

ISSUE PAPER:

**Regulating Cadmium and Mercury
in Drilling Fluid Discharges**

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REGULATING CADMIUM AND MERCURY

IN DRILLING FLUID DISCHARGES

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ISSUE PAPER ON REGULATING Cd AND Hg LEVELS IN BARITE/DRILLING FLUIDS

EPA's Effluent Guidelines Division has considered a limit on the allowable concentrations of cadmium and mercury in either barite, which is added to drilling fluids as a weighting agent, or drilling fluid effluents. Barite is a fine-grained material that is found primarily in two types of stratification either vein- and cavity-filling deposits or bedded deposits. The type of stratification is important because bedded deposits tend to be less contaminated with trace metals than vein- or cavity-filling deposits (See Appendices F and G).

The approach for the regulation is to promote product substitution of "cleaner" barite for the more contaminated variety. This objective would be accomplished by emplacing limitations on the Cd and Hg content of either the source barite (i.e., allowing discharge of only those drilling fluids in which barite with acceptable levels of these metals can be demonstrated) or the drilling fluid effluent directly.

Because barite represents approximately 60-85 percent of drilling fluid particulate additives (by weight), and because other additives contain Cd and Hg levels that are either at or below the proposed limits (Neff, testimony on EPA/Region IX BPJ permits, 1984; see Appendix F), regulating barite levels effectively regulates whole mud levels; conversely, regulating whole mud levels is tantamount to regulating barite levels.

ISSUE: TECHNOLOGIC FEASIBILITY

The limits that are being proposed are 2)ppm (mg/kg) for Cd and 1 ppm for Hg. Analyses that have been performed indicate that these limits can be achieved. The data base is limited: 21 generic muds have been analyzed (See Appendix D). Although it clearly would be a more sound proposal if more data were available, the existing data fully support the proposed limits because all 21 generic muds that were tested would be able to meet the proposed limits.

The industry's comments have indicated that the mud companies do not stock "clean" or "dirty" barite. Rather, they batch mix available stocks to meet API specifications. These specifications address operational characteristics of barites, primarily specific gravity and soluble salt contamination, and do not include Cd or Hg limits.

Also, the industry has indicated that although it may be possible to use only "clean" barite in regions with low levels of drilling activity (e.g., EPA Regions I, II, III, IV, X, and possibly IX), this feasibility should not be interpreted as equally appropriate and possible for the Gulf of Mexico operators. Thus, the matter of scale is an impediment to the implementation of this approach on a national basis.

However, the analyses of generic muds have not indicated, thus far, any difficulty in attaining the proposed limits. The industry has not claimed nor admitted to any effort to "specially" formulate these muds.

Another industry comment is that drilled strata contribute to trace metal levels. This concern can be addressed by applying these limits to barite or the mud pits, where such solids largely have been removed.

ISSUE: IMPROVEMENT

Compared to continued usage of vein- or cavity-filling deposits, the proposed limitations on Cd and Hg could reduce the loadings of Cd and Hg by an order of magnitude. The discharge of drilling fluids and cuttings is estimated at approximately two million tons annually (NAS 1983). Of this figure, about half is comprised of drilling fluids solids. Thus, the proposed limitations would allow the discharge of up to two tons of Cd and one ton of Hg.

The worst case estimate of Cd levels in drilling fluids is 16 tons (Neff 1984, Table 1; See Appendix F). Thus, this rule would reduce, for a maximum, a pollutant load of 14 tons Cd, or an 88 percent reduction. If the non-generic muds supplied by PESA are used to estimate an average loading (Appendix D), 3.6 tons could be discharged in the absence of regulation, for a reduction of 1.6 tons Cd, or a 44 percent reduction.

Data on Hg are not available for domestic nongeneric muds. However, the Cd levels in Canadian sources is in reasonably close agreement with that in domestic sources (see Neff 1984, Table 1). These muds have been considered particularly contaminated, but on the basis of their Cd content, there is no reason to exclude them from analysis. Using worst-case Hg values for these muds, 13 tons Hg could be discharged in the absence of regulation. Thus, at best, a reduction of 12 tons of Hg would result from the proposed limit, or a 92 percent reduction.

Another benefit from promoting the use of "clean" barite is the improvement in the loadings of other toxic metals (See Appendix G). These annual improvements are estimates based on Canadian data:

arsenic:	65 tons (97%)	lead :	1369 tons (99.9%)
cobalt :	3 tons (60%)	nickel:	27 tons (82%)
copper :	83 tons (91%)	zinc :	2740 tons (99.6%)

ISSUE: ENVIRONMENTAL IMPACT

There are only limited data that address this issue. Laboratory data (Appendix A) and field data (Appendices B and C) indicate bioaccumulation levels are low (2- to 10-fold) with the exception of Ba (300-fold) and Cr (36-fold). Depuration is often rapid (within 24 hours) and quantitative (40 to 90 percent of excess metals; inversely related to length of exposure). However, these data have serious shortcomings.

Exposure times in laboratory studies are short (4 to 14 days). Ba uptake for 8- to 21-day exposures was 8- to 13-fold; exposure for 106 days produced 50- to 300-fold accumulations. Data on Hg uptake are notably absent in laboratory studies. Test phases were often inappropriate, i.e., aqueous exposures for benthic fauna; solid phase tests report no time- or concentration-related data. Inappropriate tissues often were analyzed. Field studies have only been conducted on exploratory operations or small bulk discharges; rapid depuration is not assuring for development operations lasting many years.

In summary, data suggest limited uptake of toxic metals from limited exposure to drilling fluid. This uptake is especially a concern because it has occurred following exposure to substances that would be considered not readily bioavailable based on their physical and/or chemical properties.

Other programs offer limited support. No sediment quality criteria are presently available. Comparisons to water quality criteria are difficult because steady-state values are lacking. However, ocean dumping regulations, indicate that "in the case of solid materials... a limit not more than 50 percent greater than the normal ambient value in the vicinity of the dump site [should be allowed]" (42FR2467). Industry testimony on BPJ permits states that Alaskan river inputs, where ambient metal levels are quite high, approximate 1 ppm Cd and 0.1 ppm Hg. Ocean dumping criteria would approximate 1.5 ppm Cd and 0.15 ppm Hg. The proposed limits of 2 ppm Cd and 1 ppm Hg appear generous, especially because these discharges are not in a designated dump site.

APPENDIX A.

**Summary of Laboratory Studies on Metal
Bioaccumulation Following Exposure
to Drilling Fluids**

Long-term Tests: Sublethal Effects

Long-term sublethal effects following exposure to drilling fluids have been described for metal accumulation, reproduction/teratogenesis, alterations in growth/development, behavior, physiological/biochemical parameters, and histopathology. Each of these types of effect are discussed below.

Metal Accumulation

Laboratory data on metal accumulation have been summarized in Table 1-55. Exposure to drilling fluids or drilling fluid components has resulted in the accumulation of Ba, Cd, Cr, Pb, Sr, and Zn. One metal for which laboratory bioaccumulation data are conspicuous by their absence is Hg.

Maximal observed enrichment factors (tissue levels in exposed animals compared to control animal tissue levels) are generally low (1.6- to 3.4-fold), with the exception of Ba (300-fold) and Cr (36-fold). Although functional changes resulting from metal accumulation have not been explicitly addressed in these studies, neither overt functional changes nor potential alterations have been noted.

The ability of exposed animals to clear metals accumulated during exposure to drilling fluids or components has also been reported. These data are summarized in Table 1-56. Depuration studies suggest that a substantial release of Ba, Cr, Pb, and Sr may occur. For whole animal, soft tissue, and muscle tissue analyses, 40-90% of the excess metal (Ba, Cr, Pb, Sr) that was accumulated following 4- to 28-day exposures was released during 1- to 14-day depuration periods. Transient increases were observed in Cr, Pb, and Sr levels during the depuration period. The only sustained increase (48%) during this period occurred for Cr in scallop kidney. This finding is somewhat confounded by a similar trend (+24%) in control animals.

These data suggest that bioaccumulation of metals as a result of drilling fluids discharges does not appear to be a significant problem. Yet, several factors argue against this conclusion. Instead, bioaccumulation should be assessed more properly as a significant unknown.

First, uptake kinetics are not adequately described. This is largely attributable to the rather short exposure periods. These exposures were most often for 14 days or less; occasionally 16- to 28-day exposures occurred; in one case, a 106-day exposure occurred but with only one intermediate value reported.

The available data do not allow for any firm conclusions. Simple saturation kinetics occur for several metals and species, including Cr in amphipods, mussels, and oysters; and Cd, Pb, and Zn in amphipods. Zero-order kinetics with respect to time generally appear at Day 7-14.

However, complex saturation kinetics also occur frequently. For example, tissue levels of Cr in clam, and both Cr and Ba in scallop kidney, show apparently zero-order kinetics at Day 2-3, but then inflect with no apparent plateau through days 14-28 of exposure. The only reported long-term study did not report adequate data to characterize uptake kinetics. The only observation is that tissue Ba levels appear to be approximately an order of magnitude higher after 106 days of exposure than after 21 days of exposure.

These data do not support a finding of no significant potential effect. Since metals are highly persistent, long-term accumulation potential must be assessed. However, the available data on uptake kinetics are not adequate to discount metal accumulation as a potentially significant effect of drilling fluid discharges. It appears that the saturation of one body compartment may occur within 7-14 days of exposure to relatively high concentrations of drilling fluids and components. However, additional body compartments for accumulation also appear to exist because saturation kinetics that are more complex than first-order kinetics have been reported.

Second, the focus of these studies was often diffuse, and often lacked a meaningful toxic endpoint for a quantitative hazard assessment. Bioaccumulation studies first should identify which of two toxicologic problems is being addressed: (1) human health impacts (edible tissue analyses) or (2) ecologic impacts (target organ analyses). "Whole body" levels are probably the least useful data, although they may be marginally useful for assessment of human health impacts. However, even edible tissue or

target organ levels can be entirely misleading if a clear differentiation of impact is inadequately addressed.

Several examples from the existing data are illustrative. Cr and Ba accumulations in scallop kidney (in contrast to adductor muscle) and Ba accumulation in grass shrimp hepatopancreas (in contrast to carapace or abdominal muscle) identify likely target organs. Yet, measurement of accumulation without any corresponding measurement of adverse functional changes in these organs only allows for speculation. And whole body tissue levels, which cannot yield useful target organ data and can only support human health assessments, have been obtained for several metals in amphipods, a group of animals not ordinarily consumed directly by humans.

Last, exposure levels were difficult to quantify in a meaningful way for correlation to field exposure conditions. The assessment of the bioaccumulation of drilling fluids-related metals will be driven by the exposure of benthic epifauna and infauna to drilling fluid particulates. Yet, bioaccumulation studies routinely have tested whole fluids or the aqueous phase of fluids. These exposures could have either over-estimated or under-estimated potential accumulation.

Over-estimation of accumulation could result from the increased bioavailability of soluble metals present in the aqueous portion of drilling fluids. However, under-estimation of accumulation is equally likely. First, although soluble metals are more available than particulate forms, soft-tissue accumulation following exposure of grass shrimp to insoluble salts (e.g. barite) has occurred. Second, physiologic chemical reactions may release soluble metals from particulate forms (e.g., the release of Cr from drilling fluid solids as a result of acidification). Third, metal concentrations are routinely 10- to 100-fold higher in the particulate fraction of drilling fluid than in the aqueous phase.

Furthermore, in those studies that have tested solid phase material, accumulation only in response to a deposit layer was measured. Therefore, no concentration-effect relationship can be constructed that could estimate uptake from anything but a 100% exposure situation. This design does not lend itself to a meaningful quantitative hazard assessment.

Test Organism	Test Substance (Concentration, ppm)	Exposure Period (days)	Depuration Period (days)	Metals, Enrichment Factor ^a								Ref. b
				Ba	Ca	Cd	Cr	Cu	Pb	Sr	Zn	
Onisimus sp., Boekosimus sp.	XC-polymer-Unical fluid	20 static	0									1
Whole animal not gutted	(50,000) (100,000) (200,000)					3.2 6.4 6.0	1.2 1.8 1.4		2.0 2.2 1.5		1.6 1.3 1.5	
Palaemonetes pugio	Barite	7, 48-hour replacement	--	150						1.3		2
Whole animal not gutted	5 50 5 50	" " " "	-- -- 14 14	350 2.2 29						1.9 1.8 2.2		
	Barite											
Carapace	500	8 days post-ecdysis, range = 8-21 (48-hour replacement)	0	7.7						1.2-2.5		
Hepatopan- creas	500			13						1.9-2.8		
Abdominal muscle	500			12						1.5-2.8		
	Barite	106	0									
Carapace	500			60-100	0.07					1.6-7.4		
Hepatopan- creas	500			70-300	1					0.03		
Abdominal muscle	500			50-120	1					0.71		

Table 1-55. Summary of Metal Accumulation Study Results (Cont.)

Test Organism	Test Substance (Concentration, ppm)	Exposure Period (days)	Depura- tion Period (days)	Metals, Enrichment Factor ^a								Ref. ^b
				Ba	Ca	Cd	Cr	Cu	Pb	Sr	Zn	
Mytilus edulis (soft tissue)	12.7 lb/gal lignosulfonate fluid, MAF (Cr = 1.4 ppm)	7	--				6.6					3
	ferrochrome lignosulfonate (Cr = 0.7 ppm)						13					
	(Cr = 6.0 ppm)						64					
	Cr Cl ₃ (Cr = 0.6 ppm)						50					
Rangia cuneata (soft tissue)	12.7 lb/gal lignosulfonate fluid, MAF (50,000)	4, static	--				1.4		1.7			4
			4				1.1		1.2			
	13.4 lb/gal lignosulfonate fluid (100,000 MAF)	16, static					2.5					
		--	1				1.7					
		--	14				1.6					
	(layered solid phase)	4, daily replacement	--				4.3					
			1				2.0					

Test Organism	Test Substance (Concentration, ppm)	Exposure Period (days)	Depuration Period (days)	Metals, Enrichment Factor ^a							Ref. ^b	
				Ba	Ca	Cd	Cr	Cu	Pb	Sr		Zn
Crassostrea gigas (soft tissue)	9.2 lb/gal spud fluid (40,000 MAF)	10, static	0						2.1		1.1	
		4, 24, hour replacement	0				2.5					
	(10,000 SPP)											
	(20,000 SPP)	"	0				3.0					
	(40,000 SPP)	"	0				3.0					
	(60,000 SPP)	"	0				5.5					
	(80,000 SPP)	"	0				7.4					
	12.7 lb/gal lignosulfonate fluid (40,000 MAF)	10, static	0						2.3		1.4	
	(20,000 MAF)	14	0				2.9					
	(40,000 MAF)	14	0				3.9					
	(10,000 SSP)	4, 24-hour replacement	0				2.2					
	(20,000 SPP)	"	0				4.4					
	(40,000 SPP)	"	0				8.6					
	(60,000 SPP)	"	0				24					
	(80,000 SPP)	"	0				36					

Test Organism	Test Substance (Concentration, ppm)	Exposure Period (days)	Depura- tion Period (days)	Metals, Enrichment Factor ^a								Ref. ^b
				Ba	Ca	Cd	Cr	Cu	Pb	Sr	Zn	
Crassostrea gigas (soft tissue) (Cont.)	17.4 lb/gal lignosulfonate fluid (40,000 MAF)	10, static	0						0.56		1.0	5
	(20,000 MAF)	14	0				2.1					
	(40,000 MAF)	14	0				2.2					
Placopecten magellanicus	Uncirculated lignosulfonate fluid											
Kidney	(1,000)	28	0	8.8			2.6					
Adductor muscle	(1,000)	28	0	10			1.2					
	Low density lignosulfonate fluid											
Kidney	(1,000)	14	--				1.6					
Adductor muscle	(1,000)	27	--				2.1					
		--	15				2.3					
		14	--				2					
		27	--				2					
		--	15				2					
	FCLS (30)	14	--				5.7					
	(100)	14	--				3.2					
	(1,000)	14	--				6.0					
		--	14				5.2					
		14	--				7.2					
		--	14				6.0					

Table 1-55. Summary of Metal Accumulation Study Results (Cont.)

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Test Organism	Test Substance (Concentration, ppm)	Exposure Period (days)	Depura- tion Period (days)	Metals, Enrichment Factor ^a								Ref. ^b
				Ba	Ca	Cd	Cr	Cu	Pb	Sr	Zn	
Myoxocephalus quadricornis (guttated)	XC-polymer fluid	36, 48-hour replacement										6
	(5,000)											
	(10,000)						3.3 2.9	1.1 3.1	1.25 1.7		1.2 1.2	

Notes: a. Enrichment Factor = Concentration in exposed group/concentration in controls.

- b. References: 1. Tornberg et al. (1980).
 2. Brannon and Rao (1979).
 3. Page et al. (1980).
 4. McCulloch et al. (1980).
 5. Liss et al. (1980).
 6. Sohio Alaska Petroleum Company (1981).

- c. Abbreviations: MAF - mud aqueous fraction
 SPP - suspended particulate phase
 FCLS - ferrochrome lignosulfonate

Table 1-56. Depuration of Metals Accumulated During Exposure to Drilling Fluids or Components^a

Test Species	Test Substance	Exposure Period (days)	Metal	Tissue	Depuration Level ^b	Depuration Period (days)
Palaemonetes pugio	BaSO ₄	7	Ba	whole animal, not gutted	-90%	7
	"	"	Sr	"	-90%	7
Rangia cuneata	SLF ^c (LSP)	1-4	Cr	soft tissue	-(40-65%)	1
	MDLF (MAF)	4	Cr	"	-75%	4
	"	"	Pb	"	-70%	4
	SLF (MAF)	16	Cr	"	-53%	1
	"	"	"	"	-60%	3-14
Placopectan magellanicus	LDLF (WM)	27	Cr	kidney	+48% ^d	14
	"	"	Cr	adductor muscle	-63%	14
	FCLS	14	Cr	kidney	-(17-54%)	14

a. Adapted from Brannon and Rao (1979); McCulloch et al. (1980), Liss et al. (1980).

b. Percentage of excess metal released.

c. Abbreviations: SLF, MDLF, LDLF (seawater, medium density, and low density lignosulfonate fluids), FCLS (ferrochrome lignosulfonate), MAF, WM (mud aqueous fraction, whole fluid).

d. Control animals exhibited a 24% increase during the depuration period.

APPENDIX B.

**Summary of Field Studies Describing
Sediment Metal Distributions Resulting
from Discharges of Drilling Fluids and Cuttings**

Trace Metal and Physical Benthic Alterations

An environmental study was conducted in approximately 33 m of water on the South Texas Outer Continental Shelf (Block 755, Mustang Island Lease Area). Drilling began December 3, 1976 and was completed on January 15, 1977. Sampling for suspended material occurred before (September 25-27, 1976), during (January 7-14, 1977), and after (February 28-March 1, 1977) drilling operations. Suspended sediment samples were taken in 30 liter Niskin bottles at five depths at the drillsite. During drilling operations, suspended sediments in the water column were sampled both within and opposite the plume.

Benthic sediment samples were taken before and after the drilling operations. Samples for benthic trace metal analyses were taken at the drillsite and at 1000 m N, E, S, and W. Suspended sediment trace metals were determined by AAS following acid digestion. Samples were leached with concentrated nitric acid at 105°C, except for Ba, which was dissolved with a 1:1 concentrated nitric acid and 30% peroxide. Procedural blanks for Zn were sufficiently high to render the sampling data invalid, and therefore were not reported.

