pipeline Route Cross-Section (from Island to Boring D-11)

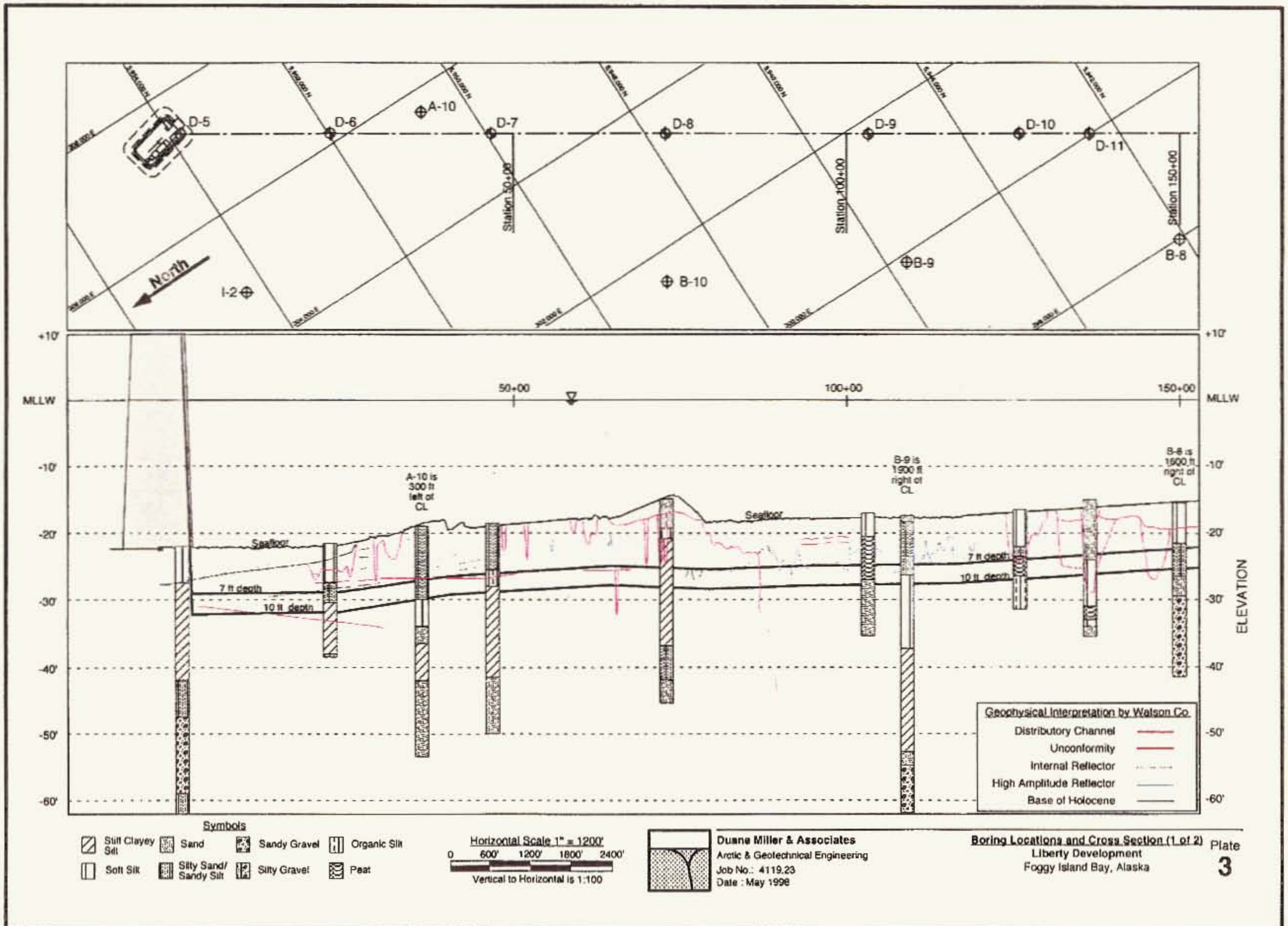

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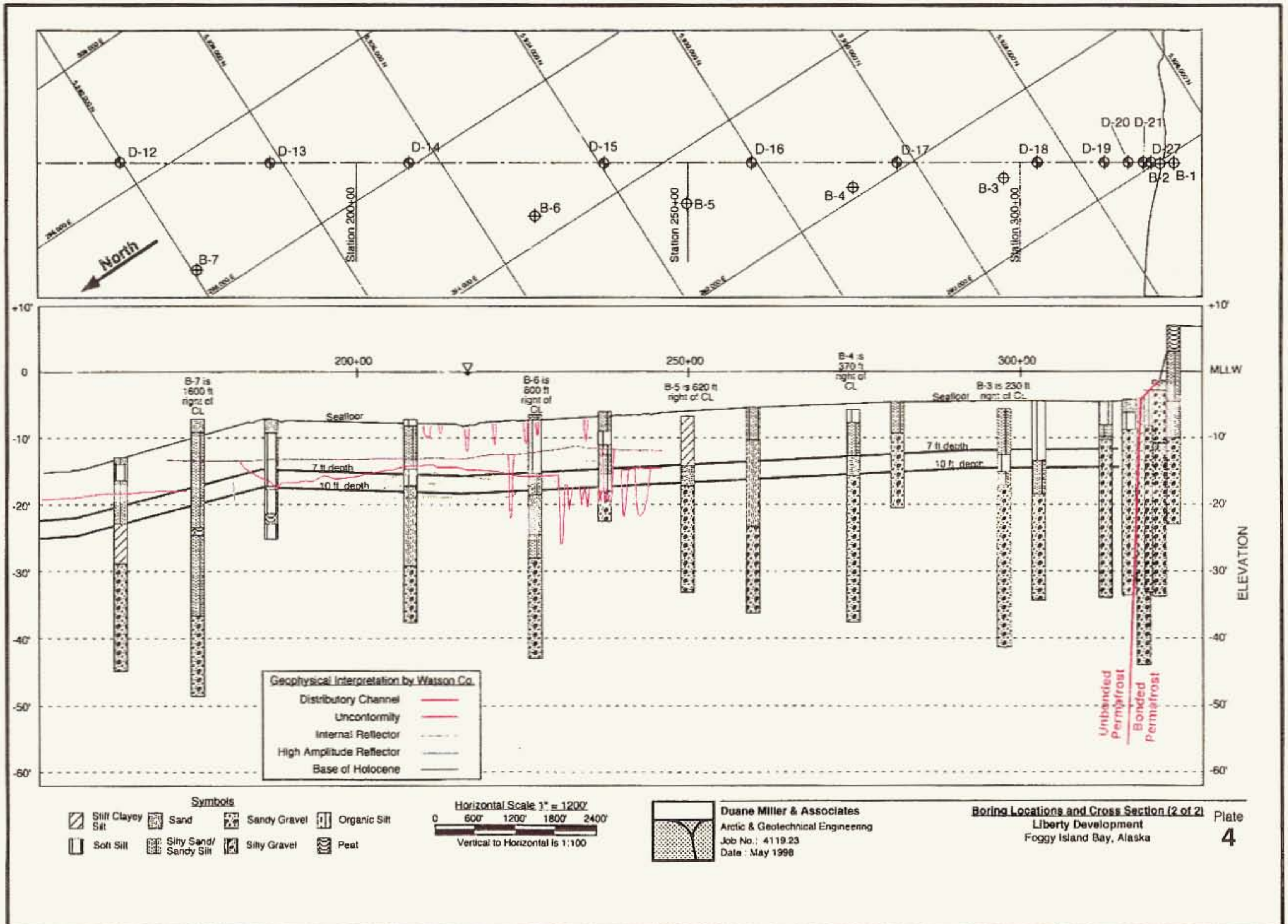
Figure 3.2 Offshore Pipeline Route Cross-Section (from Boring D-12 to shore)



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3.4.3 Sediment Quality and Geochemistry Studies

Numerous sediment samples from Foggy Island Bay have been analyzed to quantify natural background concentrations of selected heavy metals, volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), and petroleum hydrocarbons (NORTEC 1983; Montgomery Watson 1997, 1998). Prior to 1982, no petroleum exploration occurred within Foggy Island Bay. Accordingly, the samples collected by NORTEC in 1983, prior to drilling of the first well in Foggy Island Bay (Shell Oil Tern #1) served to establish the natural background concentrations.

Barium concentrations for five samples collected at one location prior to 1982 drilling activities ranged from 210 to 9,040 milligrams per kilogram (mg/kg). Further analyses indicated that the seafloor sediments in the Beaufort Sea are heterogeneous with a patchy nature; that is, it is not uncommon to find large variations in sediment grain-size and trace metal concentrations among samples taken at the same location (NORTEC 1983). The natural variability in these sediments is reflected in lead concentrations found in sediments collected in the western half of Foggy Island Bay during evaluation of several proposed pipeline routes associated with the Liberty Development (Montgomery Watson 1997).

Table 3-1 is a statistical summary of selected heavy metal concentrations for sediments collected throughout the Beaufort Sea and within Foggy Island Bay. Within Foggy Island Bay, arsenic, chromium, and mercury exhibit consistent concentrations, while barium and lead tend to be variable. On average, metal concentrations from the pipeline route studies (Montgomery Watson 1997, 1998) are lower than results from the study conducted prior to exploratory drilling in 1982 (NORTEC 1983). Also, most of the heavy metal results from samples collected from Foggy Island Bay are within the range of concentrations found throughout the Beaufort Sea. The only exception is chromium, of which Foggy Island Bay sediments contained a maximum concentration of 34 mg/kg (Montgomery Watson 1997).

In 1998, Montgomery Watson collected samples at three depths below the seafloor to describe the sediment chemistry along the applicant's preferred pipeline route. All heavy metals and VOCs, were uniformly below the screening levels set forth by the Puget Sound Dredged Disposal Analysis, which was developed for dredging operations by EPA Region X (Seattle), Corps, and the Washington State Department of Natural Resources and Ecology. One sample collected approximately 9 feet below the seafloor contained 4-Methylphenol (p-Cresol), a SVOC, at a concentration that was above the minimum screening level. However, this sample was collected approximately 1970 feet (600 m) northwest of the proposed gravel island, and outside the proposed pipeline trench.

Analyses of samples collected throughout the western portion of Foggy Island Bay in 1997 demonstrated a positive linear correlation between chromium and lead concentrations. Also, barium and arsenic levels increased proportionally with increasing chromium concentrations. Similarly, the relationship of these metals to grain-size reflects a positive linear trend. The samples collected represent undisturbed subsurface strata, and thus, the positive linear relationships found between the metals and similar relationships between metals and grain-size describe naturally existing baseline conditions. It was interesting to note that sediment chemistry analysis did not delineate any differentiation between Holocene and Pleistocene sediments.

Table 3-1 Heavy Metal Concentrations for Sediments

Investigation	Location	Arsenic (mg/kg)	Barium (mg/kg)	Chromium (mg/kg)	Lead (mg/kg)	Mercury (mg/kg)
1982 Tern Island (NORTEC 1983)[1]	Foggy Island Bay	no analysis	30 minimum **121 (537[†])** average 360 (9040[†]) maximum	13 minimum **19** average 27 maximum	12 minimum **16** average 20 maximum	no analysis
Proposed Liberty Pipeline Routes (Montgomery Watson 1997)	Foggy Island Bay	3 minimum **5.5** average 11.4 maximum	29 minimum **67.5** average 194 maximum	7.2 minimum **18.5** average 34 maximum	2.79 minimum **10.1** average 67.8 maximum	No Detect minimum **0.24** average 1.35 maximum [‡] all sample results are estimates due to failed precision criteria. The relative percent difference (RPD) for duplicate analyses exceeded acceptance limits.
Selected Liberty Pipeline Route (Montgomery Watson 1998)	Foggy Island Bay (pipeline route)	3.3 minimum **5.5** average 11.2 maximum	23 minimum **45** average 86 maximum	5.4 minimum **12.2** average 27 maximum	2.2 minimum **5.4** average 13.9 maximum	No Detect minimum **0.035** average 0.085 maximum
Northstar Development Pilot Offshore Trenching Program (Montgomery Watson 1996)	Offshore of Stump Island (Site C)	5.0 minimum **7.1** average 16 maximum	46 minimum **63** average 122 maximum	10 minimum **16.6** average 21 maximum	No Detect minimum 23 maximum	Not detected
Beaufort Sea Planning Area Oil & Gas Lease Sale 144 (MMS 1996)[2]	Beaufort Sea	no analysis	185 minimum 745 maximum	17 minimum 19 maximum	3.9 minimum 20 maximum	0.02 minimum 0.09 maximum

