

**Passaic River Post Dredging
Sediment Profile Imaging Survey,
December 2005**

Prepared for:

Aqua Survey, Inc.
469 Point Breeze Road
Flemington, NJ 08822

Prepared by:

Robert J. Diaz
R.J. Diaz and Daughters
6198 Driftwood Lane
Ware Neck, VA 23178

January 2006
(Text Revised October 2006)

TABLE OF CONTENTS

1.	INTRODUCTION	1
2.	MATERIALS AND METHODS	2
2.1.	Image Analysis	3
2.2.	Data Reduction	5
3.	RESULTS	6
3.1.	Overview	6
3.2.	Physical Processes and Sediments	6
3.3.	Apparent Color RPD Layer Depth	7
3.4.	Biological Processes and Organism Sediment Index	8
4.	DISCUSSION	9
5.	REFERENCES	11

APPENDICES

APPENDIX A:	Sediment Profile Image Data, December 2005
APPENDIX B:	Original Sediment Profile Images
APPENDIX C:	Stitched Sediment Profile Image
APPENDIX D:	Adjusted and Labeled Sediment Profile Image

TABLES

Table 1.	Relationship of SPI parameters with apparent infaunal successional stage.
Table 2.	Parameters ranges and scores for calculation of OSI. Taken from Rhoads and Germano (1986).
Table 3.	Location of SPI stations, time of sampling, and depth at time of sampling.
Table 4.	Summary of SPI data from the 15 Lower Passaic River stations, December 2005.

FIGURES

- Figure 1. Location of the LPRRP pilot dredging study area in the Passaic River. Modified from Malcome Pirine et al. (2005).
- Figure 2. Location of SPI stations within the sediment-coring grid established around the pilot dredged area.
- Figure 3. Example of image stitching used to combine original sequence of images into a single SPI.
- Figure 4. SPI from station A1-West, replicate 1 with labeled features. Light brown oxidized sediments at the surface had a thin layer of lighter gray sediments underneath than a fine-sand layer and another lighter gray layer. Sediment at the bottom of the image was darker gray. Red dotted line is the approximate location of the apparent color RPD layer. A1 is an anaerobic void and G1 is a gas-filled void. W1 appears to be a worm.
- Figure 5. SPI replicates from stations A1, A2, and A3. A is anaerobic void, G is gas void, V is oxic void, and W is worm.
- Figure 6. SPI replicates from stations C1, C2, and C3. A is anaerobic void, G is gas void, V is oxic void, and W is worm.
- Figure 7. SPI replicates from stations E1, E2, and E3. A is anaerobic void, G is gas void, V is oxic void, and W is worm.
- Figure 8. SPI replicates from stations B1-North, A1-West, and A3-West. A is anaerobic void, G is gas void, V is oxic void, and W is worm.
- Figure 9. SPI replicates from stations D1-North, E1-East, and E3-East. A is anaerobic void, G is gas void, V is oxic void, and W is worm.
- Figure 10. Mosaic of selected SPI arranged over the sediment-coring grid. Scale at top of images is 5 cm.
- Figure 11. Frames extracted from the surface video showing the sediment surface in front of the profile camera prism. Sediment surfaces are unconsolidated with many leaves. Top of image is about 40 cm wide and bottom about 30. The prism wiper bar is to the left.
- Figure 12. Location of the sediment-coring grid relative to SPI transects sampled in June 2005. Modified from Germano and Associates (2005).
- Figure 13. Mosaic of SPI from sediment-coring grid, December 2005, and nearby lower Passaic River transects, June 2005 (Germano and Associates, 2005). Figure 12 shows the actual location of stations. Scale at top of images is 5 cm.
-

1. INTRODUCTION

The U.S. Environmental Protection Agency (USEPA), the U.S. Army Corps of Engineers (USACE), and the New Jersey Department of Transportation (NJDOT) are conducting a comprehensive study of the Lower Passaic River in partnership with the New Jersey Department of Environmental Protection (NJDEP), National Oceanographic & Atmospheric Administration (NOAA) and the United States Fish & Wildlife Service (USFWS). Included is the 17-mile tidal reach below the Dundee Dam to Newark Bay with both shorelines almost completely developed, consisting of commercial and industrial properties as well as man-made recreational areas (Figure 1). This study, known as the Lower Passaic River Restoration Project (LPRRP) is a cooperative state and federal effort that will take a comprehensive look at the problems within the Lower Passaic River Basin and identify remediation and restoration options to address those problems. Details on LPRRP can be found in the Work Plan documents (Malcome Pirnie, et al., 2005).