The trace metal content of suspended sediments (Table 1-26) was not thought to have been effected from drilling activities, although Cr, Cu, and V show isolated, substantial elevations during and after drilling. Seasonal variations and the effect of ship traffic from the nearby Port Aransas shipping lane further confound the interpretation of these results.

Clay mineral analysis showed that montmorillonite was present only in post-drilling samples and in lower level samples taken during the drilling operation. This finding suggests that montmorillonite was enriched as a result of drilling fluids discharges.

Cr, Cu, Mn, and Ni levels apparently did not change in the sediment as a result of drilling activity (Table 1-27). Fe and V appeared to be somewhat lower. Pb had a 2.7-fold increase at the drillsite and a 1.9-fold increase at 1000-m stations. It was thought that this increase may have resulted from drilling activity, possibly from the use of fossil fuel at either the rig or supply vessels. The data were considered inconclusive as to the direct cause.

Given (1) the apparently distance-related effect and (2) the contamination of drilling fluids and cuttings with pipe dope-derived Pb, these effluents appear to be a contributing source, if not the only source, of the elevations in Pb levels.

Zn and Cd were the only trace metals that were directly related to drilling activity. These elements had both a marked increase in concentrations at the drillsite. Zn was elevated 2.5- to 3.5-fold and Cd was elevated 3- to 9-fold. These metals showed low levels, similar to those taken before drilling, in the sediment 300 m from the drillsite.

Comparisons of textural variability between the composite pre-drilling and post-drilling sample suites (Table 1-28) showed significant differences (95% confidence level) for the following textural parameters: skewness, silt percentge, clay percentage, silt/clay ratio, and mean diameter. The post-drilling suite was significantly coarser-grained, had a higher silt/clay ratio, and was less coarsely skewed than the pre-drilling suite. No valid conclusions were thought possible regarding the causes of the textural differences because:

- (1) the pattern and number of post-drilling sample sites were substantially modified from the pre-drilling suite;
- (2) substantial seasonal natural variability normally occurs in the area of this study;
- (3) the post-drilling sample site had been relocated approximately 25 m from the pre-drilling sample site.

The changes, however, are generally consistent with changes observed elsewhere in sediment texture as a result of drilling operations.

A rig monitoring survey was conducted at an exploratory site located near the N lease line of Mustang Island (Texas), Block 792, in 36 m of water (Department of Interior 1976b). For standard sediment parameters and clay mineralogy, two samples were collected by a diver, who filled 10 cm x 0.5 m PVC cores with sediment by scraping them horizontally along the bottom. Samples for trace metal analysis were collected in acid-cleaned 2 cm plastic tubes likewise scraped horizontally along the bottom.

Cu, Fe, Pb, and Ni were determined by atomic absorption spectrophotometry after digestion of sediment using HF, HClO₄, and HNO₃. Cd and Cr concentrations were determined by flameless atomic absorption techniques. V was determined by instrumental neutron activation analyses. Ba data have been previously discussed (see Section 1.4.2).

Significant changes in the levels of sand, clay, silt, and CaCO₃ occurred for before- versus during-drilling phases (Table 1-29). Sand, clay, and CaCO₃ levels increased significantly, while silt levels showed a significant decrease. Comparison of the during- and after-drilling levels showed that the clay and CaCO₃ levels decreased significantly and silt levels increased significantly. The after-drilling levels of sand were not significantly different from the during-drilling levels. In the during-drilling phase, drill cuttings were noted specifically at only four 100 m periphery stations and one 500 m station. Drill cuttings still were observed at these same five stations in the post-drilling survey, but were notably less abundant.

The averaged trace metal concentrations in the sediments for each station during the three sampling operations are shown in Table 1-30. These authors attributed the observed variations in their samples to errors in analysis combined with minor mineralogically and textural differences between samples.

To further support these observations, these authors examined the metal/iron ratio for Cr, Cu, Pb, Ni, and V (Cd was excluded due to its extremely low level and resulting higher degree of uncertainty). The data also indicated that no spatial trends existed in the metal concentrations.

An environmental study of the Buccaneer Gas and Oilfield in the central Gulf of Mexico has examined chronic, low-level, heavy metal contamination from active petroleum production platforms on the OCS (Tillery and Thomas 1980). Twenty platform structures and four reference sites (i.e., no structures) were selected. Surficial sediments (the upper 5 cm) were collected at 100 m, 500 m, and 2000 m from four "primary" platform structures along two transects and along the N axis of one transect for the 16 remaining "secondary" platforms.

All metal analysis, except Ba and V, were conducted on 5N HNO₃ leachates using atomic absorption spectrophotometry. Ba and V were determined by neutron activation analysis (NAA). Results from sediment chemistry data showed concentration gradients that decreased with distance from the platforms for Ba, Cd, Cr, Cu, Ni, Pb, V, and Zn at one or more platforms. These gradients were not explained by the variability in sediment characteristics. Table 1-31 is a summary of trends in the normalized trace metal data for those platforms that showed metal(s) that could be related to the platform structure.

Table 1-31 also showed that more trace metals can be related to platforms 7, 11, and 17 than to 1 and 6. The explanation for this effect was that sediment load carried into the Gulf of Mexico from the Mississippi River "masks" the sediment trace metal concentrations that are related to nearby platforms 1 and 6 compared to platforms 7, 11, 17, and 19, which are progressively further from the outfall of the Mississippi River.

Possible sources of these trace metals also were discussed. In addition to drilling fluids, sources could have been sacrificial anodes on platform structures, produced brine discharges, pipelines, discarded metal debris on the bottom, or other activities on platform structures.

Mariani et al. (1980) studied chemical and physical changes in sediments resulting from drilling fluids and cuttings discharges from an exploratory well located in NJ 18-3 Block 684, approximately 97 statute miles (156 km) from the coast of New Jersey, in 120 m of water.

The GLOMAR SEMI-I, arrived at the well site on January 4, 1979, and moved of location on July 15, 1979. A total of 2160 metric tons of solids were discharged. The first pre-drilling survey consisted of two separate cruises: August 7, 1978 and August 17-22, 1978. The second post-drilling survey was conducted approximately 2 weeks after drilling operations were terminated.

The pre-drilling survey encompassed a 2-mile diameter area around the well site and consisted of 40 sampling stations. The post-drilling survey encompassed a 4-mile diameter area and consisted of 48 sampling stations. Sediment samples were subject to a weak acid leach (25% V/V acetic acid) for 2 hours. This procedure was used to provide an approximation of the metal content that was thought to be bioavailable.

Results from sediment granulometry analyses on post-drilling samples showed that sediments within the study area were very poorly sorted, similar to pre-drill data, and had a fine-skewed distribution. However, a slight shift in the graphic mean towards finer sediments (from 2.50 phi to 2.75 phi) occurred between pre- and post-drilling cruises. Grain size analyses showed that only the clay-size fraction of the sediments changed significantly between surveys (Table 1-32), resulting in increased percentages of clays within the immediate vicinity of the well site, extending to a distance of approximately 800 m.

Significant differences in the clay mineralogy of the study area occurred between surveys (Table 1-33). Illite increased from 25.03% to 28.7% and chlorite increased from 23.7% to 27.5%. Montmorillonite decreased from 20.0% to 13.8%. Kaolinite increased from 17.9% to 21.3%. Calcite and halite decreased from 8.43% (calcite) and 50.8% (halite) to 4.4% each.

It was concluded that the increased clay content and changes in clay mineralogy were not caused by drilling activities alone, since increases in kaolinite and decreases in montmorillonite are not indicative of clay minerals

present in drilling fluids--montmorillonite (13-40%), illite (0-13%), and kaolinite (0-5%) (Ayers et al. 1980b). However, illite, chlorite, and kaolinite are characteristic of subsurface glacial deposits of the Pleistocene Period, which could have been released during spudding operations.

Changes in sediment trace metal concentrations (weak acid leachable) occurred for some elements between surveys (Table 1-34). Increases occurred in the concentrations of Ba, Pb, Ni, V, and Zn. Arsenic did not change significantly. Concentrations of Cd, Cr, and Cu decreased between surveys. Mercury below the detection limit of 0.05 g/g at all stations.

Despite the increased concentrations of Pb and Zn, concentrations were less than or within the range of values reported by Harris et al. (1977, 1979) for sampling stations approximately 11 km from the study area. Changes in concentrations of Pb and Zn were thought to reflect the natural variability of the study area.

Concentrations of V exceeded the seasonal ranges of concentrations reported by Harris et al. (1977, 1979). However, the lack of a recognizable spatial distribution for V suggested that some other factor affected this area. Increased Ba concentrations were detected at six stations and apparently were contained within a 2-mile radius of the rig. Increases in Ni were noted at ten stations and were confined within a 1-mile radius of the rig. Based on the reported concentrations of nickel (13.5 to 18.1 ug/g) and vanadium (22.7 to 29.7 ug/g) in drilled discharge solids (Ayers et al. 1980b), however, it was thought unlikely that drilling discharges were solely responsible for these increases.

Following the publication of these data, several re-evaluations of the analytical procedures occurred. To facilitate meaningful comparisons between this study and other sediment trace metal data, archived samples were analyzed for Ba and Cr using neutron activation analyses. During this re-evaluation errors in standard curves also were discovered. These revised data have been included in a final report scheduled for release by early 1983.

A study has investigated the environmental distribution of metals from drilling fluids discharged into the Beaufort Sea, near the Mackenzie River Delta (Crippen et al. 1980). A post-operational artificial island drilling site, Netserk F-40, was constructed with material consisting primarily of medium sand to fine gravel (0.4 mm to 20 mm grain size). The well was spudded on November 8, 1975 and was completed on May 19, 1976. Approximately 7,300 barrels of waste drilling fluid were discharged. Netserk was in an advanced state of erosion at the time of the post-operational survey in the summer of 1977.

Sediment samples were taken using a gravity-type corer wherever possible, or a Ponar grab at stations where the corer could not penetrate the substrate. A portion of the upper 2-5 cm of sediment was frozen for chemical analysis. The samples were analyzed for mercury (Hg), arsenic (As), cadmium (Cd), chromium (Cr), lead (Pb), and zinc (Zn).

Netserk drilling fluids and cuttings were analyzed approximately every 300 m of drilling. An estimate of the quantity of each metal discharged during drilling was calculated based on the estimated amount of each major drilling fluid constituent discharged and its approximate metal composition. An evaluation of the metals most likely to be significantly higher than background indicated that Hg was expected to be the best tracer of drilling fluids in these sediments.

Sand and gravel were observed in the upper few centimeters of sediment to at least 300 m offshore. This coarser material probably originated from the construction and erosion of Netserk and suggested that the predominant directions of subsurface water was NE-SW.

Hg contamination of sediments was obvious within 100 m of the point of discharge (Figure 1-5) and Hg levels were somewhat elevated above mean background levels (0.07 ug/g) at several other stations (Table 1-35). The highest mean value recorded was 6.4 ug/g and was located about 45 m from shore, just N of the discharge.

The concentrations of As, Cd, Cr, Pb, and Zn in surface sediments exceeded background levels at one or more stations in the vicinity of the discharge

(Figures 1-6 to 1-10, respectively). Subsurface concentrations of most metals, excluding Cr, were substantially higher than surface sediment samples 45 m SW of this discharge location. This sample was thought to be a pocket of drilling fluid from operations prior to the use of chrome lignosulfonate.

This observation suggested that dynamic sedimentation in this area was well under way prior to the completion of drilling operations, because chrome lignosulfonate was a major additive of the drilling fluid during the last 600 m of drilling. Erosion of the Netserk gravel island was thought to have had an advantage in that discharged drilling fluid components had been diluted and/or buried, thus reducing exposure to these contaminants.

These sediment metal studies (including an above-ice discharge study, described in detail in Section 1.1.5.1), when considered as a group (Table 1-A), suggest the enrichment of certain metals in surficial sediments may occur as a result of drilling activities. While confounding factors occur in most of these studies (i.e., seasonal variability and other natural and anthropogenic sources of these metals) a distance-dependent decrease in metal levels frequently is observed. However, although drilling activities are implicated as a source of metal enrichment, discharged drilling fluids and cuttings probably are not the only drilling-related source.

The only two metals that appear to be elevated around rigs or platforms and are clearly associated with drilling fluids are Ba and Cr. A study in the Canadian Arctic found that Hg would be the best trace metal tracer of discharged fluids. The examination of Hg levels in fluids and sediments for domestic operations is notably under-represented in the studies that have been reviewed. The degree of similarity between Canadian and domestic operations has not been evaluated. However, the findings of the Netserk study and lack of information on domestic operations indicate that the relationship between drilling fluid discharges and sediment Hg levels should be further clarified.

Metals that appear to be elevated as a result of drilling activities and not solely related to drilling fluids include Cd, Hg, Ni, Pb, V, and Zn. Cd, Pb, and Zn may be associated with drilling fluids as contaminants that occur from the use of pipe dope or pipe thread compounds. Hg, Ni, and Zn may originate from sacrificial anodes. Cd, Pb, and V may also originate from the release of fossil fuel in drilling operations. This release can result from burning, incidental discharges or spills from the rig or supply boat traffic, or use as a lubricant in drilling fluids. In the Gulf of Mexico platform study, brine (formation water) discharges were identified as an additional potential source of metal contamination.

Although these metals were enriched in the sediment, enrichment factors were generally low to moderate, seldom exceeding a factor of 10. The spatial extent of this enrichment also was limited. Either of two cases occurred: enrichment was generally distributed but undetectable beyond 300-500 m or

enrichment was directionally-biased by bottom current flows and extended further (to about 1800 m) but within a smaller angular component.

These considerations suggest that exploratory activities will not result in environmentally significant levels of trace metal contamination. However, other factors, such as normal sediment loading or proximity either to commercial shell fisheries or to subsistence populations, could alter this conclusion. Sediment trace metal levels resulting from development drilling operations needs further clarification, especially relating to the dynamics and extent of sediment contamination.

Above- and Below-Ice Dispersion

Above-Ice Discharges

A study was conducted to monitor the environmental fate associated with above-ice disposal of drilling fluids and cuttings in the Beaufort Sea (Schio Alaska Petroleum Company 1982). Three well sites were chosen (Figure 1-11): Sagavanirktok Delta wells #7 and #8 (Sag 7 and Sag 8) and Challenge Island well #1 (Challenge 1).

Approximately 3,000 bbl of drilling fluids and cuttings obtained from the Challenge 1 operation were discharged as evenly as possible at Sag 7 during mid-April 1981. Water depths at this site ranged from 2.9-3.5 m. At Sag 8, a snow berm 0.5-1.5 m high was constructed to test its impact on river overflowing. Water depths varied from 1.3-1.7 m. Ice thickness ranged from 0.9-1.5 m and was grounded at five of eight sampling stations. Approximately 2160 bbl of drilling fluid effluents were discharged at this site from March 16-30, 1981.

Challenge 1 consisted of three disposal sites. Two disposal sites (A and B) were located in water depths ranging from 2.4-2.9 m, while at Site C, water depths ranged from 2.7-5.0 m. Approximately 5,000 bbl of frozen fluids and cuttings were discharged at Challenge 1 from March 14-25, 1981. At Site A, approximately 1010 bbl of effluent was spread in a 2-3 cm thick layer over most of the site. An additional 250 bbl of effluent was mixed with snow and piled in a corner of Site A. Approximately 2,860 bbl of frozen drilling effluent was spread in a 10-20 cm thick layer over disposal Site B. At Site C, approximately 890 bbl of frozen drilling effluent was placed in piles, nominally 75-90 cm high.

Trace metal analyses were conducted on samples of drilling fluid from both Challenge 1 and from disposal site samples that were collected in late March, 1981 and variously thereafter. Comparison of pre- and post-discharge bottom sediment samples from Sag 7 indicated significant decreases in levels of Ba, Cd, and Hg that were judged unrelated to drilling fluids. Analyses of pre- and post-discharge bottom samples from Sag 8 indicated that only Ba levels significantly decreased.

Results from pre- and post-discharge analyses of Challenge 1 sediment samples indicated significant increases in levels of Cd, Cr, Pb, and Zn at Sites A and B, and in levels of Cu, Pb, and Zn at Site C. Increases of Cr and Zn were considered related to drilling fluids disposal. Cd data were not considered to be explained by effluent discharges because Cd levels in the effluents and predischage sediments were similar. Elevations in Pb were not judged to be drilling fluid-related because of spatial patterns, other sediment characteristics, and because Site C did not melt in place.

However, elevations of Cd and Pb levels could be effluent-related in view of the following data. Although Cd levels in early drilling fluid samples (0.2 mg/kg) were similar to pre-discharge sediment levels (0.19-0.35 mg/kg), an enrichment of Cd in drilling fluid effluents occurred at all disposal sites over time, to 0.8-1.1 mg/kg. And for Cd, Cr, Pb, and Zn, sediment levels were inversely related to distance from disposal sites (A and B) for 0-60 m, 60-85 m, and 250 m data sets (Table 1-36).

Also, for Cd, Pb, and Zn at Sag 7 and Cr, Cu, Pb, and Zn at Sag 8 a consistent spatial pattern of enrichment at the near-field stations (approximately 85-200 m) occurred relative to pre-discharge levels and either within-site or far-field (315-585 m) stations. These enrichments were not statistically significant. However, trace metal levels had 95% confidence levels 30-130% of the mean, averaging about 65%. This large variability reduces the ability to statistically resolve differences among data sets.

Nonetheless, near-field enrichments were consistent. For both Pb and Zn, enrichment was 1.3-fold at Sag 7 and 1.2-fold at Sag 8, versus 2.3- to 2.6-fold for Pb and 1.4-fold for Zn at Challenge 1. Cr levels at Sag 7 increased 2-fold versus 1.4-fold at Challenge 1.

These data suggest that drilling fluid disposal may have increased sediment levels of Cd, Cr, Pb, and Zn. However, these increases generally were small (1.2- to 4-fold) and localized (within approximately 200 m). An unresolved paradox is why better spatial trends were observed for Challenge 1 (Sites A and B), which did not melt in place than for Sag 7 and Sag 8, which did melt in place.

A study has assessed the impacts of above-ice drilling effluent disposal techniques in the Beaufort Sea (Schio Alaska Petroleum Company 1981), between the Midway Islands and Prudhoe Bay (Figure 1-15). The Reindeer Island Stratigraphic Test (RIST) well was drilled during January through April, 1979. Water depths and sea ice thickness were measured in April, 1979.

Field tests were conducted to describe the fate of drilling effluents discharged above the sea ice. Effluents were discharged at three locations (Figure 1-16). An offshore site (Test Plot 6) was located in approximately 6.1 m of water. A nearshore site (Test Plot 7) was located on grounded sea ice, in an area overflowed by the Sagavanirktok river. A multi-source, below-ice discharge of drilling effluents was conducted to simulate a worst case from above-ice disposal. This offshore test site (Test Plot 4) was located in approximately 6.7 m of water.

Bermed snow subdivided Test Plot 6 into nine pits, each of which received approximately 120 bbl of effluent. At Test Plot 7 dispersion resulting from overflowing was maximized by pumping effluent directly on the ice surface and allowing it to free-flow, without berms.

Observations at Test Plot 6 indicated that most drilling effluent solids remained in place until later stages of breakup. Reconnaissance on June 1, 1979 indicated the offshore site was generally intact. On two occasions (June 8 and 11, 1979) partial effluent drainage, presumably through the ice, was noted for the liquid phase. On June 14, 1979 the ambient ice sheet showed 0.7 m of surface melt. Within the disposal site, an additional 0.3-0.7 m melt occurred. By July 12-14, 1979 the ice sheet had completely broken up. The site was not located, although a 0.2 km section of the ice road adjacent to the disposal site was located about 28 km E of its original position.