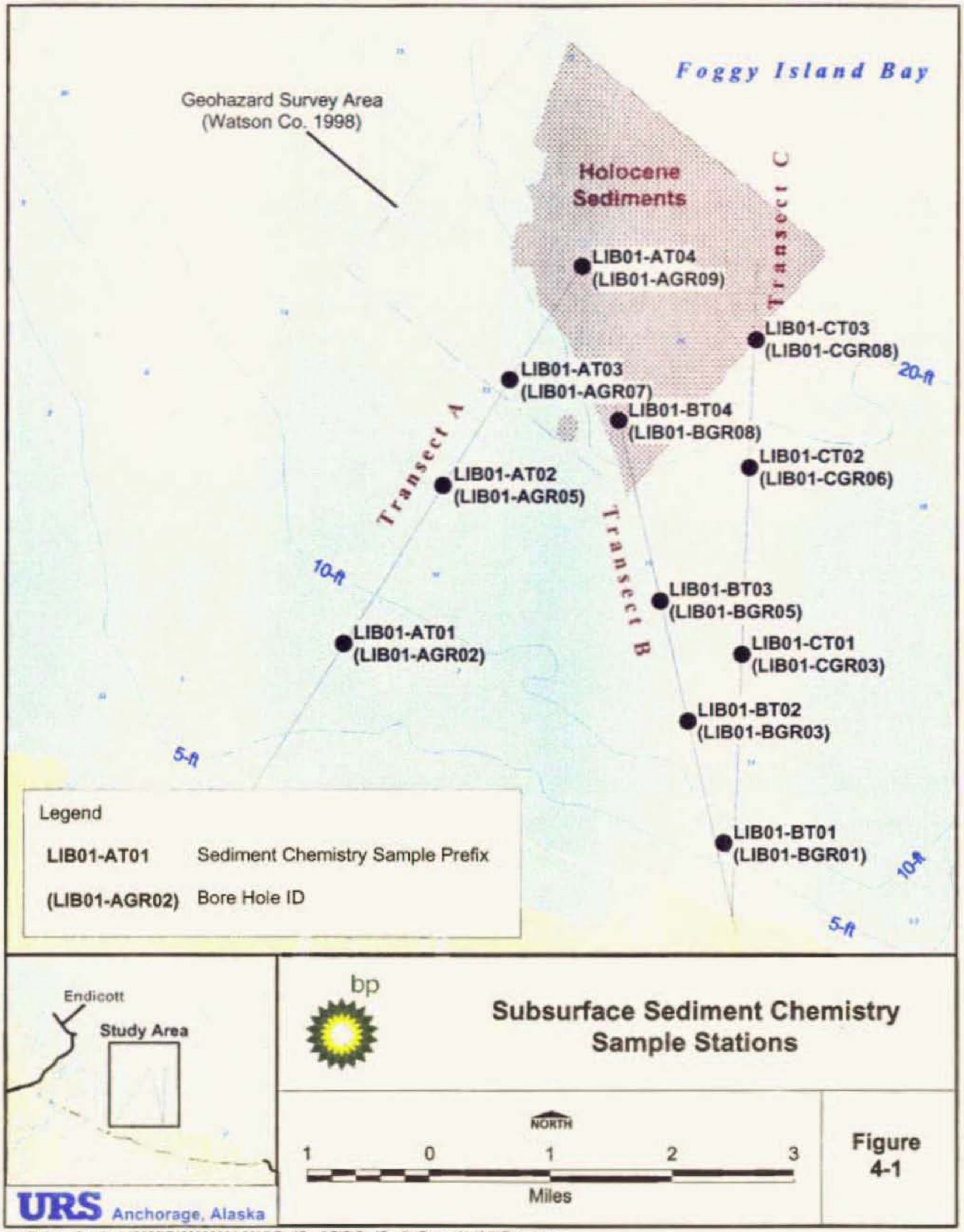
[1] Samples collected prior to exploratory drilling.
[2] Regional summary
[†] Five samples collected at Station 1 resulted in barium concentrations ranging from 120 to 9040 mg/kg.

4.1 FIELD ACTIVITIES

The sediment sampling program was based on the *Liberty Development 2001 Sediment Quality Study Work Plan*, and field activities for this study were conducted between April 25th and May 8th, 2001. The field team successfully collected a representative sample set along the three alternative pipeline routes based on statistical performance criteria noted in the Work Plan (see Appendix A, Section 4.2.2). The Liberty Island (applicant's preferred) route was designated Transect A. Survey Transects B and C followed the Southern Island and Tern Island pipeline routes respectively. Twenty stations were occupied during the sampling effort. Sampling methods and other field protocols were completed as described in the Work Plan (Appendix A). Appendix C provides a summary of the field activities, including a description of other operations that affected the field program.

A sampling priority plan was developed due to tundra travel closure potential, inclement weather and time constraints. Sampling proceeded according to scheme intended to maximize the likelihood that a representative number of samples would be collected.

- Subsurface chemistry and the associated grain size samples were collected first, beginning with Transect A stations and continuing to Transect B and C stations, respectively. This west to east order followed the route of cleared trails on the ice after leaving the Prudhoe Bay in-field road system. Approximately 94 percent (%) of the subsurface sediment chemistry samples (51 total) were collected (Figure 4-1). All of the subsurface sediment chemistry sampling was completed; however, there was low sample recovery at two stations, BGR03 and BGR05, due to heaving, fluid (completely saturated) sands. Thus, a total of three samples from the two stations were not submitted for analysis as originally detailed in the Work Plan.
- Secondly, surface sediment chemistry and the associated grain size samples were collected from east to west along the cleared trails. 100% of surface chemistry samples (4 total) were collected (Figure 4-2).
- Finally, the outstanding grain size samples were collected as time allowed, commencing with Transect A stations, which were the nearest stations to the surface sediment locations, and proceeded from west to east. Although all attempts were made to complete the planned sampling as detailed in the Work Plan, the drilling and sampling program was terminated on May 6th, 2001 due to time constraints. At that time, Transect A grain size sampling had been completed and approximately 61 percent of the grain-size samples (68 total) had been collected (Figure 4-3). The drilling and sampling program proceeded at a slower pace than originally planned due to a number of unforeseen difficulties. A delay in the seal structure identification was encountered, due to a delay in obtaining a letter of authorization (LOA) from the US Fish and Wildlife Service (USFWS). The presence of Western GeoCo geophone cable lines increased the one way travel time to approximately three (3) hours and prevented efficient usage of CATCO trails. Weather, seal structures and the geophysical survey caused delays throughout the program.



Subsurface Sediment Chemistry Sample Stations

Figure 4-1

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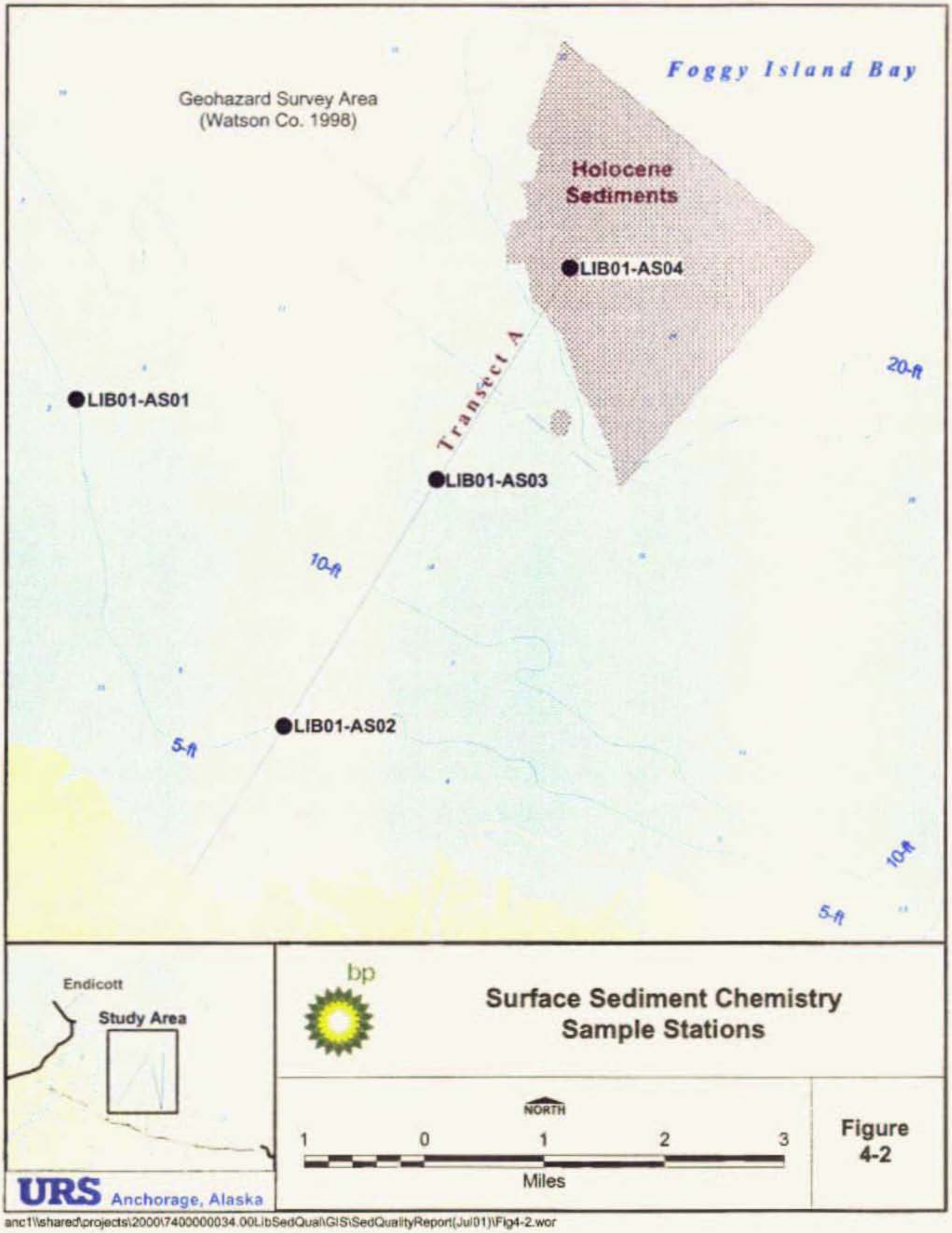

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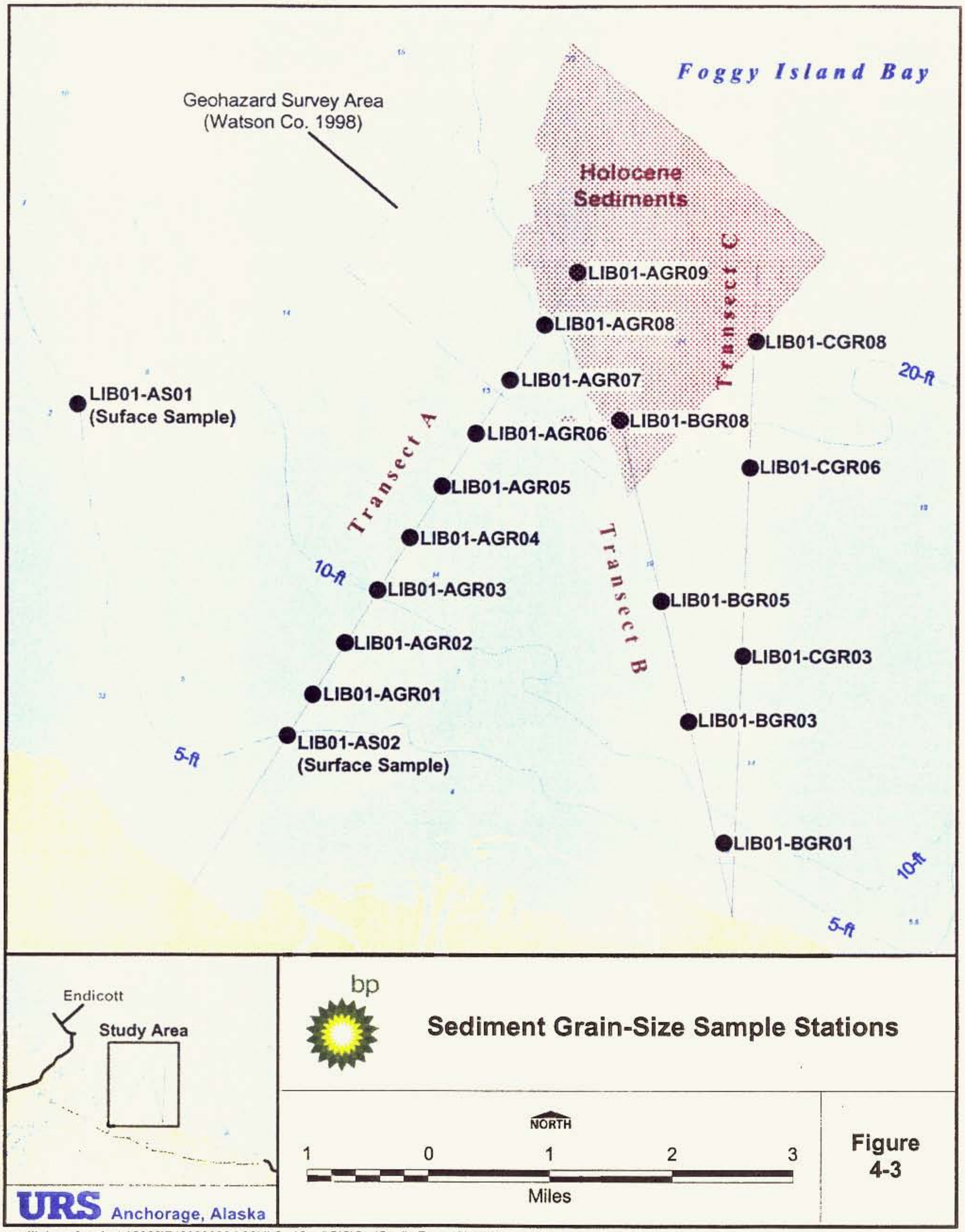

Sediment Grain-Size Sample Stations

Figure 4-3

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As specified in the Work Plan, samples were collected at four depths at a minimum of four stations along each of the three transects, fulfilling the statistical requirements of the stratified systematic sampling design. This design, intended to provide statistically sufficient characterization of sediment chemistry and thus grain size data, was based on EPA (1992) guidance and statistical methods summarized by Gilbert (1987). However, as noted above, not all of the grain-size samples were collected as initially prescribed by the Corps.