The project's goals include:

- Remediate contamination found in the river to reduce human health and ecological risks.
- Improve the water quality of the river.
- Improve and/or create aquatic habitat.
- Reduce the contaminant loading in the Passaic and the New York/New Jersey Harbor Estuary.

The specific goals of the environmental dredging pilot study are to collect data on environmental dredging technology performance and the extent of sediment re-suspension in the Lower Passaic River during dredging operations. Information gained from the dredging pilot study will help guide technical evaluations for the Lower Passaic River. During the week of December 5 - 9, 2005 approximately 5,000 cubic yards of contaminated sediments was dredged from a 1.5-acre area in the Harrison Reach of the river between river mile 2 and 3. As part of the overall LPRRP study, SPI was used to characterize the physical and biological condition for the entire 17-mile stretch of the river (Germano and Associates 2005). In June 2005, Germano and Associates (2005) conducted an initial SPI survey along a series of cross-river transects from just below Garfield, NJ to Newark Bay. A sediment profile camera was used again four to eight days post-dredging (December 2005) as a method to qualitatively measure residuals from the dredging activities.

The sediment profile camera was developed by Rhoads and Cande (1971) to investigate processes structuring the sediment-water interface and as a means of obtaining *in situ* data on benthic habitat conditions. The technology of remote ecological monitoring of the sea floor (REMOTS) or SPI has allowed for the development of a better understanding of the complexity of sediment dynamics, from biological and physical points of view (for examples see: Rhoads and Germano, 1986; Valente, et al., 1992; Bonsdorff, et al., 1996; Nilsson and Rosenberg, 2000; and Rosenberg, et al., 2001; Solan, et al., 2004). This approach to evaluating the environment, and potential impacts to it, can be easily combined with classical approaches to habitat and impact assessment providing scientists and managers with a more holistic ecosystem view.

2. MATERIALS AND METHODS

On December 13, 2005, the SPI Survey was conducted as part of the Lower Passaic River Restoration Project (LPRRP) after the test dredging that was done between December 5 to 9, 2005. Digital SPI were collected at nine stations (A1, A2, A3, C1, C2, C3, E1, E2, and E3) within an established sediment-coring grid setup around the area that was dredged and six stations (A1-West, A3-West, B1-North, D1-North, E1-East, and E3-East) around the sediment-coring grid and outside the dredging footprint (Figure 2). Reference for the sediment-coring grid was sediment collected in the summer of 2005 to characterize the geochemistry in the selected pilot area.

The sediment profile camera system consisted of a digital camera enclosed in a pressure-resistant housing, a 45° prism, and a mirror that reflects an image of the sediment through the camera lens. A strobe was mounted inside the prism and was used to illuminate the sediment. The camera/prism system was mounted in a cradle secured to a larger frame ensuring that the prism penetrated the sediment at a 90° angle. An electric winch was used to lower the entire assembly (at a consistent rate) to the seafloor. When the system was on the seabed, a hydraulic piston controlled the penetration rate of the camera/prism assembly into the sediment. More detail on sediment profile camera operation can be found in Rhoads and Cande (1971) and Germano and Associates (2005).