Samples of drilling fluids were obtained from Test Plot 6 on July 1, 1979 and natural sediments were obtained from the surface of sea ice during the later stage of breakup. Analyses of trace metal levels indicated that the remaining drilling effluents were similar to natural sediments for most trace metals analyzed. The exceptions were elevated levels of Ba (47,500 ppm versus approximately 1000 ppm) and Fe (72,500 ppm versus 36,000-40,000 ppm).

Reconnaissance of Test Plot 7 indicated that overflowing with at least 0.2-0.3 m of river water occurred between May 9-12, 1979. Qualitative observations indicated that this overflowing dispersed much of the effluents. By June 14, 1979 a major flood channel had removed ice and effluent from approximately half of the site. Coastal fog precluded observations during late June, 1979. All ice had moved out of the disposal site area by July 12, 1979.

Satellite beacons at Test Plot 7 ceased to transmit on June 19 and 30, 1979. Although these beacons were not located, they had not moved more than 2 km (the limit of accuracy) prior to signal loss. The base for one beacon was later located 0.5 km S of the disposal site.

A simulated, above-ice disposal test was conducted on May 6, 1979 at Test Plot 4. Twenty-five holes were augered on 6.1 m (20-foot) spacings at the center of the test plot. During the test, 40 bbl of drilling fluids were discharged through each hole to simulate a worst-case release of drilling effluents falling to the seafloor directly below the above-ice disposal site.

Grain size analyses of settling pan sediment indicated that a rapid decrease in deposition rates occurred for most particle sizes. At the center of the discharge hole, deposition was 729 mg/cm² for all grain size fractions. At 1.5 m and 3.0 m, average deposition was 313 mg/cm² and 168 mg/cm², respectively. It was estimated that the average deposition of all particle sizes was about 200 mg/cm² over the test site. The average deposition rate for particles less than 45 microns, measured 3 m from the discharge point, was in the same general range of deposition rates measured at two below-ice disposal site (166 mg/cm² versus 66-368 mg/cm², respectively; see Section 1.1.5.2). Bottom sediment trace metal levels indicated the presence of drilling effluents 3 days after the discharge, but not 3 months post-discharge.

Modeling of above-ice disposal site dynamics was considered too difficult to perform because of the complexity of the breakup process. Deposition of solids was thought to be gradual and primarily controlled by currents, wave-induced turbulence, and flocculation of the clay-sized fraction of the effluent. Most solids (with the exception of cuttings) probably would be resuspended several times or remain in suspension throughout the summer. Dilution of the effluent liquid fraction was thought probable during the breakup process, primarily as a function of local melting and drainage patterns of the parent ice sheet.

1.3.1 Below-Ice Discharges

A study has assessed the impacts of below-ice drilling effluent disposal in the Beaufort Sea (Sohio Alaska Petroleum Company 1981), between the Midway Islands and Prudhoe Bay (Figure 1-15). Water depths and sea ice thickness were measured in April, 1979. Field and laboratory tests were conducted at Test Plots 1 and 2 (Figure 1-17) to assess physical effects of below-ice of effluent disposal and to provide data for modeling efforts.

Field discharges were monitored through a series of 48 cm diameter auger holes along predetermined transects at varying distances from the discharge point. Approximately 3-4 liters of Rhodamine WT dye were pumped into an effluent transporting truck. The mixture was agitated for several hours to insure complete mixing and stabilization of the dye and drilling effluents. Discharge conditions and physical characteristics of the drilling effluents are summarized in Table 1-37.

Settling pans were recovered approximately 24 hours after the completion of the test discharge and wet sieved. Results of the analyses for Test Plots 1 and 2 are summarized in Tables 1-42 and 1-43. The deep-water test resulted in a broader deposition pattern than the shallow-water test. Deposition at Test Plot 1 peaked at 6.1 m (158 mg/cm^2) and decreased to 38 mg/cm^2 at 24.4 m and 62 mg/cm^2 at 30.5 m. At Test Plot 2, deposition was maximal at 3.0 m (77 and 440 mg/cm^2) and decreased to 0.7 and 0.4 mg/cm^2 at 30.5 m.

Trace metal analyses of drilling fluid samples and of bottom sediments were conducted both within and near the disposal sites. At Test Plot 1 there were no notable differences as a result of drilling activities. At Test Plot 2, however, three metals showed possible enrichment: Co, Cu, and Fe. Compared to sediments levels obtained on 4/8/79, Co was enriched 1.9-fold (20 ppm to 38 ppm) 1-4 months later. Cu was enriched 1.7-fold after 1 month (44 ppm versus 26 ppm) but only 1.5-fold after 4 months (38 ppm versus 26 ppm). Fe was enriched 1.25-fold after 1 month, (2.98% versus 2.38%) but not after 4 months.

Table 1-26. Trace Metals (ppm) in Suspended Sediments*

		<u>Cd</u>	<u>Cr</u>	<u>Cu</u>	<u>Fe</u>	<u>Mn</u>	<u>Ni</u>	<u>Pb</u>	<u>V</u>
<u>PRE-DRILLING</u>									
	SURF	8.4	305	69.5	12700	128	TR	82.8	TR
	8m	380.0	174	56.0	47000	116	TR	128.0	TR
	16m	405.2	188	82.8	10900	1293	TR	258.6	TR
	24m	744.1	255	94.0	12500	1185	TR	86.2	TR
	32m	305.7	32	18.9	21300	2779	27	30.2	24
<u>DURING DRILLING</u>									
	SURF	9.9	173	76.1	22700	128	TR	173.1	TR
In	8m	61.9	69	42.1	19500	605	26	522.6	41
Sed.	16m	15.8	189	68.6	16200	366	TR	58.2	TR
Plume	24m	1.8	470	642.1	16800	71	761	15.2	TR
	32m	411.0	106	27.0	15300	55	TR	19.6	TR
	SURF	511.9	172	61.4	15600	60	TR	51.2	TR
Opp.	8m	16.7	266	61.8	18000	116	TR	40.0	TR
Sed.	16m	22.5	46	23.3	17400	337	TR	45.0	TR
Plume	24m	3.8	62	27.7	14600	57	TR	35.2	TR
	32m	0.7	93	38.2	18600	212	40	62.4	136
<u>POST-DRILLING</u>									
	SURF	0.8	291	64.1	13000	501	TR	62.9	267
	8m	1.2	263	67.4	15700	444	TR	38.3	139
	16m	13.2	2417	TR	17200	139	TR	TR	TR
	24m	7.3	1287	93.3	12700	220	TR	46.7	TR
	32m	7.0	1011	425.8	21800	387	247	224.1	588
	BLK A	0.0	0.0	0.0	0	0	0	0	0
	BLK B	0.0	0.0	0.0	0	0	0	0	0

*From Department of the Interior (1976a).

Table 1-27. Trace Metals - Benthic Sediments (PPM)*

Pre-Drilling											
Site	Ba	Cd	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn	Code
DS	110.8	0.07	23.8	5.9	20200	312	14.3	7.6	17.7	64.7	TAK
N-1000	112.2	0.07	25.3	6.5	20500	320	17.7	7.1	17.6	69.4	TCK
E-1000	107.0	0.06	19.6	4.9	18200	279	17.0	6.0	17.3	61.0	TCB
S-1000	95.1	0.08	31.4	6.8	22100	275	16.5	6.3	20.3	71.0	TJB
W-TMB	89.0	0.08	40.9	5.4	19000	292	13.6	6.1	15.9	66.1	TMB
TQT	94.8	0.07	29.7	6.0	21000	293	15.6	6.4	18.2	69.6	TQT
TQZ	104.4	0.08	29.1	5.9	21400	252	14.6	7.4	15.9	69.5	TQZ
Post-Drilling											
DS-1	470.7	0.61	21.5	6.7	16400	279	12.3	20.5	9.2	168.6	BNSM
-2	512.7	0.49	16.9	5.0	14200	10	9.0	18.3	8.4	219.6	BNSU
-3	77.8	0.22	21.3	6.3	18700	18	12.7	15.8	11.9	68.6	BDEW
N-1000	50.0	0.11	19.5	6.8	19000	3	14.1	12.1	12.4	62.2	BMIQ
E-1000	46.5	0.03	21.9	5.9	17400	10	14.7	11.8	12.3	58.1	BOTR
S-1000	52.6	0.04	20.6	6.7	18300	11	12.6	12.9	13.7	62.7	BOWB
W-1000	59.2	0.04	21.6	6.8	19300	9	14.5	14.5	11.7	63.8	BMIH

*From Department of the Interior (1976a).

Table 1-28. Analysis of Variance for Pre-Drilling
and Post-Drilling Suite Comparisons^a

Hypothesis: $H_0: \mu_1 = \mu_2$

Statistic: F

Risk of Type 1 Error: = 5%

Critical Region: $F > F_{5\%} (1,36 \text{ d.f.}); F_{5\%} = 4.12$

Parameter	F-value
Sand % ($\bar{x}_1 = 4.67, \bar{x}_2 = 6.08$) ⁺	1.58
Silt % ($\bar{x}_1 = 45.47, \bar{x}_2 = 55.09$)	14.97*
Clay % ($\bar{x}_1 = 49.82, \bar{x}_2 = 38.82$)	22.93*
Sand/Mud ratio ($\bar{x}_1 = 0.049, \bar{x}_2 = 0.068$)	1.87
Silt/Clay ratio ($\bar{x}_1 = 0.931, \bar{x}_2 = 1.556$)	17.98*
Mean Diameter ($\bar{x}_1 = 7.72, \bar{x}_2 = 7.13$)	24.25*
Standard Deviation ($\bar{x}_1 = 2.04, \bar{x}_2 = 2.15$)	3.80
Skewness ($\bar{x}_1 = -0.157, \bar{x}_2 = -0.008$)	7.41*
Kurtosis ($\bar{x}_1 = -0.947, \bar{x}_2 = -0.822$)	0.70

+ \bar{x}_1 = pre-drilling mean, \bar{x}_2 = post-drilling mean

* = significant difference

a. From Department of Interior (1976a)

Table 1-29. Percentage weight of sand, clay, silt and CaCO_3 in the bottom sediments of the oil rig study site^a

Drilling Phase	Sand	Clay	Silt	CaCO_3
Before				
$\bar{X} \pm 1$ S.D.	1.3 \pm 1.4	45.0 \pm 5.0	57.3 \pm 13.3	3.9 \pm 2.3
Range	0.5-7.9	31.6-51.5	45.0-98.0	0.8-9.3
During				
$\bar{X} \pm 1$ S.D.	6.9 \pm 2.8	53.8 \pm 17.6	39.3 \pm 18.2	12.3 \pm 2.4
Range	4.1-17.3	38.0-93.6	1.3-55.7	8.5-17.9
After				
$\bar{X} \pm 1$ S.D.	9.1 \pm 5.3	39.7 \pm 5.7	50.6 \pm 4.4	6.8 \pm 8.2
Range	4.1-26.8	27.0-48.3	36.6-57.9	1.4-43.5
t Tests (≤ 0.05)				
Before vs during	-8.964*	-2.292	3.971*	-12.415*
During vs after	-1.750	3.800*	-3.031*	3.186
* Significant difference at ≤ 0.05				

a. Department of Interior (1976b).

Table 1-30. Rig Monitoring Study, Surface Sediment Trace Metal Concentrations^a

	Ba^b	Cd	Cr	Cu	Fe	Pb	Ni	V
Before	575±95	0.07±0.2	49.5±7.8	14.0±1.2	3.000±0.3	19.2±1.6	25.6±2.3	87±15
During	1000±112	0.07±0.03	55.4±5.2	14.2±0.9	2.90±0.3	22.0±.2	24.6±2.1	84±10
After	1096±109	0.07±0.03	52.7±6.4	14.0±1.7	2.90±0.3	21.9±2.0	29.1±4.3	85±18

a. From Department of Interior (1976b)

b. All metals as ppm, except Fe (%)

Table 1-31. Summary of trace metal concentration in surficial sediments normalized to the hydrous iron fraction (I), the % clay content (C) and the total hydrocarbon content (HC)*

Petroleum Platform	Ba			Cd			Cr			Cu			Fe		Ni			Pb			Zn			V			Metals Associated with Platforms
	I	C	HC	I	C	HC	I	C	HC	I	C	HC	C	HC	I	C	HC	I	C	HC	I	C	HC	I	C	HC	
1	+	+	+	0	0	0	+	0	+	0	0	+	0	+	0	+	+	+	+	+	0	0	+	0	0	0	Ba, Pb
6	0	0	0	0	0	0	+	+	0	0	0	0	0	0	+	+	0	0	0	0	+	0	0	0	0	-	Cr, Ni, Zn
7	+	+	+	0	0	0	+	+	+	+	+	+	0	0	0	0	+	+	+	+	+	+	+	0	0	0	Ba, Cr, Cu, Pb, Zn
11	+	+	+	+	+	+	+	0	+	+	+	+	0	0	0	0	0	+	+	+	+	+	+	0	0	0	Ba, Cd, Cr, Cu, Pb, Zn
17	+	+	+	+	+	+	0	+	0	+	+	+	0	0	0	+	0	+	+	+	+	+	+	0	0	0	Ba, Cd, Cu, Pb, Zn
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	+	+	0	-	-	0	Zn

+ = normalized data increases as distance from platform decreases.

- = normalized data decreases as distance from platform decreases.

0 = no change in normalized data with distance from platform or no trend detected in normalized data with distance from platform.

*From Tillery and Thomas (1980).

Table 1-32. Grain Size T-Tests for Groups Means of Pre-Drilling and Post-Drilling Data*

Grain Size	Range of Concentrations (%)		Distance from Well Site for Post-Drilling Data (Meters)	t-Value	Range of Concentrations (%) for Southern Quadrant		Comparison of Southern Quadrants Pre- and Post-Drilling Data t-Value
	Pre-Drilling	Post-Drilling			Pre-Drilling	Post-Drilling	
Gravel	0.30-9.45	0.05-4.05 ¹	1609	1.52	0.30-9.45	0.20-3.35 ¹	1.19
	0.30-9.45	0.05-3.35	731	1.90			
	0.30-9.45	0.05-1.75	365	1.69			
Sand	74.1-82.65	71.1-82.70	1609	1.60	74.10-82.65	73.35-82.65	1.77
	74.1-82.65	71.1-82.65	731	1.82			
	74.1-82.65	71.1-82.65	365	1.37			
Silt	8.80-13.55	8.30-16.5	1609	1.45	8.80-13.55	8.85-14.95	1.89
	8.80-13.55	8.85-16.5	731	1.86			
	8.80-13.55	8.85-16.5	365	1.57			
Clay	4.95-11.35	4.95-12.10	1609	2.74*	6.45-11.35	7.15-11.40	2.35*

*Significant at $\alpha = 0.05$.

¹Post-Drilling values generally less than Pre-Drilling values.

*From Mariani et al. (1980).

Table 1-33. Clay Mineralogy t-Tests for Group Means of Pre-Drilling and Post-Drilling Data^a

City Mineral	Range of Concentrations (%)		Distance from Well for Post-Drilling Data (Meters)	t-Value	Range of Concentrations (%) for Southern Quadrants		Comparison of Southern Quadrants Pre- and Post-Drilling Data t-Value
	Pre-Drilling	Post-Drilling			Pre-Drilling	Post-Drilling	
Montmorillonite	14.45-26.90	10.2 -18.10 ^b	3218	-9.81 ^c	16.80-22.50	10.20-17.80 ^b	-8.20 ^c
Illite	21.75-30.20	25.0 -30.4	3218	8.86 ^c	22.45-28.30	27.4 -29.6	7.42 ^c
Chlorite	21.3 -26.05	21.8 -29.6	3218	9.26 ^c	21.40-26.05	21.80-28.7	6.10 ^c
Kaolinite	14.50-20.70	18.50-24.0	3218	8.91 ^c	14.75-20.7	19.0 -24.0	6.75 ^c
Calcite	6.45-10.80	3.0 -10.10 ^b	3218	-10.78 ^c	6.45-10.95	3.1 -10.1 ^b	-7.60 ^c
Halite	4.05- 6.05	3.70- 5.80 ^b	3218	-4.84 ^c	4.05- 5.80	3.8 - 5.8 ^b	-2.60 ^c

^aFrom Mariani et al. (1980).

^bPost-drilling values generally less than pre-drilling values.

^cSignificant at $\alpha = 0.05$.

Table 1-34

Trace Metals in Sediments t-Tests for Group Means of Pre-Drilling and Post-Drilling Data
(From Marian et al., 1980)

Trace Metals	Range of Concentrations (ug/g)		Distance from Well Site for Post-Drilling Data (Meters)	t-Value	Range of Concentrations (ug/g) for Southern Quadrants		Comparison of Southern Quadrants Pre- and Post-Drilling Data t-Value
	Pre-Drilling	Post-Drilling			Pre-Drilling	Post-Drilling	
Arsenic	0.79-1.295	0.69-1.60	3218	0.44	0.790-1.295	0.69-1.60	0.05
	0.79-1.295	0.69-1.60	1609	0.36			
	0.79-1.295	0.69-1.60	731	0.17			
	0.79-1.295	0.69-1.60	365	0.57			
Barium	<1.60-9.65	<1.60-41.46	3218	0.73	1.60-5.3	1.60-41.46	0.72
	<1.60-9.65	<1.60-41.46	1609	0.84			
	<1.60-9.65	<1.60-13.17	731	0.40			
	<1.60-9.65	<1.60-13.17	365	0.53			
Cadmium	0.002-0.112	0.004-0.033 ¹	3218	-7.69*	0.015-0.087	0.004-0.031 ¹	-7.70*
Chromium	0.047-0.347	0.007-0.510 ¹	3218	-3.70*	0.047-0.309	0.009-0.510 ¹	-1.29
	0.047-0.347	0.007-0.510 ¹	1609	-3.68*			
Copper	0.007-0.215	0.006-0.089 ¹	3218	-0.76	0.011-0.068	0.008-0.089	0.39
	0.007-0.215	0.006-0.089	1609	-0.70			
	0.007-0.215	0.008-0.089	731	-0.43			
	0.007-0.215	0.008-0.089	365	-0.30			
Lead	0.16-1.56	2.30-6.20	3218	13.82*	0.27-1.56	2.55-6.20	9.46*
	0.16-1.56	2.30-6.20	1609	13.52*			
Nickel	<0.20-1.70	0.490-4.150	3218	4.22*	0.20-1.70	0.62-4.15	2.88*
	<0.20-1.70	0.490-4.150	1609	4.24*			
Vanadium	0.545-1.48	1.14-14.16	3218	6.60*	0.64-1.48	1.14-14.16	4.20*
	0.545-1.48	1.14-14.16	1609	6.62*			
Zinc	0.715-3.015	0.28-12.28	3218	2.89*	0.735-2.410	0.65-12.28	2.67*
	0.715-3.015	0.48-12.28	1609	2.92*			

*Significant at $\alpha = 0.05$.

¹Post-Drilling values generally less than Pre-Drilling values.

Table 1-35. T-test results for a comparison of metal levels in sediments at four Netsrk F-40 transects (greater than 90 m offshore)^a

Transect	Mean Hg ($\mu\text{g g}^{-1}$)	Level of significance			
		60°	150°	225°	335°
60°	0.098	-	>99.9	99	>99.9
150°	0.041	>99.9	-	NO	NO
225°	0.073	99	NO*	-	NO
335°	0.069	>99.9	NO	NO	-

* less than 99 percent

^aFrom Crippen et al. (1980).