4.2 SURFACE SEDIMENT CHEMISTRY RESULTS

Four surficial sediment samples were collected from stations in the study area at depths ranging from the surface to 0.5 feet below the existing seafloor (Figure 4-2). Table 4-1 presents a complete list of the chemical and physical parameters analyzed by an independent laboratory and the reported minimum, maximum, and average concentrations.

The EPA and Corps have not promulgated guidance for environmental evaluation of dredging activities specific to Alaska. However, guidance exists for the Lower Columbia River and other Pacific Northwest estuaries in the form of the *Dredged Material Evaluation Framework, Lower Columbia River Management Area* (November 1998). EPA Region X directed that this guidance be applied to the Liberty Development sampling program. Screening levels for specific chemicals-of-concern (CoCs) are provided in Table 4-1.

Metal and PAH analyses conducted on the sediment samples collected for this baseline study resulted in concentrations consistently less than the regulatory screening levels (Table 4-1). Notable results are summarized below for select physical properties and the CoCs. The quality control/assurance (QA/QC) for all laboratory analyses is summarized in Appendix E and laboratory results for all sample analyses are presented in Appendix F.

Physical properties and conventional chemicals-of-concern:

- Ammonia as Nitrogen: Concentrations generally increased toward the north (offshore). Station AS02 exhibited the lowest concentration at 0.7 milligram per kilogram (mg/kg) and Station AS04 the highest at 3.3 mg/kg. Stations AS01 and AS03 (Figure 4-2) had similar concentrations ranging of 2.6 mg/kg and 2.4 mg/kg, respectively.
- Total Organic Carbon (TOC): Results ranged from 8,000 mg/kg (0.8 percent) TOC, for Station AS02, to 40,400 mg/kg (4.04 percent) for Station AS01.
- Total Volatile Solids (TVS): Sample results showed a distribution similar to that of TOC. Results ranged from 12,700 mg/kg (1.27%) in a sample collected at the nearshore Station AS02 to 46,500 mg/kg (4.65%) in a sample collected at Station AS01.
- Sulfides: Sulfides were detected in all samples, with the lowest concentration, 51.6 mg/kg, reported in a sample collected at the nearshore Station AS02. The highest concentration, 882 mg/kg, was measured from a sample collected at Station AS01.

Metals:

- All sediment analyses for the selected metals resulted in concentrations lower than (below) the screening levels prescribed *in Dredged Material Evaluation Framework, Lower Columbia River Management Area* (November 1998). See Table 4-1.

- Measurable concentrations of all metals were found in all surface sediment samples.
- Mercury was detected in low (≤ 0.05 mg/kg) concentrations near the method detection limit (MDL).
- Antimony concentrations were lower than 0.2 mg/kg for all samples. The highest concentration reported was for a sample collected at Station AS04 at 0.17 mg/kg.
- Silver concentrations were lower than or equal to 0.105 mg/kg for all samples. The highest concentration reported was for Station AS04 at 0.105 mg/kg.

Polycyclic Aromatic Hydrocarbons (PAH):

- All sediment samples analyzed for PAH compounds indicated concentrations lower than (below) the screening levels prescribed in *Dredged Material Evaluation Framework, Lower Columbia River Management Area* (November 1998). See Table 4-1.
- With the exception of 14 µg/kg of phenanthrene measured in a sample collected at Station AS03, the low molecular weight PAH (LPAH) and high molecular weight PAH (HPAH) compounds were not detected above the method reporting limit (MRL) in the surface sediment samples. Only estimated (J) values are reported.

Additional Analyses:

Additional analyses were performed on the four surface samples. The samples were analyzed for pesticides, PCBs, semi-volatile organic compounds (SVOC) and select volatile organic compounds (VOC). The majority of the analytes were not present in measurable quantities. Estimated (J) values near the MDLs were reported for select compounds not present at concentrations above the method reporting limits.

Table 4-1 Surface Sediment Chemistry Results and Screening Levels

Chemical	Screening Level	Minimum Result	Maximum Result
Physical Properties and Conventional Chemicals of Concern			
Total Solids (Percent)	--	68	79.7
Total Volatile Solids (Percent)	--	1.27	4.65
Total Organic Carbon (Percent)	--	0.8	4.04
Total Sulfides (mg/kg)	--	51.6	882
Ammonia as Nitrogen (mg/kg)	--	0.7	3.3
Metals (mg/kg)			
Antimony	150	0.1	0.17
Arsenic	57	4.6	8
Barium	--	29.5	58.5
Cadmium	5.1	0.11	0.34
Calcium	--	25100	73200
Chromium	--	8.51	13
Copper	390	6.29	15.1
Iron	--	11300	16500
Lead	450	6.03	9.29
Manganese	--	142	256
Mercury	0.41	0.01 B	0.05
Nickel	140	12.4	20.7
Silver	6.1	0.033	0.105
Zinc	410	34.9	57.8
Organics (mg/kg)			
Low Molecular Weight Polynuclear Aromatic Hydrocarbons (mg/kg)			
2-Methylnaphthalene	670	ND (3.8)	12 J
Acenaphthene	500	ND (3.7)	ND (4.1)
Acenaphthylene	560	ND (2.3)	ND (2.6)
Anthracene	960	ND (2.9)	ND (3.7)
Fluorene	540	ND (3.3)	ND (3.6)
Naphthalene	2,100	ND (2.3)	6.7 J
Phenanthrene	1,500	4.1 J	15 J
High Molecular Weight Polynuclear Aromatic Hydrocarbons (mg/kg)			
Benzo(a)anthracene	1,300	ND (1.8)	3.1 J
Benzo(a)pyrene	1,600	ND (1.2)	3.8 J
Benzo(b+k)fluoranthene	3,200	ND (2.8)	4 J
Benzo(g,h,i)perylene	670	ND (1.3)	4 J
Chrysene	1,400	2.7 J	7.6 J
Dibenzo(a,h)anthracene	230	ND (1.3)	2.3 J
Fluoranthene	1,700	ND (3.2)	ND (4)
Indeno(1,2,3-cd)pyrene	600	ND (0.64)	ND (0.74)
Pyrene	2,600	ND (3.7)	7.8 J

Table 4-1 (Cont.) Surface Sediment Chemistry Results and Screening Levels

Chemical	Screening Level	Minimum Result	Maximum Result
Chlorinated Hydrocarbons (mg/kg)			
1,3-Dichlorobenzene	170	ND (0.9)	ND (1)
1,4-Dichlorobenzene	110	ND (1)	ND (2)
1,2-Dichlorobenzene	35	ND (0.9)	ND (1)
1,2,4-Trichlorobenzene	31	ND (3.3)	ND (3.9)
Hexachlorobenzene (HCB)	22	ND (3.8)	ND (4.9)
Phthalates (mg/kg)			
Dimethyl Phthalate	1,400	ND (3.4)	ND (4.1)
Diethyl Phthalate	1,200	ND (4)	ND (4.7)
Di-n-butyl Phthalate	5,100	ND (3.7)	ND (4.1)
Butyl Benzyl Phthalate	970	ND (2.2)	ND (2.5)
Bis(2-ethylhexyl)phthalate	8,300	ND (200)	ND (230)
Di-n-octyl Phthalate	6,200	ND (2.3)	ND (2.6)
Phenols (mg/kg)			
Phenol	420	24 J	35 J
2-Methylphenol	63	ND (3)	ND (3.8)
4-Methylphenol	670	ND (3.4)	9.2 J
2,4-Dimethylphenol	29	ND (19)	ND (27)
Pentachlorophenol	400	ND (3)	ND (3.8)
Miscellaneous Extractables (mg/kg)			
Benzyl Alcohol	57	ND (3.5)	ND (4.5)
Benzoic Acid	650	37 J	57 J
Dibenzofuran	540	ND (3.6)	ND (4.7)
Hexachloroethane	1,400	ND (2.9)	ND (3.7)
Hexachlorobutadiene	29	ND (3.5)	ND (4.5)
N-Nitrosodiphenylamine	28	ND (3.5)	ND (3.9)
Pesticides and PCBs (mg/kg)			
Total DDT	6.9	ND (0.2)	0.3 J
(sum of 4,4'-DDD, 4,4'-DDE and 4,4'-DDT)			
Aldrin	10	ND (0.3)	ND (0.4)
a-Chlordane	10	ND (0.2)	ND (0.2)
Dieldrin	10	ND (0.4)	ND (0.5)
Heptachlor	10	ND (0.2)	ND (0.2)
g-BHC (Lindane)	10	ND (0.4)	ND (0.7)
Total PCBs	130	ND (3)	ND (3)

Notes:
1 *Dredged Material Evaluation Framework, Lower Columbia River Management Area* (November 1998);
-- No screening level
J The result is an estimated concentration that is less than the MRL but ≥ the MDL.
ND Analyte Not Detected, the maximum method detection limit (MDL) is shown in parentheses as applicable

4.3 SUBSURFACE SEDIMENT CHEMISTRY RESULTS

Ninety-four subsurface sediment samples were collected from stations aligned along the three alternative pipeline routes (Figure 4-1). Table 4-2 presents a complete list of the chemical and physical parameters analyzed by independent laboratories and the reported minimum, maximum, and average concentrations and the regulatory screening levels as listed in the *Dredged Material Evaluation Framework, Lower Columbia River Management Area* (November 1998). Analyses conducted on the sediment samples collected for this baseline study resulted in concentrations consistently less than the screening levels (Table 4-2). Notable results are summarized below for physical properties and the CoCs.

Physical properties and conventional chemicals-of-concern:

- Ammonia as Nitrogen: Sample results indicate two positive trends: a depth relationship where ammonia as nitrogen concentrations increased with depth below the seafloor; and a nearshore/offshore trend where concentrations were notably higher for offshore sediments as compared to nearshore sediments. However, there were two exceptions, Stations CGR06 and CGR08. These stations had similar concentrations ranging from 3.8 mg/kg (3-4 feet) to 49.7 mg/kg (7.8-8.8 feet). The highest concentrations reported were for sediments collected at Stations AGR09 (11.5-12.5 feet) and BGR08 with results up to 710 mg/kg. The only sample having no ammonia as nitrogen reported was the near surface sediment sample collected at Station BGR01 (1.5-2.5 feet), non-detect (ND) at 0.3 mg/kg. The deepest sample at Station BGR01 (13-14 feet) had the lowest concentration reported at all depths of all samples taken, at 0.7 mg/kg.
- Total Organic Carbon (TOC): Results ranged from 2,200 mg/kg (0.22 percent) in a sample collected at Station BGR01 (5.5-6.5 feet) to 147,000 mg/kg (14.7 percent) TOC in a sample collected at Station AGR05 (4.5-5.5 feet, peat). Coarse-grained offshore sediments collected in shallow nearshore waters (Station BGR01 [sand]) exhibited the lowest concentrations. TOC levels tended to increase as the percentage of fine-grained (silt and clay) surficial sediment increased.
- Total Volatile Solids (TVS): Sample results showed a distribution similar to that of TOC. Results ranged from 7,100 (0.71%) in a sample collected at the nearshore Station BGR01 (13-14 feet, gravel) to 264,000 (26.4%) in a sample collected at Station AGR05 (4.5-5.5 feet, peat).
- Sulfides: Sulfides were detected in all samples. The lowest concentration, 18.8 mg/kg was reported in a sample collected at the nearshore Station BGR01 (1.5-2.5 feet). The highest concentration, 3,290 mg/kg was present in a sample collected at Station AGR02 (11.5-12.5 feet, organic silt).

Metals:

- All sediment analyses for the selected metals resulted in concentrations lower than (below) the screening levels prescribed *in Dredged Material Evaluation Framework, Lower Columbia River Management Area* (November 1998). See Table 4-2.

- Measurable concentrations of all metals were found in all of the samples with the exception of one analysis for cadmium at Station BGR01 (5.5-6.5 feet, sand) and one analysis for mercury at Station AGR02 (6.5-7.5 feet, silty sand).
- All reported cadmium concentrations were less than 1 mg/kg with the exception of samples taken at Station AGR05 (4.5-5.5 feet), which contained concentrations up to 1.12 mg/kg. These sample concentrations were notable as compared the other samples taken at the same station, but below the regulatory screening level of 5.1 mg/kg. The next highest concentration reported at the same station was 0.24 mg/kg (10-11 feet).
- Mercury was detected in low concentrations near the method detection limit (MDL). All samples contained mercury at concentrations less than or equal to 0.09 mg/kg.
- Antimony concentrations were lower than 0.35 mg/kg for all samples. The highest concentrations were reported for samples taken at Station AGR05 (4.5-5.5 feet, peat) and AGR09 (6.5-7.5 feet, silty sand and 11.5-12.5 feet, clayey silt).
- Silver was detected at concentrations lower than 0.3 mg/kg in all samples. Like antimony, the highest concentrations were reported for samples at Station AGR05 (0.267 and 0.297 mg/kg at 4.5-5.5 feet) and AGR09 (0.229 mg/kg at 6.5-7.5 feet, and 0.226 mg/kg at 11.5-12.5 feet). Additionally, one sample collected at Station AGR07 (1-2 feet, silty sand) contained silver at 0.266 mg/kg.