At each station, a digital Hulcher sediment profile camera was deployed three times. The digital profile camera captured a 5.2-megapixel image using a Minolta Dimage-7i camera. The camera was set to ISO 200, white balance to flash color temperature, contrast to normal, saturation to normal, maximum image size of 2560 X 1920 pixels, and saved using super-fine jpg compression. Images were stored in the camera on a 1-gigabyte IBM microdrive. A surface video camera was also mounted on the profile camera frame to monitor prism penetration and provide information on surface sediments. The video output of the Dimage-7i was also used to monitor prism penetration during sampling. The video feeds from the surface and profile cameras were sent to the surface vessel to allow monitoring of the Hulcher camera operation and image capture in real-time. The combination of video and digital images ensures a more reliable collection of SPI data. If the video indicated the camera frame did not deploy properly, additional replicates were taken. Between replicates, a rubber wiper bar attached to the frame cleaned the Plexiglas window of the prism when the camera was raised from the bottom. Station and time of each camera penetration were recorded by hand in a field log. The location of each replicate was marked as an event by Aqua Survey personnel using Differential Global Positioning System (DGPS) interfaced to a laptop computer running HYPACK® hydrographic survey software. HYPACK® provided the vessel captain with distance and direction to each sample station.

The camera was triggered from the surface on contact with the sediment with a series of images taken at about an interval of 1.5-sec until the prism stopped penetrating the sediment. No penetration stops were used and the prism was allowed to penetrate until stopped by the sediment. Approximately 75 pounds of lead were added to the camera frame to improve penetration at all stations. Images stored on electronic media in the camera were downloaded

onto a laptop computer once the fieldwork was completed, checked for image quality, and transferred to CD-ROM for more permanent storage prior to leaving the field site.

2.1. Image Analysis

A subset of images from the sequence of images captured was “stitched” together to form a single composite image for 18 of the 45 station-replicate combinations (15 stations x 3 replicates per station). Using this technique for the soft sediments encountered in the Passaic River, as much as 35 cm (13.8 inches) of sediment was imaged. For example, four images were stitched together to form the final image for replicate 3 at station E3-East (Figure 3). Because the prism can move laterally or tilt as it penetrates soft sediments and some smearing of sediments occurs as the faceplate passes through the sediment, the alignment of sequential images is not completely registered. There was also a light gradient from top to bottom in the prism that resulted in the bottom 3-4 cm (1.2-1.5 inches) of the image being about a half of an f-stop darker than the top.

All sediment profile images were evaluated visually with data of all features recorded in a preformatted spreadsheet file. Images selected for analysis were digitally processed to enhance contrast and color using a Red-Green-Blue (RGB) color space. Each image was histogram equalized and trimmed from 0.2 to 2.0% using the image program Adobe PhotoShop®. Steps in the computer analysis of each image were standardized and data sequentially saved to a spreadsheet file for later analysis. Details of how these data were obtained can be found in Diaz and Schaffner (1988) and Rhoads and Germano (1986). A description of each parameter measured and evaluated follows.

Prism Penetration - This parameter provided an estimate of sediment compaction with the profile camera prism acting as a dead weight penetrometer. The further the prism entered into the sediment, the softer the sediments, and likely the higher the water content. Penetration was measured as the distance the sediment moved up the 23-cm length of the faceplate.

Surface Relief - Surface relief or boundary roughness was measured as the difference between the maximum and minimum distance the prism penetrated. This parameter also estimated small-scale bed roughness, within the view of the 15 cm width of the prism faceplate, which is an important parameter for predicting sediment transport and in determining processes that dominate surface sediments. The origin of bed roughness can be determined from visual analysis of the images.

Apparent Color Redox Potential Discontinuity (RPD) Layer - This parameter is an important estimator of benthic habitat conditions, which relates directly to the quality of the habitat (Rhoads and Germano, 1986; Diaz and Schaffner, 1988; Nilsson and Rosenberg, 2000). The apparent RPD provides an estimate of the depth to which sediments appear to be oxidized. The term “apparent” is used in describing this parameter because no actual measurement was made of the redox potential. It is assumed that given the complexities of iron and sulfate reduction-oxidation chemistry, the reddish-brown sediment color tones (Diaz and Schaffner, 1988; Rosenberg et al., 2001) indicate sediments are in an oxidative geochemical state, or at least are

not intensely reducing. This is in accordance with the classical concept of RPD layer depth, which associates it with sediment color (Fenchel, 1969; Vismann, 1991). The RPD boundary was traced across the SPI by eye then the area of the image from the sediment-water-interface to the boundary was calculated and divided by the width of the image to get an estimate of the average RPD layer depth for the image. See Figure 4 for an example RPD layer trace.

