NOAA Technical Memorandum NOS OCRM 4

US CRUISE REPORT FOR BIE II CRUISE 1

July 30 - September 9, 1993

R/V YUZHMORGEOLOGIYA

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Washington, D.C.
October 1993
National Oceanic and Atmospheric Administration

National Ocean Service

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Acknowledgements

The success of this cruise was in large part due to the contribution of the Russian scientists from the Yuzhmorgeologiya Institute. NOAA would especially like to thank Dr. Ivan Glumov for his continuing support for our countries joint Benthic Impact Experiment (BIE) program. Special thanks also are due to Mr. Vladimir Stoyanov for providing R/V YUZHMORGEOLOGIYA ship support for the BIE program. The BIE program would not have been possible without the use of this capable ship, superbly captained by Master Yury Sherin. I would personally like to thank my good friend and colleague Dr. Mikhail Pilipchuk, who has served as the Russian chief scientist on all the BIE cruises, His scientific and technical contributions to the BIE study have been invaluable. NOAA also wishes to thank Mr. Yuriy Mironov and Mr. Oleg Lyaskovskiy for their expert direction and skillful coordination of deck the operations. Special thanks also go to Mr. Evgeniy Shevelev who did an outstanding job directing the underwater navigation and to the navigation chief navigator who's crew did an outstanding job the maneuvering the ship even under difficult wind conditions. Finally, NOAA wishes to thank Mr. Vyachesav Melnik for his exceptional contributions in helping conduct the box coring operations, and to the camera sled engineers for processing the hundreds of photographs we requested over the last 5 days of the cruise.

Introduction

In 1984 the National Academy of Sciences' recommended that a "small scale resuspension experiment" be conducted "to identify the biological parameters that record the impact of mining most reliably". Since this report was published the Ocean Minerals and Energy Division (OME) of NOAA has attempted to conduct just such an experiment. In 1990 OME developed an experimental strategy designated the Benthic Impact Experiment (BIE) in consultation with academic researchers. The BIE is designed to simulate the environmental effects of sediment resuspension by deep seabed mining operations and to assess the environmental impact of sediment redeposition on the deep -sea benthos. The ecological effects of sediment redeposition on the deep -sea benthos is hypothesized to be a consequence of sediment burial or food resource dilution. The BIE attempts to address the effects of these potential environmental problems before commercial mining commences on the abyssal plane. In the BIE concept, a large area of the deep-sea floor is blanketed with sediment in a manner simulating deep -sea manganese nodule mining activity. The response of the deep-sea benthic community to different levels of sediment burial is then monitored both spatially and temporally. The results of this research effort can then be used by NOAA to evaluate the terms, conditions and restrictions for commercial permitting by the deep seabed mining consortia so that mining can proceed in a environmentally sound manner.

OME made two attempts to initiate the BIE in 1991 and 1992, but was unsuccessful due to ship equipment problems (1991) and design problems with the first generation Deep Sea Sediment Resuspension System (DSSRS) (1992). In December 1992 OME conducted a through review of the original DSSRS design using Japanese and US engineers. The design review questioned a number of the conceptual ideas used to build the DSSRS and recommended that a second generation Deep Sea Sediment Re -suspension System (DSSRS -II or Disturber) be designed and built. Following this advice, OME chose Sound Ocean Systems, Inc. (SOSI) to design and build the DSSRS-II in close collaboration with Japanese engineers from Sumitomo Metal Mining Co.

who were funded by the Metal Mining Agency of Japan.

Cruise Goals and Objectives
The main goal of the 1993 BIE-II cruise was to create a sediment redeposition impact on the benthic community at the BIE study site located in the Pacific Ocean at 12° 56' N and 128° W. Our primary objectives on the 1993 BIE -II cruise were as follows:

- Establish a transponder net and collect baseline information on nodule coverage and megafaunal abundance from bottom photographs and side-scan sonar;
- Test five different pump configurations of the second generation Deep Sea Sediment Resuspension System (DSSRS-II) at the Patton Escarpment test site off Long Beach, California;
- Collect baseline box core samples;
- Recover two Russian current meters and deploy an array of two Aanderaa current meters and 18 sediments traps within the study area;
- Create a large -scale redeposition event by towing the Disturber through a 150-m-x-3000-m tow zone;
- Map the resedimentation plume using sediment-traps and CTD casts;
- Collect post-disturbance box core samples to assess short -term impacts on meiofauna and macrofauna;
- Deploy 4 current meter moorings to obtain long-term information about the deep ocean currents in the BIE-II study area.

The remainder of this cruise report details the results of each of these six objectives.

Cruise Summary

Experimental Site Groundwork
This portion of the BIE-II project was conducted under the leadership of Russian scientists aboard the R/V YUZHMORGEOLOGIYA. During this part of the experiment a transponder net was deployed and calibrated, two current meters were deployed, and detailed information about the topography in the BIE area was collected using Russian sidescan sonar (Fig. 1). In addition, photographic camera transects were made across the BIE-II site to assess manganese nodule coverage and to establish a baseline database of bottom features and megafauanal abundance and diversity (Fig. 2).

Test Cruise
The ship departed Long Beach, California at 1715 on 30 July 1993 arriving at the Santa Catalina Basin test site, 33° 10' N and 118° 30' W, four hours after leaving port. The Santa Catalina Basin was chosen as a test site for the Disturber because 1) the sediments there are very similar in grain size to those found at the BIE-II study site, and 2) the water depth is only 1000 m providing rapid vehicle deployments and recoveries. The purpose of the Disturber test tows was to decide which pump and nozzle configuration was optimal for resuspending the most sediment.

Figure 1. The position of side scan sonar transects conducted during July 1993.

SSS TOW SCHEME
BIE-II REGION

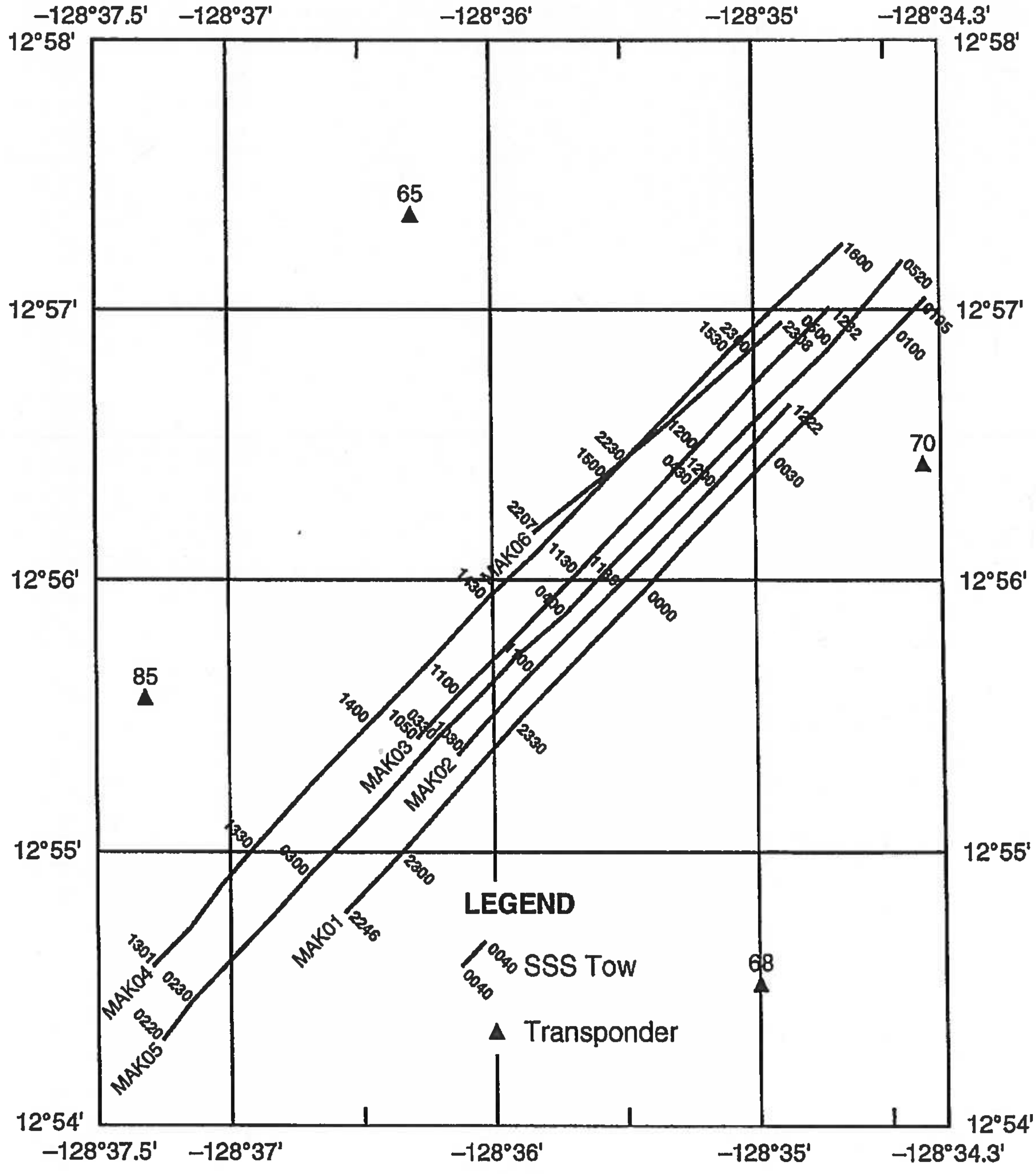

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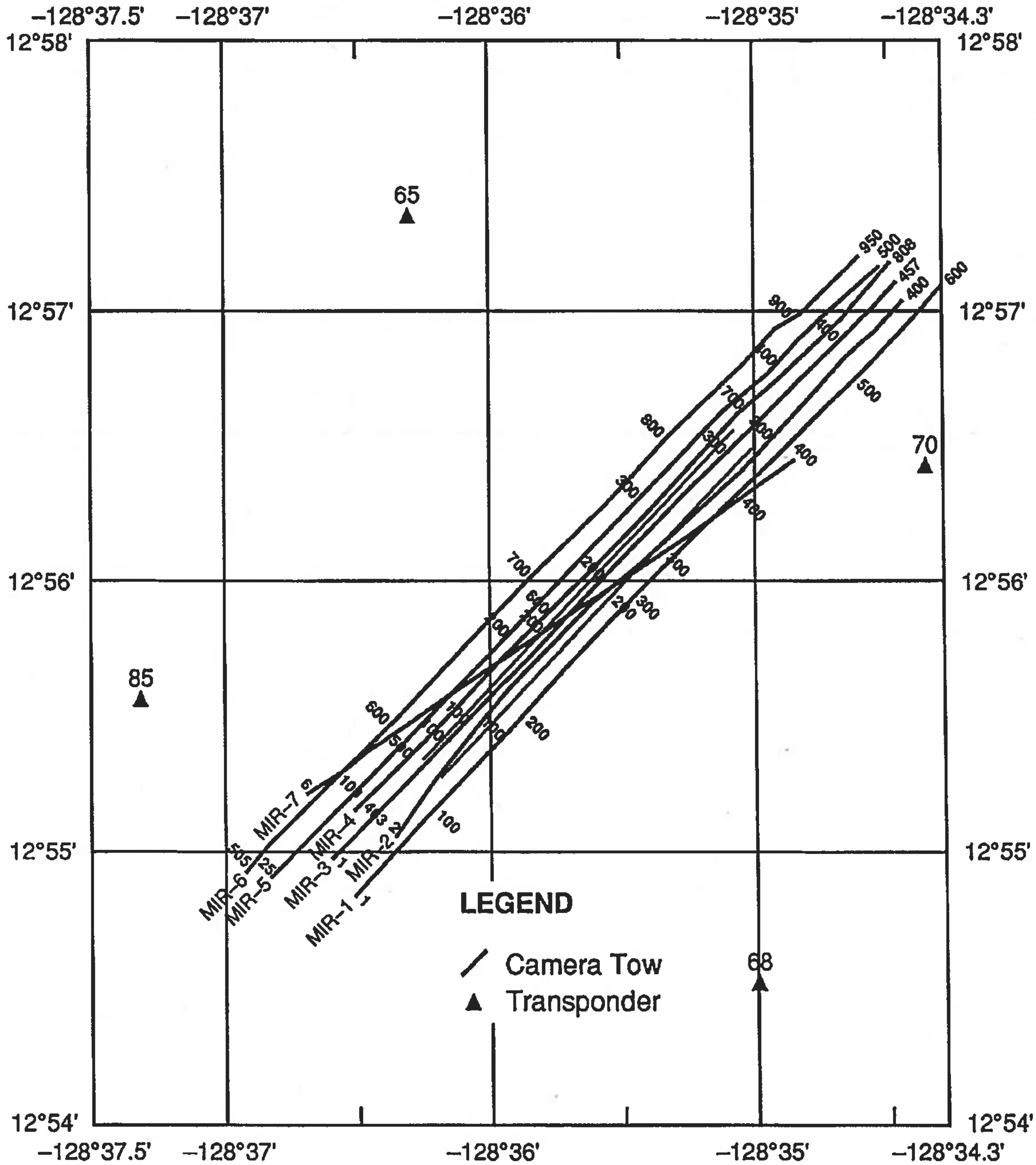
Figure 2. The position of photographic camera transects conducted during June 1993.