Polycyclic Aromatic Hydrocarbons (PAH):

- All sediment samples analyzed for PAH compounds resulted in concentrations lower than (below) the screening levels prescribed in *Dredged Material Evaluation Framework, Lower Columbia River Management Area* (November 1998).
- The low molecular weight PAH (LPAH) compounds acenaphthene, acenaphthylene, and anthracene were not detected above the method reporting limit in the sediment samples. Only estimated (J) values are reported.
- The high molecular weight PAH (HPAH) compounds benzo(a)anthracene, benzo(a)pyrene, benzo(k)fluoranthene, dibenzo(a,h)anthracene, and indeno(1,2,3-cd) pyrene were not detected above the method reporting limit in the sediment samples. Only estimated (J) values are reported.
- All reported estimated concentrations for all PAH compounds were less than or equal to 52 parts per billion (ppb) or micrograms per kilogram (μg/kg). The maximum PAH concentration of 52 μg/kg were reported for 2-methylnaphthalene and phenanthrene at Station AGR07 (1-2 feet).

Table 4-2 Subsurface Sediment Chemistry Results and Screening Levels

Chemical	Screening Level	Minimum Result	Maximum Result
Physical Properties and Conventional Chemicals of Concern			
Total Solids (Percent)	--	43.7	93.1
Total Volatile Solids (Percent)	--	0.71	26.4
Total Organic Carbon (Percent)	--	0.22	14.7
Total Sulfides (mg/kg)	--	18.8	3290
Ammonia as Nitrogen (mg/kg)	--	ND (0.3)	710
Metals (mg/kg)			
Antimony	150	0.04 B	0.35
Arsenic	57	2.4	15.2
Barium	--	28.6	171
Cadmium	5.1	ND (0.03)	1.12
Calcium	--	2160	86600
Chromium	--	5.84	33.1
Copper	390	2.91	41.2
Iron	--	6620	36000
Lead	450	2.33	18.4
Manganese	--	52.7	738
Mercury	0.41	ND (0.01)	0.09
Nickel	140	6.48	47.1
Silver	6.1	0.02 B	0.297
Zinc	410	20.1	110
Organics (mg/kg)			
Low Molecular Weight Polynuclear Aromatic Hydrocarbons (mg/kg)			
2-Methylnaphthalene	670	ND (3)	52
Acenaphthene	500	ND (2)	2 J
Acenaphthylene	560	ND (2)	ND (3)
Anthracene	960	ND (2)	6 J
Fluorene	540	ND (2)	6.8
Naphthalene	2,100	ND (3)	28
Phenanthrene	1,500	ND (2)	52
High Molecular Weight Polynuclear Aromatic Hydrocarbons (mg/kg)			
Benzo(a)anthracene	1,300	ND (2)	6 J
Benzo(a)pyrene	1,600	ND (3)	5 J
Benzo(b+k)fluoranthene	3,200	ND (2)	12
Benzo(g,h,i)perylene	670	ND (2)	8
Chrysene	1,400	ND (3)	22
Dibenzo(a,h)anthracene	230	ND (2)	3 J
Fluoranthene	1,700	ND (2)	14
Indeno(1,2,3-cd)pyrene	600	ND (0.7)	3 J
Pyrene	2,600	ND (2)	14

Notes:

1 *Dredged Material Evaluation Framework, Lower Columbia River Management Area* (November 1998);
-- No screening level
B The inorganic analyte result is an estimated concentration that is less than the MRL but ≥ to the MDL.
J The organic analyte result is an estimated concentration that is less than the MRL but ≥ to the MDL.
ND Analyte Not Detected, the maximum method detection limit (MDL) is shown in parentheses as applicable

4.4 GRAIN SIZE RESULTS

Grain-size sediment samples were collected at a minimum of four locations along each transect, with a total of 43 samples collected along Transect A, 15 along Transect B, and 20 along Transect C (including four samples collected from Station BGR01). Grain-size distribution data obtained from the 74 total samples collected in 2001 add to the existing knowledge base of Foggy Island Bay sediments, where 53 marine sediment samples were collected in 1997 and 34 samples were collected in 1998 (Duane Miller & Associates 1997, 1998).

- Sediments are predominantly clastic with organic silt and thin inter-bedded layers of peat. Silts and fine sands dominated the surficial sediment distribution for the offshore samples. Coarser-grained nearshore sediments transitioned to finer-grained sediments offshore as shown in boring logs presented in Appendix D (Duane Miller & Associates 2001).
- On average, sediments samples contained 62% fines (silt and clay).
- Sediment samples collected from offshore (water depths greater than 15 feet) boreholes contained 70% fines.
- Offshore sediments typically consisted of sand, silty sand, with some soft Holocene silt, and many pockets and layers of peaty soil. Organic silt generally was found overlaying firmer Pleistocene deposits (Duane Miller & Associates 2001).
- Sediment samples collected from nearshore (water depths less than 15 feet) boreholes contained 45% fines.
- Nearshore, sandy zones were more prevalent and in some cases dominant with sandy gravel found below (Duane Miller & Associates 2001).
- Complex features (e.g., distributary channels, submerged shoreface) identified in a geophysical survey conducted along Transect A (Figures 3-1 and 3-2) were not delineated along Transects B and C. Grain-size samples collected within these complex features tended to be coarser-grained than the surrounding sediment; however, these were small-scale features and coarse-grained material only comprise a small portion of sediments in these features.
- Sediments sampled in 2001 displayed grain-size distributions consistent with those found previously in geotechnical studies in the area (Figures 3-1 and 3-2) (Duane Miller & Associates 1997, 1998).

Concern regarding suspended sediment generated by the pipeline construction (i.e., excavation and fill) and ocean dumping activities and its probable movement through the nearby Boulder Patch community prompted the requirement to conduct this sampling program. Representative samples from sediment anticipated to be excavated and used as fill during pipeline construction activities were collected and analyzed for selected physical properties and CoCs. The sampling effort was restricted to water depths that coincide with the floating land fast sea ice, where bay waters will be encountered below the sea ice during construction activities, and thus, provide a medium to suspend sediment. The grounded sea ice zone is typically restricted to shallower (<6.5 feet) nearshore areas where the sea ice rests directly on the seafloor with little to no free water to suspend sediments.

Sediment chemistry samples were collected to ascertain concentrations of selected CoCs and compare the results to regulatory screening levels. Grain size distribution samples were collected to support a predictive modeling effort led by the Corps to delineate areas that would probably be directly affected by the suspended sediment generated by construction activities, and determine its significance to the Boulder Patch community.

5.1 SEDIMENT CHEMISTRY

Transformations & Correlations: Variability among hydrocarbons concentrations (e.g., PAH) tend to be relatively large, and thus, it can be problematic to delineate natural and anthropogenic sources from the data set. To reduce the variability for a selected analyte, TOC and grain-size distribution are common physical properties used to normalize results. The State of Washington established sediment management standards (SMS) for PAH results normalized by TOC.

The sediment quality values (i.e., screening levels) listed in the *Dredged Material Evaluation Framework, Lower Columbia River Management Area* (November 1998) and the *Puget Sound Dredged Disposal Analysis* or PSDAA (Corps et al. 1998b) do not normalize PAH results by TOC or any other physical property. Therefore, the PAH results are not normalized by TOC in this report.

Correlation is a useful method to delineate relationships and trends between the CoCs and physical properties if there is a reason to believe that such correlations might exist. The relationship between TOC and the percent fines (silt plus clay size particles) results in a linear trend (Figure 5-1). Similar proportional relationships exist between TVS and percent fines, and thus between TOC and TVS (Figure 5-2). Past analyses (Corps 1999) indicated that TOC concentrations are higher near the river mouths; however, this spatial distribution with proximity to fluvial discharges could not be distinguished using sample data obtained this study. Figures 5-3 and 5-4 show the near-surface distributions of manganese and calcium. These figures illustrate the complexity involved in distinguishing spatial correlations (e.g., fluvial proximity) from depositional environments.

Relationships between metal concentrations and percent fines were found in this study to be roughly proportional (Appendix G). These correlations are similar to those of previous investigations in the region where metal concentrations were typically higher in fine-grained, clay-rich sediments because of their greater surface area and differences in mineralogy. Due to