Sediment Grain Size -Grain size is an important parameter for determining the nature of the physical forces acting on a habitat and is one of the major factors in determining benthic community composition (Rhoads, 1974; Snelgrove and Butman, 1994). The sediment type descriptors used for image analysis follow the Udden-Wentworth classification as described in Folk (1974) and represent the major modal class for each image. Maximum grain size was also estimated. Grain size was determined by comparison of collected images with a set of standard images for which mean grain size had been determined in the laboratory.

Surface Features -These parameters included a wide variety of physical (such as bedforms or flocculent sediment surfaces) and biological features (such as biogenic mounds, shell, or tubes). Each contributes information on the type of habitat and its ability to support benthic organisms. Surface features were visually evaluated from each image and compiled by type and frequency of occurrence.

Subsurface Features – These parameters included a wide variety of features (such as infaunal organisms, burrows, water filled voids, gas voids, or sediment layering) that reveal a great deal about physical and biological processes influencing the bottom. For example, habitats with grain-size layers or homogeneous color layers are generally dominated by physical processes while habitats with burrows, infaunal feeding voids, and/or visible infaunal organisms are generally dominated by biological processes (Rhoads and Germano, 1986; Diaz and Schaffner, 1988; Valente et al., 1992; Nilsson and Rosenberg, 2000). Subsurface features were visually evaluated from each image and compiled by type and frequency of occurrence. Up to five subsurface features in each image were labeled (see Appendix D images) and their distance from the sediment surface measured (see Appendix A). See Figure 4 for examples.

Apparent Successional Stage - Sediment profile data have been used to estimate the apparent successional stage of the infauna (Rhoads and Germano, 1986). Characteristics associated with pioneering or colonizing (Stage I) assemblages (in the sense of Odum, 1969), such as dense aggregations of small polychaete tubes at the surface and shallow apparent RPD layers, are easily seen in sediment profile images. Advanced or equilibrium (Stage III) assemblages also have characteristics that are easily seen in sediment profile images, such as deep apparent RPD layers and subsurface feeding voids. Stage II is intermediate to Stages I and III, and has characteristics of both (Rhoads and Germano, 1986). A set of SPI parameters is evaluated to estimate the apparent successional stage with the generalized associations described in Table 1.

Organism Sediment Index -Rhoads and Germano (1982, 1986) developed the multi-parameter organism-sediment index (OSI), from data provided by SPI, to characterize benthic habitat quality in soft-bottom estuarine and coastal embayments. The OSI defines quality of benthic habitats by evaluating the depth of the apparent RPD layer, apparent successional stage of infauna, the presence of gas bubbles in the sediment (an indication of high rates of

methanogenesis that are associated with high carbon inputs to the sediments), and visual signs of the presence of low dissolved oxygen conditions (sulfide covered tubes, anaerobic sediment at the interface, bacterial mats) at the sediment-water interface. The parameter ranges and scores are used in the calculation of the OSI are in Table 2.

Stage I on III refers to the presence of pioneering Stage I species present on or near the sediment surface and equilibrium Stage III species present below the sediment surface. Similarly Stage II on III is the presence of intermediate successional stage species at the surface with equilibrium species at depth in the sediments. The OSI ranges from -10, poorest quality habitats, to +11, highest quality habitats. For example, replicate 1 from station A1 had an OSI of 5, calculated as follows: RPD layer depth of 5.5 cm was scored as 6, estimated successional stage was Stage I and scored as 1, gas voids were present and scored as -2, dissolved oxygen did not appear to be low and thus did not contribute to the scoring. The three parts were summed to get the OSI ($6 + 1 - 2 = 5$). At stations where the RPD layer was deeper than prism penetration and penetration was >3.7 cm, which is the lower limit for the highest RPD depth category in the OSI calculation (see Table 2), the value of 6 was assigned to the RPD contribution and the OSI was not assigned a "greater than" ($>$) designation. For example, two replicates from station A3-West had apparent RPD layer depths deeper than the prism penetration (18 to 25 cm) and 6's were assigned for calculation of the OSI.