CAMERA TOWS
BIE-II REGION



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To determine the amount of sediment the Disturber was pumping using the different configurations, a rosette sampler, holding 12 1.7 -l Niskin bottles, was attached to the top of the Disturber's discharge pipe. The position of the rosette sampler on top of the discharge pipe put the sample bottles directly in the Disturber's discharge sediment plume. During each tow the 12 Niskin bottles were remotely tripped at 5 or 10 min intervals. After all twelve sample bottles were triggered, the Disturber was recovered and the samples processed to determine the amount of sediment being pumped. A detailed description of the Disturber as well as an overview of the BIE-II towing operation is presented in Appendix 1.

Three methods were used to measure the amount of sediment pumped by the Disturber. The first technique used for determining the amount of sediment in the rosette samples consisted of taking an optical backscatter (OBS) measurement from sediment slurry. The OBS is a miniature nephelometer that measures the scattering of infrared radiation by suspended particles. Since scattering is strongly affected by the number and size of particles, the OBS is calibrated with sediment from the field site. The second method consisted of taking a 50 -ml subsample of the collected sediment slurry which was then centrifuged for 5 min. After centrifugation, the volume (ml) of sediment in the bottom of the centrifuge tube was measured. The third method consisted of taking a 100-ml subsample sediment slurry and placing it into a 100-ml graduated cylinder. The subsample was allowed to settle for 2 h and the volume of the settled sediment then measured.

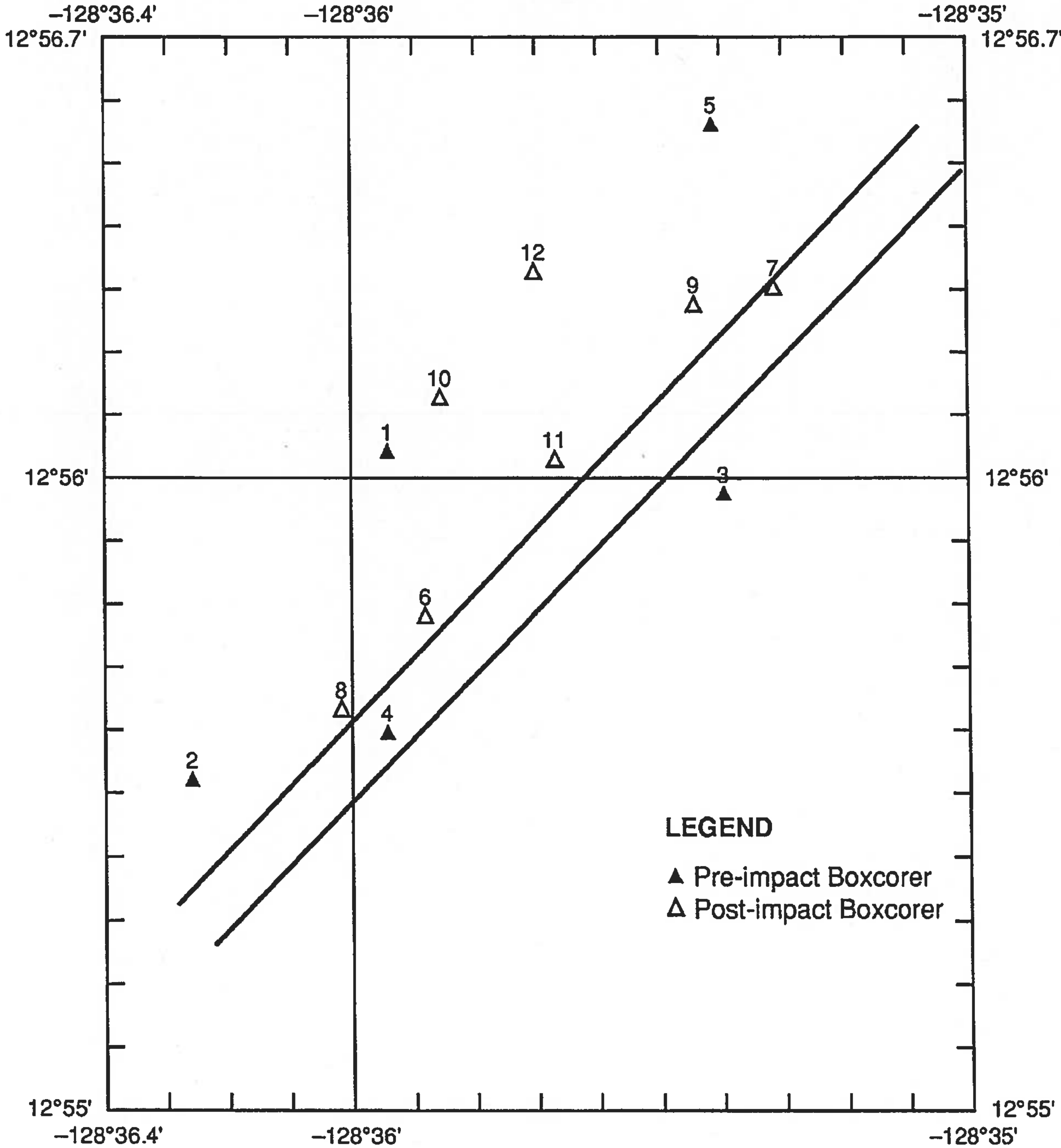
From 30 July thru 2 August we successful completed 11 Disturber tows (Table 1). The data indicates that the fourth configuration tried (Table 1, tows 10-11) consisting of the high pressure fluidizing pump, plugged horizontal nozzles on the fluidizing head, and the bell intake lowered as far as practical, yielded the greatest amount of pumped sediment. We found the centrifugation technique to be the fastest and most unbiased of the three techniques used to measure the amount of sediment in the subsamples. The OBS technique was discontinued after tow 9 because the OBS was not producing realistic sediment concentration values when compared with the centrifugation technique. Based on the results presented in Table 1 we determined that the optimal sediment pumping configuration for the Disturber was configuration 4. Therefore, configuration 4 was used to conduct the Disturber tows at the BIE-II study site.

Baseline Sampling

Before beginning the sediment disturbance portion of the BIE-II experiment, five 0.25 m^2 UNSELtype box cores were collected to serve as baseline samples. It should be noted that the five baseline samples collected for the BIE-II will be compared, and if possible combined, with the pre-impact samples collected from the BIE-I area which is only 14 nm east of the current study site.for the benthic community (Fig. 3). These samples were collected randomly from within a 1.7 nmi centered in the BIE study area. The box core samples were collected at night from 7-13 July. It took four deployments over three nights to obtain the first box core sample due to deployment problems with the new box corer. It was necessary to add weights to both legs of the box corer so that we could reach the bottom (4900 m) with the 5500 m of 9/16" wire. The placement of the weight created a problem with the box corer's "front" door which was being hit by the corer's base frame supports. We finally solved the problem by adding metal door stops that prevented the door from opening too far during deployment. It was also necessary to drill drain holes in the new box corer, drill a hole in the pull-pin so that the corer could be cocked, and

Figure 3. Location of the box core samples collected during the first cruise of BIE-II.

BOX CORES
BIE-II REGION



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MAIN PARALLEL 12° 30'

Table 1.Summary of the DSSRS-II test tow configuration results. The sediment volume for each rosette sample was determined by centrifuging for a 50-ml subsample for 5 min and then measuring the amount of compacted sediment in the bottom of each centrifuge tube. The Optical backscatter (OBS) data was determined by placing the sensor in the sediment suspension. *NOTE:* This table was corrupted in the original cruise report file and has been reconstructed as best as possible from the information present in the corrupted file.

Configuration	Sediment Volume (ml)	Settling Column (mm)	OBS (V)
1. Standard bell intake height, low Pressure fluidizing head, all nozzles open	2.0 +/- 0.7	8.2 +/- 3.4	1.4 +/- 0.7
2. Standard bell intake height, low pressure fluidizing head, horizontal nozzles plugged	3.0 +/- 1.0	12.9 +/- 4.8	2.1
3. Standard bell intake height, high pressure fluidizing head, horizontal nozzles plugged	3.3 +/- 0.7	14.4 +/- 4.9	2.0
4. Bell intake lowered 2”, high pressure Fluidizing head, horizontal nozzles plugged	5.4 +/- 1.8	24.4 +/- ??	Lost data
5. Bell intake lowered 2”, high pressure Fluidizing head, all nozzles open	3.2 +/- 0.3	13.2 +/- ??	Lost data

to cut out a portion of the box corers base to allow the dolly to be rolled under the corer's sample box. All baseline box core samples were subdivided into 25 10-cm subcores, hence forth referred to as vegematic samples. Apportionment for different analyses was done by dividing the 25 vegematic samples into two groups: the "inner 9" consisting of the central nine subcores of the box core sample, and an "outer 16" consisting of the cores from around the edge of the box core sample. One randomly chosen vegematic core from the "outer 16" group was used for sediment grain size analysis. Additionally, one randomly chosen vegematic sample from each of these two groups was used for meiofaunal community analysis. The meiofauna sample from the "inner 9" was sliced into six 0.5 cm layers samples that were preserved in 10% formalin for community diversity and abundance analysis; the sample from the "outer 16" was similarly sliced and then frozen for lipid analysis. All remaining vegematic samples were sliced into 0-2, 2-5, and 5-10 cm sections and preserved in 10% formalin for community diversity and abundance analysis. After 7 days in 10% formalin, the samples were rinsed with fresh water and transferred to 70% ethanol for long term storage.

Pre-disturbance Current Meter Recovery and Sediment Trap Deployment

On 7 August we successfully recovered the two Aanderaa type current meters that the Russians deployed on 9-10 July 1993. The current meter data from these two current meters indicated a northwesterly transport of water at speeds averaging 2 cm/s from 9-18 July. The currents then reversed flowing in a southeasterly direction from 19 July thru 5 August. This flow pattern is similar to that observed at the BIE-I study site eleven miles to the east. The changing flow direction affirmed the necessity of instrumenting both sides of the study area with sediment traps, current meters and transmissometers in order to determine the direction and extent of the Disturber's sediment plume.

On 7-9 August we deployed the sediment trap array in the study site (Fig. 4). The sediment traps consisted of 1-m long PVC cylinders with a cross-sectional area of 100 cm. Two replicate cylinders were mounted on each mooring using an aluminum frame having fins which served to orient the cylinders perpendicular to the flow. Each sediment trap mooring was designed so that the sediment traps were positioned 2 m above the sea floor. The sediment traps were arrayed symmetrically in three lines on each side of the tow zone. The first two lines of sediment traps, consisting of four sediment trap moorings each, were deployed with in 50 m on either side of the tow zone. The second two lines of sediment traps in the array, consisting of three sediment trap moorings each, were deployed 150 m on each side of the tow zone. The third two lines of sediment traps, consisting of two moorings each, were deployed 300 m from the tow zone.

Two of the moorings on the outer edge of the array (Fig. 4) had Aanderra current meters with Sea Tech transmissometers (25 cm path length) mounted on their tail fins deployed 2 m above the bottom in addition to sediment traps deployed 5 m above the bottom. A total of 18 sediment traps and 2 current meters with transmissometers were therefore arrayed in the BIE -II study area to ascertain the fate of the sediment re-deposited during the experiments genesis.

Creation of the Benthic Resedimentation Environmental Impact

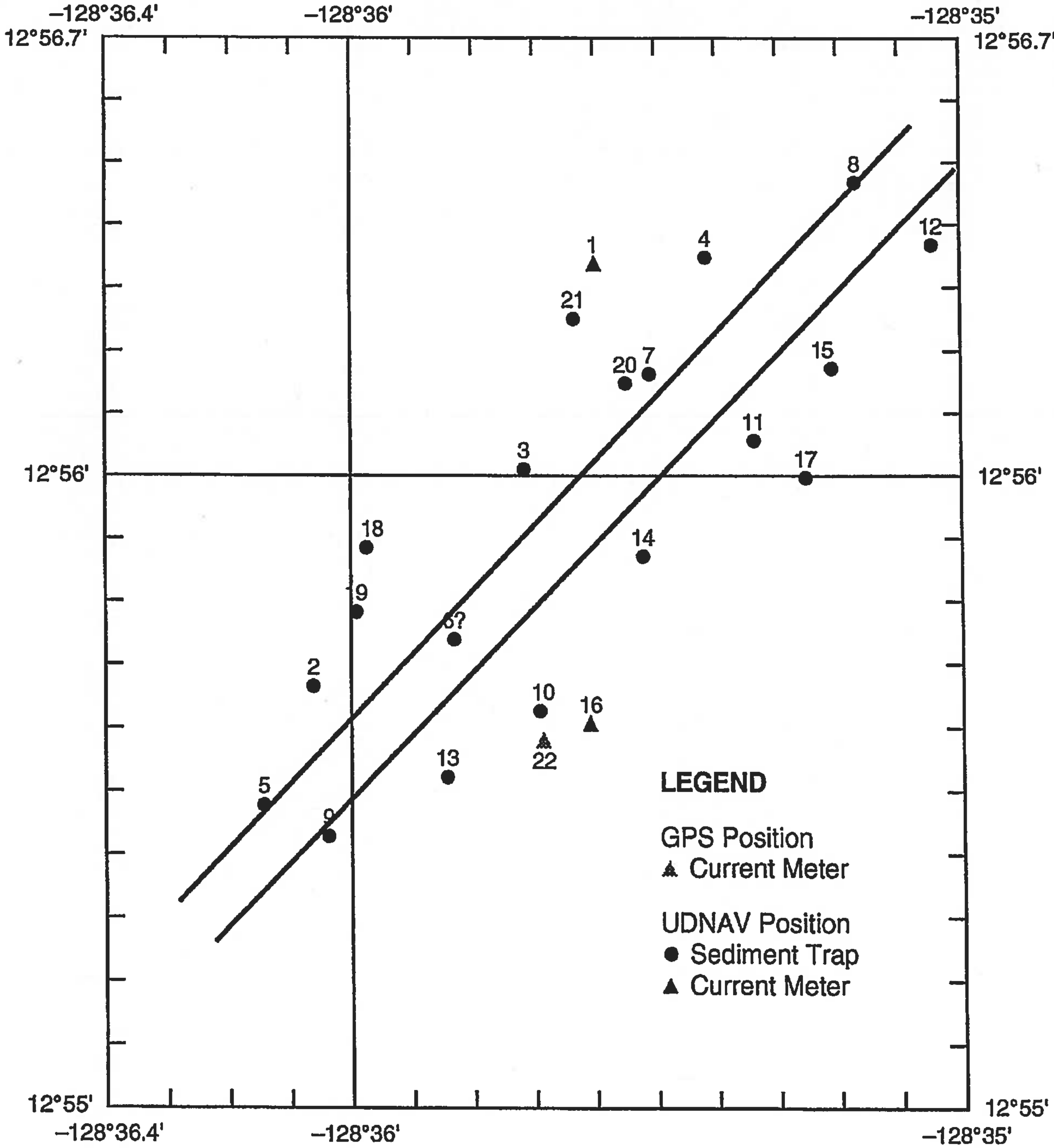
The main goal of the cruise was to create a sediment plume that would blanket a 2 km^2 area of the benthos immediately adjacent to the northeasterly oriented 150-m-x-3000-m tow zone. Our goal was to create a re-deposition area with a monotonic decrease in sediment thickness (10 to 1 mm) grading away from the tow zone. Based on last years cruise it was calculated that 50-60 Disturber tows should accomplish this task. Therefore, 19 days were scheduled for Disturber operations in order to achieve our goal of 50-60 tows. A detailed description of the Disturber as well as an overview of the BIE-II towing operation is presented in Appendix 1.