Figure 5-1
Relationship Between TOC and Fines

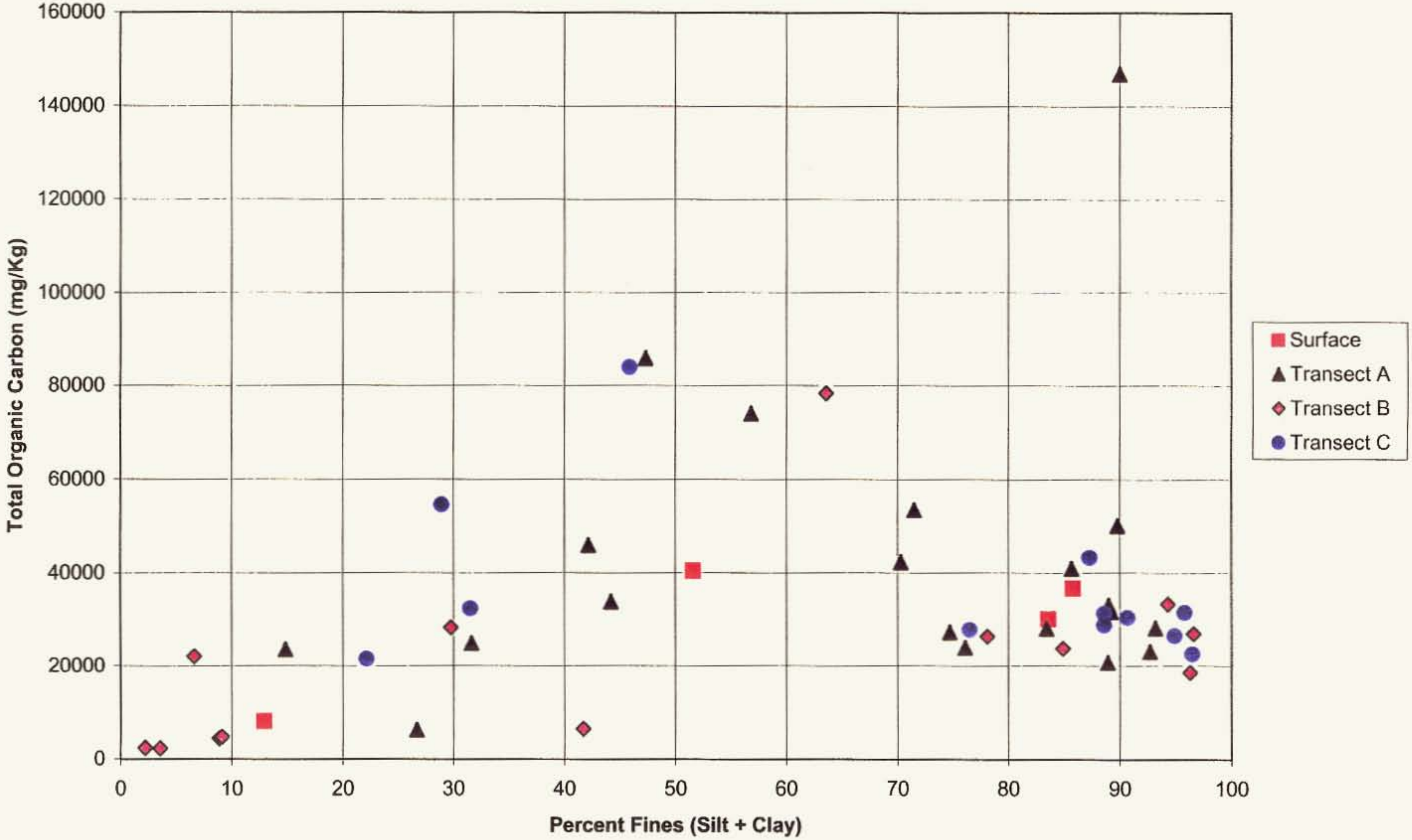
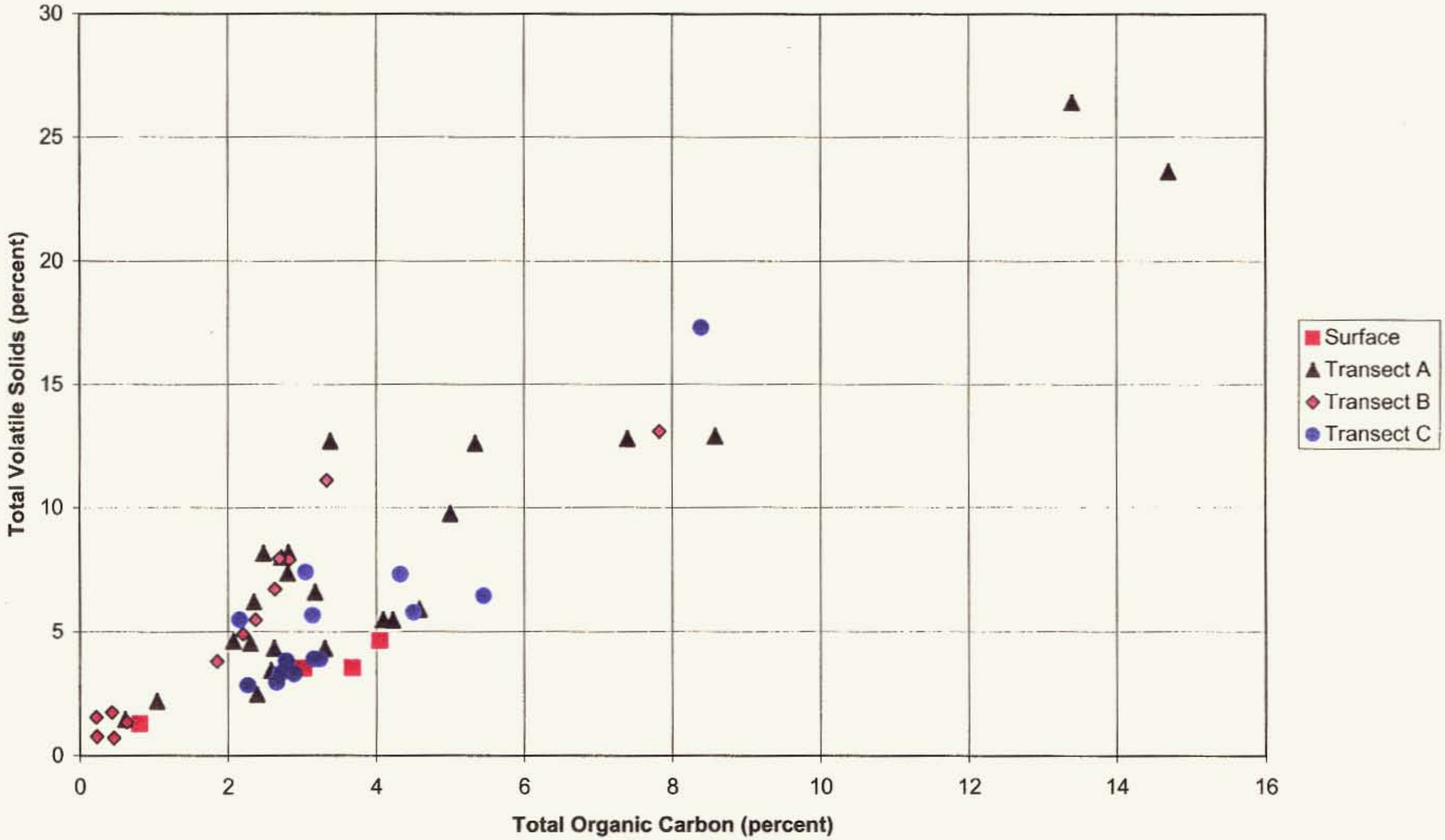
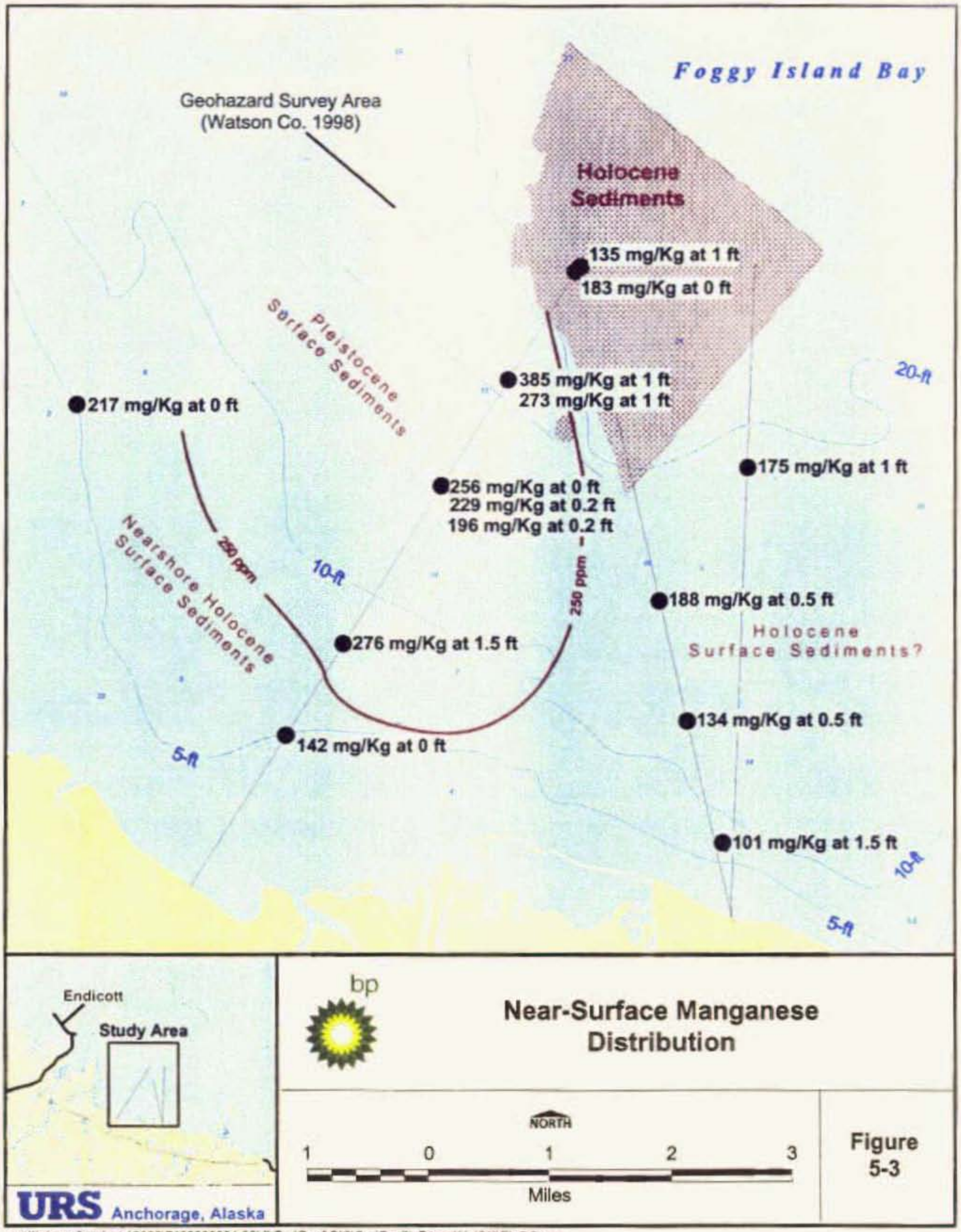


Figure 5-2
Relationship Between TVS and TOC

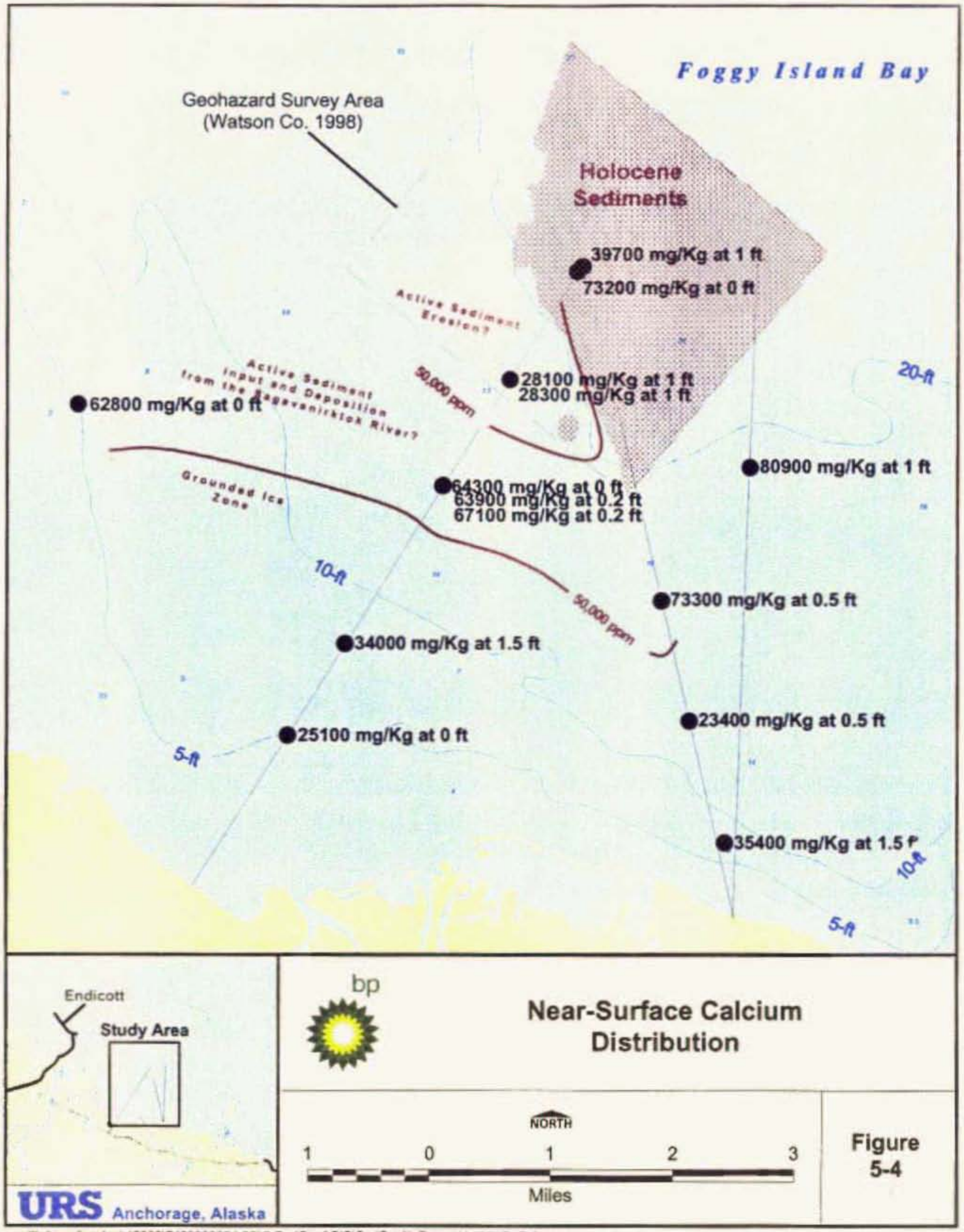




Near-Surface Manganese Distribution

Figure 5-3

anc1\\shared\projects\2000\7400000034.00LibSedQual\GIS\SedQualityReport(Jul01)\Fig5-3.wor



anc1\\shared\projects\2000\7400000034.00LibSedQual\GIS\SedQualityReport(Jul01)\Fig5-4.wor

the relatively low concentrations found in this study for many of the metals, the correlation with percent fines could not be quantified. Similar uncertainty in determining spatial relationships was encountered for metals as is illustrated in Figures 5-3 and 5-4 for manganese and calcium. However, relationships between metals were evident.

Correlation of concentrations of cadmium, chromium, copper, iron, lead, nickel, and zinc demonstrated various levels of proportionality, with the strongest correlations existing between chromium, nickel, and zinc (Figures 5-5, 5-6, 5-7, and 5-8).

Although metal concentrations were generally too low to establish definitive relationships with grain-size, relationships between metals showed a positive correlation for both surface and subsurface samples. These proportional metal-to-metal relationships are indicative of natural variability. Also, there was no notable difference in analyte concentrations between surface and subsurface samples. All CoC concentrations were low, with many PAH results below method reporting limits being designated as estimates.

Because the subsurface sediments have not been affected by anthropogenic activity, the CoC concentrations are considered to represent natural background conditions. Furthermore, since the surface sediments exhibited similar concentrations for all of the CoCs as the subsurface sediments, it is likely that these results also describe natural background values.

Comparison with Findings from Previous Studies: Numerous studies have collected and evaluated sediment geochemistry within the study area. Samples collected by NORTEC in 1983 prior to the first drilling in Foggy Island Bay (Shell Oil Tern #1) served to establish the natural background concentrations. Two additional studies have also provided information on selected heavy metals, volatile organic compounds (VOCs), semi volatile organic compounds (SVOCs), and petroleum hydrocarbons (Montgomery Watson 1997, 1998).

Similar to the results of previous investigations, no CoCs exceeded screening levels in this study. Table 3-1 presents a statistical summary of heavy metal concentrations from previous studies for sediment quality samples collected in Foggy Island Bay and other Beaufort Sea areas. Metal concentrations found in this study were found to be consistent with historic and regional data. Barium, chromium, lead and mercury concentrations were within the ranges previously established for the study area.

Metal-to-metal correlations agreed with findings from the Beaufort Sea Monitoring Program (BSMP) sponsored by the MMS (Battelle 1987; A. D. Little 1990), 1995 Northstar Unit Sampling Program (Woodward Clyde 1996), and the 1999 Northstar baseline sampling (URS 2000). Past studies have shown correlations between PAHs and percent fines to be similar to the relationship between metals and percent fines. However the concentrations of the compounds reported in this study were only slightly above the MDLs and many were reported as estimates. The relationship between PAH compounds and percent fines has not been characterized because using very low, estimated values could be misrepresentative.

Previous investigations noted natural background concentrations and this study had similar results. This observation supports the conclusion that these sediment samples are representative of natural background conditions.