The formulation of the OSI and contribution of each component are scaled to reflect the increasing importance of bioturbation, sediment mixing mediated by organisms, and other biogenic activity, such as structure building, in defining good benthic habitat quality. For higher salinity estuarine and coastal bay benthic habitats in the northeastern United States, OSI values >6 indicate good habitat conditions and are generally associated with bottoms that are not heavily influenced by stress, either physical or anthropogenic (Rhoads and Germano, 1986). However, the level of OSI that defines the breakpoint between stress and non-stressed habitat in lower salinity brackish and tidally dominated systems like the Passaic River has not been determined. It could be higher or lower than 6. Within the Chesapeake Bay ecosystem, a temperate coastal system with tributaries that have benthic habitats similar to those in the lower Passaic River, Diaz et al. (2003) found that an OSI of 3 was the breakpoint between stressed and non-stressed habitat. Thus for this LPRRP study, the OSI is used only as a relative indicator of habitat conditions with higher OSI values associated with higher benthic habitat quality.

2.2. Data Reduction

To summarize the data reduction performed on the SPI data, quantitative parameters were averaged from the three replicate images (prism penetration, surface relief, maximum RPD depth, average RPD depth, OSI, and number of infauna, burrows, and voids per image). For categorical parameters, the highest value or presence for all replicate images was assigned to a station. For example, if only one replicate had shell hash then the summary for that station would be shell hash present. When a quantitative parameter for one replicate at a station had a "greater than" symbol ($>$) assigned and the other replicates were measured, only the measured values were used in the calculation of the average. For example, at station E1, the RPD was deeper than the prism penetration for replicate 1 and was assigned the value of >7.9 cm; replicates 2 and 3 had a measured RPD of 1.6 and 1.1 cm, respectively. Only the 1.6 and 1.1 cm values were used to calculate the mean for the station.

3. RESULTS

3.1. Overview

On December 13, 2005, four days after the completion of the pilot dredging, a SPI survey was conducted in and around the dredged area. Images were collected at 15 stations (Figure 2). At each station, three replicates were taken for a total of 45 station-replicates. Location and other station data are presented in Table 3. SPI data for all replicate images are presented in Appendix A with a station summary in Table 4. The 108 original SPI image files analyzed for this report are presented in Appendix B. Stitched images are presented in Appendix C. Adjusted and labeled images in high resolution are presented in Appendix D. Lower resolution images are presented in Figures 5, 6, 7, 8, and 9. Figure 10 is a mosaic of representative images from each station arranged spatially. A 5-cm scale bar is located at the top of all images.

Because of high turbidity levels, the resolution from the surface video camera was poor. The bottom was observed with some clarity at only stations A3, C2, C3, E3, B1-North, and E3-East (Figure 11). The area viewed by the surface video was in front of the profile camera prism with the field of view being about 0.12 m² (30 by 40 cm). The video revealed that a strong ebb current was flowing during the collection of SPI.

3.2. Physical Processes and Sediments

Physical processes appeared to dominate the study area with the sediment surfaces being unconsolidated silt-clay greater than 4 Phi at all stations except E1-East where a 6.8 cm layer of medium-coarse-sand (2 to 0 Phi) was present. There was no evidence of biological processes structuring surface sediments at any of the stations. Surface sediments were also unconsolidated, flocculent, and easily disturbed by the SPI frame (Figure 11). Even at E1-East with a medium-coarse-sand layer at the surface there was silt-clay mixed in the sandy layer (Figure 9). Bed roughness at all stations was due to uneven sediment surfaces and ranged from 0.7 cm at station C2 to 3.1 cm at station E3-East (Table 4, Figures 5 to 9).