We began tow operations on 13 August on schedule. We were able to successfully tow the Disturber for 19 days completing a total of 49 tows (Fig. 5) and averaging 2.6 tows per day. Table 2 provides a summary of the data for each tow. Over the 49 tows we pumped a total of 4,888 mt of sediment, averaging 100 mt of sediment pumped per tow.

In order to assess how well the Disturber was dispersing the sediment being pumped during the towing operation, we recovered sediment trap moorings after completing tow 15 (Trap 6) and tow 29 (Traps 7, 11, and 16). Mooring 6 was recovered early because there was concern that it had landed with in the tow zone (Fig. 5). There was 1.1 ml of sediment in trap 6 after 15 tows (Table 3). After 29 tows, moorings 7, 11 and 16 were recovered. Moorings 7 and 11 were located north and south of the tow zone, respectively. Mooring 16 was located south of the tow zone having both sediment trap 16 and an Aanderra current meter on the mooring. There was 3.0 ml, 0.2 ml and 0.1 ml of sediment in these three traps, respectively (Table 3). The data clearly indicate that the majority of the sediment being pumped by the Disturber was going northwest of the tow zone. The current meter data confirmed that the currents were indeed moving in this direction and that only occasional turbidity signals were being observed south of

Figure 4. Location of the sediment trap and current meter array in the BIE-II study area.

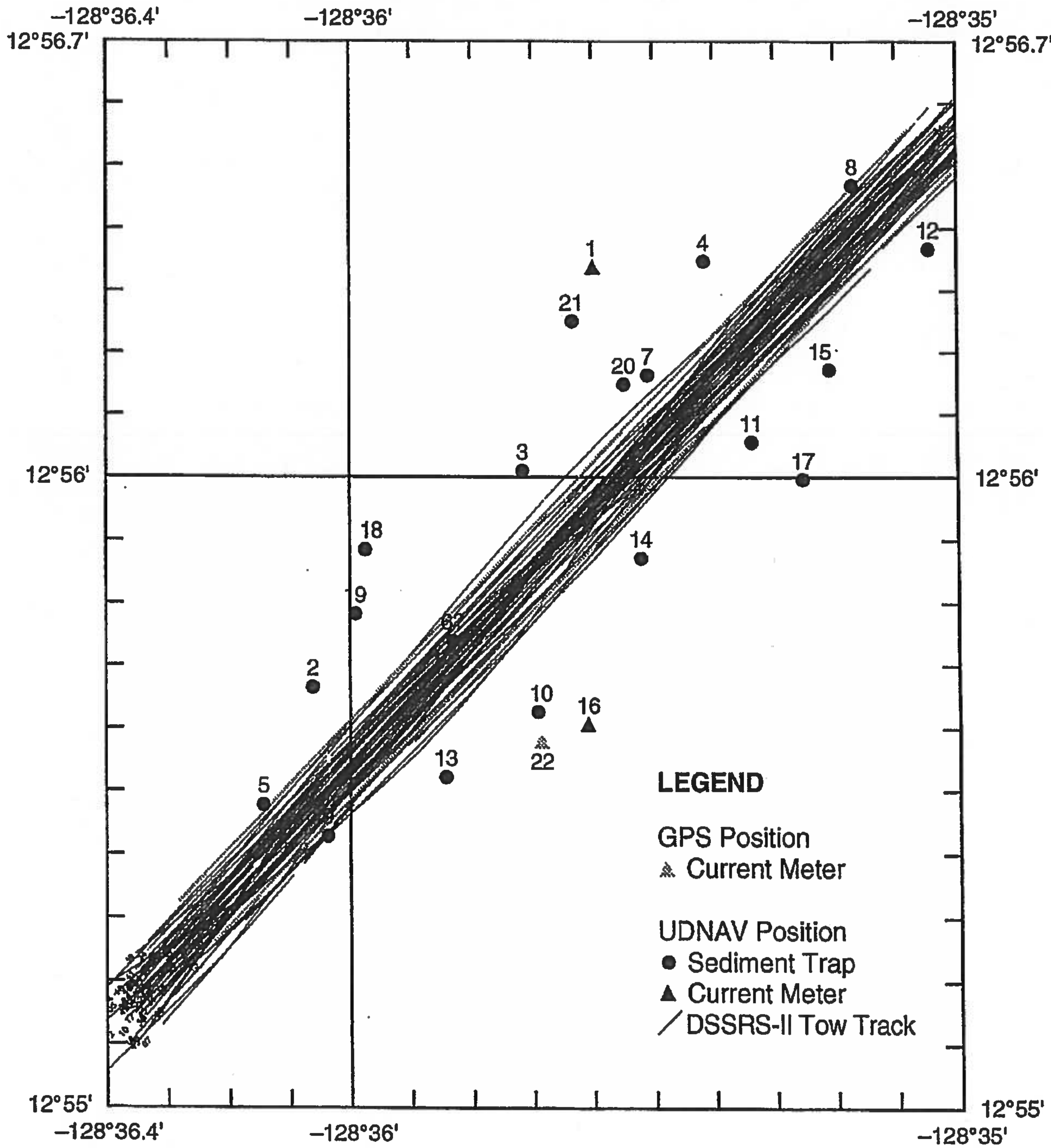
BIE-II SEDIMENT TRAP & CURRENT METER ARRAY
AUGUST 1993



S 1 : 10 000
MAIN PARALLEL 12° 30'

Figure 5. Location of the 49 Disturber tow tracks within the BIE-II tow zone.

DSSRS-II TOWS 1-49 IN BIE-II REGION
AUGUST 1993



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MAIN PARALLEL 12° 30'

Table 2. Summary of the DSSRS-II tows conducted at the BIE-II study site.

Date (UCT)	Tow #	Tow Starts	Tow Ends	Bottom Time (min)	Avg SOG* (Nmi/h)	Wet Grain Volume Pumped (m3)
14 August 1993	1	0729	0903	94	0.93	83.5+
14 August 1993	2	1648	1826	98	0.90	87.0+
15 August 1993	3	0407	0536	86	0.67	76.4+
15 August 1993	4	1503	1602	59	0.80	52.4
15 August 1993	5	2202	2336	94	1.06	83.5
16 August 1993	6	1831	2038	127	0.88	112.8
17 August 1993	7	0211	0358	97	0.99	86.1
17 August 1993	8	0957	1147	110	0.98	97.7
17 August 1993	9	1842	2036	114	0.95	101.2
18 August 1993	10	0214	0401	107	1.01	95.0
18 August 1993	11	1016	1050	34	0.76	30.2
18 August 1993	12	1701	1852	111	1.00	98.5
19 August 1993	13	0105	0237	92	1.14	81.7
19 August 1993	14	0825	1031	126	0.89	111.9
19 August 1993	15	1615	1803	108	1.00	95.9
20 August 1993	16	0006	0202	116	0.98	103.0
20 August 1993	17	0734	0940	126	0.89	111.9
20 August 1993	18	2112	2346	154	0.74	136.7
21 August 1993	19	0511	0702	111	1.01	98.5
21 August 1993	20	1315	1505	110	0.98	97.7
21 August 1993	21	2039	2231	112	0.97	99.4
22 August 1993	22	0409	0558	109	0.93	96.8
22 August 1993	23	1203	1346	103	1.05	91.4
22 August 1993	24	1942	2129	107	1.03	95.0
23 August 1993	25	0332	0532	120	0.93	106.5
23 August 1993	26	1131	1318	107	0.99	95.0
23 August 1993	27	1857	2050	113	0.98	100.3
24 August 1993	28	0234	0410	96	1.06	85.2
24 August 1993	29	0958	1130	92	1.15	81.7
25 August 1993	30	0729	0927	118	0.92	104.8+
25 August 1993	31	1619	1835	136	0.79	120.7+
26 August 1993	32	0108	0300	112	0.80	99.4
26 August 1993	33	0837	1012	95	1.13	84.3
26 August 1993	34	1608	1802	114	0.95	101.2
27 August 1993	35	0002	0139	97	1.09	86.1
27 August 1993	36	0736	0926	110	0.92	97.7
27 August 1993	37	1524	1700	96	1.03	85.2
28 August 1993	38	0059	0257	118	0.93	104.8+
28 August 1993	39	1122	1313	121	0.98	107.4
28 August 1993	40	1847	2033	106	1.04	94.1
29 August 1993	41	0218	0416	118	0.96	104.8

Table 2 (Cont.)

Date (UCT)	Tow #	Tow Starts	Tow Ends	Bottom Time (min)	Avg SOG* (Nmi/h)	Wet Grain Volume Pumped (m3)
29 August 1993	42	0946	1138	112	1.03	99.4
29 August 1993	43	1819	2018	119	0.92	105.7
30 August 1993	44	0144	0335	111	0.99	98.5
30 August 1993	45	0906	1111	125	0.92	111.0
30 August 1993	46	1719	1916	117	1.11	103.9
31 August 1993	47	0057	0242	105	1.03	93.2
31 August 1993	48	0815	1000	105	0.99	93.2
31 August 1993	49	1548	1747	119	0.94	105.7

* The grain volume of mud pumped was calculated as follows: (Min of Tow)(114 ml/l)(129.8 l/s)(60 s/min)(1 m)
+ Rosette samples were collected on this tow.

the tow zone (Fig. 6). All of the recovered traps were re-deployed and Disturber operations continued through 31 August.

The addition of a slow-scan video camera to the Disturber was a boon to the Disturber operations. When the video camera was pointed at the Disturber's discharge plume it was possible to observe the Disturber pumping sediment and to see if the rosette sampler, when installed, tripped properly. We were also able to mount the video camera on the front of the sled and observe the seafloor in front of the towed Disturber. This provided valuable information about the Disturber's previous tow tracks and about the behavior of the tow cable as the Disturber was being towed across the seafloor. Only one major electro-mechanical problem was encountered during the Disturber operations. This failure occurred following Disturber tow 5 at the BIE-II study site. A system failure occurred resulting in blown fuses in the surface interface junction box. After recovery, it was discovered that the sliprings in the swivel assembly connecting the cable to the Disturber had failed. The swivel was removed and the cable mechanically and electrically re-terminated to the Disturber . After disassembling the slipring swivel, it was found that a carbon -like material had built up inside the unit. There was significant scorch damage to the electrical components inside the swivel indicating sever arcing inside the assembly. Fortunately, it was not necessary to use the swivel assembly for the remainder of the cruise since we had no spare parts. The alternate method of cable termination worked very well and resulted in few cable hockles or electrical problems. A minor problem encountered in the Disturber operations was the failure of the optical backscatter sensors (OBS). Both sensors failed, the first after tow 7 and the second after tow 30. An alternative remote sensor is needed for estimating on a continuous bases the amount of sediment being pumped by the Disturber. It is clear that the OBS does not provide a realistic estimate of the amount of sediment being pumped by the Disturber based on the comparison of the OBS sediment concentration estimates with the rosette sample sediment concentration estimates (Table 1). Overall the Disturber tow operations were successful. The Disturber was able to lift sediment

Table 3. Summary of BIE-II sediment trap data. NOTE: This table was reconstructed from the original data.