Table 1-A. Summary of Sediment Trace Metal Alterations from Drilling Activities^a

	Trace Metal								
	As	Cd	Cr	Cu	Hg	Ni	Pb	V	Zn
Gulf of Mexico, Mustang Island area suspended sediment	ND	-	+	±	ND	-	-	±	-
			(8-31x)	(7-10x)				(6-25x)	
surficial sediment	ND	+	-	-	ND	-	-	-	+
		(3-9x)							(2.5-3.5x)
Gulf of Mexico, Mustang Island area	ND	±	±	±	ND	±	-	-	ND
Central Gulf of Mexico	ND	+	+	+	ND	+	+	+	
Mid-Atlantic	-	-	-	-	BLD	+	+	+	+
						(2.5x)	(4-4x)	(2-9.5x)	(4x)
Mackenzie River Delta	+	+	+	ND	+	ND	+	ND	+
	(1.2-2.5)	(2-6x)	(4-7x)		(1.2-15x)		(1.5-2.2x)		(11.7x)
Beaufort Sea	ND	+	+	±	-	ND	+	ND	+
		(2-6x)	(1.4-2x)				(1.2-2.6x)		(1.2-1.4x)

a. Adapted from Department of Interior (1976a, 1976b, 1977); Tillery and Thomas (1980); Mariani et al. (1980); Crippen et al. (1980).

b. Abbreviations: ND (not determined)
 + (increased levels (magnitude change in parentheses) related to drilling)
 - (decreased levels related to drilling)
 ± (isolated increases, not a clearly distance-related pattern)
 BLD (below the level of detection)

Table 1-36. Sediment Trace Metal Levels at Challenge 1, Sites A and B*

Data Set	Metal (mg/kg)			
	Cd	Cr	Pb	Zn
0 - 60 m	1.40	12.4	17.2	49.8
60 - 85 m	1.29	7.07	15.8	47.3
250 m	1.18	7.43	14.3	45.8
Pre-discharge	0.19	5.2	6.1	33

* Adapted from Sohio Alaska Petroleum Company (1982)

Table 1-37. Summary of Discharge Conditions and Physical Characteristics of Drilling Effluents Used in Below-Ice Test Discharges*

	Test Plot 1	Test Plot 2
Test Date	April 30, 1979	April 22, 1979
Volume Discharged	100 bbl	60 bbl
Discharge Rate	1508 bbl/hr	21.6 bbl/hr
Discharge Temperature	23° C	19° C
Density (at 20° C)	1.16 g/ml	1.05 g/ml
Ice Thickness	1.8 m	1.9 m
Water Depth	8.4 m	5.5 m

* Adapted from Sohio-Alaska Petroleum Company (1981)

Table 1-42. Summary of Deep Water Below-Ice Particulates Deposition of Discharged Drilling Fluids and Cuttings (Test Plot 1)*

Distance (m)	Sediment Pan Deposition (mg/cm ²)				
	N	E	S	W	Average
3.0	124.7	137.3	159.3	129.0	137.6
6.1	146.5	175.4	132.7	176.3	157.7
12.2	110.1	100.8	61.5	71.0	85.9
24.4	36.3	-	40.1	-	38.2
30.5	-	92.9	-	31.1	62.0

* Adapted from Sohio Alaska Petroleum Company (1981)

Table 1-43. Summary of Shallow Water Below-Ice Particulates Deposition of Discharged Drilling Fluids and Cuttings (Test Plot 2)*

Distance (m)	Sediment Pan Deposition (mg/cm ²)		
	15 ⁰ T	105 ⁰ T	Average
3.0	77.0	440.4	258.7
12.2	27.0	49.8	38.9
18.3	29.1	34.2	31.7
30.5	0.7	0.4	0.550
121.9	< 0.2	0.4	< 0.300
243.8	< 0.2	< 0.2	< 0.200
487.7	< 0.2	0.4	< 0.300

* Adapted from Sohio Alaska Petroleum Company (1981)

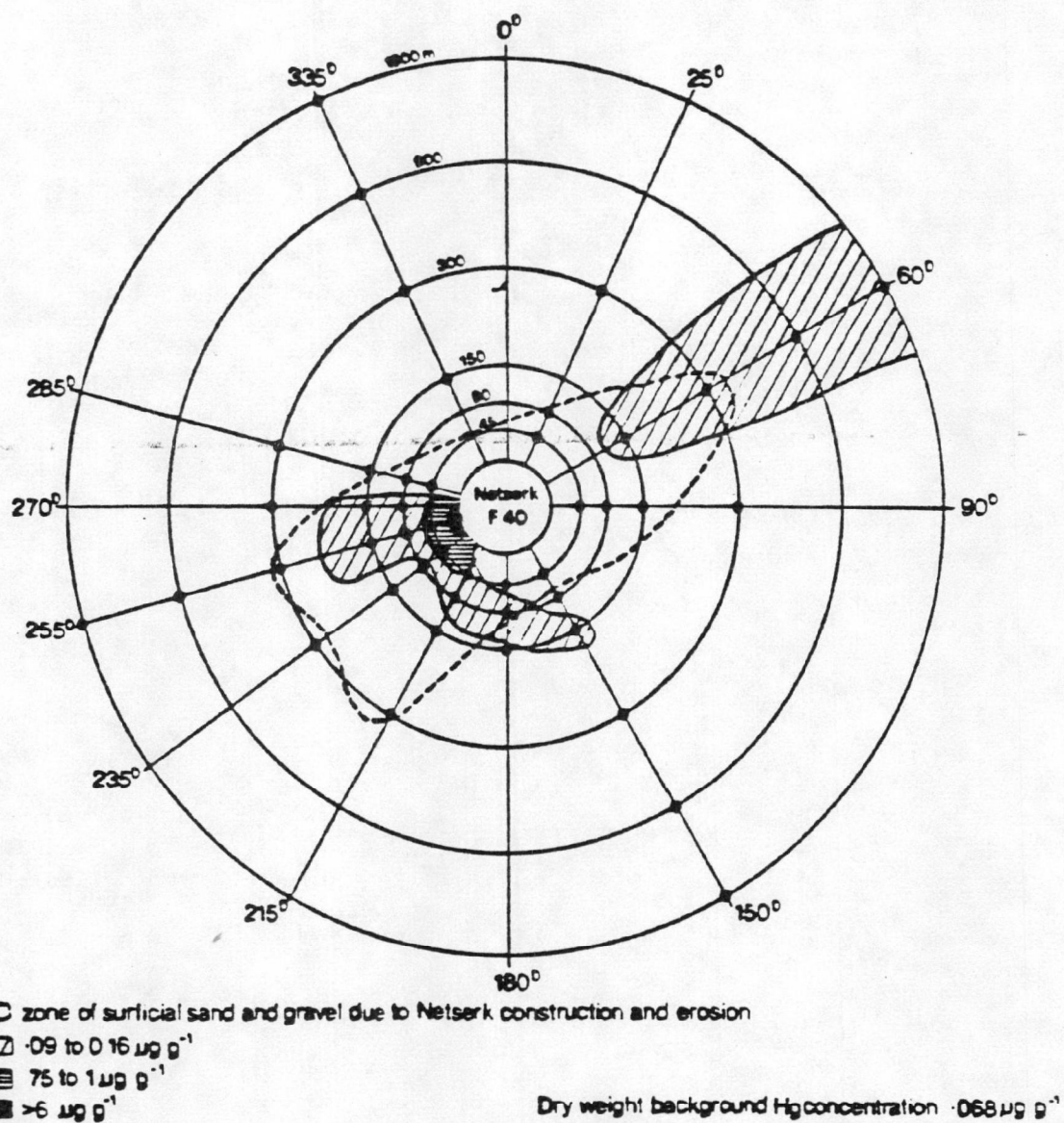


Figure 1-5. Distribution of Mercury in the Surficial Netserk Sediments

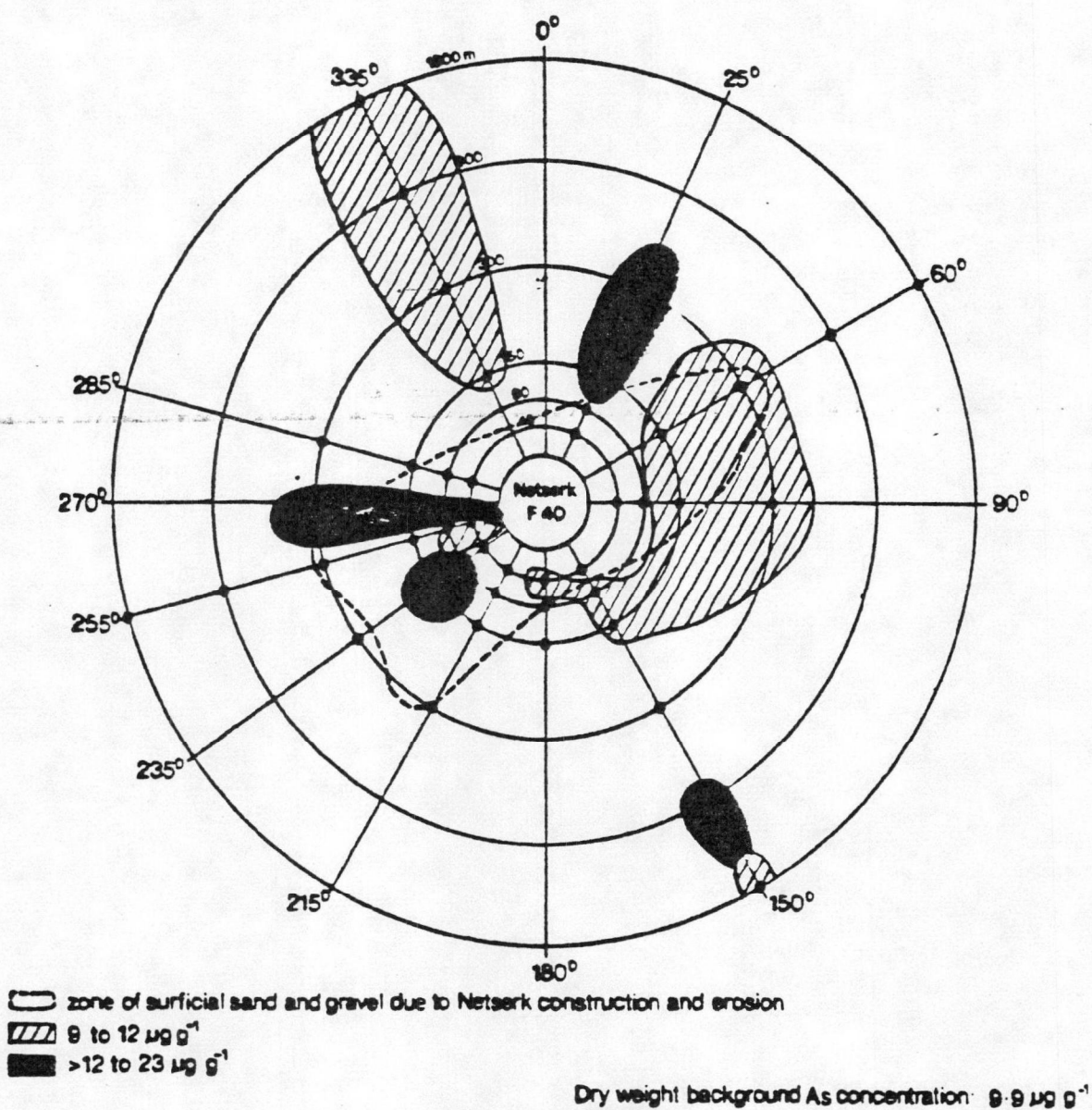
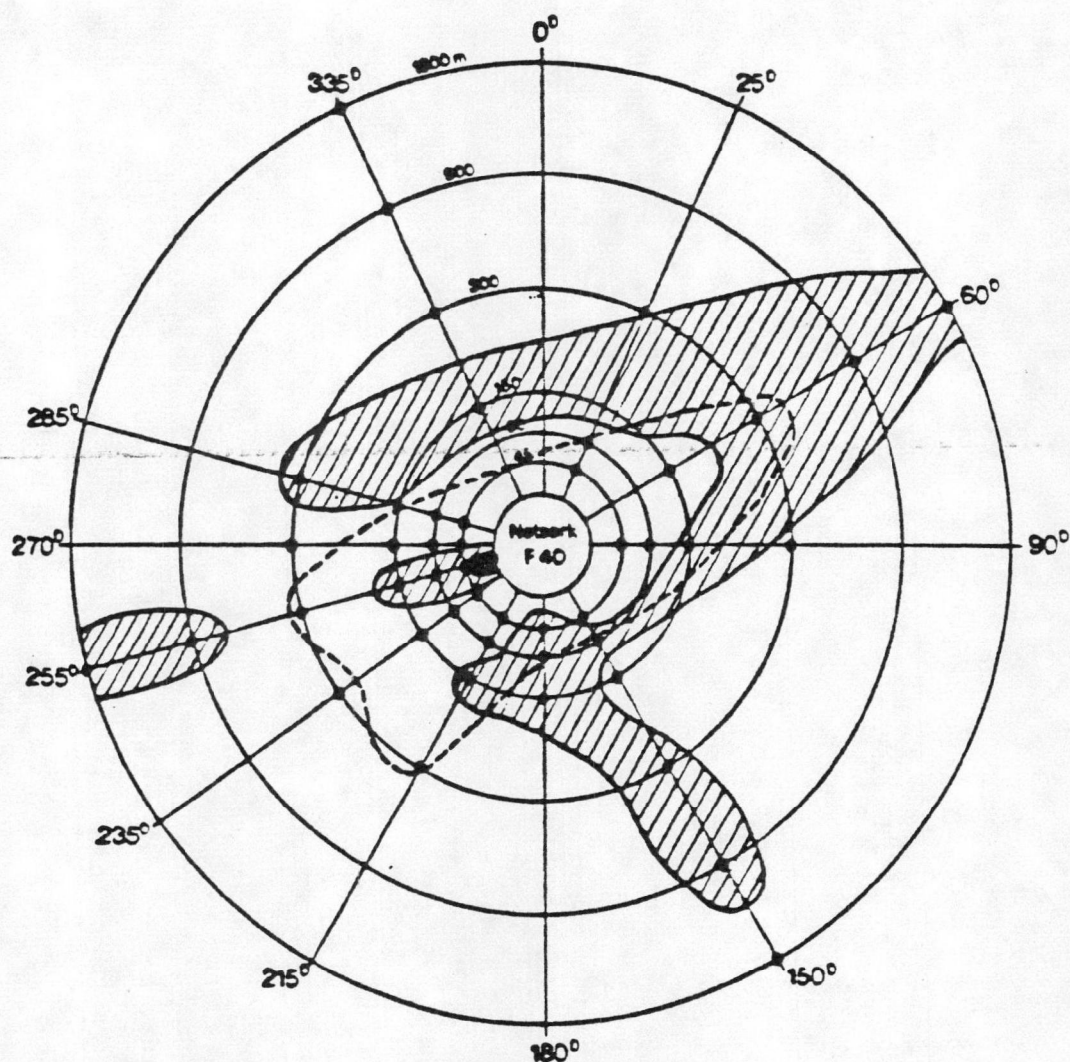


Figure 1-6. Distribution of Arsenic in the Surficial Netserk Sediments



— zone of surficial sand and gravel due to Netserk construction and erosion
 // 1 to 2 $\mu\text{g g}^{-1}$
 ■ 2 to 5.9 $\mu\text{g g}^{-1}$