Average station prism penetration ranged from 14.0 cm at station B1-North to 29.3 cm at E3East and likely reflected a range in sediment compaction with higher compaction (shallower penetration) on the northern side of the pilot project area outside of the dredging pilot area. Lowest compaction (deeper penetration) stations tended to be on the southern side of the pilot project area and within the dredging pilot area (Figure 10). Within a station there was considerable variation between the three replicate SPI in prism penetration. The largest range between replicates was 21.2 cm and occurred at station E1 (Figure 7). The smallest range of 2.1 cm occurred at station B1-North, which was also the station that had the shallowest penetration (Figure 8). At station E1 the shallow penetration for replicate 1 appeared to be due to small twigs that stopped the prism.

Color layering of sediments occurred at stations E3-East, B1-North, and D1-North all outside of the sediment-coring grid (Figure 10). At station D1-North, darker gray sediments overlaid lighter gray sediments (Figure 8). At station E3-East there were two color layers observed with the first a darker gray sediments over a second lighter gray sediment layer that was over darker gray

sediments (Figure 9). Layering at B1-West was lighter gray sediments over darker gray (Figure 8). The stations with the most uniform brownish silt-clay surface sediments were A2, C2, C3, E2, E3, and E3-East (Figures 5, 6, 7, and 9). At stations A1, A3, C1, E1, A1-West, A3-West, and E1-East the brownish silt-clay sediments also had small gray colored clasts included (Figures 5, 6, 7, 8, and 9), which could also be an indication of a recent major deposition event. The only stations to have brownish surface sediments that did not appear to be recently deposited were B1-North and D1-North (Figures 8 and 9).

Grain-size layering occurred at stations A1-West and E1-East, also outside the sediment-coring grid (Figure 10). At A1-West replicate 1, a layer of lighter gray silt-clay overlaid a layer of fine-sand that overlaid another layer of lighter gray silt-clay. The other two replicate SPI at A1-West did not have sediment layering and were mostly brownish silt-clay (Figure 8). At station E1-East replicates 1 and 2 had a layer of medium-coarse-sand at the surface overlying silt-clay. Replicate 3 from E1-East was silt-clay at the surface with no indication of sandy sediment, but had a lighter gray color layer overlying a layer of dark colored detritus (Figure 9). At A3-West, the only other station outside the grid, sediments were almost completely brownish in color with no layering (Figure 8). The brownish color tones and uniform texture or fabric of the silt-clay sediments are both indications that the sediments have been recently deposited, likely from the dredging event.

If all the sediment layers observed in SPI were associated with the dredging, as much as 10 to 14 cm of deposition occurred in the area immediately around the dredged area. The amount of sediment that was deposited within the dredged area appeared to be on the order of 4 to 10 cm, based on the assumption that the apparent oxidized sediments as measured by the RPD layer depth were dredging related (Table 4). Station E1 had the least RPD layer depth at 1.4 cm. The thickness of dredged material deposited around the dredged site, both up stream and down stream, were about the same.

3.3. Apparent Color RPD Layer Depth

Average station RPD layer depths ranged from 0.6 cm at station D1-North (Figure 9) to 10.4 cm at station A3-West (Figure 8). All of the RPD layers appeared to be associated with physical processes and not with biological processes. In silty-clay sediments physical diffusion limits oxygen penetration to <1 cm (Jørgensen and Revsbech, 1985). This was likely the case for stations D1-North and B1-North (Figures 7 and 8) where the shallower RPD layer depths were examples of diffusion-limited RPD layers. When the RPD layers in fine sediments are >1 cm, it is bioturbation by infauna (Rhoads, 1974; Aller and Aller, 1998) or major resuspension/deposition events (Don Rhoads, personal communication) that are responsible for oxygenating sediments. For all other stations, the >1 cm RPD layer depths appeared to be related to resuspension/deposition events as there was no evidence that the deeper RPD layer depths were related to biogenic activity of infauna. The most important factors determining the depth of the RPD layers at the 15 stations sampled appeared to be the recent dredging event that resuspended large quantities of muddy fine-grained sediments, subjected them to oxidation, and then subsequent rapid deposition into layers.