Trap #	Position**	Deployment Distance and direction	Content (ml)***	# of Tows
1	12° 56.26'N, 128° 35.64'W**	300 North	1.6	49
2	12° 55.66'N, 128° 36.06'W	150 North	1.8	49
3	12° 56.01'N, 128° 35.71'W	150 North	2.5	49
4	12° 56.35'N, 128° 35.41'W	150 North	1.8	49
5	12° 55.47'N, 128° 36.14'W	<50 North	4.3	49
6	12° 55.79'N, 128° 35.90'W**	<50 North	1.1	15
7	12° 56.16'N, 128° 35.50'W	<50 North	3.0	27
8	12° 56.47'N, 128° 35.16'W	<50 North	4.8	49
9	12° 55.42'N, 128° 36.04'W	<50 South	2.5	49
10	12° 55.62'N, 128° 35.69'W	<50 South	2.0	49
11	12° 56.05'N, 128° 35.33'W	<50 South	0.1	29
12	12° 56.37'N, 128° 35.04'W	<50 South	0.2	49
13	12° 56.52'N, 128° 35.84'W	150 South	1.3	49
14	12° 55.87'N, 128° 35.52'W	150 South	0.1	49
15	12° 56.17'N, 128° 35.20'W	150 South	0.1	49
16*	12° 55.61'N, 128° 35.69'W**	500 South	0.1	27
17	12° 56.00'N, 128° 35.25'W	500 South	0.1	49
18	12° 55.88'N, 128° 35.97'W	500 North	2.0	49
19	12° 55.79'N, 128° 35.90'W**	<50 North	2.3	34
20	12° 56.15'N, 128° 35.54'W	<50 North	1.8	22
21	12° 56.25'N, 128° 35.62'W	150 North	1.8	22
22*	12° 55.58'N, 128° 35.68'W**	300 South	Trace	22

* Sediment trap was mounted on current meter mooring at 5 m above the sea floor.
** GPS drop positions were approximately the same distance from the tow zone (Fig. 5).
*** Average of two replicate sediment traps on the same mooring.

and disperse it into the experimental area of the BIE study site in sufficient quantities to generate a far-field impact similar to what would occur during seabed mining operations.

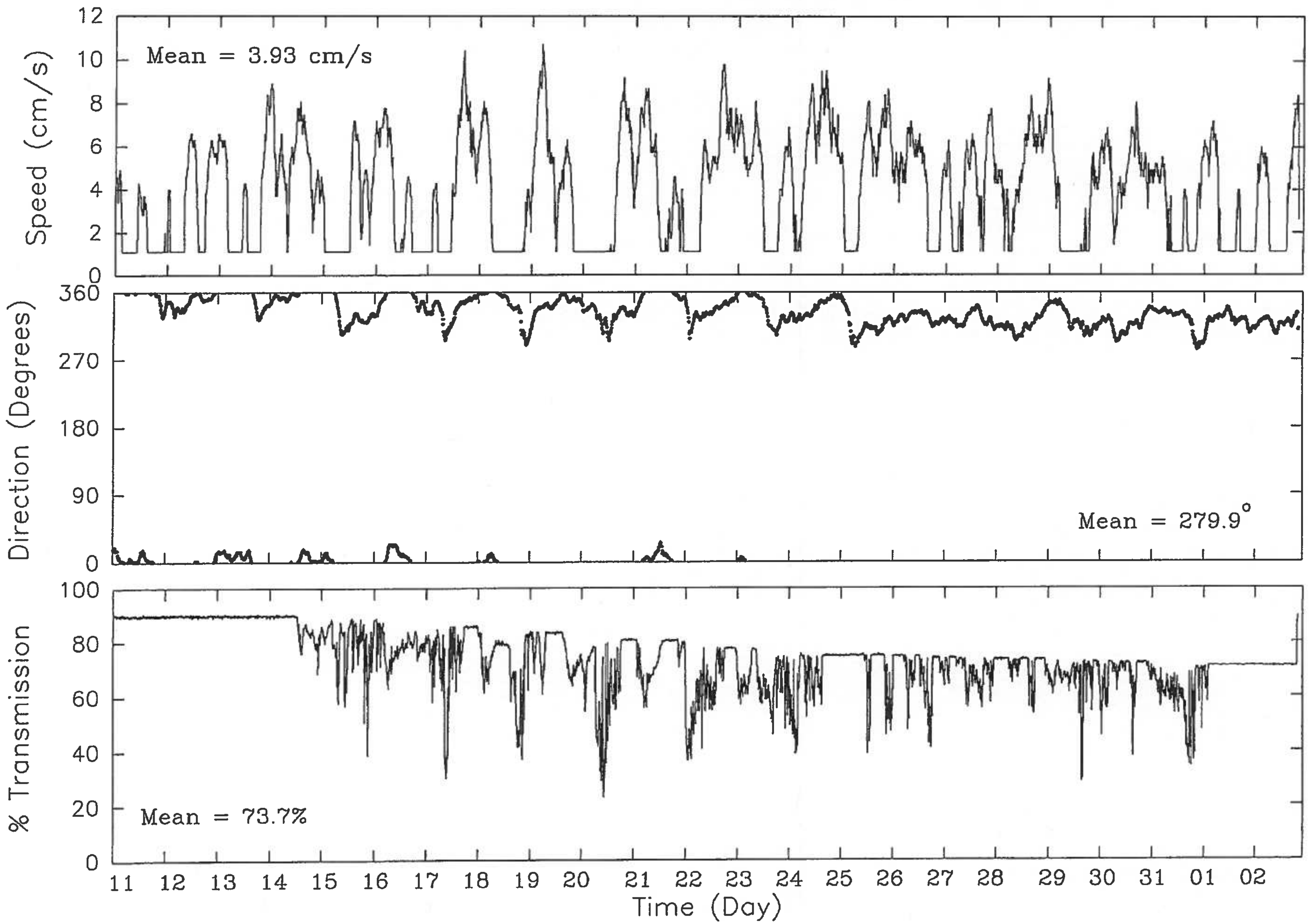
Mapping the Redeposition Sediment Plume

Three techniques were used to map the sediment plume created by the Disturber: CTD casts, sediment traps, and radionuclide analysis of sediment cores. A CTD cast was done after tow 49 by the Russian scientists along a south-to-north transect (Fig. 7). The CTD transect indicated that the sediment plume was being transported north of the tow zone. A very faint sediment plume was detected within 5 m of the bottom at the last three stations of the CTD transect. It is likely that since there was 6 hours between the end of the last tow and the beginning of the CTD transect that the plume had moved out of the study area. The time delay between the end of the Disturber tow and the start of the CTD transect was unavoidable since the Disturber had to be recovered (2 h) before the CTD transect could begin. A much better way of mapping the extent

Figure 6. Current meter data from Mooring 16 in the BIE-II study area. A. Current velocity (cm/s). B. Current direction (degrees). C. Current turbidity (% transmission).

BIE-II Current Meter Data From NOAA-21

11 August 1993 to 2 September 1993



of the Disturber's sediment plume using a CTD would be to have a second ship execute the CTD operation.

Between 1 and 2 September we recovered all 18 sediment trap moorings. A detailed description of the sediment trap processing protocol in provided in Appendix 2. The amount of sediment recovered from traps deployed for 18 days ranged from 0.1 ml to 4.8 ml of sediment (Table 3). Because the gravimetric analysis of the sediments from the traps is completed, deposition thicknesses can't be calculated. However, there is definitely an order of magnitude more sediment material deposited in the traps north of the tow zone than to the south of the tow zone (Table 3). Additionally, the current meter on the northern side of the study area recorded distinct peaks in the transmissometer signal at 4-6 h lags following the time of each tow (Fig. 8). Results from the radionuclide analyses will not be available until the end of the December 1993 when a more detailed map of the deposition environment at the BIE study site will be made.

Post-disturbance Meio- and Macrofaunal Sampling

Sediment samples were collected from 7 box cores to assess the short-term effect of sediment redeposition on the meio- and macrofaunal communities (Fig. 3). The samples collected following the towing operation were all collected north of the tow zone since this is where the majority of the sediment was deposited. The location of these samples was determined randomly, but from within predetermined zones distances from the tow zone. Three box cores were randomly collected north of the tow zone along a line that was parallel and 50 m from the tow zone; likewise two box cores were randomly collected along parallel lines 100 and 300 m north of the tow zone, respectively.

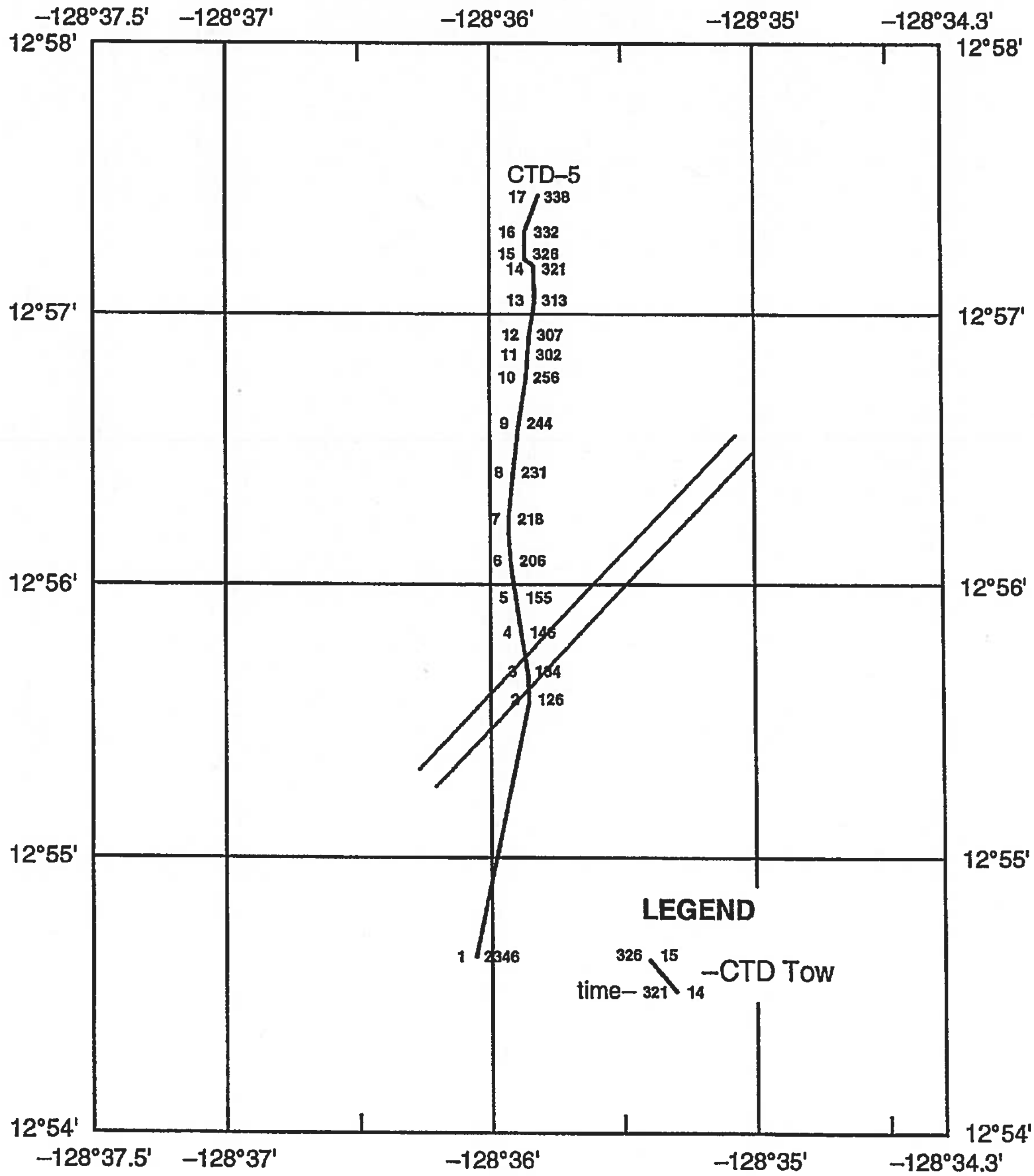
The post-impact box core samples were sub-sampled and processed as outlined above in section C with one exception. An additional vegematic core from the "inner 9" subcores of each box was saved for analysis. This was done by saving the top 2 cm fraction of the vegematic core in a plastic ziploc bag. No preservatives were used on this sample. It was shipped "as is" to the subcontractor conducting the analysis. The 2-5 and 5-10-cm fractions were preserved for macrofaunal analysis as outlined above in section C. The results of these analyses will not be available for another year.

Post-impact Current Meter Deployments

On 4 September four current meter moorings were deployed in the immediate vicinity of the BIE-II study site in order to get a better assessment of the deep ocean current regime in this area. Two Russian and two US current meters were deployed on four moorings (Table 4). Current meters were deployed on the four moorings so that the current regime between 5 and 1000 m above the seafloor could be characterized. These moorings will be deployed for approximately 10 months and their data will be used to model the flow over the topography in the BIE -II region.

Figure 7. Conductivity, temperature and depth transect through the BIE-II study area following 49 Disturber tows.