Figure 5-5
Relationship Between Nickel and Zinc

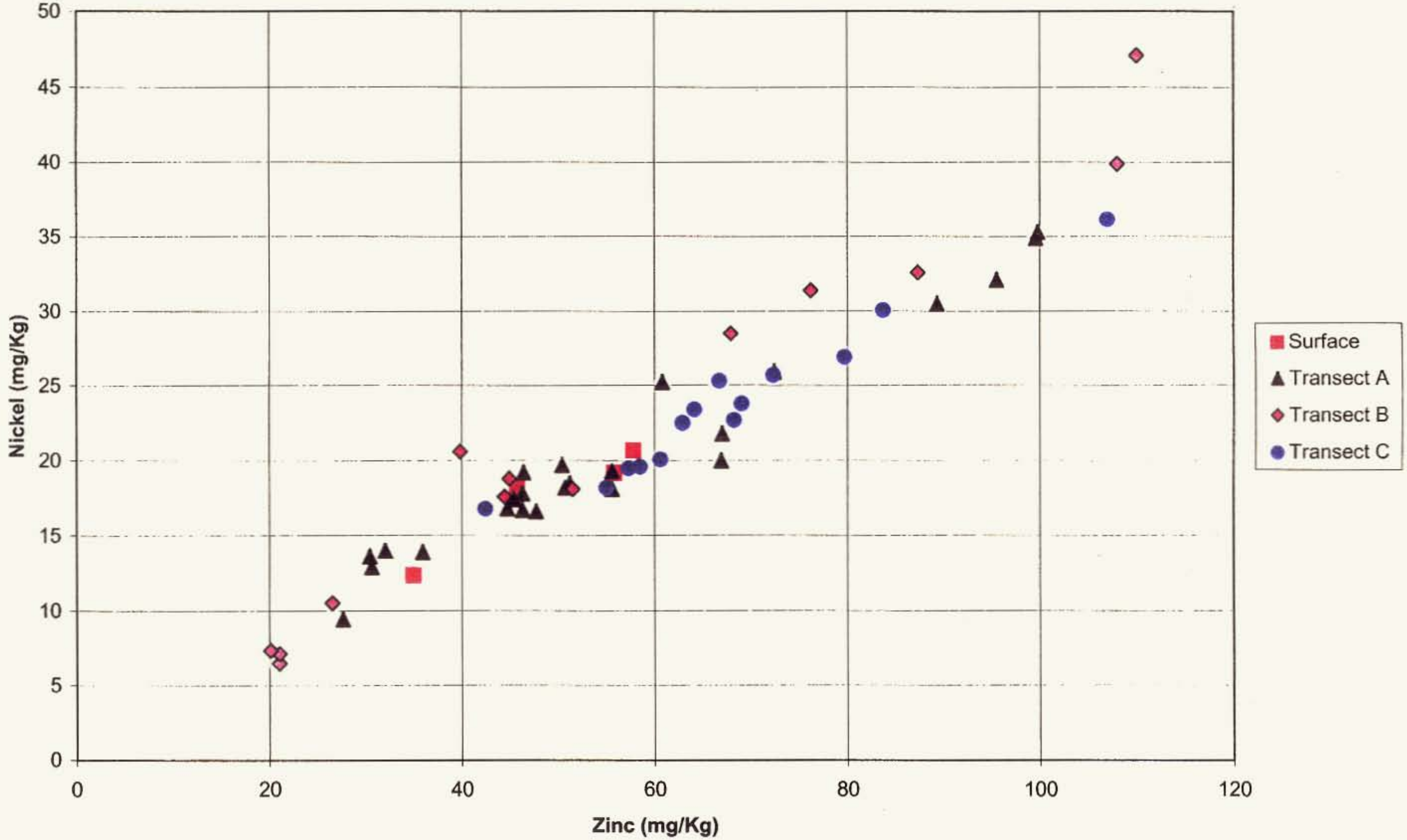


Figure 5-6
Relationship Between Chromium and Zinc

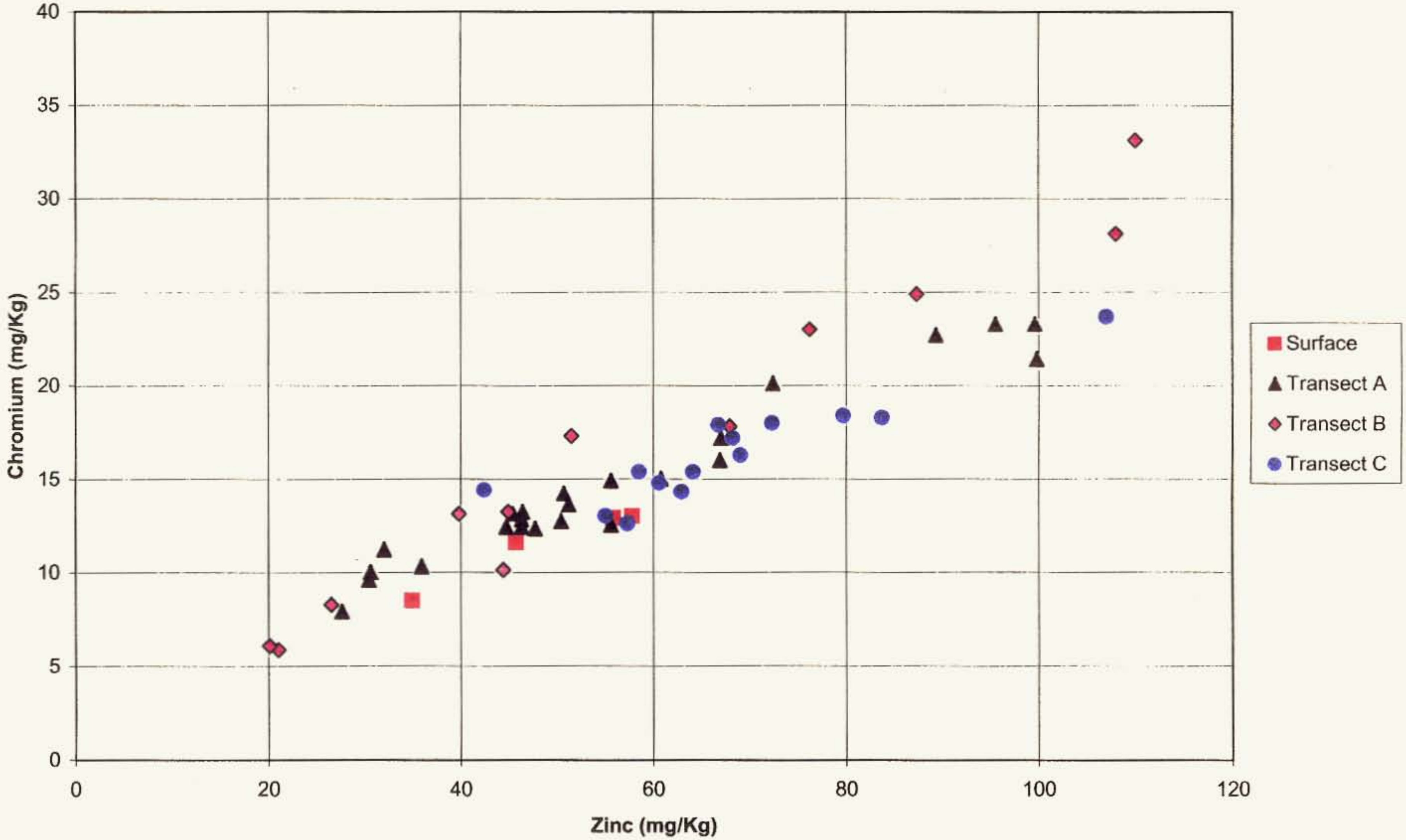


Figure 5-7
Relationship Between Chromium and Nickel

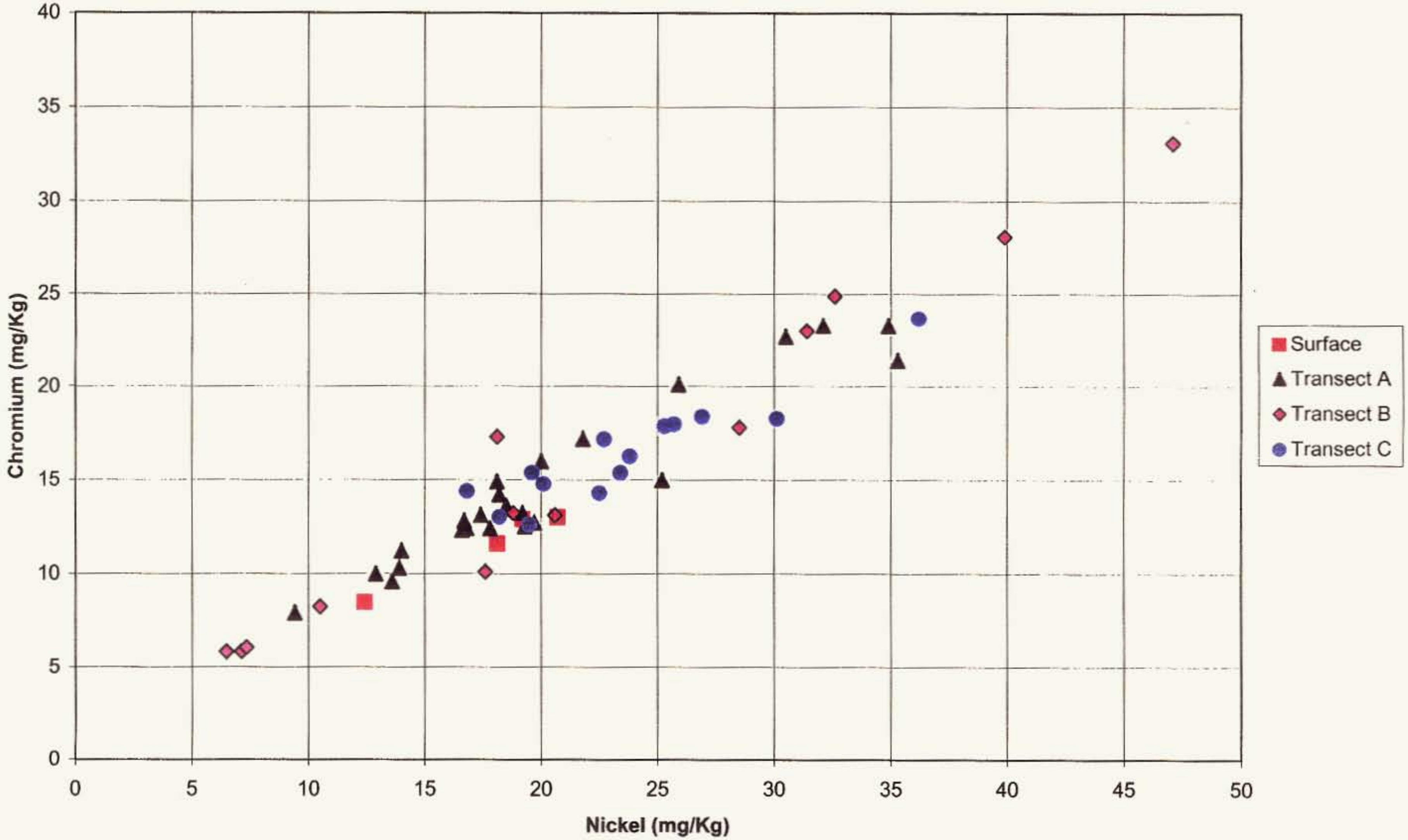
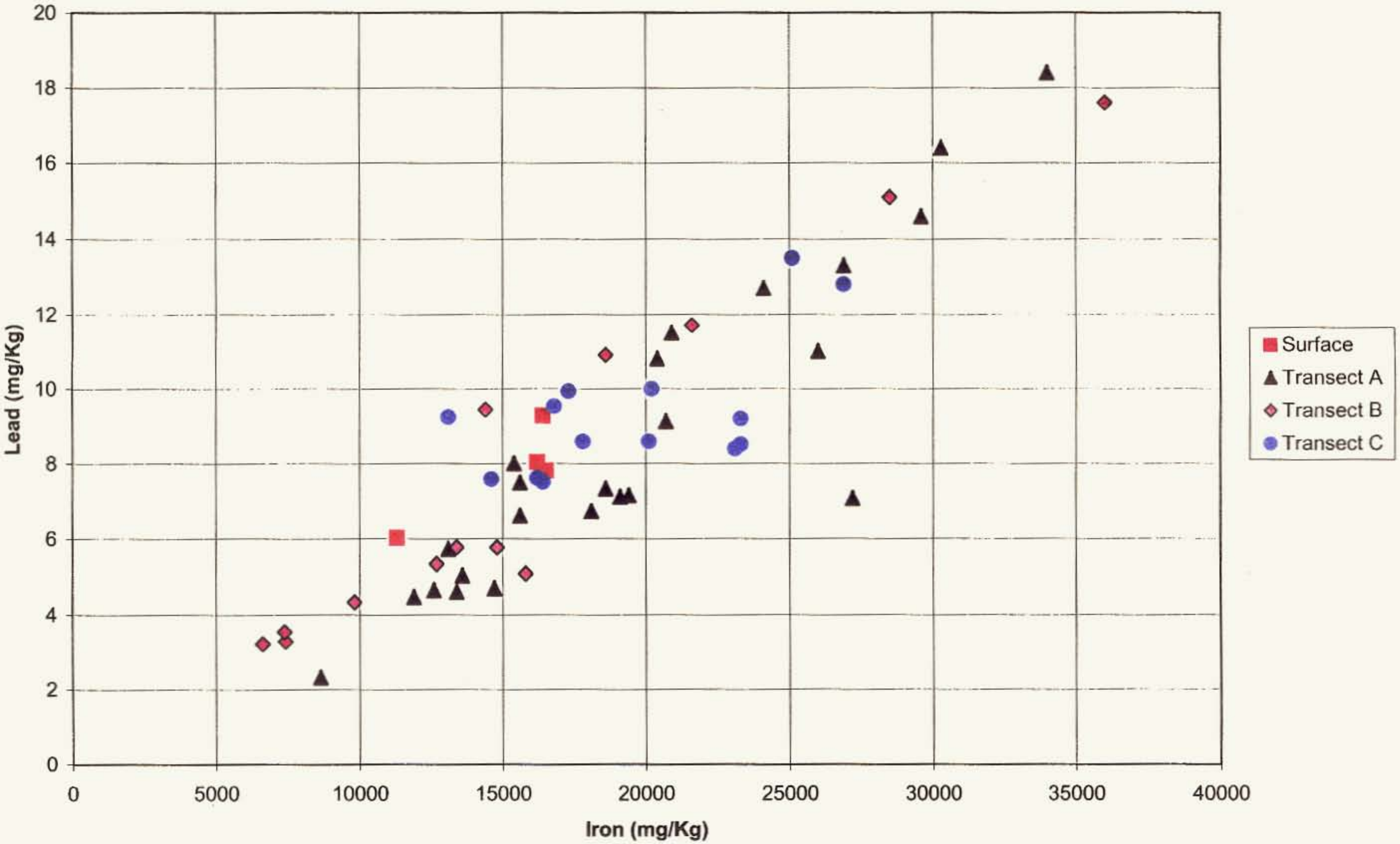


Figure 5-8
Relationship Between Lead and Iron



5.2 GRAIN SIZE

Excavation and fill activities related to marine pipeline construction will generate suspended sediment in water depths greater than 6.5 ft. Coarser sediments such as gravel and sands that are suspended by the construction activities will fall out of the water column in proximity of the construction site. However, the finer-grained sediments (silt and clay size particles smaller than the #200 sieve [0.075 mm]) are anticipated to be transported further down current, possibly affecting the nearby Boulder Patch community.