Dry weight background Cd concentration 1.0 $\mu\text{g g}^{-1}$

Figure 1-7. Distribution of Cadmium in the Surficial Netserk Sediments

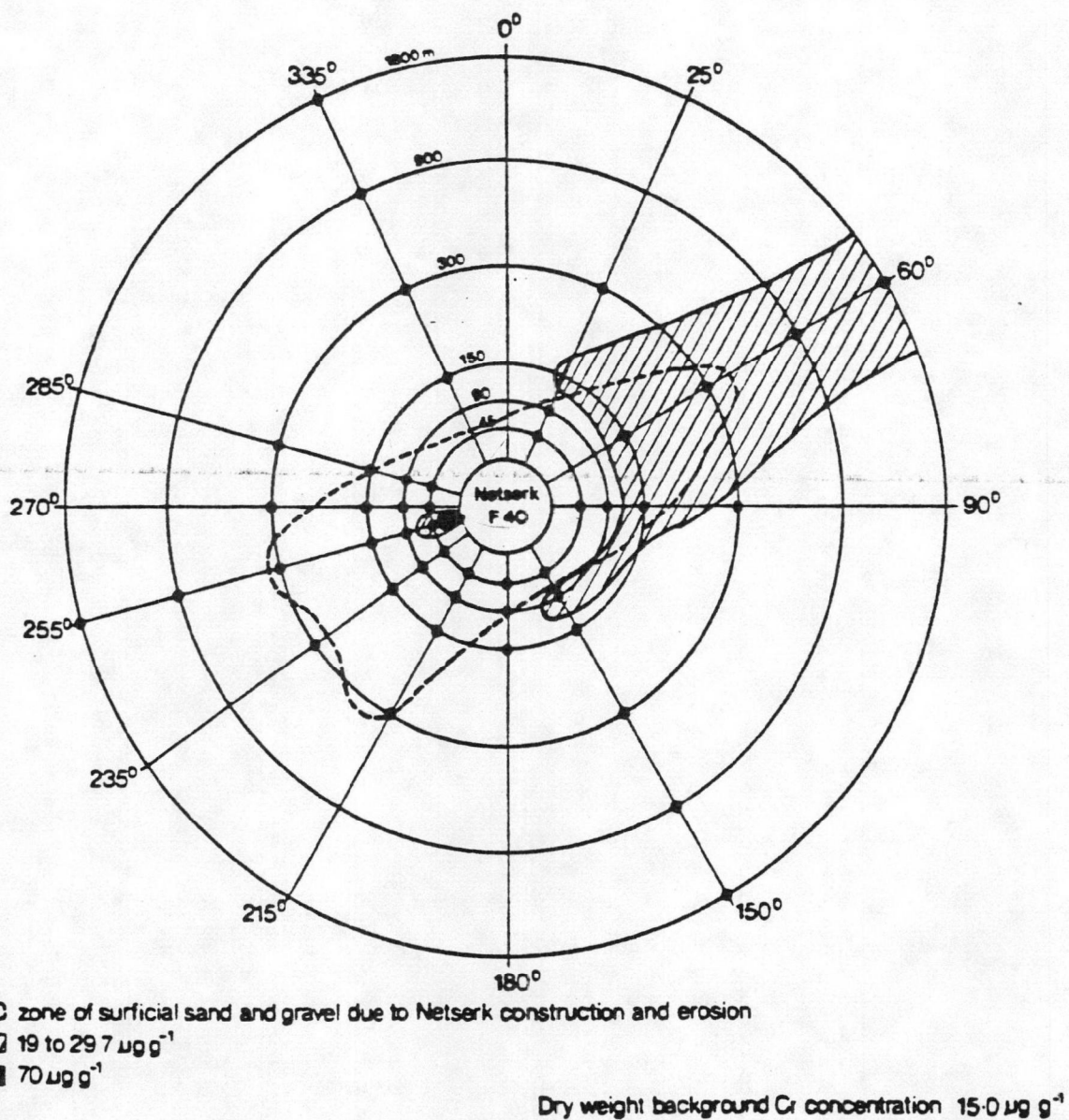


Figure 1-8. Distribution of Chromium in the Surficial Netserk Sediments

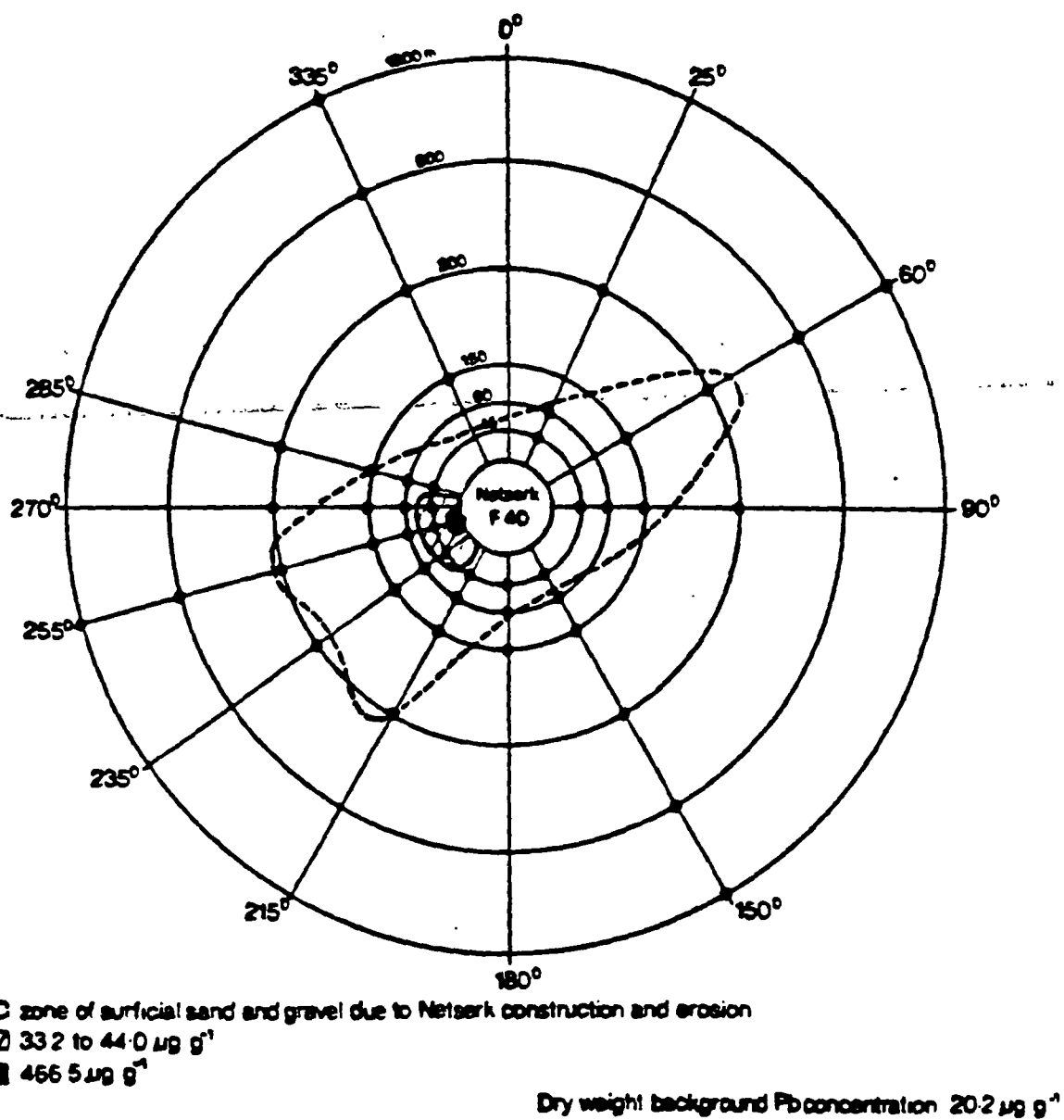
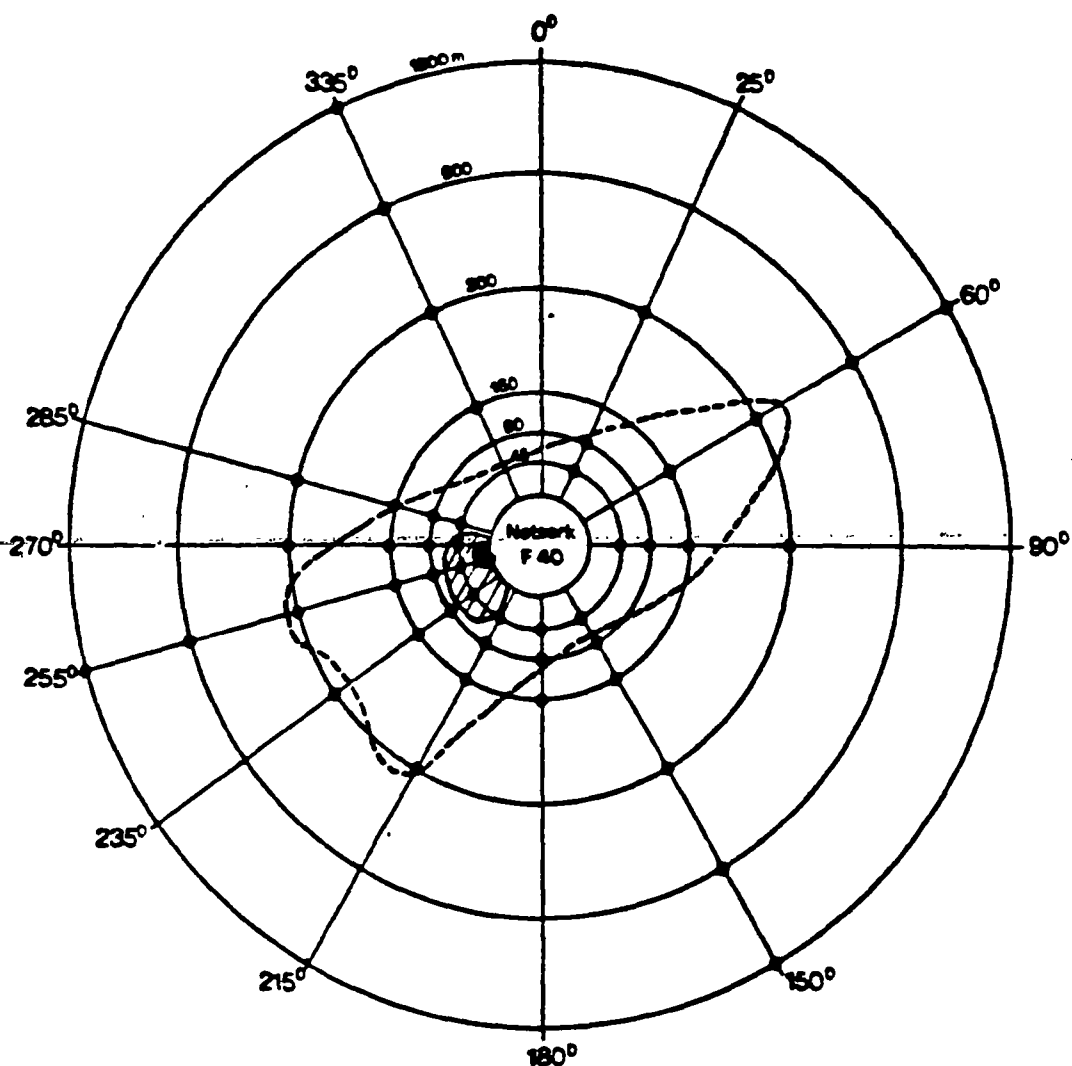


Figure 1-9. Distribution of Lead in the Surficial Netserk Sediments



(dashed line) zone of surficial sand and gravel due to Netserk construction and erosion
 (hatched) 157 to 213 $\mu\text{g g}^{-1}$
 (solid black) 1360 $\mu\text{g g}^{-1}$

Dry weight background Zn concentration: 115.5 $\mu\text{g g}^{-1}$

Figure 1-10.. Distribution of Zinc in the Surficial Netserk Sediments

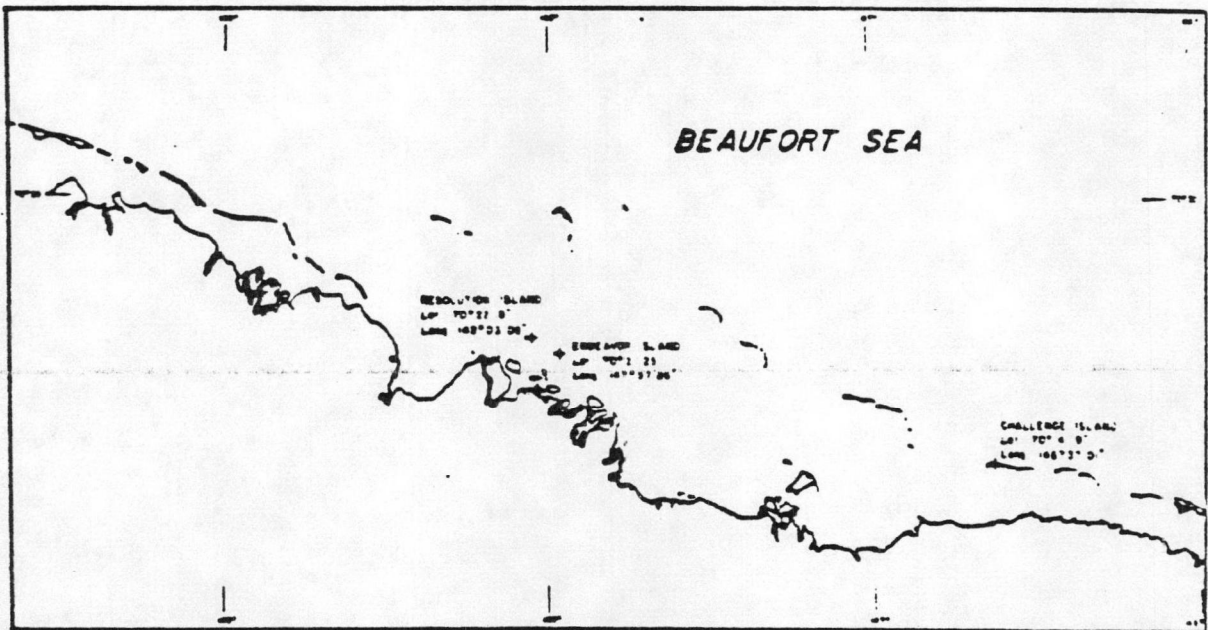
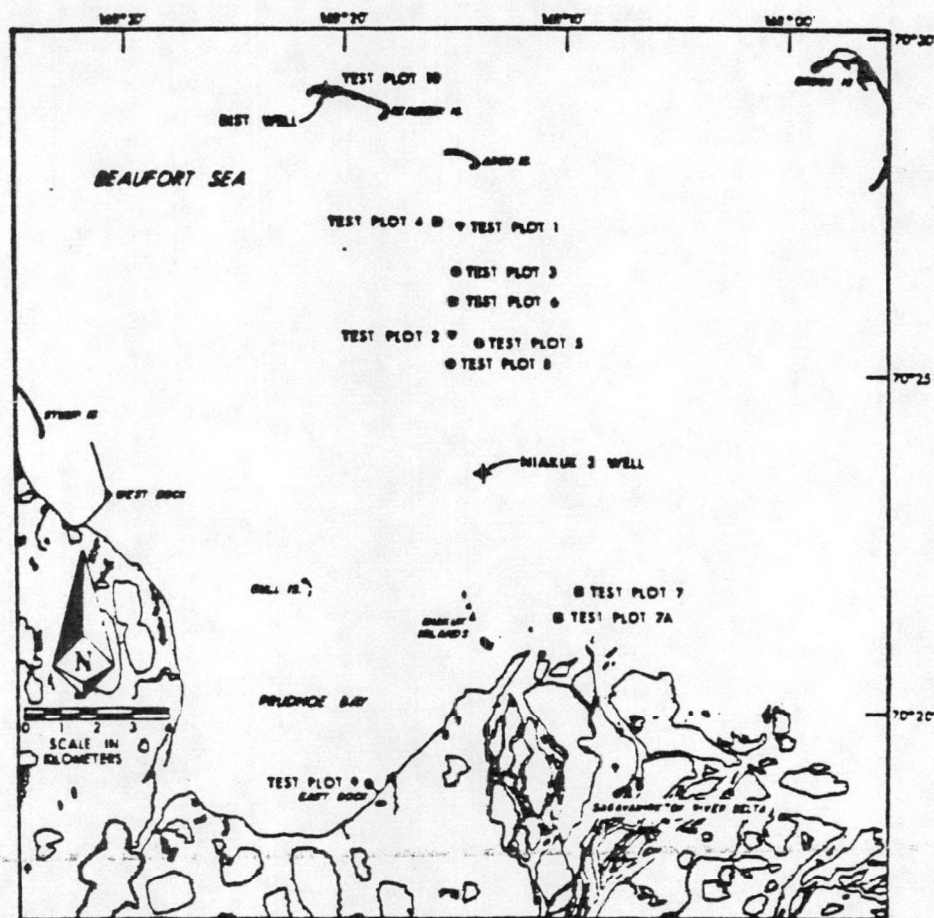


Figure 1-11. Location Map for Endeavor, Resolution and Challenge Islands*

*From Sohio Alaska Petroleum Company (1982).



<u>Test Plot</u>	<u>Latitude</u>	<u>Longitude</u>	<u>Primary Purpose of Site</u>	<u>Water Depth (m)</u>
1	70°27'12"	148°14'56"	Deep water below ice disposal site	8.2
2	70°25'31"	148°15'38"	Shallow water below ice disposal site	5.5
3	70°26'34"	148°15'22"	Deep water benthic control site	7.6
4	70°27'22"	148°16'01"	Simulated above ice disposal site	6.7
5	70°25'28"	148°14'03"	Shallow water benthic control site	4.9
6	70°26'07"	148°15'24"	Offshore above ice disposal site	6.4
7	70°21'52"	148°09'26"	Nearshore above ice disposal site	1.0
7A	70°21'27"	148°10'37"	Nearshore above ice disposal site	1.0
8	70°25'10"	148°15'30"	Bioassay trailer location (winter)	4.6
9	70°19'00"	148°19'00"	Bioassay trailer location (summer)	NA
10	70°29'09"	148°21'44"	Reindeer Island Wind Sensor Location	NA

Figure 1-15. Location Map and Summary of Test Plots for the Study Area*

*From Sohio Alaska Petroleum Company (1981).

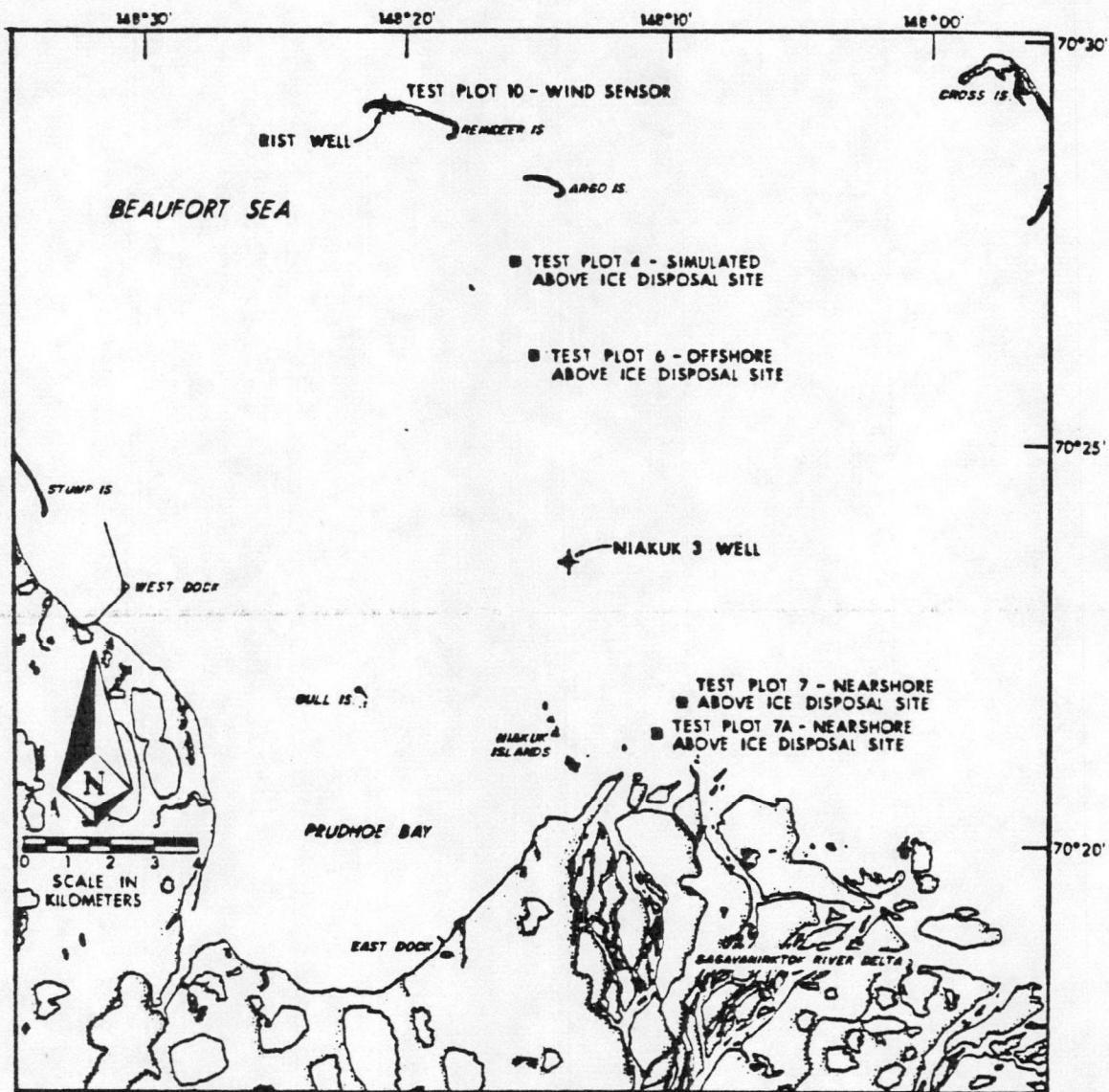
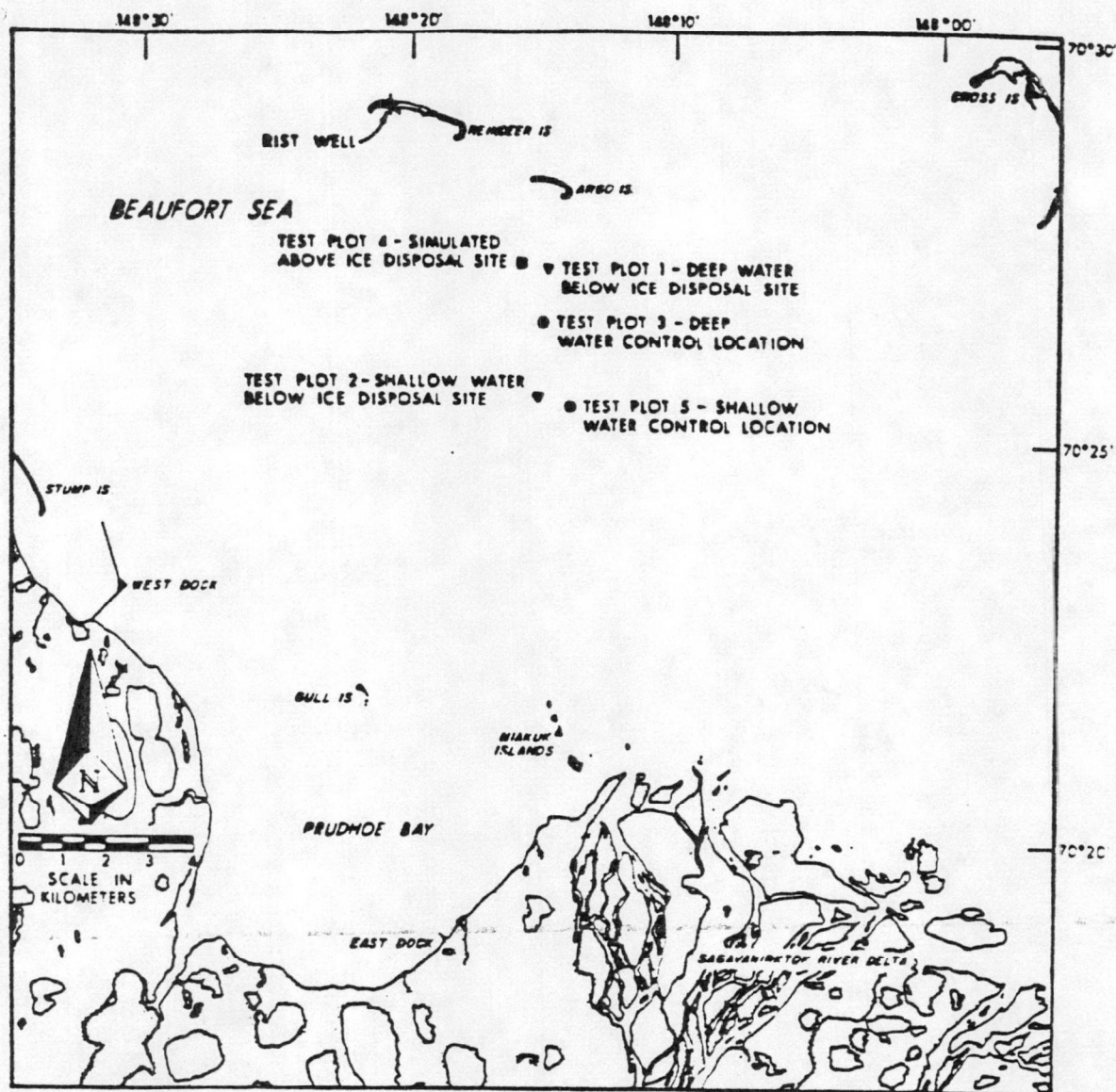


Figure 1-16. Location Map for Above-Ice Disposal Tests*

*From Sohio Alaska Petroleum Company (1981).