CTD DEPLOYMENT SCHEME
BIE-II REGION

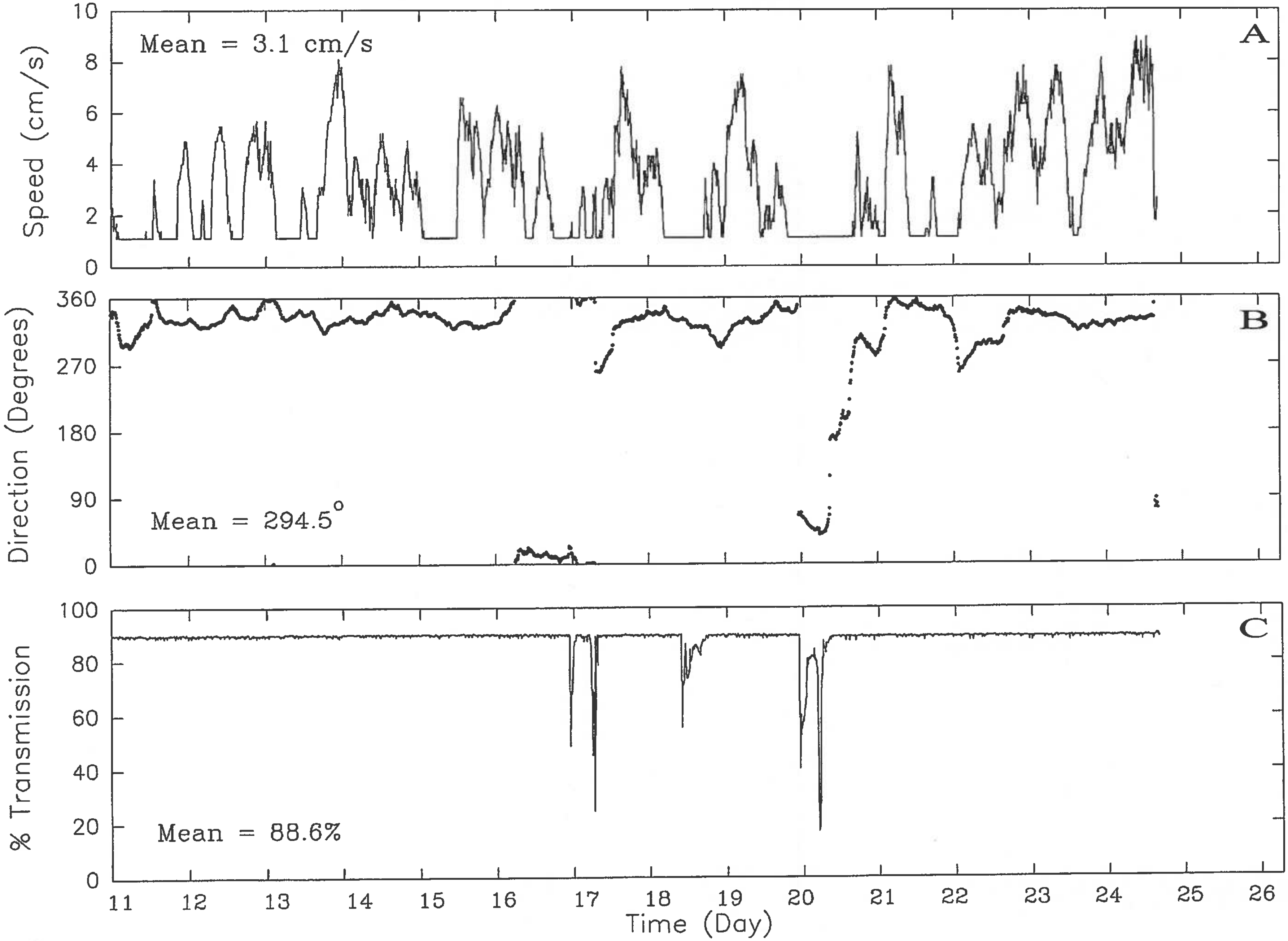


S 1 : 25 000

Figure 8. Current meter data from mooring 1 in the BIE-II study area. A. Current velocity (cm/s). B. Current direction (degrees). C. Current turbidity (% transmission).

BIE-II Current Meter Data From NOAA-22

11 August 1993 to 25 August 1993



Conclusions

The 1993 BIE-II cruise was very successful. We were able to generate a sediment redeposition impact in the BIE-II study site using the second generation Disturber. We were also to determine in which direction the sediment plume traveled. The depth of sediment deposition in the impacted area remains to be determined.

The box coring, sediment trap and current meter deployments and recoveries were all successful and will provide insightful data regarding the environmental impacts of sediment redeposition from deep seabed mining. I have nothing but the highest regard for the US and Russian crews. Everyone worked hard and at a consistently professional level throughout the entire cruise. I wish every cruise could go as smoothly as this one did!!

Table 4. BIE-II current meter deployment scheme.

Mooring #	Latitude (N)	Longitude (W)	Water Depth (m)	Height Above Bottom (m)
1*	12° 56.34'	128° 35.59'	4892	
2	12° 55.66'	128° 36.06'	4843	
3	12° 56.01'	128° 35.71'	4851	
4	12° 56.35'	128° 35.41'	4860	
5	12° 55.47'	128° 36.14'	4858	
6	12° 55.74'	128° 35.83'	4897	
7	12° 56.16'	128° 35.50'	4868	
8	12° 56.47'	128° 35.16'	4859	
9	12° 55.42'	128° 36.04'	4856	
10	12° 55.62'	128° 35.69'	4906	
11	12° 56.05'	128° 35.33'	4869	
12	12° 56.37'	128° 35.04'	4858	
13	12° 55.52'	128° 35.84'	4870	
14	12° 55.87'	128° 35.52'	4837	
15	12° 56.17'	128° 35.20'	4833	
16**	12° 55.60'	128° 35.61'	4907	
17	12° 56.00'	128° 35.25'	4864	
18	12° 55.88'	128° 35.97'	4842	
19	12° 55.79'	128° 55.79'	4882	
20	12° 56.15'	128° 35.54'	4852	
21	12° 56.25'	128° 35.62'	4852	
22*	12° 55.58'	128° 35.68'	4906	

*Russian meter, Potok-2, Vector averaging.

**NOAA, Ocean Minerals and Energy, Aanderra meter

Appendix 1

BIE-II DEEP SEA SEDIMENT RESUSPENSION SYSTEM REPORT

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Summary

The Disturber portion of the 1993 Benthic Impact Experiment (BIE-II) was highly successful. Prior to departure to the actual BIE-II site, a shallow water test was conducted in water depths of approximately 1,000 meters. The purpose of the test was to determine the optimum Disturber configuration and component height adjustments necessary to maximize sediment throughput. During this test, twelve tows were conducted utilizing three basic Disturber configurations. It was found that the high pressure fluidizing pump with sixteen active nozzles was the best configuration. The most productive height of the fluidizing header was found to be 4-1/2 inches which positioned the vertically oriented nozzles about 3 inches above the base of the sled runners. The optimum height of the lift pump intake bell was determined to be 6-1/2 inches measured from the bottom of the entrance plate to the bottom of the runners.

During the BIE-II itself, a total of forty-nine tows were completed in water depths of approximately 4,800 meters. The average time required for a complete tow cycle was about eight hours which yielded three complete tows per twenty-four hour period. During each cycle, the Disturber was on the seafloor approximately two hours. This represented a total of about ninety-eight hours of on bottom disturbance. The average speed over ground of the Disturber while on the seafloor was one knot. Of the forty-nine tows, six were conducted using the rosette sampler and its diffuser base, thirty-three were conducted utilizing the riser extension, and the remaining nine were conducted without the riser extension. Discharge heights measured from the base of the runners were fifteen feet, seventeen feet, and thirteen feet, respectively. Based on estimates of solids concentration taken from the acquired samples, approximately 5,000 tons of sediment were fluidized and discharged into the water column at rates as high as 150 gallons per liter.

Disturber

The Disturber is a passively towed two runner sled type device that weighs approximately 7,000 pounds. The sled itself is approximately eight feet wide, five feet high, and sixteen feet long. The active portion of the sled between the runners is about forty-one inches wide. The open frame tubular steel construction of the sled supports two primary active components: the fluidizing platform assembly and the riser platform assembly. Located in the forward half of the frame, the fluidizing assembly contains a 230 volt, 60 Hz, single phase, 7.6 horsepower centrifugal type fluidizing pump. The pump is a Flygt Model CP3127.180, Type HT that has been modified and pressure compensated for deep water operation. This pump is mounted vertically on the top of the platform base and provides approximately 300 gpm at 40 feet of head. The pump discharge is connected via six inch diameter pipe to the fluidizing header. The high pressure configuration, uses a single header assembly that is horizontally oriented across the space between the sled runners. This header has 22 nozzle locations equally spaced along the length of the header in two rows of six nozzles and two rows of five nozzles. The standard nozzle opening is 3/8" inch diameter. Nozzle inserts are removable so that nozzle openings of different sizes or blank nozzles can be used. When viewed from the side, the four rows of nozzles are oriented to point down vertically as well as back at 15° from vertical. The fluidizing header assembly has a forward facing flange which allows the addition of a second header identical to the first. This header is only used with the high volume fluidizing pump which can provide approximately 1,000 gpm at 16 feet of head. The fluidizing header assembly is adjustable in height from parallel to the runners upward in excess of two feet in increments of two inches.

The riser platform assembly is located aft of the fluidizing platform and contains a 230 volt, 60 Hz, single phase, 7.6 horsepower axial flow pump. The pump is a Flygt Model PL3127.180, Type LT that has been modified and pressure compensated for deep water operation. This pump is mounted vertically in the platform base and provides approximately 2,000 gpm at 15 feet of head. Attached to the intake of the pump is large bell mouth type intake duct. This duct is approximately forty inches wide and contains forward & aft oriented bars to prevent large solid objects from entering the riser system. The pump itself is housed in a cylindrical faring that is designed to contain the discharge of the pump. Attached to the top of this faring is a tapered interface duct that connects the pump discharge to the eight foot long riser duct. Similar to the fluidizing platform, the riser assembly is adjustable in height from parallel to the runner base up vertically two feet in increments of two inches. The intake duct has a curved upward sloping rigid entrance that allows solids and water to flow unrestricted into the riser system. The aft portion of this duct contains a similarly curved exit plate that is hinged to act as a door. This door allows solid materials to exit out the back of the device without clogging the system. The height of the base of this door is approximately four inches lower than the forward plate. Integrated into the back of the duct is a spring loaded relief valve that allows water to enter the system when the suction head exceeds a pre set limit. The oversize rejection bars are located up inside the duct at a height several inches above the leading edge.

Attached to the forward and aft sides of the riser duct is a two part stabilizing fin, or sail. The rigid aluminum fin is also attached to the forward and aft ends of the frame and is secured in place with 5/32 inch diameter stainless steel guy wires. The primary purpose of the fin is to insure that the Disturber lands right side up on the seafloor. It similarly provides a stable attitude while the Disturber is towed through the water when it is not on bottom. The fin was sized such that as long as forward velocity is maintained, the Disturber will automatically orient itself with the runner surfaces facing forward. As the Disturber is slowly lowered to the seafloor, it will therefore land right side up.

The Disturber is attached to the tow cable at the front of the sled. A special tow bit was constructed that allows the cable termination to pivot both vertically and horizontally. This tow bit has an adjustable attachment tothe frame that can be moved according to changes in center of gravity or desired hydrodynamic attitude. A Focal Model 196 Underwater Electrical Swivel was provided to help eliminate the formation of hockles in the cable caused by drastic changes in cable tension during the seafloor landing operations. This elector-mechanical swivel/slipring assembly has a safe working load of five tons and is electrically rated at 3,000 volts and 7 amps.

Sensors & Electrical System

The Disturber System contains a sophisticated command and control subsystem provided by Williamson & Associates. The details of this system are provided elsewhere by that company, but a brief summary of the major subsurface components and sensors is provided here. The electrical power distribution and telemetry systems has three primary components on the Disturber. The subsurface interface/transformer box is an oil filled, pressure compensated, junction box that houses the 10:1 step down transformer and specially developed electrical interface panel. This panel represents a significant departure form the previous design and was developed specifically to eliminate the need for underwater high voltage connectors. Previous experience had shown these connectors to be prone to failure and the cause for significant down time while the system was repaired. Their elimination therefore would potentially reduce down time and increase overall system performance.

The second major component is the power distribution housing. This 17-4PH stainless steel housing contains the motor starting and control circuitry for the pumps. Oil filled connector cable assemblies were used to interconnect the main interface box and the pumps with the power distribution housing. These assemblies contained Teflon insulated conductors that were impervious to the deteriorating effects of the oil contained in the pump motors and the junction box.

The telemetry housing is the third major component of the electrical system. This housing contains the brains of the system and provides the command and control necessary for the system to function. Also contained in this housing are the pitch, roll and heading sensors, as well as the printed circuit boards for the slow scan video system. While pitch, roll, and heading were monitored throughout the operation, pitch was extensively used as an indicator during landing and lift off operations.

In addition to the sensors contained in the telemetry housing, an altitude sensor, video camera, two lights, and two Optical Back Scatter sensors were also provided. The altitude sensor was mounted on a pivot at the aft end of the main frame. It had a range of 52 meters and proved to be invaluable during the seafloor landing operations. It was primarily used to give the system and ship's winch operators warning of the impending bottom contact and provided the opportunity to slow down the winch and prepare for landing. The video system including the camera and two lights were used to both monitor the riser discharge and to view the seafloor in front of the Disturber. They were located on top of the fin forward of the riser looking aft, and could be moved down to the main frame where they were oriented forward toward the seafloor. This slow scan system worked very well and provided updated frames in less than one second intervals. The OBS sensors were located near the top of the riser with their sensor heads physically in the discharge stream. Plates were incorporated in the mounting brackets to protect the heads from direct impacts by nodules, sediment, and other solid materials. These sensors had unobstructed views across the inside of the riser.