Grain size samples have been collected during three separate efforts in support of the Liberty Development: 1997 geotechnical investigation (D. Miller & Associates 1997); 1998 geotechnical investigation (D. Miller & Associates 1998); and this study. The 1997 geotechnical investigation collected representative samples nearby the applicant's preferred pipeline route (Transect A) and nearby the South Island alternative pipeline route (Transect B), while the 1998 effort focused on Transect A. This study added to the sample set for Transects A and B, and collected samples along the Tern Island alternative pipeline route (Transect C).

Earlier analysis of grain-size distribution results for Transect A determined that the fine-grained materials (silt and clay size particles smaller than the #200 sieve [0.075 mm]) were approximately 23% of the sediment that would be excavated and used as fill during pipeline construction (USGWC 1998). However, this earlier analysis inadvertently included results from sediment samples collected within the grounded ice zone where coarser-grained (sands and gravel) are the predominant sediments. Thus, for this discussion, samples that coincide with the maximum trench depth and water depths greater than 6.5 feet below sea level were used to characterize the sediment grain-size distribution along the three alternative pipeline routes.

This analysis is based on the following assumptions:

- The maximum trench depth will be 15 feet
- The trench lengths under consideration extend from the seaward limit of the grounded ice zone (6.5 feet below sea level) to the proposed alternative production islands
- The trench excavation dimensions are:
  - Bottom width = 10 feet
  - Side slopes = 3:1 or 45 feet:15 feet
  - Effective cross-sectional trench width = 55 feet

Two analyses were performed to characterize the grain-size distribution for each transect. First, an average grain-size distribution was determined for each proposed trench excavation prism based on samples that were collected along or immediately adjacent to each alternative pipeline route. This simplified representation should only be used as a rough estimate of sediment texture. Second, spatial analysis was performed to estimate the distribution of percent fine-grained sediments (silt and clay) along each of the pipeline route alternatives evaluated in *Liberty Development and Production Plan Draft Environmental Impact Statement* (MMS 2001). To assure that a conservative (i.e., slight overestimate of percent fines) approach was taken, the highest result of fine-grained sediments was used when there were two or more samples (typically duplicate samples) collected within a single depth interval for a given core.

5.2.1 Average Grain-Size Percent Fraction

The heterogeneous nature of the sediments encountered in borings located along the pipeline route alternatives indicate that no one grain-size sample describes the different sediments that will be removed from the pipeline trench. A generalized estimate of grain-size distribution can be made by computing the average percent fraction by retained weight for each sieve size from the samples collected along each transect. This approach estimated that Transect A and C trench prisms contained similar percentages, 64% and 61% respectively, of fine-grained sediments, while 42% of the Transect B trench prism contained fined-grained sediments (Table 5-1). This generalized approach does not consider sample location along the transect, so if the samples are clustered or biased in any manner to a particular portion of the transect, there is a possibility for erroneous conclusions. To gain a better understanding of the distribution and volume of fine-grained sediments within the trench prisms, spatial analysis was used.

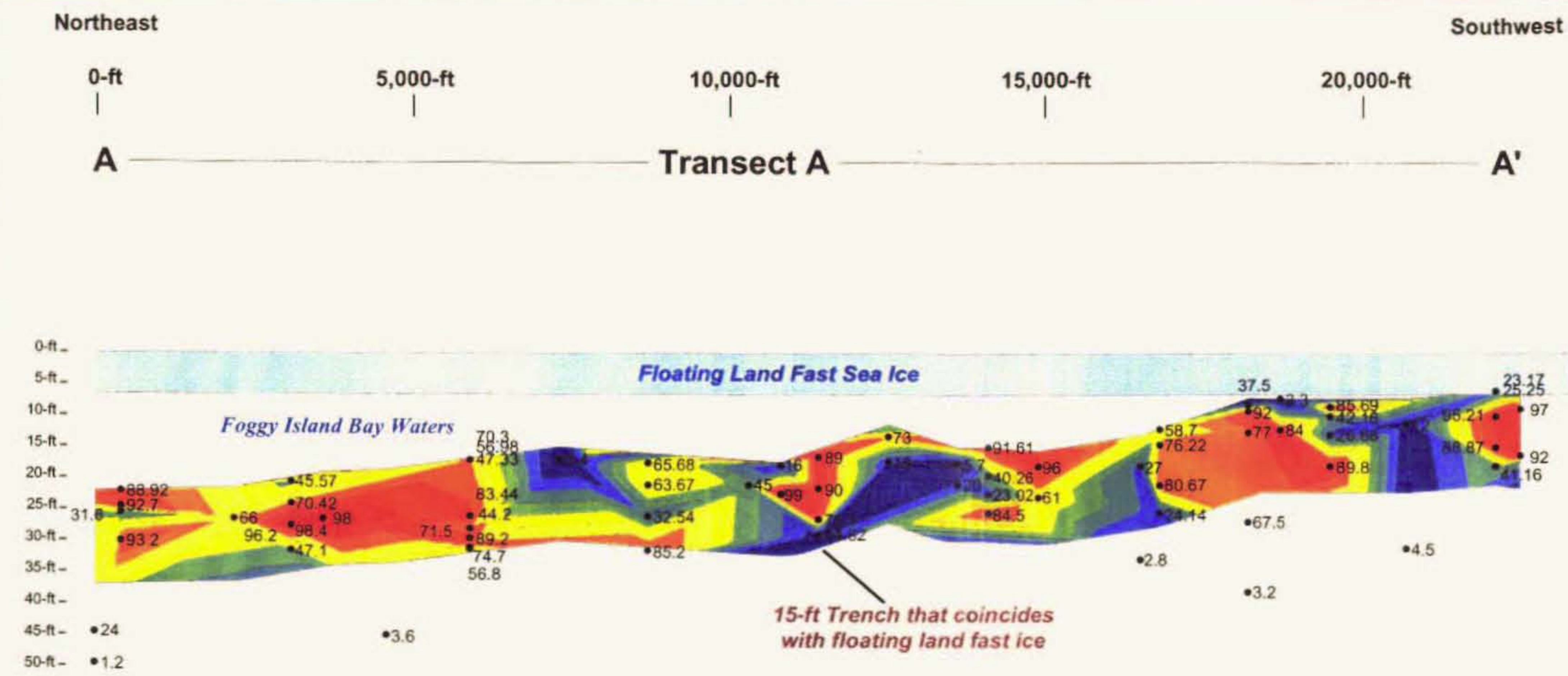
Table 5-1 Grain-size Distribution

Soil Classification	Sieve/Particle Size	Sieve Number	Percent Fraction Average (weight retained)		
			Transect A	Transect B	Transect C
Gravel	4.75 mm	4	1.3	14.4	5.4
	2.00 mm	10	0.9	4.2	1.7
Sand	0.850 mm	20	1.0	2.0	0.7
	0.425 mm	40	1.3	3.7	1.7
	0.250 mm	60	4.3	13.9	8.6
	0.106 mm	140	18.2	17.2	14.2
	0.075 mm	200	7.3	2.9	4.9
Silt	0.0039 - 0.0625 mm	NA	52.8	27.7	49.0
Clay	<0.0039 mm	NA	11.2	13.8	11.9
Average Fines (Silt and Clay)			64%	42%	61%

5.2.2 Spatial Grain-Size Analysis

Spatial analysis was used to determine the volume of fine-grained sediments that are anticipated to be excavated in waters that coincide with floating land-fast sea ice. Cross-sections were constructed for each pipeline alignment illustrating profile depths and grain-size results reported for samples collected at each applicable bore hole. Vertical distributions of grain-size gradations along Transects A, B, and C are shown on Figures 5-9, 5-10 and 5-11 respectively. Based on the trench dimension assumptions, the following volume estimates were computed for fine-grained (silt and clay) sediments to be excavated in water depths great than 6.5 feet:

- Transect A: 60% fines or 419,036 cubic yards (cy)
- Transect B: 52% fines or 292,984 cy
- Transect C: 63% fines or 489,677 cy



CLASSIFICATION	ESTIMATED TOTAL VOLUME (CUBIC YARDS [CY])	PERCENT VOLUME OF TRENCH	ESTIMATED VOLUME OF SILT & CLAY (CY)
Less than 10% Fines	3,905	1%	391
10 to 20% Fines	50,880	7%	10,176
20 to 30% Fines	57,518	8%	17,255
30 to 40% Fines	74,050	11%	29,620
40 to 50% Fines	93,158	13%	46,579
50 to 60% Fines	99,709	14%	59,825
60 to 70% Fines	106,095	15%	74,267
70 to 80% Fines	120,610	17%	96,488
80 to 90% Fines	69,330	10%	62,397
Greater than 90% Fines	22,038	3%	22,038

Total Fines (Silt + Clay) Size Fraction is approximately 419,036 cy or 60% of the trench volume.

bp

Liberty Development

Figure 5-9

Interpolated Percent Fines Grain-Size Distribution

Applicant Preferred Pipeline Route (Transect A)

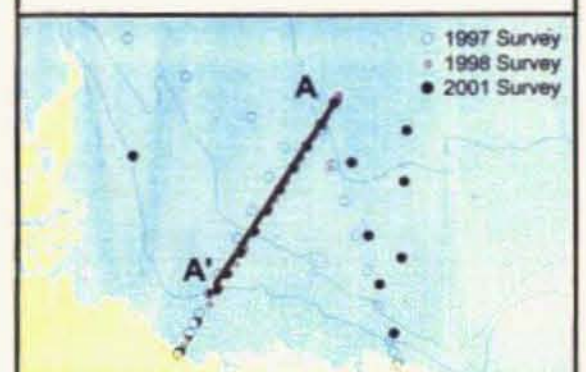
Legend

• 4.5 Percent Fines (Silt + Clay) from laboratory sample results

Notes:

100 to 1 Vertical Exageration

This anaylsis used the maximum value for percent fines for depth intervals where more than one sample was collected.