Site Identification	Water Depth (m)	Latitude	Longitude	Primary Purpose of Site
Test Plot 1	8.2	70°27'12"	148°14'56"	Deep water below ice disposal site (100 bbl of drilling fluids discharged on April 22, 1979)
Test Plot 2	5.5	70°25'31"	148°15'38"	Shallow water below ice disposal site (of drilling fluids discharged on April 22, 1979)
Test Plot 3	7.6	70°26'34"	148°15'22"	Deep water benthic control site
Test Plot 4	6.7	70°27'22"	148°16'01"	Simulated above ice disposal site (100 bbl of drilling fluids discharged on May 6, 1979, 4 bbl discharged through 25 holes.)
Test Plot 5	4.9	70°25'28"	148°14'03"	Shallow water benthic control site

Figure 1-23. Location Map and Summary of Test Plots for Benthic Studies*

*From Sohio Alaska Petroleum Company (1981).

APPENDIX C.

Summary of Field Studies or Studies
In Situ Describing Metal Bioaccumulation
Following Exposure to Drilling Fluids
and Cuttings

Studies In Situ

Single Species Studies

Single species toxicity tests in situ, have been conducted in Cook Inlet and in the Beaufort Sea, near Reindeer Island. In the Reindeer Island study (Sohio Alaska Petroleum Company 1981), amphipods and clams were deployed in live boxes for 4 days and 89 days. Technical problems (lost or damaged boxes) prevented any meaningful interpretation of mortality data because of lost animals and lost control station live boxes. Similarly, the live box arrays in Cook Inlet (ARCO 1978), using pandalid shrimp, hermit crabs, or pink salmon fry, also were susceptible to similar technical problems. Meaningful interpretations from these data are limited in their utility in a hazard assessment.

Toxicity tests in situ were conducted in the Prudhoe Bay area of the Beaufort Sea, near Reindeer Island (Sohio Alaska Petroleum Company 1981). Live boxes were placed at shallow-water (5.5 m) and deep-water (8.5 m) below-ice discharge sites (Tests A and B, respectively) and at a simulated above-ice disposal site (Test C). Each box contained 20 amphipods (not specified, but probably Onisimus and Boeckosimus spp, as for related laboratory tests).

For Tests A and B, live boxes located both at the seafloor and suspended 2.4 m above the seafloor were placed 3 m and 12 m from the discharge and at a control location. Live boxes were recovered after 97-169 hours. Only seafloor live boxes were deployed for Test C, and were recovered 94 hours and 89 days after deployment.

Only the bottom live box at 3 m from the discharge (Test B) and the long-term live box (Test C) showed any mortalities (Table 1-58). Since the live boxes were recovered intact, it was assumed that amphipods missing from these tests had been eaten by remaining amphipods. Whether they were affected in any way by drilling fluids could not be determined.

Metal accumulation also was examined in amphipods deployed in Test C (Table 1-59). Cr and Zn in disposal site organisms were not different from controls. Both Cu and Pb showed a 1.3-fold enrichment factor. These factors

are consistent with data obtained from laboratory studies of an Alaskan species for Cu (1.1-3.1) and for several species tested for Pb (1.2-2.3).

A confounding factor in the Cu data is that although sediment Cu levels were similar to background levels 3 days after the test discharge, Cu levels in sediment collected at the recovery of the live boxes were 60-70% above background levels. It was not known whether the higher sediment levels were drilling fluid-related.

Another experiment near Reindeer Island was conducted in situ to assess the potential for long-term impacts from drilling effluents (Sohio Alaska Petroleum Company 1981). Clam trays were deployed at a control site and at a simulated above-ice disposal site. Each tray contained 26 clams, including 20 Astarte spp. (ranging in size from 5-20 mm) and 6 Liocyma fluctuosa (approximately 5 mm in diameter).

Five of 12 trays were recovered during these surveys. Two trays recovered 96 hours after the simulated above-ice discharge had an average of 1.5 dead clams per tray. The one tray recovered at the control site contained two dead clams. Seven clams were missing from the disposal site trays. None were missing from the control clam tray.

Approximately 3 months after deployment, only one control clam tray mortality was observed. Only one tray was recovered from the disposal site. Ten clams were recovered alive, nine clams were missing, and the remaining clams were dead. The tray cover was no longer firmly attached and the tray contained only about half the original volume of sediment. It was unknown whether a lack of substrate in the tray or exposure to predation contributed to the observed mortalities.

A series of 96-hour toxicity tests in situ has been reported for pandalid shrimp (Pandalus hypsinotus), hermit crabs (Elasochris gilli), and pink salmon fry (Oncorhynchus gorbuscha) maintained in live-box arrays near an Alaskan OOST well in Cook Inlet (ARCO 1978). Live-box arrays were located 100 m and 200 m NNE of the rig, along a major current axis, and at a control site some 2 km WNW of the rig.

Field Studies

Gulf of Mexico OCS

A study has provided pre-, during-, and post-operational assessments of selected biological parameters in the immediate vicinity of an exploratory drilling rig (Department of the Interior 1976b). The survey was located in 36 m of water on the south Texas OCS, near the north lease line of Mustang Island, Block 792. Macroepifaunal samples for trace metal and histopathologic analyses were collected by a semi-balloon trawl. Samples for foraminiferal analyses were collected by divers using a 10 cm x 0.5 m PVC corer, scraping it horizontally along the bottom.

The concentration of Cd, Cr, Cu, Fe, Pb, Ni, and V was examined in trawl-collected samples. These values were comparable to levels in organisms from other areas in the Gulf. The values for shrimp reported in this rig monitoring study were thought to agree well with levels found in shrimp collected from Station I on Transect II (at a depth of 22 m) of the BLM South Texas Outer Continental Shelf Baseline Study.

The decrease in Cr, Pb, and Ni levels from pre- through post-drilling surveys was attributed to a change from flame to flameless AAS techniques during the analysis of these samples. Cd, Cu, and V showed significant intraspecific variation among the three phases for any of the species analyzed.

Fe was the only element exhibiting significant intraspecific changes between the three phases of this study. However, these changes were not consistent among species that were analyzed, in regard to any spatial or temporal pattern. For Penaeus setiferus, the Fe concentration during drilling was significantly ($P < 0.01$) greater than pre- or post-drilling levels. Tissue Fe levels were significantly greater during drilling compared to post-drilling levels in Trachypenaeus similis and Squilla chydrea. For S. empusa, the Fe concentration before drilling was significantly greater than post-drilling levels. The Fe values for various species showed neither spatial localization or significantly different Fe values nor any correlation to significant changes in sediment Fe concentrations among the three surveys.

Only two species of penaeid shrimp was collected in sufficient quantities for histopathological analysis. A total of 150 specimens of Trachypenaus similis (25 pre-, 25 during- and 100 post-drilling) were analyzed for evidence of histopathology.

Tissue sections examined included the cornea, carapace, muscle, hepatopancreas, kidney, and gonad. Pathology was not detected in any of the samples. These observations were believed to be unremarkable because these shrimp were thought to move into and out of the study area. Thus, the same population was not repeatedly sampled.

Trace metal data from trawl samples do not indicate any systematic pattern of uptake resulting from drilling activities. However, the selection of mobile species for tissue analyses limits the general applicability of this finding. Furthermore, this sampling design does not address this potential effect in benthic species, which are the more probable sites of impact for bioaccumulation.

A rig monitoring study was conducted on the south Texas Outer Continental Shelf (Department of Interior 1976a). The rig monitoring site (Block 755, Mustang Island Lease Area) was located between Transects I and II of the STOCS baseline study area, south of Port Aransas, Texas. The site was located in 33 m of water and was close to the main Port Aransas shipping lane, which was partially located in Block 755. The rig was on site from December 1, 1976 through January 20, 1977. Drilling began December 3, 1976 and was completed at a depth of 3352.8 m (11,000 ft) on January 15, 1977.

The pre-drilling survey was conducted September 25-27, 1976. The during-drilling survey was conducted January 7 and 14, 1977. Post-drilling sampling occurred February 28-March 2, 1977. Comparisons were made of meiofaunal abundances per 10 cm² for five numerous taxa in samples collected in pre-drilling and post-drilling sampling periods. An increase in the post-drilling abundances for all groups, except polychaetes, was noted.

The data set on metal levels in epifauna and demersal fishes was considered to be of very limited use as a means to detect changes in tissue trace metals concentrations resulting from drilling operations. Only three species were collected both before and after rig operations. Only one species (*Loligo pealei*; squid) occurred in both pre- and post-drilling sample groups. For this species, modest increases occurred for Cr (> 1.2-fold), Cu (2-fold), Fe (1.1-fold), Ni (> 3-fold), and V (5-fold). Of these, only Cr, Ni, and V showed a post-drilling tissue level greater than the mean value + 1 standard deviation for samples collected on the south Texas OCS, outside the area of the rig (Table 1-68).

The species analyzed were all mobile. The residence time of the organisms sampled within the immediate vicinity of the rig was unknown but could have been very limited. Due to seasonal variability in species composition of epifaunal and demersal fish populations, it was difficult to draw conclusions on the relationship between drilling activities and trace metal content of the samples.

Tillery and Thomas (1980) reported a study of the Buccaneer Gas and Oilfield in the central Gulf of Mexico, which provided 3 years of data on the chronic, low-level, heavy metal contamination from active petroleum production platforms on the OCS.

Twenty platform structures and four reference sites (i.e., no structures) were selected by the Bureau of Land Management (BLM). At least 27 species were collected and analyzed for trace metals. Of these, only four species were collected in sufficient numbers to conduct a statistical analysis for comparison with other literature data. These were Penaeus aztecus (brown shrimp), Micropogon undulatus (Atlantic croaker), Archosargus probatocephalus (sheepshead) and Chaetodipterus faber (spadefish).

Although these species are very mobile and less than ideal for trace metal bioaccumulation studies, they were selected because of (1) availability at the platforms, (2) prohibitive time and cost constraints in implanting and collecting sessile organisms, (3) availability of trace metal data from the literature, and (4) importance as commercial species.

Trace metal concentrations in muscle tissue of these species did not generally show significantly higher metal concentrations than similar organisms from other areas of the Gulf of Mexico. However, concentrations of Cu and Fe were 1.9-fold and 2.3-fold higher in A. probatocephalus; Ni was two-fold higher. Cu and Fe also were 2.2-fold and 2.1-fold higher in C. faber.

The mobility and limited knowledge of the life cycles of A. probatocephalus and C. faber prevented a definitive correlation between the concentrations of Cu, Fe, and Ni in their muscle tissues and petroleum production activities on the OCS. These elevated concentrations only suggested that the source may be related to petroleum production platforms.

Sohio Alaska Petroleum Company (SOHIO) conducted a study program to monitor environmental effects associated with above-ice disposal of drilling fluids and cuttings in the Beaufort Sea (Sohio Alaska Petroleum Company 1982). These studies were conducted at three well sites: Sagavanirktok Delta wells #7 and #8 (Sag 7 and Sag 8) and Challenge Island well #1 (Challenge 1).

At the Sag 7 above-ice disposal site, water depths ranged from 2.9-3.5 m. At Sag 8 water depths varied from 1.3-1.7 m. Challenge 1 southern disposal sites (Sites A and B) were located in 2.4-2.9 m of water. The northern disposal area (Site C) was located in water depths that ranged from 2.7-5.0 m.

Approximately 3,000 bbls of saltwater/freshwater lignosulfonate drilling fluids and cuttings from the Challenge Island well were discharged at the Sag 7 disposal site, during mid-April 1981. Effluents were spread as evenly as possible. Approximately 490 bbl of lightly-treated freshwater lignosulfonate liquid effluents and 1,670 bbl of fluid solids and cuttings were discharged at the Sag 8 above-ice disposal site from March 16-30, 1981.

Approximately 5,000 bbl of frozen fluids and cuttings were discharged at disposal sites adjacent to the Challenge Island well from March 14-25, 1981. At Site A, approximately 1,010 bbl of freshwater drilling effluents were spread in a layer 2-3 cm thick over most of the disposal site. An additional 250 bbl of drilling effluents mixed with snow were piled in the SE corner of Site A by end-dumping directly from trucks. Approximately 2,860 bbl of frozen drilling effluents were spread in a 10-20 cm layer over disposal Site B. At Site C, approximately 890 bbl of frozen drilling effluents were placed in piles, nominally 75-90 cm high, to assess the effects of overloading the ice outside the barrier islands.

Bioaccumulation studies were designed to reveal variations in concentrations of selected trace metals (Ba, Cd, Cr, Cu, Hg, Pb, Zn) in benthic and epibenthic organisms during disposal tests. Samples were collected for these analyses prior to island construction, prior to effluent disposal, and after effluent disposal. A number of sampling techniques were used to collect marine organisms for trace metal analyses. During the July, 1980 pre-construction survey, Ponar samplers, pipe dredges, divers, and trawl nets all were used with limited success.

A disappointing catch of sessile and sedentary benthic organisms suitable for metal analyses confounded the attempt to implement a valid sampling program. In view of the substantial efforts expended in sampling with various methods for these organisms, their abundance was considered low in the vicinity of the study sites. Since organisms that were collected and analyzed were primarily motile, individual data points were grouped only by sampling period and general site.

At Sag 7, samples of isopods (Saduria entomon), sculpin (Myoxocephalus quadricornus), and kelp (Laminaria sp.) were obtained in July 1980, December, 1980 and July, 1981. Two notable trends appeared in the trace metal analyses (Table 1-72). First, Ba concentrations decreased considerably in the winter samples (December, 1980 - January, 1981) in each species. In isopods, Ba concentrations continued to decrease from December, 1980 to July, 1981. Ba concentrations in kelp and sculpin increased from December, 1980 to July, 1981 but mean concentrations remained below that of July, 1980.

~~A second trend appeared in the trace metal concentrations in kelp.~~ From July, 1980 to December, 1980 all trace metal levels decreased. The concentration of all metals except Ba and Cr continued to decrease to July, 1981. Other variations in trace metal concentrations in samples from the vicinity of Sag 7 appeared random.

At Sag 8, with the exception of Zn and Ba, all trace metals increased in isopods from July, 1980 to July, 1981 (Table 1-73). Sculpin, however, exhibited a trend in which all metals except Cd decreased from 1980 to 1981. Samples of kelp, although showing a slight variation, remained statistically unchanged. Isopods and sculpin at Sag 8 showed a decrease in Ba concentrations similar to that observed at Sag 7. Also a comparison of July, 1980 and July, 1981 Ba concentrations for both species at Sag 7 and Sag 8 showed that tissue Ba concentrations were lower at Sag 8 in post-discharge samples. Trace metal levels in isopods from Challenge 1 were lower than those from the Sag 7 and Sag 8 sites except for Ba, which was higher, and Cr which was approximately the same.

There are several confounding factors that do not allow these data to support a conclusion that metal bioaccumulation has not resulted from drilling

fluid discharges. First, data obtained from mobile species may not allow for valid conclusions in bioaccumulation studies. The concern is that the mobility of such species is incompatible with identifying effects from a highly sediment-bound and localized source of exogenous metals. Sessile or sedentary benthic epifauna and benthic infauna are more appropriate organisms upon which conclusions regarding metal accumulation may be made.

Second, the statistical precision of these data does not allow for a strong reliance on statistical tests to interpret these data (Table 1-74). Assessing general trends probably is more justified than a rigorous qualification of the data based on statistical tests. Third, the Ba analyses may not have measured total Ba levels because of the incomplete extraction procedures that were employed.

Last, there occurred several notable findings if general trends are considered. The most obvious trends were noted for isopods. Both whole and gutted animals (at Sag 7) showed decreased levels of Ba and Cr between pre-discharge and the first post-discharge samples. This finding is counter-intuitive in view of the fact that the two metals most clearly and abundantly related to drilling fluid discharges are Ba and Cr. This finding is made all the more confusing in that while Ba and Cr were found to decrease, all other metals examined increased over the same time period.

Since no reference station analyses were conducted by which natural temporal variations may be factored into an evaluation of these data, it is difficult, if not impossible to rely on these findings too heavily. Spatial patterns may have been useful, but given the mobility of the collected organisms, even a spatial analysis would not be conclusive. These data suggest that no large amplitude variations in tissue metal levels resulted from these discharges of drilling fluids, but these data do not address any lesser level of potential impact.

A study conducted by Crippen et al. (1980) investigated the environmental levels of metals resulting from drilling fluids discharges to the Beaufort Sea, near the Mackenzie River Delta. The concentration of metals in the water, surface and subsurface sediments, and zoobenthos was measured near a post-operational artificial island drilling site, Netserk F-40. The well was spudded November 8, 1975 and was completed May 19, 1976. Approximately 7,300 barrels of waste drilling fluids were discharged.