Mobilization
The Disturber Team arrived in Long Beach on the evening of 7/27/93. We started early the morning of 7/28/93 getting the system ready for tests and putting away the materials, supplies, and parts that had been shipped from Seattle. The diesel generator battery was found to be dead and required charging. During the next several days we continued to get the system ready, tested the telemetry system and the pumps, etc. The lift pump did not start initially, but after freeing up the impeller with a pry bar it ran fine. The no load (in air) current for these pumps is only 10.5 amps. We also discovered that the video camera had a loose connector and a broken internal wire. We recognized the importance of the camera and determined that a spare was essential. Arrangements were made with MECCO to lease their camera. It was shipped via Federal Express on the 30th. We also installed and tested the General Oceanics rosette sampler. The spare video camera arrived on the 31st. It was installed and tested. We completed last minute shopping for miscellaneous spares and supplies before the ship departed about 17:00 that evening.

Shallow Water Tests
We arrived on site at about 21:00 on the 31st. The water depth at the test site was about 1,000 meters which allowed for rapid deployments and recoveries through the water column. The shallow water phase lasted until the evening of 8/2/93. During that time we successfully completed 12 tows using the Disturber in several different configurations and at several different nozzle and intake heights.

We completed four tows in the initial configuration which utilized the high volume fluidizing pump with all 44 nozzles installed. The Lift pump and intake header were left at the height used in the previous shallow water cruise. Three successful test runs were made after an initial tow in which the rosette bottles were triggered before the Disturber was fully on bottom. The next three runs went well and resulted in numerous samples with sediment concentrations that looked good. The video pictures of the riser discharge had also looked good.

We then switched to configuration number 2. This was essentially the same as the first except that the top row of nozzles on each fluidizing header were replaced with blanks. Three tows were made with this configuration, and the sediment concentrations in the rosette bottles were found to higher than that of the four previous tows.

The third configuration tested used the high pressure fluidizing pump. The high volume pump was exchanged for the high pressure pump and the forward header was removed. The top row of nozzles on the remaining header was left unchanged with the individual nozzles blanked off. The results were even better than the previous tows. We then lowered the lift pump and intake header two inches. The amount of sediment contained in the sample bottles went up considerably. We completed two runs in this configuration.

The final shallow water tow utilized the same configuration except that the blank nozzles were replaced with open nozzles. The results were not as good and it was determined to use the previous configuration as our primary BIE-II format. We headed for the BIE-II site.

BIE-II

During transit to the BIE-II site, we installed a remote voltage adjustment potentiometer in the control room that could be used to adjust Disturber system voltage. Tim repaired the broken wire and loose connector on the video camera. It was then tested and found to be OK. We also removed the miscellaneous extension cables that were no longer required and generally tried to clean cable routes and tie down all cables for deployment.

We finally arrived at the BIE-II site on 8/7/93. We tried to start the diesel generator but could not keep it running. The problem was traced to dirty fuel filters which were then cleaned by the ship's crew. We tested the system, including the lift pump, and it started with no problems. We also tested the rosette sampler and found that the circuitry worked fine, but the trigger mechanism did not release every bottle. We flushed the rosette sampler trigger mechanism with sea water and then lubricated it with WD-40. It still did not draw back the release balls at each location without a little help.

After many days of taking box cores, deploying sediment traps and hiding from a hurricane, we were finally ready to deploy the Disturber. The generator was again tested and checked out OK. We again checked out the sampler electrically & mechanically. It seemed to work fine when a small loop of mono-filament line was used under the release pin to apply slight tension. We checked out the motors/pumps, and found that they didn't always start as expected. We opened the power distribution can and generally cleaned all contacts and connectors. We tried to fill the can with dry nitrogen gas as we closed it. Afterwards, we again fired up the system and repeatedly started the motors. Everything looked good. Note that some method for purging the cans with dry nitrogen is a good idea and is something that should be considered for next year. Finally, the Disturber was launched about 9 PM on the Friday the 13th. The first tow, BIE2-01, had mixed results. During the shallow water tests, the Disturber pitch was normally zero degrees when the Disturber was fully on the seafloor. During this tow, however, the pitch stayed at five degrees or higher. We had several significant current surges as high as 140 amps. With about 800 meters to go to the end of track, and only samples taken, the current went high and could not be brought down to an acceptable level. We turned off the lift pump and pulled in the cable to lift the Disturber off bottom. When the pitch was at 60 degrees, we turned off the fluidizer pump and tried to restart the lift pump. The current up to went to 120 amps and the pump would not start. We therefore aborted the tow. When the Disturber was brought to the surface it was determined that the pump starting capacitor was blown. Once the capacitor was replaced, the pump started as normal. The rosette sample bottles were removed and found to contain over 7 cc of sediment which corresponded to 117 gallons per liter. This was the highest concentration found to date.

The next two tows also utilized the rosette sampler. During towing, a number of current surges were experienced, but by increasing system voltage, the current quickly dropped back to acceptable levels. After the second deployment we asked the ship's crew to add weight to the depressor. It had been removed before the first tow because of concern for the cable, but we were unable to maintain an acceptable depressor altitude without continuously paying out cable. Also unbeknown to us, the tow cable had been shortened to 6,500 meters. The rosette samples taken during the first three tows showed consistently good results. We did experience some problems getting all the bottles to close properly. The ship speed was generally kept between 0.6 and 1.2

knots, averaging about .9 to 1.0 knots. The average duration of the tows was about two hours. The pump/motor currents stayed low most of the time, but at times we were forced to shut down the lift pump due to high current. We developed a method for clearing and restarting the pump that worked remarkably well. See the operational section elsewhere in this report for details.

Before Tow BIE2-04 we removed the rosette sampler and installed the riser extension. This configuration was used up through tow BIE2-29. We also adjusted the video camera and lights to view the riser discharge. Tow BIE2-04 was successfully completed with only one minor problem. The diesel generator ran out of fuel during the middle of the tow which caused a twenty minute shut down. When the system shut off, we raised the Disturber up off bottom to a depressor altitude of 300 meters. Once the diesel was fueled and restarted, we restarted the pumps and set the Disturber back down on the bottom to complete the tow.

After the test, the ship's crew rigged a special sheave on the tow line so that we could turn the ship and head back to the start point with the Disturber still deep in the water. We winched cable in until the scope was slightly less than water depth. The scope was 4700 meters and water depth is about 4800 meters.

During the return trip after tow BIE2-05, we experienced a system failure that resulted in blown fuses in the surface interface box. Upon recovery of the Disturber, we discovered that sliprings were the cause of the problem. We removed the slipring assembly, re-terminated the cable both mechanically and electrically, and then drained, flushed, and refilled the subsurface transformer box. The system then tested fine. We also installed the gasket between the riser and the riser extension. We switched the OBS cables to check if we had the correct one labeled #1 & #2.

Tows BIE2-06 through BIE2-10 went well with very few problems. We occasionally experienced short duration current surges as high as 140 amps, accompanied by visual indications of minimal discharge from riser. We were periodically required to shut down the lift pump, lift off bottom, and clean out the pump before restarting. This procedure became routine and typically only required that the system be non-productive for two to four minutes. Surging of the Disturber was evident by monitoring the discharge plume in the video. As the Disturber surged ahead, the plume would lay back and appear small. As the Disturber slowed down, the plume would become very large, and at times engulf the video camera.

We disassembled the slipring/swivel unit and found an incredible amount of carbon-like material inside the unit. The insulation was burned off one of the brush leads for a distance of about one inch. Additionally, two insulator rings and one insulator tube on the same end were damaged (burned) significantly. There were relatively minor burns on the two brush assemblies as well. The rings themselves and the brushes looked OK. We do not have spares of the tube or the insulating ring. We made a drawing for the machinist and have asked him to make replacements.

At about 1,000 meters from the end of tow BIE2-11, the generator started acting unusual. The voltage periodically dropped from 225 to 180 volts which forced us to abort the tow. The problem turned out to be dirty fuel filters which where then changed by the ship's crew. We used our last two spare filters and cleaned the one that had been installed by the ship. By the time we were able to restart the diesel and the Disturber pumps, almost one hour had lapsed. The good news is that we determined that the Disturber pumps could be turned off for extended periods and then restarted at depth. We arranged with the ship to have the filters cleaned on a regular basis.

Tows BIE2-12 through BIE2-14 progressed without problems. In fact, tow number 14 was essentially perfect with no current surges or lift off required. Generally, the cable scope at the end of tows was on the order of 5,400 meters.

Tow number BIE2-15 was unusual in that the current started relatively high and progressed to 75 amps fairly early in the tow. It then went above 80 and stayed there so we shut the lift pump off and performed a lift off to clear it. After restarting the pump and landing back on the bottom, the current again stayed between 70 and 75 amps. We kept the depressor altitude high, closer to 100 meters than to 50 meters, and periodically lifted the nose of the sled up by winching in to clear the lift pump. This seemed to work well and as the tow progressed the current went back down and stayed at the low end of normal. We think that maybe the sediment conditions were different in the early part of the tow, or that maybe we were in a track that had been disturbed by one of our previous tows.

After tow number BIE2-17 we recovered the Disturber. Once on deck, we moved the camera and lights to look ahead and down in front of the Disturber. Several brackets were made to accomplish this. We checked the lift pump impeller and found it to look slightly worn , but OK. The leading edges of the impeller blades were slightly damaged and the radial clearance appeared to be a little larger than when we started. We removed the OBS unit that had gone bad during one of the earlier tows and replaced the head. We also switched the cables back to the original configuration.

Moving the video camera so that it looked forward proved to be of value. We encountered previous tracks many times and were convinced by what we saw that the lift pump indeed removed the material that was between the runners. It was difficult to tell depth, but there was virtually no windrowed material on the inside of the runner tracks. In places, the tracks were very flat from outside of one runner to the outside of the other. It looked as though the excavation was complete to a depth flush with the bottom of the runners.

During tow number BIE2-14, the port lights went out which in turn reduced the quality of the video picture. However, the Disturber continued to perform tow after tow with only minor problems. Throughout the tows we routinely saw "rat tail" fish, shrimp, and other marine creatures in the area and at times on the previous track lines. We were also able to see areas where the Disturber had landed or lifted off the seafloor. During our 25th tow, the second light went out, which essentially eliminated the video.

During the return trip to tow number BIE2-26, we experienced a communications failure of the telemetry system. Twice during the tow we had situations where the current went high and a communications failure occurred at the same time. Adjusting the voltage up did not bring the current down to an acceptable level. Because of the communications failure, we were not able to turn off the pumps. We therefore had to make a mad dash up to the generator and open the circuit breaker. We assumed that maybe the problems we were facing had something to do with the fact that the fuel gage indicated that we needed to change and or clean the fuel filters. It had been threes days since that was last accomplished. We decided to shut the system down, including the generator, and informed the ship's crew that it was now time to change the filters. We also informed the Chief Engineer that we wanted the first filter cleaned on a daily basis and that we would shut the system down each day so that it could be accomplished. Approximately three and one half hours after we shut the system down the filters had been changed and I was able to restart the pumps with no problem. This clearly proved that we could shut the system down for extended periods and then restart the pumps. Starting with tow BIE2-28 we decided to shut the system down after lift off at the end of each tow and then restart it just before landing on the next subsequent tow.

After completion of tow number BIE2-29, the Disturber was recovered to the deck. We made some new brackets and moved the lights and camera. The camera was located on the port side just aft of the tow point and below the top frame. The two lights were located on the opposite side. The riser extension was removed and the rosette sampler was installed. The burned out light bulbs were replaced with new ones. We painted the tow cable termination and the aft side of the port diagonal brace that supports the tow point with black paint. This was done in an effort to reduce possible glare and improve visibility. When we conducted the shallow water check at 150 meters, the lights did not function. We then recovered the sled and found blown fuses in the light circuits. After replacing the fuses, the lights worked fine. The video camera and lights were in good position to show previous tracks. Upon recovery, ten of the sample bottles were found to contain sediment. One sample bottle had two nodules and two large pieces of clay in it. The samples in general, however, contained less sediment than was found during the initial runs.

The rosette sampler was again installed on the riser before the next launch. The samples obtained from that tow were similarly found to contain less sediment than was anticipated. We therefore removed the intake duct and attempted to remove the impeller. It was not possible. We put the intake duct back in place. We removed the rosette sampler and installed the riser extension.

The next several tows went without a hitch. Assuming that high current was an indicator of sediment pumped, several of these tows should have been exceptional. We had high current the majority of the track length. It typically ranged from 68 to 75 amps. We crossed over many previous tracks including one that was unusual. We came upon a previous landing and could clearly see the point of touch down. We had approached this track from the right side. Because the sled had just touched down, the track had large windrows both inside and outside the runner grooves. As we started to cross over the track, the Disturber got caught in the old track and turned to follow it. As we moved along, we could see the point where the Disturber had started to fluidize and remove the material from between the runners.

It was discovered that during the last four runs the data files had been cut short part way through the tows. It was later determined that the program had not been executed properly resulting in loss of the data. It is essential that the Alt-X command be used to terminate the program at the end of each run.

At Erdogan's request we were asked to remove the riser extension and change the impeller the next time the Disturber was on deck.