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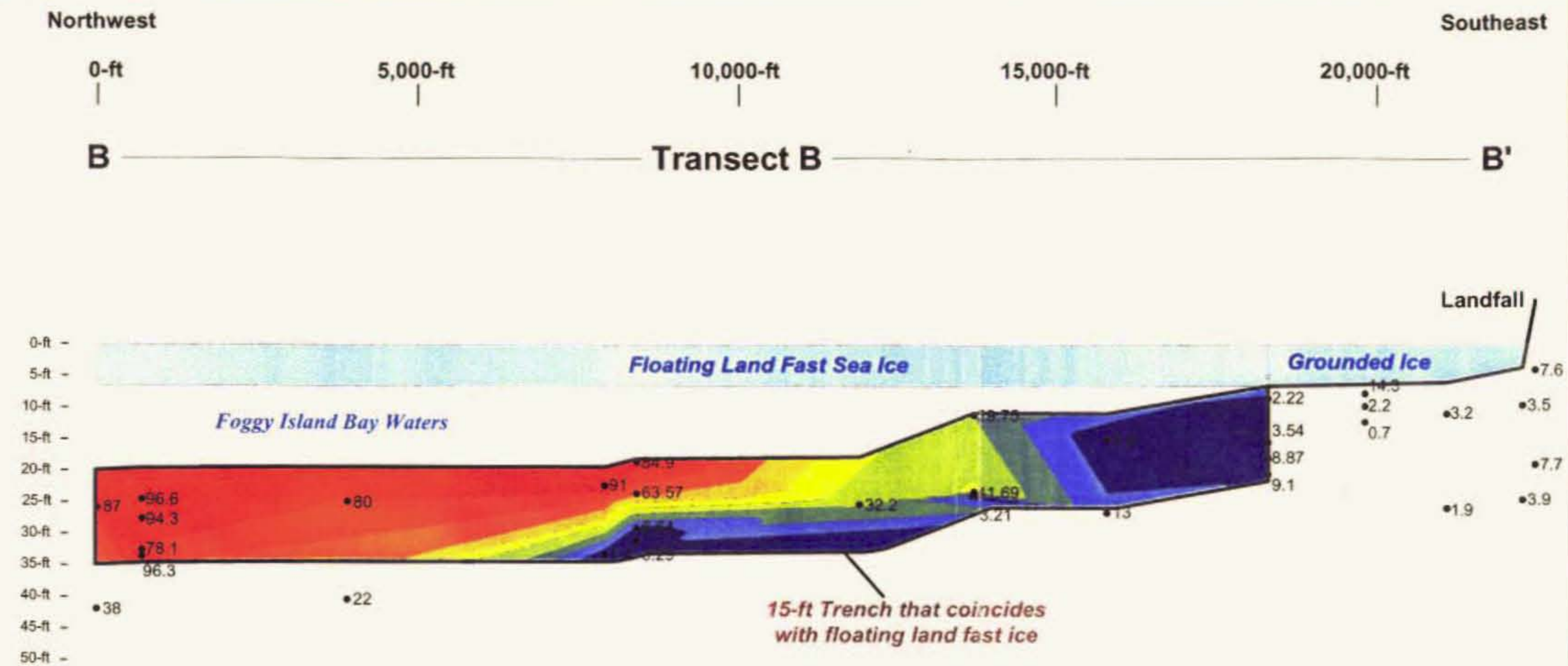

CLASSIFICATION	ESTIMATED TOTAL VOLUME (CUBIC YARDS [CY])	PERCENT VOLUME OF TRENCH	ESTIMATED VOLUME OF SILT & CLAY (CY)
Less than 10% Fines	105,169	19%	10,722
10 to 20% Fines	63,540	12%	13,477
20 to 30% Fines	44,014	9%	15,097
30 to 40% Fines	63,571	12%	27,738
40 to 50% Fines	25,144	6%	17,211
50 to 60% Fines	24,508	6%	21,680
60 to 70% Fines	48,795	7%	27,092
70 to 80% Fines	67,293	7%	31,562
80 to 90% Fines	70,475	12%	63,428
Greater than 90% Fines	52,431	9%	52,431

Total Fines (Silt + Clay) Size Fraction is approximately 292,984 cy or 52% of the trench volume.

Liberty Development

Figure 5-10

Interpolated Percent Fines Grain-Size Distribution

South Island Alternative Pipeline Route (Transect B)

Legend

• 4.5 Percent Fines (Silt + Clay) from laboratory sample results

Notes:

100 to 1 Vertical Exageration

This anaylsis used the maximum value for percent fines for depth intervals where more than one sample was collected.

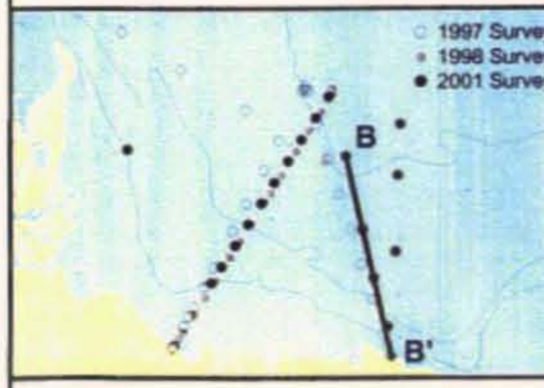

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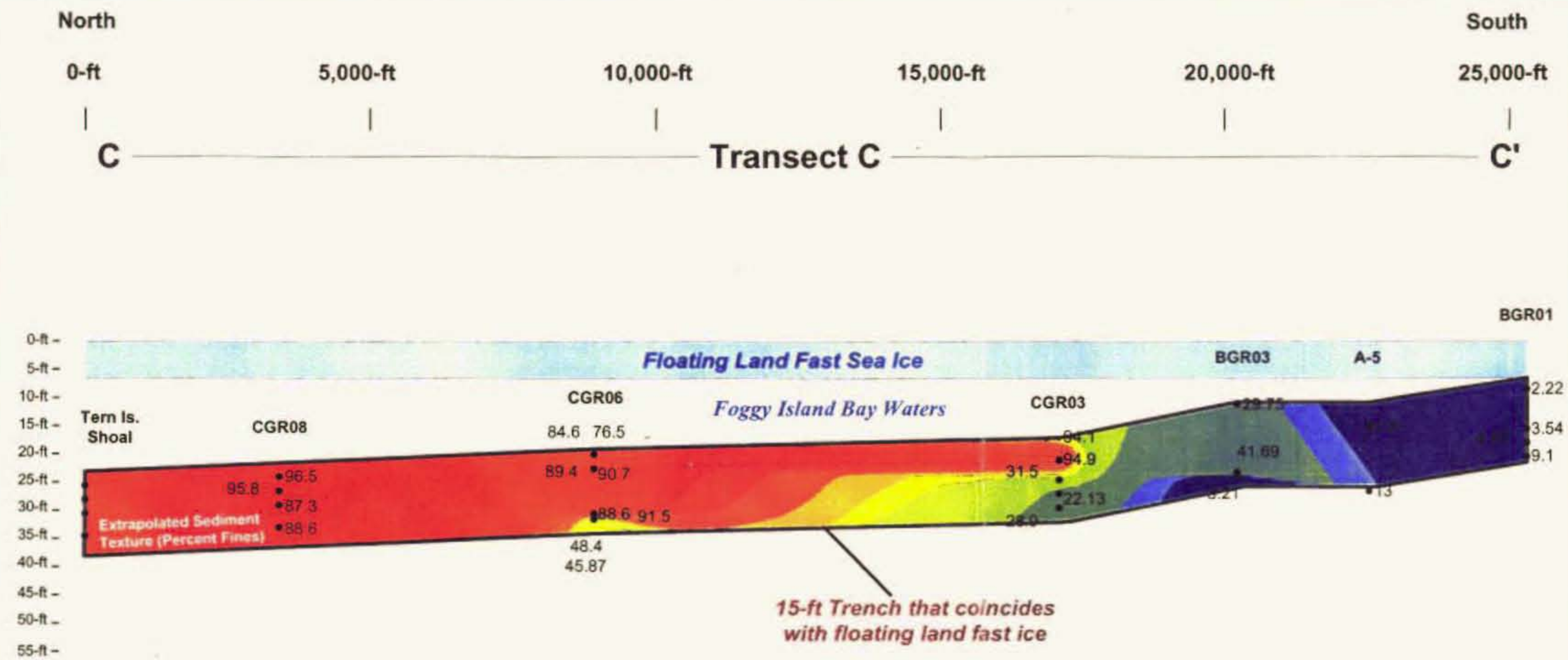
Figure 5-11

Interpolated Percent Fines Grain-Size Distribution

Tern Island Alternative Pipeline Route (Transect C)



CLASSIFICATION	ESTIMATED TOTAL VOLUME (CUBIC YARDS [CY])	PERCENT VOLUME OF TRENCH	ESTIMATED VOLUME OF SILT & CLAY (CY)
Less than 10% Fines	107,925	14%	10,793
10 to 20% Fines	30,140	4%	6,028
20 to 30% Fines	102,814	13%	30,844
30 to 40% Fines	50,373	6%	20,149
40 to 50% Fines	22,342	3%	11,171
50 to 60% Fines	31,295	4%	18,777
60 to 70% Fines	42,507	5%	29,755
70 to 80% Fines	36,037	5%	28,830
80 to 90% Fines	194,006	25%	174,605
Greater than 90% Fines	158,725	20%	158,725

Total Fines (Silt + Clay) Size Fraction is approximately 489,677 cy or 63% of the trench volume.

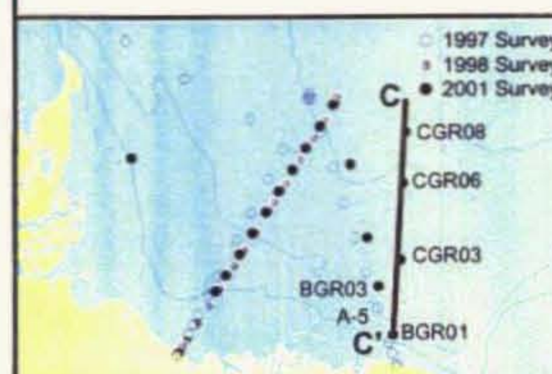
Legend

• 4.5 Percent Fines (Silt + Clay) from laboratory sample results

Notes:

100 to 1 Vertical Exageration

This anaylsis used the maximum value for percent fines for depth intervals where more than one sample was collected.



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Grain-size distribution in sediments along the three pipeline route alternatives showed variability according to distance offshore and transect location.

- Coarser-grained sediments were predominantly found in samples collected from cores located near the shallow waters adjacent to the grounded ice zone
- Finer-grained sediments dominated the grain-size distribution for samples collected at the northern end of all three alternative pipeline routes
- Transect A exhibited complex sediment distribution as a result of small-scale depositional features such as distributary channels and a submerged shoreface that were identified during a previous geophysical hazard survey (Watson Co. 1998b)
- Small-scale depositional features that typically correspond with Pleistocene deposits were not identified along Transects B and C. Watson Co. (1998a) delineated a surface outcrop of Pleistocene deposits seaward of the grounded ice zone near the 1998 bore hole D-12 and extending to approximately 2,800 ft south of the proposed Liberty Island (Figures 3-1 and 3-2). These Pleistocene lag deposits provide sufficient clasts (i.e., pebbles and occasional cobbles) for kelp recruitment, and thus, serves as the substrate for the nearby Boulder Patch communities. However, the finer-grained Holocene deposits cover the Pleistocene sediments at the northern and southern ends of Transect A, restricting kelp recruitment. Also, small-scale features delineated within the Pleistocene deposits were not observed in the abundance within the Holocene sediments (Figures 3-1 and 3-2). It is possible that the near surface distribution of manganese as shown in Figure 5-3 represents the contact between the surface outcrops of Pleistocene and Holocene deposits. Also, the absence of sizable amounts of kelp east of Transect A probably is indicative of finer-grained Holocene sediments covering the Pleistocene lag deposits throughout the length of Transects B and C. Thus, the apparent lack of encountering small-scaled features along Transects B and C is consistent with our current understanding of the surficial geology within the study area.

5.2.3 Comparison with Findings from Previous Analyses

Previous studies employed similar spatial analyses to estimate the volume of fine-grained sediments that would be excavated along the offshore pipeline route (URSGWC 1998; URS 2000). These analysis were completed using data obtained during 1997 and 1998 geotechnical investigations (Duane Miller and Associates 1997, 1998).

The earlier spatial analysis correlated grain-size (percent fine-grained sediment) results with the Unified Soil Classification System (USCS) units. Based on proposed excavation descriptions provided in the *Liberty Development Project Development and Production Plan* (BPXA 1998), volume estimates were computed for each excavated USCS unit. Based on average percent fines for each USCS unit, estimated volumes of fine-grained (silt and clay) sediments were computed. (Table 5-2).

Table 5-2 Fine-grained Material Estimated for Trench Excavations

Location	Grain-size Sample Result Analysis				USCS-based Analysis (Previous Analysis)			
	Trench Depth[1] (feet)	Trench Length (feet)	Percent Fines (Silt and Clay)	Volume of Fines to be Excavated (cy)	Trench Depth[1] (feet)	Trench Length (feet)	Percent Fines (Silt and Clay)	Volume of Fines to be Excavated (cy)
Transect A	15	22,500	60	419,036	10	22,500	65	148,100
Transect B[2]	15	18,300	52	292,984	10	23,500	69	162,500
Transect C	15	25,300	63	489,677	NA - Western pipeline route to Endicott had been third alternative			

[1] Trench depths for the two analyses are different because of pipeline burial depth changes. The increased depths in the present analysis result in larger volumes being calculated for excavated sediments.

[2] In the previous analysis, Transect B extends approximately 4,000 feet north of Southern Island to Liberty Island. This length, which covers an offshore area containing Holocene fine-grained sediments was not included in the present analysis, and thus results in a lower percentage of fine-grained sediments.

The two analyses employed different assumptions that must be considered when comparing the findings. First the USCS-based spatial analysis was based on an average grain-size (percent fines) and the resulting distribution based on interpolating USCS units. Second, the trench volumes calculated in the previous analysis were based on a shallower trench depth of 10 feet rather than 15 feet; therefore, volumes of fine-grained sediment were lower. Third, the trench length for Transect B in the previous analysis extended approximately 4,000 feet beyond Southern Island to the proposed Liberty Island. Thus, the percent fine-grained sediment was higher as compared to the truncated South Island Alternative pipeline route used in the current analysis since the 4,000-foot section between Southern Island and Liberty Island is composed of Holocene fine-grained sediments (Figure 4-3). The values for percent fine-grained sediments in the proposed excavated material were relatively consistent, and thus it is unlikely that additional sampling along any of these transects would result in significantly different volume estimates for fine-grained sediments.

5.2.4 Grain-size Distribution Conclusions

1) Based on grain-size spatial analysis, the percent fines are relatively consistent between the three transects (52-63%).
2) Earlier analyses using USCS-based spatial analysis to calculate the estimated volume of fine-grained sediments within the pipeline trenches produced similar results to this report.
3) Additional sampling would probably encounter similar sediments, with local variations due to small-scale features such as distributary channels and submerged shoreface – especially from samples collected within the Pleistocene lag deposits. However, it is anticipated that the overall percentage (and calculated volume) of fine-grained sediments would be similar to results in this and previous reports.