Quantitative benthic samples were collected at 33 stations with a 0.05 m² Ponar grab that sampled to a depth of 5-10 cm. Samples were sorted using 0.5 mm mesh stainless steel or brass sieves. Each sample consisted of four to seven Ponar grabs to obtain sufficient biomass for analysis. Duplicate samples were collected at each station. Extra benthic specimens were collected at nine stations for metal analyses on purged organisms. These organisms were purged for 24-48 hours in water from the station at which they were collected.

~~Thirty-three taxa of benthic organisms were identified--to species when possible--from around Netserk.~~ The lowest benthic densities were found at stations located within 45 m of the island. These densities usually ranged from 20-450 m⁻². At stations 90 m offshore, mean density values of 1100 m⁻² were found; densities were 2000 m⁻² at stations 150 m offshore and were greater than 2500 at stations 300 m offshore and beyond. The stability of mean densities for these latter stations suggested that they were beyond the major influences of both the artificial island and the drilling operations. Benthic biomass, similar to density, was depressed at stations located within 300 m of the island.

The majority of analyses for metals in the benthos were performed on deposit-feeding infauna. Due to the low benthic biomass, it was necessary to combine three taxonomic groups (Polychaeta, Oligochaeta, and Pelecypoda) to obtain sufficient tissue for metal determinations. Habitat, niche, and feeding habits were the criteria chosen for such a classification.

To determine whether sediment chemistry at Netserk had an effect on metal concentration in infaunal benthic tissue, linear regressions were calculated for sediment metal concentrations versus benthos metal levels. A linear model

was assumed and an F-test constructed to test for positive correlation between these parameters. Both the r-values generated from the F-test (not significant at the 90% confidence level) and the scattered or random points on the graphs in Figure 9 suggest no correlation between metal levels in the sediment and metal levels in benthic tissue within the study area at Netserk.

The biological impairment (low benthic densities and biomass) that was noted in the vicinity of Netserk primarily reflected the modification and smothering of the benthic environment resulting from rapid sediment accumulation that occurred during island construction and that was occurring from island erosion during the summer of 1977 .

Erosion of Netserk and the resulting smothering of surrounding sediments may have had certain advantages. Sediments contaminated with metals from the disposal of drilling fluids have been diluted and/or buried, thus reducing the exposure of aquatic organisms to these contaminants. Smothering and modification of natural marine sediments by the borrow material during construction and subsequent erosion of Netserk probably had a greater impact to the marine environment than the disposal of drilling fluids.

Two conclusions of this paper, however, are not supported unambiguously by the data presented. These conclusions were (1) that there were no correlations between sediment and tissue levels and (2) that biological alterations were primarily the result of gravel island construction and erosion.

First, the absence of significant correlations between sediment and tissue metal levels is compromised by the assumption of a linear relationship. On the contrary, a linear response is much less appropriate than a log-normal or a log-log relationship. The absence of significant linear correlations only provides weak support for the conclusion that no effect occurred. An additional factor that would substantially contribute to the inability to detect any correlations between these data sets was the unfortunate necessity of pooling biological samples among broad taxonomic groups, a requirement that decreased the statistical resolution possible from these data.

Attempting to identify correlations from visual inspection of graphical data can be very difficult. From the data provided (Figures 1-24), it appears that several correlations could be significant if more appropriately transformed data were analyzed (e.g., As, Cd, Cr). Data on Hg were presented poorly with regard to scale and difficult to evaluate, although biomass vs sediment Hg (Figure 1-25) may be better regressed as an exponential decay. Pb and Zn do not appear to show any correlation between tissue levels and sediment levels.

Second, the attribution of biological impact to gravel island construction and erosion also is not unambiguously supported because there were no analyses that clearly segregated potential drilling fluid impacts from gravel island-related impacts (for example, clay mineralogy or Ba content). While the data suggest an association between island construction/ erosion and biological impact, data from other studies indicate that discharged fluids and cuttings may also affect local biological communities. The question of the relative contributions of these two potential sources of biological impact remains unresolved.

**Table 1-59. Metals Concentrations in Amphipods From Live Box Test C
At the Simulated Above-Ice Disposal Site (Test Plot 4)**

Location	Exposure (days)	Number of Organisms	Metals Concentration (mg/kg dry weight)			
			Cr	Cu	Pb	Zn
Test Plot 3 (Control)	87	15	4.6	89	11	99
	87	16	3.3	90	15	108
Test Plot 4 (Disposal Site)	89	16	4.6	110	19	114
	89	15	3.4	118	15	100

a. Adapted from Sohio Alaska Petroleum Company (1981)

Table 1-68. Trace Metal Levels in Muscle Tissue From Loligo pealei Collected Before and After Drilling Operations^a

Metal	Tissue Levels (ppm dry weight)		
	Before Drilling	After Drilling	BLM-STOCS (1976) Survey
Cd	1.3	0.29	0.18±0.20
Cr	< 0.05	0.06	0.03±0.02
Cu	11	22	13±13
Fe	3.6	4.0	4.6±4.5
Ni	< 0.09	0.27	0.16±0.13
Pb	< 0.03	0.02	0.13±0.10
V	< 0.1	< 0.5	0.2±0.2
Zn	50	43	47±9

a. Adapted from Department of Interior (1976a)

Table 1-72. Trace Metal Levels in Organisms Collected at the Sag 7 Disposal Site^a.

Organism	Sampling Period ^b .	Metal (mg/kg)						
		Ba	Cd	Cr	Cu	Hg	Pb	Zn
Isopods (whole)	I	790	2.8	8.7	72	0.06	24	99
	II	125	3.2	1.8	82	0.22	49	291
	III	121	2.7	4.5	60	0.15	20	68
Isopods (gutted)	I	203	1.6	3.0	36	0.06	11	61
	II	82	5.3	1.3	52	0.17	12	187
	III	ND ^c						
Sculpin (whole)	I	370	1.3	9.6	13	0.06	9.9	140
	II	33	1.2	2.7	14	0.61	8.2	120
	III	166	1.2	3.3	9.1	0.08	9.4	94
Sculpin (gutted)	I	150	1.0	6.3	12	ND	11	80
	II	50	3.0	2.0	12	<0.01	12	550
	III	ND						
Kelp	I	703	2.5	13	35	<0.01	52	540
	II	211	1.6	3.9	16	<0.01	6.9	67
	III	303	1.6	5.1	14	0.05	12	54

a. Adapted from Sohio Alaska Petroleum Company (1982)

b. Sampling periods: I July 1980
 II December 1980 - January 1981
 III July - August 1981

c. Not determined

Table 1-73. Trace Metal Levels in Organisms Collected at the Sag 8 Disposal Site^a.

Organism	Sampling Period ^b	Metal (mg/kg)						
		Ba	Cd	Cr	Cu	Hg	Pb	Zn
Isopods (whole)	I	154	1.7	2.3	66	0.11	14	79
	II	38	3.7	3.0	81	<0.05	22	76
Isopods (gutted)	I	208	3.2	2.2	86	0.15	17	108
	II				ND ^c			
Sculpin (whole)	I	71	1.4	2.3	11	0.38	16	103
	II	14	1.0	1.8	9.4	<0.05	8.7	80
Sculpin (gutted)	I	181	1.6	2.5	32	0.14	15	114
	II				ND			
Kelp	I	282	1.6	5.4	21	<0.25	12	73
	II	226	3.3	3.9	41	<0.05	15	70

a. Adapted from Sohio Alaska Petroleum Company (1982)

b. Sampling periods: I July 1980
II December 1980 - January 1981

c. Not determined

Table 1-74. Statistical Precision of Tissue Trace Metal Determinations from Organisms Collected at Sag 7 and Sag 8^a.

Study Site	Precision ^b						
	Ba	Cd	Cr	Cu	Hg	Pb	Zn
Sag 7	158	95	113	89	128	109	155
Sag 8	73	73	111	107	152	71	40

a. Adapted from Sohio Alaska Petroleum Company (1982)

b. Precision expressed as the upper 95% confidence level as a percentage of the mean.

Table 1-77. Trace Metals in Brittle Stars t-Test for Group Means of Pre- and Post-Drilling Data
(From Mariani et al., 1980)

Trace Metals	Range of Concentrations (µg/g)		Distance from Well Site for Post-Drilling Data (Meters)	t-Value	Range of Concentrations (µg/g) for Southern Quadrants		Comparison of Southern Quadrants Pre- and Post-Drilling t-Value
	Pre-Drilling	Post-Drilling			Pre-Drilling	Post-Drilling	
Arsenic	2.10-29.00	0.80-15.5 ¹	1609	-2.85*	4.81-29.00	0.80-15.10 ¹	-2.90*
Barium	0.45-6.43	1.0-322.6	1609	-3.71*	0.84-6.43	1.0-139.1	3.20*
Cadmium	<0.0009-28.6	0.12-14.22 ¹	1609	1.75	0.0009-28.60	0.26-14.22	-2.31*
	<0.0009-28.6	0.26-14.22	731	1.39			
	<0.0009-28.6	0.26-14.22	365	1.26			
Chromium	0.142-137.203	0.34-1205.00	1609	0.77	0.975-23.6	0.86-47.4	0.63
	0.142-137.203	0.80-1205.00	731	0.88			
	0.142-137.203	0.80-1205.00	365	1.05			
Copper	8.80-156.00	0.85-205.92	1609	-3.74*	31.1-156.0	1.06-31.80	-6.80*
Lead	<0.003-5.700	0.10-141.0	1609	1.13	0.9-4.8	0.1-26.6	0.87
	<0.003-5.700	0.10-141.0	731	1.35			
	<0.003-5.700	0.10-141.0	365	1.54			
Mercury	<0.009-0.665	0.05-11.26	1609	2.69*	0.009-0.542	0.05-11.76	2.82*
Nickel	4.0-420.0	0.05-255.69 ¹	1609	0.74	8.0-420.0	6.12-118.7 ¹	1.36
	4.0-420.0	2.69-255.69	731	0.46			
	4.0-420.0	2.69-255.69	365	0.19			
Vanadium	0.58-16.30	0.10 All Values ¹			2.02-16.30		
Zinc	43.2-27,879.7	17.0-4,000.0 ¹	1609	0.99	77.2-3570.0	17.0-570.0 ¹	1.15
	43.2-27,879.7	17.0-4,000.0	731	0.76			
	43.2-27,879.7	17.0-4,000.0	365	0.54			

*Significant at $\alpha = 0.05$.

¹Post-Drilling values generally less than Pre-Drilling values.

Table 1-78. Trace Metals in Polychaetes t-Test for Group Means of Pre- and Post-Drilling Data
(From Mariani et al., 1980)

Trace Metals	Range of Concentrations (µg/g)		Distance from Well Site for Post-Drilling Data (Meters)	t-Value	Range of Concentrations (µg/g) for Southern Quadrants		Comparison of Southern Quadrants Pre- and Post-Drilling Data t-Value
	Pre-Drilling	Post-Drilling			Pre-Drilling	Post-Drilling	
Arsenic	0.26-2.1	0.10-1.21 ¹	1609	1.78	0.26-1.70	0.10-1.21 ¹	0.53
	0.26-2.1	0.10-1.20	731	1.43			
	0.26-2.1	0.10-1.15	365	1.35			
Barium	<1.0-73.35	0.30-476.4	1609	2.41*	<1.0-73.35	0.3-476.4	1.75
Cadmium	0.23-5.579	0.31-16.18	1609	0.77	0.23-4.27	0.38-16.18	0.85
	0.23-5.579	0.31-16.18	731	1.08			
	0.23-5.579	0.31-16.18	365	0.95			
Chromium	<0.01-0.65	0.40-69.7	1609	3.82*	<0.01-0.56	0.40-69.7	2.88*
Copper	1.75-24.1	0.14-23.36 ¹	1609	-2.66*	1.75-24.1	0.08-6.01 ¹	-3.74*
Lead	<0.003-52.0	0.10-17.50 ¹	1609	1.66	<0.003-24.6	0.10-17.5 ¹	0.05
	<0.003-52.0	0.10-17.50	731	1.32			
	<0.003-52.0	0.10-17.50	365	1.11			
Mercury	<0.009-0.39	0.05-1.88	1609	4.34*	<0.009-0.390	0.05-1.88	1.99
Nickel	1.7-746.0	0.54-97.29 ¹	1609	1.97	1.7-746.0	0.89-97.29 ¹	1.13
	1.7-746.0	0.54-97.29	731	1.61			
	1.7-746.0	0.54-97.29	365	1.13			
Vanadium	<1.0-8.5	0.10-23.84	1609	3.26*	1.1-7.3	0.10-23.84	1.80
Zinc	64.19-802.0	13.0-1681.0	1609	1.84	64.19-802.2	184.0-1681.0	1.35
	64.19-802.0	13.0-1681.0	731	1.57			
	64.19-802.0	13.0-1681.0	365	1.43			

*Significant at $\alpha = 0.05$

¹Post-Drilling values generally less than Pre-Drilling values.

Table 1-79. Trace Metals in Brittle Stars t-Test for Group Means of Pre- and Post-Drilling Data
(From Mariani et al., 1980)

Trace Metals	Range of Concentrations (µg/g)		Distance from Well- Site for Post-Drill- ing Data (Meters)	t-Value	Range of Concentrations (µg/g) for Southern Quadrants		Comparison of Southern Quadrants Pre- and Post- Drilling Data t-Value
	Pre-Drilling	Post-Drilling			Pre-Drilling	Post-Drilling	
Arsenic	0.65-2.10	0.10-1.90 ¹	1609	1.07	0.96-2.10	0.10-1.65 ¹	1.82
	0.65-2.10	0.79-1.90	731	0.98			
	0.65-2.10	0.79-1.90	365	0.55			
Barium	0.71-2.44	57.0-5125.0	1609	1.95	0.95-2.44	57.0-791.0	4.08*
	0.95-2.44	57.0-791.0	731	5.89*			
Cadmium	<0.0009-0.319	0.16-19.59	1609	2.01*	0.0009-0.319	0.16-8.92	1.72
Chromium	0.23-7.69	0.14-0.45 ¹	1609	1.47	0.23-1.76	0.14-3.55	8.34
	0.23-7.69	0.14-3.55	731	1.58			
	0.23-7.69	0.14-3.55	365	1.53			
Copper	0.65-8.70	0.14-7.43 ¹	1609	-2.63*	0.89-8.70	0.14-7.43 ¹	-1.85
Lead	<0.003-14.0	2.8-71.1	1609	3.55*	0.003-14.0	2.8-14.4	3.94*
Mercury	<0.0009-0.104	0.050-0.908	1609	3.15*	0.012-0.085	0.050-0.908	2.02*
Nickel	31.0-76.0	0.47-197.89 ¹	1609	-2.73*	31.0-76.0	0.47-163.48	-1.95
Vanadium	<0.01-1.79	0.10-7.48	1609	3.54*	0.20-1.79	0.10-6.54	3.73*
Zinc	58.0-579.0	10.0-346.0 ¹	1609	0.37	58.0-579.0	55.0-346.0 ¹	0.04
	58.0-579.0	55.0-346.0	731	0.74			
	58.0-579.0	55.0-346.0	365	0.88			

*Significant at $\alpha = 0.05$.

¹Post-Drilling values generally less than Pre-Drilling values.

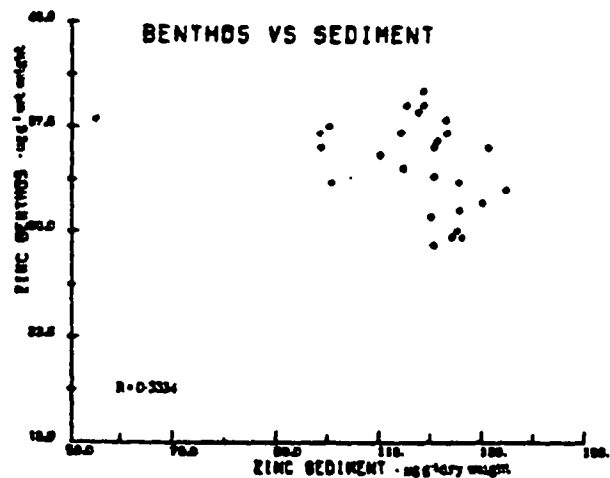
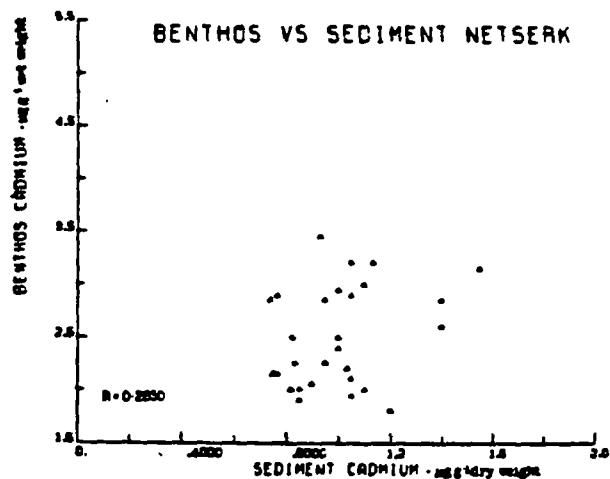
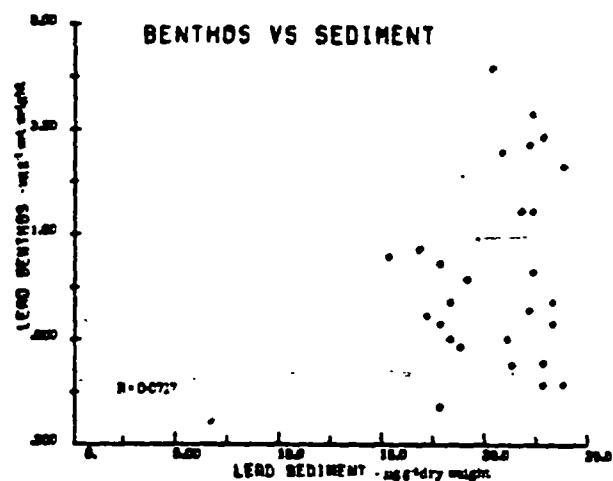
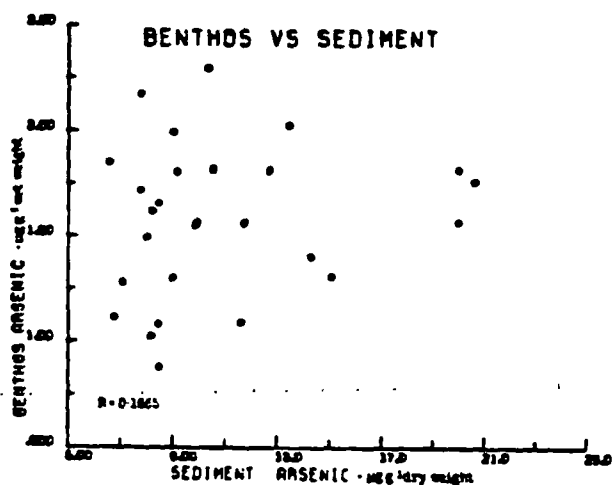
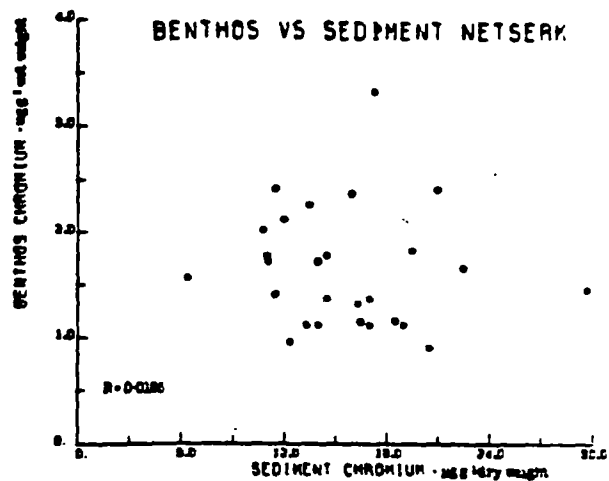
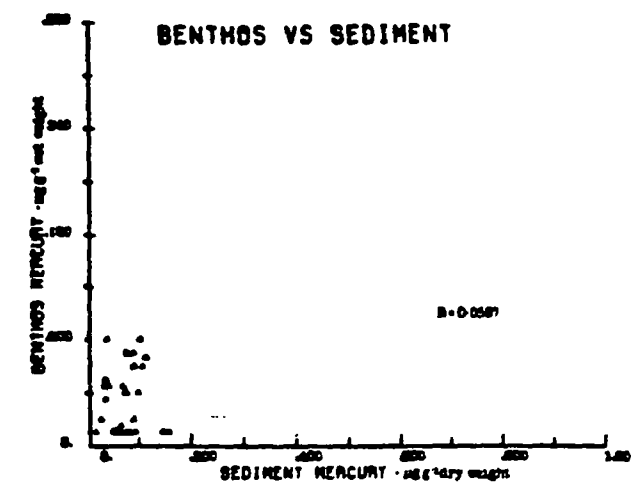


Figure 1-24. Comparison of Metal Concentrations in Benthos and in Sediments at Netserk F-40*

*From Crippen et al. (1980).