Tow BIE2-37 started out just fine but went downhill near the end of the tow. We started getting high current levels and had to lift off several times to clear the lift pump. When cleared, the current was still higher than normal, and stayed above 70 amps. It was planned to the recover the Disturber after this tow so that the riser extension could be removed and the impeller changed. The ship's crew had made a special tool that we could use to remove the impeller that we could not previously get off.

When we replaced the impeller with the spare, we found nodules and several large pieces of pumice jammed in the pump. These solid materials clearly blocked the flow of water through the pump and we were of the opinion that they were responsible for the unusually high current of the previous tow. It is apparent that additional means to restrict the size of solids entering the pump must be provided. With the special tool that had been made for us, the impeller came off with little trouble. We removed the riser extension and moved the camera and lights up to the top of the riser. We installed the rosette sampler so that we could determine the impact of replacing the impeller.

The motor current during the next tow was 10 amps lower than the previous tows. It was typically 58 amps, with one high current surge that required that we shut off the lift pump. We triggered the rosette sampler every 10 minutes through twelve samples, and then rapidly gave the command 12 more times just to be sure. Unfortunately, after we lifted off we could see that four of the five bottles visible were not closed. Seven good samples were recovered and Dwight decided that another sample run was not necessary. There were some turns in the cable up near the depressor when it was brought aboard, and the Deck Crew Chief decided that the cable must be disconnected from the Disturber and strung out behind the ship in order to remove the twists. We partially drained the subsurface junction/transformer box and removed the cable. We oriented the camera and lights towards the discharge of the riser.

The remaining 10 tows were conducted with no riser extension and no rosette sampler. We periodically experienced high current situations that required shutting the lift pump off and listing off bottom. These operations became routine and only caused a couple of minutes of down time. During the few times that high current existed, the video picture of the riser discharge showed reduced flow. During the remainder of the time, the discharge plume was full giving an indication of consistently good pumping.

During tow BIE2-45 the second OBS was finally declared dead. Tow number BIE2-47 was a tough one. When we first started the pumps, the current was unusually high, 64 amps. This was while the Disturber was still off bottom. Once it landed, it went higher. For a while, it did settle down to a reasonable level, but for the majority of the tow, the current was between 68 and 74 amps. We had to shut the lift pump down and lift off four times. It may be that the throat of the lift pump was again clogged with nodules and pumice. Since we had only three tows to go, we decided to watch it carefully and hope that we did not have to recover before the end of the last tow.

The final two tows were painless. No problems; only one lift off due to high current, and in fact, very few current surges. The system current generally ran in the 64 amp range and the video pictures showed good discharge. The decision was made to stop after number 49 to insure that the CTD runs and one box core could be accomplished before starting the box coring and mooring recoveries.

When the Disturber was brought back on deck, we started the disassembly and packing process for the return trip back to Long Beach and then Seattle. We removed the video camera, lights, and OBS sensors from the Disturber. We similarly removed the two fin sections, two ladders, and riser from the Disturber. We washed everything down, including the Disturber, with fresh water as best we could. The fresh water supply on deck is small and not sufficient for washing large structures such as the Disturber. It is recommended that the Disturber be thoroughly rinsed with fresh water once it has been transported back to Seattle.

Results and Conclusions

Indications from the OBS sensors, while they were still functional, indicated good sediment concentrations. Analysis of the rosette sampler bottles showed that sediment concentrations ranged from 50 to 150 gallons per liter with an average of 100 gallons per liter or more. Video pictures of the riser discharge consistently showed substantial sediment plumes. Video pictures of previous Disturber tracks clearly showed that sediment, and particularly sediment windrows plowed up by the sled runners, had been consistently removed by the disturber. Video pictures of the seafloor also showed clear evidence that sediment had settled down onto the bottom. This was particularly evident in areas of previous tracks where the cracks and voids normally found in the windrows were rounded and filled in with new layers of sediment. When the Disturber was on the seafloor, the system current was consistently 5 to 10 amps higher than when the Disturber was off bottom. All real time indicators of sediment throughput pointed towards a successful sediment resuspension operation.

Recovery of the sediment traps and transmissometers after the tows were completed also indicated a successful mission. The near track traps contained significant amounts of sediment while the traps recovered from farther away showed lessor amounts. The transmissometer data clearly indicated cyclic periods where the turbidity of the water was reduced substantially to values only 30% of their clear water level. The CTD casts taken many hours after the last Disturber tow showed the existence of a near bottom sediment plume.

Using estimates of average pumping time and sediment concentrations, it was calculated that approximately 5,000 tons of sediment were fluidized and dispersed into the water at heights from 13 to 17 feet above the seafloor. Preliminary indications are that the majority of this material settled back to the seafloor in the designated study area. The project data is currently being evaluated by NOAA to determine the actual thickness of sediment deposits as a function of distance away from the disturbed area. Preliminary indications point towards a successful operation.

Ship's Crew

The ship's crew did a remarkable job and should be commended for the excellent work and support that they provided. From the Acoustic Navigation team through the winch operators and deck crew, navigators, engineers, mechanics and machinists, our successes could not have been accomplished without their tireless dedicated support.

Recommended Changes

As a whole, the Disturber system and its subsystems performed admirably and is considered to be highly successful. That is not to suggest that problems, although mostly minor, did not exist. Based on the experience gained during the BIE-II program, there are a number of recommended changes that should be considered prior to future deployments. Many of these changes are not absolutely necessary, but instead provide for a more efficient operation. This in turn translates into more productive bottom time and more materials suspended. The following is a brief description of these changes and additions.

1. The Disturber pumps and other parts of the system were selected on the basis of the existing tow cable onboard the R/V Yuzhmorgeologiya. This cable has substantially more copper in the center conductor than it does in the surrounding shield. The entire system was therefore designed around the deficiencies of this electrical shield. If any subsequently purchased cables can be constructed with additional copper in the shield, conductor resistance will be reduced. This in turn will reduce loses in the cable and may allow larger horsepower pumps to be used.

2. It is recommended that the existing ship's acoustic navigation software be modified so that it can provide selected navigation data to the Disturber control computer. This way, the much needed data can be displayed to the Disturber team and logged in one place with the other critical data.

3. A cable meter should be provided in the control room that indicates the cable speed and amount of cable paid out by the winch. Cable tension would also be desirable. If possible, this data should also be provided in a format that can be recorded by the disturber control computer.

4. Leak detectors should be installed in the subsurface interface box as well as the power distribution and telemetry housings. An accumulation of sea water in any of these components can be fatal to the system. If detected early, serious damage can often be avoided.

5. Disturber motor voltage and current should be integrated into the telemetry system, displayed on the control monitor, and recorded. Presently, only surface voltage and current are displayed on independent meters and are not recorded.

6. A back up video camera should be provided. This system should include a camera, lights, and a switch controlled by the telemetry system that can be used to selectively switch between the two cameras. in the event that one camera should fail, the second camera could be switched on without having to shut down the system and recover the system. Similarly, additional back up lights should be installed and switches provided.

7. The existing lights should be repaired to include replacement of the burned reflectors.

8. A 35 mm camera should be installed on the Disturber that can be used to photograph previous tracks and the riser discharge. It was clear from the video that much can be learned about

disturber performance by studying previous tracks. Unfortunately, video quality is not sufficient to perform detailed analysis of the tracks.

9. A significant amount of supplies and spare parts were consumed on this cruise. These materials and additional quantities of many items need to be replaced and acquired.

10. A second access door needs to be installed on the lift pump housing. This door will allow jammed solids to be removed from the pump chamber without removing the intake duct.

11. Access holes should be cut and doors installed in the inside walls of the runners to allow the header clean out covers to be removed without removing the header from the Disturber. Solid materials that have been entrained into the pump and forced into the header need to be periodically removed as does scale and corrosion build up that could potentially block the nozzles and reduce system efficiency.

12. The oversize material rejection bars located in the underside of the intake duct should be made removable. This will allow the impeller to be inspected and replaced as required without removing the intake duct assembly which is a time consuming process.

13. The intake portion of the fluidizing pump should be screened to prevent solids from entering the pump and plugging the fluidizing nozzles.

14. Means for providing dry nitrogen purging of both the power distribution and telemetry housings should be provided. Moist atmosphere in these housings can cause significant damage and there is simply no convenient way to prevent moisture from entering the housings when they must be opened on deck. Purging of the moist marine air with nitrogen is a proven effective way to eliminate these types of failures.

15. The failed depth sensor should be replaced. The depth sensor was destroyed when the housing flooded during the preliminary shallow water test conducted in June. A new sensor should be purchased and a new housing should be built. The existing housing was loaned to this project by Williamson & Associates and may no longer be available. A spare sensor should also be provided.

16. A spare altimeter should be purchased. The altimeter sensor was instrumental during bottom landings, and should be considered indispensable. No spare currently exist

17. Spare video system printed circuit boards should be purchased. The video system proved to a very valuable tool during these tests. Because of the failure of the OBS sensors, the video provided the only real time indicator of disturber performance. Currently no spares exist for this much needed system.

18. The surface interface box should be compensated with a larger oil accumulator system. The existing compensator is simply too small to accommodate the changes in oil volume caused by the changes in temperature experienced during operations in the Equatorial Pacific.

19. A second compensator should be added to the subsurface interface box. The existing compensator has insufficient volume. The bladder was often found to be deflated when the Disturber was returned to the deck, but after sitting in the sun, the bladder was over full and dangerously close to potential rupture. The addition of a second accumulator could be used to alleviate this problem.

20. New OBS sensors need to be provided. Both of the existing sensors failed during the course of the BIE-II tests, and similar failures occurred during the BIE-I in 1992. It is recommended that an alternate source of sensors be investigated. At a minimum, the existing sensors need to be replaced with improved versions and spare sensors need to be provided.

21. Install nodule sample baskets on the sled runners. Obtaining manganese nodules seemed to draw particular interest during this experiment. Relatively simple and cost effective sample baskets can be easily installed on the sled runners. They should provide ample nodules to keep all crew members happy.

22. Investigate whether or not the pump motor starting circuits can be made more durable and to have increased capacity. Motor starting capacitors failed on several occasions during the shallow water tests. While operational changes seemed to alleviate this problem during the BIE, this potential failure causes significant down time while the system is recovered to the surface and repaired. If relatively simple changes can be made to the circuit that would harden its design, it may well be worth the expense.

23. Replace the relief valve and springs on the riser system intake duct. The hinges on the existing relief valve door are probably rusted shut. The closure springs are also badly corroded. These items need to be replaced and properly tested for function.

24. Provide system computer. The existing system computer belongs to NOAA and rumors indicate that this machine may not be available for future tests. A replacement and a backup need to be provided.

25. Install a dual marine filter system on the diesel generator so that filters can be changed while the generator is running. Clogged fuel filters were a continuing source of problems and could be easily avoided with the addition of a dual filter system. These filters should be large marine grade filters and should have sight bowls incorporated into their design. Many sets of spare filter cartridges should be provided.

26. Develop and install a permanent remote voltage control circuit on the generator. Real time control of system voltage proved to be essential for efficient Disturber operations. While the temporary system utilized this year worked, it should be replaced with a more permanent solution.

27. Develop and install a remote circuit breaker trip that can be actuated from the control room. On several occasions during the BIE-II program, a high current situation developed at the same time that a communications failure occurred. Because of the communications failure, the Disturber pumps could not be shut off and the system current therefore remained dangerously

high until someone could run up and open the main circuit breaker at the generator. A remote breaker trip installed in the control room would eliminate this problem.

29. Install remote gauges for the diesel fuel pressure, water temperature and oil pressure. The diesel engine parameters were monitored and recorded once every hour during operation. These parameters could be more easily and more frequently checked if the gauges were contained in the control room.

30. The surface slipring assembly performed without any problems or malfunctions. This unit should be returned to the manufacturer for inspection and maintenance. Since this device is crucial to the operation, a complete spare slipring assembly should be considered.

31. Maintenance: There are a number of maintenance items that must be addressed before the next operational season. As examples, the pumps should be overhauled and inspected for damage or wear. The Disturber itself should be completely stripped down, sand blasted and painted. A detailed list of maintenance items will be developed and submitted at a later date.

32. Provide the following major system spares:

a. Fluidizing pump
b. Lift pump
c. Video camera
d. Lights & bulbs
e. Control computer
f. Video annotator & microphone
g. Splitter box for Acoustic Navigation system
h. Altimeter
i. Depth sensor
j. Surface slipring assembly

33. Weld fin bracket back on to fin. The aft most bottom mounting bracket for the aft fin section had broken from the fin. It needs to be rewelded to the fin.

33. Make dummy connectors to replace the four high voltage Kemlon connectors and the Brantnor (?) bulkhead connector that was used for the telemetry cable. These connectors are no longer used and should be replaced with the dummy plugs.

DSSRS-2 DEPLOYMENT SEQUENCE

LAUNCH

Pre-Launch

- Position Disturber in pre-launch location.
- Disturber team complete pre-launch check-out and give "go-ahead" to launch.

Launch

- Launch Disturber

Lowering

- Winch Speed - 0.5 meters/second
- Ship Speed 1.0 to 1.5 knots (Ship Speed must be maintained at this level for at least 1 hour prior to landing.)

Navigation

- Navigate ship so that Disturber will touch down approximately 100 meters before start of track.

LANDING

STOP!

- Stop paying out winch when depressor altitude is 300 meters above bottom, and notify Disturber Watch Team.

Winch Speed

- Only after "go-ahead" from Disturber Team, continue paying out cable at 0.2 meters per second until directed to stop by Disturber Team.

Ship Speed

- Do not change ship speed without consulting with Disturber Team first.

TOWING

Winch Speed

- Normally 0, but from time to time Disturber Team may require that winch cable be paid out or pulled in.

Ship Speed

- Maintain 0.75 to 1.5 knots. Do not change ship speed without prior notification to Disturber Team.

Winch Speed

- After "go-ahead" from Disturber Team, pull in winch cable at 0.5 meters per second.

Ship Speed

- Maintain ship speed the same as during towing.

RAISING

Winch Speed

- Approximately 0.5 meters per second, or as dictated by normal winching procedures until cable scope is 5,000 meters. If rosette sampler is being used, continue to surface. If not, stop winch.

Ship Speed

- Maintain ship speed at tow speed

TURNING (Down Wind)

Turn

- Once depressor altitude has reached 300 meters, start a 0.4-0.5 nautical mile radius turn with the ship.

Ship Speed

- Maintain ship speed as required to negotiate the desired maneuver or until the turn is completed or until the cable scope has reached 5,000 meters. Then increase ship speed as desired, but not to exceed 4 knots.

TURNING (Up Wind)

Turn

- Start turning maneuver so that when completed, the Disturber will be one half to one nautical mile down wind to track start.

Ship Speed

- Gradually slow ship speed so that at completion of the turn, the speed will be 0.75 to 1.5 knots.

DSSRS-2 OPERATING PROCEDURES

1. PRE-DIVE CHECK OUT

a. Check Disturber for loose bolts, connectors, and improperly secured cables. Tighten any bolts and nuts that may have become loose. If bolts or nuts need to be replaced, always use thread lubricant before inserting the bolts. Properly clean and make up any electrical connectors that have been disconnected or opened. Simply tighten connector locking collars that may have come loose. Check cables that run between various components on the system. Install tie wraps or duct tape as required to insure that the cables will not flap and become damaged during deployment.

b. Check the tow cable interface assembly to be sure that the bolts are securely locked and that excessive wear has not developed between the rotating parts. Replace cotter keys or worn bushings and washers as required.

c. Check fluid level in all compensator bladders, and top up with clean oil as required. Keep in mind that if the system is sitting in the sun, the hot oil may overfill the bladders and have to be bled.

d. If the swivel has been installed, check the oil contained in the connecting tubing for signs of contamination. If arcing has occurred, small amounts of black carbon like materials may be seen floating in the oil. Also, if water has entered the system, it may be visible through the clear tubing. If either water or carbon is found, remove the swivel/slipring assembly and repair or replace as required.

e. Check to be sure that the Altimeter transducer is free to pivot about its mounting bolts. Lubricate mating surfaces and loosen or replace bolts as required.

f. Start the system in accordance with normal starting procedures. Prior to starting, insure that no personnel are in contact with the main cable or the Disturber. Alert the crew that the system will be "hot" and to avoid contact until after the deck check is complete. Also check all deck system components including the surface interface box to insure that no one is in contact with any of the system components.

g. Individually turn on lights to verify operation. Note that the lights may not be turned on while on deck for more than a few seconds without damage to the bulb of the reflector surface.

h. Upon startup of system, the video camera will automatically be on. Momentarily remove protective cover from the camera to check operation. Be sure that camera is not pointing towards the sun.

i. Individually start and stop the Fluidizing and the Lift Pumps. Stand adjacent to Disturber and listen for the pumps to start. Remember that on deck, the pumps will not be loaded when running and they will draw only minimal current.

j. Normally the rosette sampler, if installed, will be checked, cleaned, assembled and tested prior to mounting on the top of the riser. It should therefore not require a deck check.

k. Open the main circuit breaker located on the generator. It is not necessary to shut down the diesel at this time.

l. Alert the deck crew that the system is safe and that they can launch the Disturber.

2. SHALLOW WATER CHECK OUT

a. After the Disturber has been lowered to a depth of approximately 150 meters, or at the desired attachment point of the depressor, stop the main winch and alert the deck crew that the cable will be "hot" for a short period of time. Insure that they are not in contact with any component of the system equipment.

b. Close the circuit breaker to activate the system.

c. Check with the control room to insure that communication between the computer and the Disturber is in tack.

d. Individually turn on the two lights to check their function.

e. When the lights come on, the function of the video camera can also be checked.

f. Turn on the Fluidizing Pump and the Lift Pump in accordance with Pump Starting Procedures. Turn off the pumps.

g. If all functions are normal, open the circuit breaker by moving the breaker switch to the off position.

h. Shut down the diesel in accordance with normal shut down procedures.

i. Advise the deck crew that the system is OK and to install the depressor.

3. STARTING PUMPS WHEN SUBMERGED

a. Adjust voltage control potentiometer to so that generator voltage is between 210 volts and 225 volts.

b. Push the Fluidizing Pump start key, currently F4, (see computer display) and immediately rotate the voltage control potentiometer clockwise to full voltage. While doing so, monitor the system current meter. The current should go from a minimum value of about 10 amps up to 80 or more and should then quickly start to fall. As soon as the system current drops back down between 23 amps and 30 amps, rotate the potentiometer counter clockwise until the system voltage is again between 210 and 225 volts.

c. Push the Lift Pump key, currently F6, (see computer display) and immediately rotate the voltage control potentiometer fully clockwise. While doing so, monitor the system current meter. The current should go from the 30 amps value up over 100 amps and should then quickly start to fall. As soon as the current drops down to approximately 50 amps to 60 amps, rotate the voltage control potentiometer counter clockwise until the voltage is about 225 volts.

d. Note that when starting either pump, if the current does not quickly drop back down as described, push either Stop button for that pump or push the Escape key which will turn off both pumps. The Stop keys for the Fluidizing Pump and Lift Pump are F5 and F7, respectively.

4. DEPLOYMENT

a. During all phases of the deployment when the Disturber is in the water, a minimum speed of 0.5 knots should be maintained. A maximum speed of 3.5 knots through the water should not be exceeded.

b. Winch speed during lowering should not exceed 0.8 meters per second.

c. The maximum cable scope during deployment maneuvers such as turns and down wind legs returning to the subsequent profile should be 150 meters less than the minimum water depth.

d. The ship should be navigated in such a manner that she comes into line with the next profile at least one nautical mile down wind from the start of the track.

e. Once the ship is in line with the next profile the speed over ground should be maintained at 1.0 knots.

f. The depressor can now be lowered to an altitude of approximately 500 meters. This altitude should be maintained until the Disturber is approximately 500 meters from the start of the profile.

5. BOTTOM LANDING

a. Once the Disturber is within 500 meters of the start of the profile, it should be lowered to a depth where the altitude of the depressor is 300 meters above the seafloor.

b. Also at this time, the system should be started and the pumps turned on in accordance with normal starting procedures.

c. The ship speed over ground should be held constant at 1.0 knots. Changes in ship speed significantly affect the shape of the tow cable catenary and therefore depressor as well as Disturber altitude above bottom.

d. When the Disturber is approximately 300 meters from the beginning of the profile, it should be lowered towards the bottom at a rate of approximately 0.5 meters per second.

e. During this phase, the Disturber watch team must pay close attention to the Disturber altitude display on the computer monitor. When the Disturber gets with in 52 meters of the seafloor, the Altimeter will start to indicate altitude above the seafloor. When the altitude is between 10 and 15 meters, alert the winch operator, and slow the winch to approximately 0.1 meters per second. Note that higher speeds may cause the disturber to stop forward motion resulting in damage of the tow cable and potential loss of the Disturber.

f. As the Disturber contacts the seafloor, watch carefully the Pitch display on the control monitor. The pitch should transition from the normal tow level of about 60 to 80 degrees downward to zero. If the pitch starts to progressively climb (ignoring variations caused by pitch and heave of the support vessel) immediately stop the winch and pull in cable until the disturber is at least 15 meters above the seafloor. Increase the ship speed and again attempt to land the Disturber. As long as sufficient forward speed through the water exists, the Disturber should land correctly. Attempting to land when the pitch angle is increasing will result in an upside down landing potentially sever damage to the Disturber.

g. Continue to pay out cable at this slow rate until the depressor altitude is approximately 100 meters. The winch operator should then be advised through the acoustic navigation team to slowly (0.1 meter per second) pull in or pay out cable to maintain a depressor altitude of 75 to 100 meters.

6. ON BOTTOM TOWING

a. Normal towing operations should be conducted with a speed over ground of between 0.7 and 1.3 knots. The minimum speed is typically determined by the minimum speed at which the ship can maintain steerage.
b. The depressor altitude should be maintained between 75 and 100 meters. Excursions down to 50 meters or up to 125 meters will generally not be cause for concern.

c. The normal operating range for system current when the two pumps are running is 53 to 75 amps. During operations, the system current will normally rise and fall depending upon the load on the lift pump. As the current tends to climb to 75 amps, the system voltage can be raised to keep the current in the acceptable range. Usually the current will quickly go back to normal. The voltage should not be maintained above 240 volts for extended periods. If high current persists, the Lift Pump should be shut off immediately. This is accomplished by pushing the F7 key on the control keyboard. If one or both pumps are turned off, the system voltage should be reduced to approximately 210 to 220 volts.

d. Sudden current surges may also happen from time to time, and should be immediately counteracted by rotating the system voltage control potentiometer fully clockwise and then back counter clockwise as the current falls. Experience has shown that current surges of 135 to 140 amps will occur. If the current does not immediately fall back to acceptable levels, push the F7 key to turn off the lift pump. If this does not immediately solve the problem, push the F5 key or the Escape key to shut off the other pump. Note that generally, the fluidizing pump current will remain constant and shutting down the lift pump will reduce the current load back to 25 amps to 30 amps Two exceptions to this would be a locked rotor condition caused by ingesting a solid object into the Fluidizing Pump, or by an electrical short in the circuit.

e. Communications failure between the control computer and the Disturber will potentially occur for a variety of reasons. Normally, this is not cause for panic. If, however, a communication failure should occur at the same time as a high current condition, the computer keys will not function to turn off the pumps. Under this condition, the main circuit breaker at the generator must be switched off, open, as quickly as possible. This may require a high speed dash up to the generator.

7. RESTARTING THE LIFT PUMP

a. If the Lift Pump has been shut off during operation while on the seafloor, a large amount of sediment contained in the riser pipe will settle back onto the pump. An attempt to start the pump while it is filled with sediment will normally result in damage to the motor starting capacitors and will require recovery of the system back to ship's deck. To restart the Lift Pump, first winch in cable until the Disturber has lifted off bottom approximately 10 meters. Hold this altitude a minute or two to allow the forward motion through the water to clean out the Lift Pump and Riser system. Then simply restart the Lift Pump in accordance with normal starting procedures.

b. The Disturber may then be lowered back to the seafloor in the usual and accustomed manner at 0.1 meters per second.

8. LIFT OFF AND RECOVERY

a. During lift off, the ship speed can be maintained at the on bottom tow speed, or it can be increased, but not to more than the maximum 3.5 knots.

b. The winch speed for lift off should be 0.8 meters per second. This speed should be maintained until the depressor is at the desired altitude for the return leg, or until the depressor is near the surface for recovery. The general idea is to affect the lift off as quickly as possible.

c. Once the Disturber has cleared the seafloor and at an altitude of at least 20 meters, the pumps should be turned off by pressing the F7 and F5 keys or the Escape key on the control keyboard. Note that when the pumps are turned off, the system voltage should be returned to approximately 210 volts.

d. Once the pumps have been turned off and the Disturber altitude has reached approximately 50 meters, the system can be shut down in accordance with normal procedures.

e. The ship should maintain a straight coarse until the cable scope has been reduced to a length of at least 200 meters less than the water depth. Once this has occurred, the ship is free to make necessary turns as required. Keeping in mind, of course, that the proper cable fleet angle be maintained off the stern so as to not damage the tow cable.

f. The Disturber may remain deployed indefinitely without recovery. However, every three or four days it should be recovered to the deck of the ship for a complete check out. This happens to match with the expected battery life of the navigation transponder on the depressor. When the depressor has to be recovered in order to replace the batteries, it is suggested that the Disturber also be recovered and given a thorough pre-dive check. If all is satisfactory, it may be immediately launched for the next deployment.

APPENDIX 2

Sediment Trap Processing Protocol

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The sediment traps recovered on the BIE -II cruise were processed with in 2 hours of their recovery. First the traps were removed from their mooring frames and taken below where they were tied upright in a wooden rack. The lids on the traps, which were put into place when they were recovered by the small boat, were first removed the water clarity in the trap determined using a small flashlight. If the water was clear and sediment could be seen in the bottom of the trap, the top water (6.5 l) was siphoned into a cubitainer for later analysis. The remaining sediment and water remaining in the trap was carefully transferred into a beaker, and subsequently into 4 to 8 50-ml centrifuge tubes. The number of tubes required was determined by the amount of water and sediment left in the bottom of the trap. The centrifuge tubes were then spun for 7 minutes, the top water decanted into the cubitainer and the remaining sediment in the 4 to 8 centrifuge tubes concentrated into two or three tubes. The samples were spun once again for 7 minutes and entire process repeated until all of the sediment was concentrated into one tube. The volume of material was then determined and then sediment sample saved for later gravimetric analysis.

For moorings 6, 7 and 11, both replicate sediment traps were processed. For all of the sediment traps recovered at the end of the cruise, one trap from each mooring was chosen randomly for centrifuge processing and the other trap's material was transferred into a cubitainer and shipped "as is" for Th analysis.