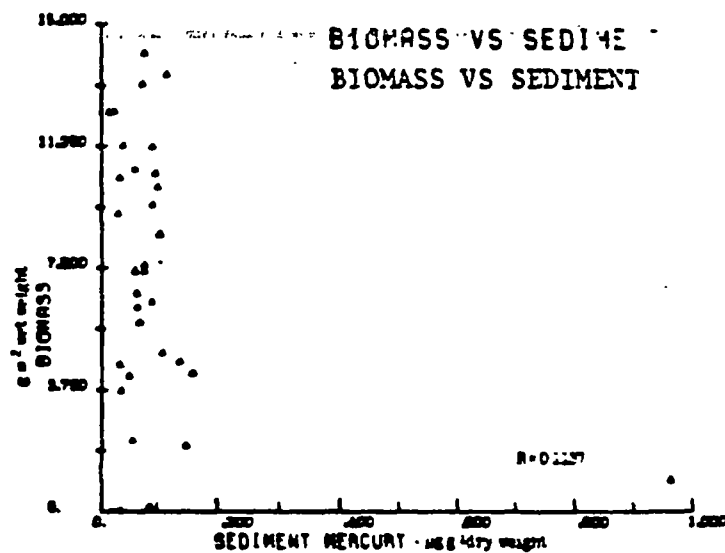
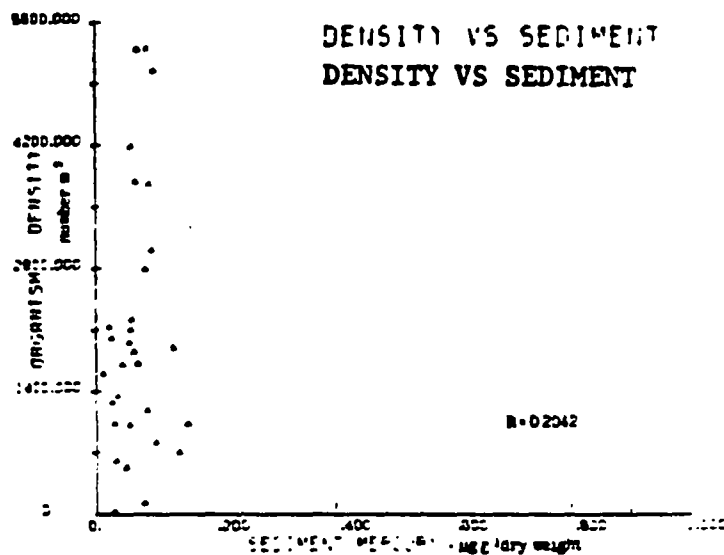


Figure 1-25. Comparison of Mercury Concentrations in Sediments with Benthic Density and Biomass at Netserk F-40*

*From Crippen et al. (1980).

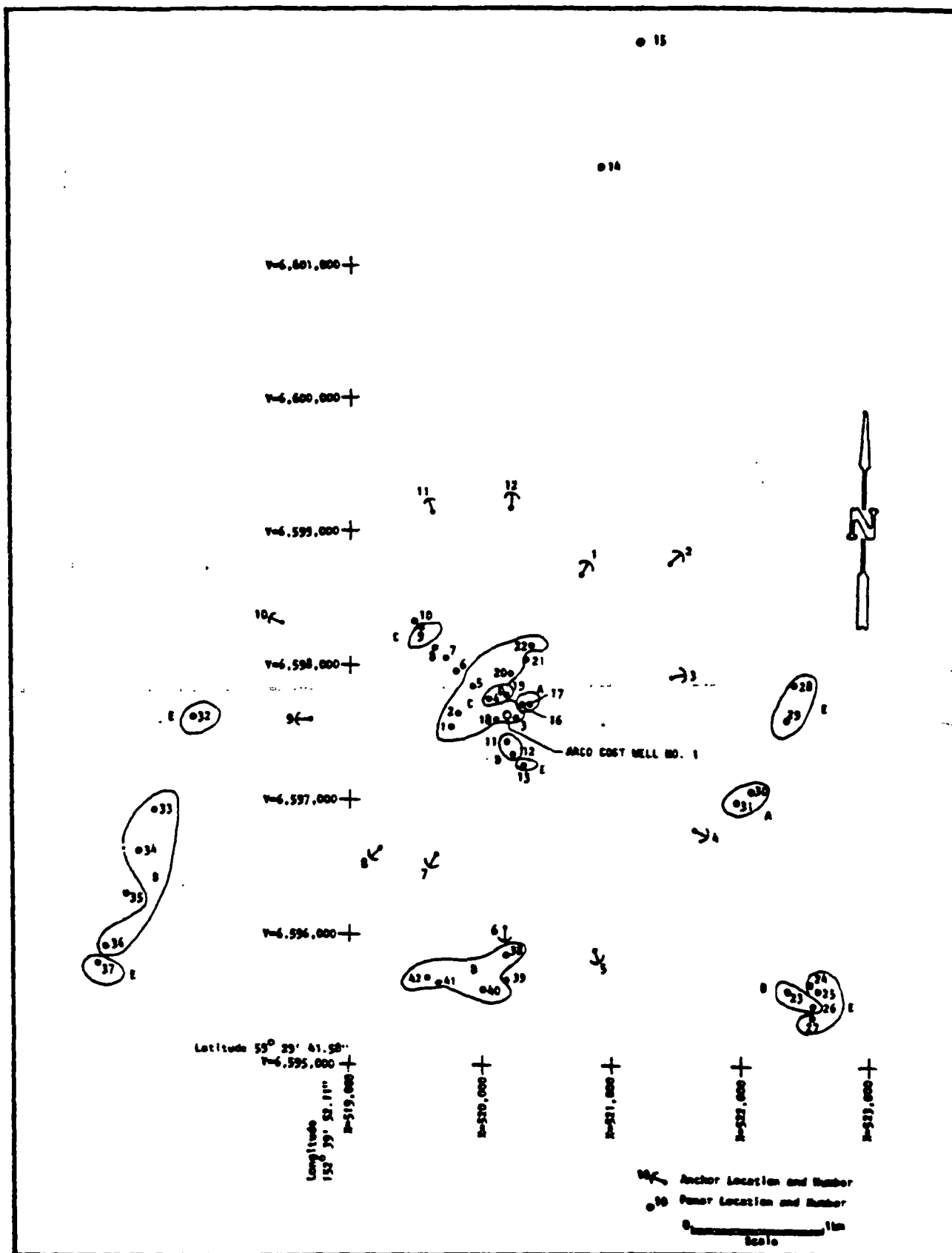


Figure 1-26. Location of Benthic Samples and Geographic Grouping of Infaunal Samples from the June 1977 Survey*

*From Lees and Haughton (1980).

APPENDIX D.

**Summary of Cadmium and Mercury Content
in Generic Drilling Fluids**

Table 1. Mercury and Cadmium Analyses of
Alaskan Generic Drilling Muds (1983-1984)

<u>Location</u>	<u>Mud Type/Density (lb/gal)</u>	<u>Hg (mg/kg, dry wt.)</u>	<u>Cd (mg/kg, dry wt.)</u>
Gulf--Cross Island <u>1/</u>	Seawater lignosulfonate/13	0.102	1.36
Sohio--Mukluk Island <u>1/</u>	Seawater lignosulfonate/10	0.24	0.635
Shell--Seal Island <u>1/</u>	KCl/10.2	0.05	1.21
ARCO--Kenai Peninsula <u>2/</u> (onshore)	KCl/10 KCl/13	0.16 0.001	0.05 1.1

1 ~~End-of-well analyses conducted and reported in accordance with EPA~~
Region 10 NPDES permit requirements.

2 To EPA Region X

Table 2. Mid-Atlantic Generic Mud Program

<u>Mud Type</u>	<u>Cd (ppm)</u>	<u>Hg (ppm)</u>
Mud #1		
KCl Polymer Mud	1	6
Mud #2		
Seawater Lignosulfonate Mud	<1	<1
Mud #3		
Lime Mud	<1	<1
Mud #4		
Non-Dispersed Mud	<1	<1
Mud #5		
Seawater Spud Mud	<1	<1
Mud #6		
Seawater/Freshwater Gel Mud	<1	<1
Mud #7		
Lightly Treated Lignosulfonate Freshwater/Seawater Mud	<1	<1
Mud #8		
Lignosulfonate Freshwater Mud	<1	<1

Table 3. EPA PESA Generic Mud Program

<u>Generic Mud Number</u>	<u>Cd mg/kg</u>	<u>Hg mg/kg</u>
008-00	.365	.343
002	.471	.2639
007	.143	.1386
001	.22	.2606
005	.074	.0100
006	.0425	.2969
003	.378	.7530
004	.446	.4374

Table 4. Southern California Generic Muds Analysis*

<u>Drilling Mud Identification Code</u>	<u>Cd (mg/kg)</u>	<u>Hg (mg/kg)</u>
2 REV073	0.10	0.015
4 REV073	0.10	0.013

* Report from Pacific Environmental Laboratory to EPA Region IX, reported October 20, 1983.

APPENDIX E.
Cadmium Contents
in Non-Generic Drilling Fluids

Table 1. EPA Gulf of Mexico Non-Generic
Drilling Mud Program

Mud Identification Number	Cd (µg/g dry weight)	Hg (µg/g dry weight)
MIBLKA51	.387	N.D.
AN31-1-6	2.38	N.D.
MILGEL	.494	N.D.
SV76-2-5	1.62	N.D.
P1-1-3	1.85	N.D.
P2-1-3	11.8	N.D.
P3-1-3	2.10	N.D.
P4-1-3	8.27	N.D.
P5-1-3	2.34	N.D.
P6-1-2	10.5	N.D.
P7-1-2	.21	N.D.
P8-1-1	.410	N.D.

N.D. - Not Determined

APPENDIX F.

**Comments on Testimony of Dr. Jerry Neff
to EPA Region X on Proposed BPJ Permits**

Appendix F

Comments on Jerry Neff Testimony to Region X on Proposed BPJ General Permits

1. Metallic Impurities in Barite

In this section, on page 2, Neff discusses the difference between bedded deposits of barite and vein and cavity-filling deposits noting that bedded deposits are usually much purer than the vein and cavity-filled type. Concentrations of cadmium and mercury may vary by more than ten-fold depending on the source of the barite.

Because of this distinction Neff rightly notes that the bedded deposits, particularly those clean deposits from the Battle Mountain area of north-central Nevada, are the preferred source of barite for muds on the U.S. outer continental shelf.

In this section, Neff is verifying that there are "clean" and "contaminated" barite, and that (1) it is technologically feasible to limit the amount of cadmium and mercury discharged, and that (2) whatever hazard exists can be reduced in this manner.

2. Fate of Discharged Barite

In this section, Neff makes the statement that, "Barium concentrations may reach 10 to 20 times above background in sediments near the discharge." What he does not make clear is that this is true only for exploration. Although he notes several situations where barium concentrations have been found to be much higher than background, he does clearly state that during development barium concentrations can reach 100 times background or more.

3. Long-Term Accumulation of Cadmium and Mercury in Sediments

A) In the first paragraph of this section Neff states that ". . . drilling fluid solids average 60 percent barite by weight." This is not accurate. Barite might average 65 percent of all drilling

fluids, including both soluble and particulate additives by weight, but it is more likely to approximate 80 percent barite by weight of mud solids.

B) Neff goes on to predict that, "In the next ten years, if all the wells projected by MMS are drilled, 320,300 metric tons of drilling mud solids containing 192,180 metric tons of barite will be discharged. The discharged barite will contain 192 kilograms of cadmium and 95 kilograms of mercury." These concentration figures are calculated using low and/or unrealistic numbers. First, they are based on the 60 percent barite figure which we have previously discussed as being too low. Also, they are based on low estimations of the concentrations of cadmium and mercury in the barite. In fact, Neff uses values even lower than those proposed in the draft permits. Neff assumes an average of 1 ppm cadmium and 0.5 ppm mercury in barite by weight. Neff's Table 1 shows these figures to be on the low end of the spectrum, which averages approximately 3 ppm cadmium and 1.6 ppm mercury and has a maxima of 16 ppm cadmium and 13 ppm mercury. Using these figures to calculate the amount of cadmium and mercury discharged in the next ten years portrays a different scenario, as shown below:

<u>CADMIUM</u>				<u>MERCURY</u>			
	<u>minimum</u>	<u>average</u>	<u>maximum</u>		<u>minimum</u>	<u>average</u>	<u>maximum</u>
Assume				Assume			
60% barite	192 kg	576 kg	3072 kg	60% barite	96	307	2496
Assume				Assume			
80% barite	256	768	4096	80% barite	128	409	3328

C) In this section Neff goes on to compare the amounts of suspended solids discharged into coastal and outer continental shelf waters by rivers and by drilling operations. He states, "If the suspended sediments discharged by the rivers contain 1.0 ppm cadmium and 0.1 ppm mercury (Based on ambient levels in clean surficial sediments of the area Table 2), a total of 142 metric tons of cadmium and 14.2 metric tons of mercury will be introduced to coastal waters each year in river-borne particles."

There are a number of points confounding this observation. The first is that one cannot assume that marine sediment metal levels and river sediment levels are the same, which he does by using the figures from Table 2. Also, 5 out of 6 of the Alaskan sites mentioned in this Table are in the Beaufort Sea, which is a highly erosional area. Therefore, surficial sediments can be higher due to simple coastal erosion. The relative contribution of river inputs versus marine sediments in situ is unknown.

Neff also assumes that the river contribution to background levels is all natural. In most areas this cannot be assumed because rivers are often affected by man's activities. For instance, in many Alaskan and Canadian rivers, the effects of placer mining would be difficult to distinguish from natural background levels. Even if natural levels are high, it does not necessarily follow that no regulation is needed. It has been previously noted that mercury levels in whales taken as subsistence catch is already high. This may well be due to natural causes. However, this finding could be interpreted as making a reduction in any anthropogenic sources of metal pollutants even more necessary precisely because of high natural inputs.

Finally, EPA Effluent Guidelines Regulations are based on technologic feasibility and not on the basis of industrial versus "natural" sources of pollution. This is particularly relevant considering that it is difficult to determine "natural" background levels.

4. Mobilization of Cadmium and Mercury from Barite

In this section Neff notes that, "In seawater equilibrated with high trace metal vein barite, the concentration of soluble mercury was significantly higher than open ocean concentrations. Addition of bentonite clay (a normal ingredient of drilling muds) reduced aqueous mercury concentrations to below oceanic levels." What is happening in this situation is that with the addition of bentonite clay, the metals are re-distributing to the sediment with the clay.

Neff further notes here that ". . . a maximum of 4 percent of the cadmium and 0.4 percent of the mercury originally present in the barite

was solubilized in 12 days." This statement is confusing because later in the section he refers to an Espy Houston and Associates study by saying, "These studies show that cadmium sulfide and mercuric sulfide associated with barite are not readily solubilized." The confusion may be in the definition of the term readily; however, referring to the previous 12-day estimate, this seems to be a short amount of time when compared to the time the metals will stay in the system.

In the last paragraph of this section Neff furthers his contention that the leaching rate of cadmium and mercury in sediment is so slow as to preclude biological damage. Although it is certainly true that solids reduce the uptake of these metals, they certainly do not prevent it and not enough to conclude a preclusion of biological damage. To illustrate this point we consider Hardy et al's study of "Marine Sediment and Interstitial Water." Figure 3 of this study shows the accumulation of cadmium by gills of the Clam Protothaca staminea to be reduced by the addition of sediment. However, even in this case, with an addition of washed sediment bringing the sediment:cadmium ratio to 100,000:1 accumulation is reduced by only 80%.

The evidence cited in this section supports EPA's efforts to regulate barite discharges since there are data that support a potential for environmental impacts.

5. Bioavailability of Cadmium and Mercury from Barite

In this section Neff cites Gerber et al (1981) on accumulation of cadmium by sand shrimp and mussels, Tornberg et al (1980) on accumulation of cadmium, chromium, lead and zinc by amphipods, Crippen et al (1980) and Tillery and Thomas (1980) on metal concentrations in sediments and biota, and Mariani et al (1980) on concentrations of metals in sediments and benthic invertebrates. For an alternate interpretation of this data see Petrazzuolo (1981, 1983) (See also Appendix A). It should also be noted that Espy Houston and Associates, Inc. (1981) which Neff cites in the beginning of this section, has not been published.

6. In conclusion, in light of limited lab and field data showing accumulation (see Brannon and Rao, Table 1-55), to say there is "no hazard

whatever to the marine environment from cadmium and mercury present as insoluble sulfides in barite" is hasty and not supported by the data.

Neff has used lab studies that were limited or that used wrong test phases. He has used data from exploratory operations only; and in short, is not looking closely enough at the end-point of biological uptake, but is predicting effects on the basis of physical-chemical principles that are attractive in theory, but which are not supported by bioaccumulation data. The best example of this latter situation is Ba uptake from exposure to BaSO_4 , a notably "insoluble" material. Nonetheless, despite the low predictable uptake on the basis of physical-chemical data, high levels of Ba were found in hard and soft tissues of shrimp exposed to barite for three months (Brannon and Rao).

APPENDIX G.

**Trace Metal Content of
"Clean" and Contaminated Barite**

Table 2. Composition of barites used in solubility studies.*

	High trace metal sample	Low trace metal sample
Ni mg/kg	33	5.7
Cu mg/kg	91	7.6
Cd mg/kg	12	0.65
Co mg/kg	5.4	2.2
Zn mg/kg	2750	9.8
Pb mg/kg	1370	0.95
Hg mg/kg	8.1	0.13
As mg/kg	67	1.8
BaSO ₄ %	85.1	-
Sr mg/kg	-	540
LOI %	0.3	-
SiO ₂ %	6.2	8.2
MnO %	<.04	<.04
Fe ₂ O ₃ %	3.1	0.60
MgO %	1.3	<.1
CaO %	1.9	0.3
K ₂ O %	0.08	0.08

* frpm Kramer et al. 1980