Anaerobic sediments below the RPD layer appeared to be reducing or sulfidic (dark gray-blue in

color) at all stations. This along with the presence of gas voids indicated that organic carbon loading to the sediments was high and that in general the study area was net depositional. Comparison of 1989 and 2004 bathymetry indicated that the sediment-coring grid was located in an area of the Passaic River that experienced a patchy mosaic of deposition with as much as 3 ft in some areas (see Plate 37 in Malcome Pirine, et al. (2005). The darker color of reduced sediments underlying the oxidized lighter colored sediments is a function of organic carbon content and geochemistry (Vismann, 1991). Depositional areas that receive relatively higher organic content sediments than surrounding areas would tend to have darkly colored and more gaseous anaerobic sediments.

3.4. Biological Processes and Organism Sediment Index

As expected after the dredging and removal of 2 to 3 feet of material from the pilot area, there was little evidence in the SPI that biological processes were important in structuring sediments at any of the 15 stations sampled. No tubes were observed at the sediment-water-interface and no active burrows were observed in the sediments. At about half of the stations what appeared to be infaunal organisms occurred (Table 4). Given the amount of detritus and leafs seen in the images, however, the organism-like structures may have been bits of detritus. The only mobile epifaunal organism observed was a single mysid shrimp at station A1-West replicate 2 swimming above the sediment-water-interface (Figure 8).

The apparent successional stage estimated for SPI was Stage I, indicating that benthic communities would be composed mainly of small pioneering species that would be the first colonizers after a major disturbance such as dredging. There was no evidence of advanced successional Stage III equilibrium communities observed in any image. The oxic voids observed at stations A1, A2, and A3 (Figure 5) did not appear to be biogenic in origin and were likely caused by leafy detritus being cut by the edge of the prism and disturbing the sediments. This artifact is more obvious in images from stations E1 and A3-West (Figures 7 and 8). It appeared that the dominance of physical processes in the form of fluctuating tidal currents and sediment deposition/resuspension lead to dynamic surface sediments that prevented the development of more advanced successional stages. Low salinity would also contribute to the stressors acting to keep the benthos in an early stage of colonization.

The average station Organism Sediment Index (OSI) ranged from 0.7 at station D1-North (Figure 9) to 7.0 at stations A3, C1, C3, and A3-West (Figures 5, 6, and 8). However, the higher OSI values were determined mainly by the deeper RPD layer depths, which appeared to be physical in origin and likely related to the dredging, as stations A3, C1, and C3 were within the area dredged. There was no evidence that the deep RPD layers were related to bioturbation by infauna, which is the premise upon which the OSI scoring for RPD is based (Rhoads and Germano, 1986). This problem compromises the value of OSI in assessing relative benthic habitat conditions. The lowest values of the OSI were associated with stations that had both shallow RPD layer depths and gas voids (Table 4).

4. DISCUSSION

The sediments within and around the sediment-coring grid established as part of the pilot dredging project for the Lower Passaic River Restoration Project (LPRRP) were primarily silt-clays and appeared to be dominated by physical processes (Figure 10). The unconsolidated nature of the surface sediments along with their uniform light brownish colors at all stations except the two stations north of the sediment-coring grid (B1-North and D1-North) also indicated physical processes dominated sediment surfaces likely associated with the dredging event. Additional evidence of dredging was the occurrence of sands as only thin layers either at the sediment surface (station E1-East, Figure 9) or layered between silt-clay sediments (station A1-West, Figure 8). A SPI survey of the entire LPRRP study area by Germano and Associates (2005) in June 2005 concluded that the lower Passaic River represented a dynamic sedimentary environment characterized by cycles of resuspension/deposition based on multiple layering within the upper 20 cm of the sediment column. The presence of gas void and dark colored anaerobic sediments in the brackish reach of the Passaic River indicated excessive organic enrichment, particularly in the highly developed and densely populated segment in the vicinity of the city of Newark. Comparison of 1989 and 2004 bathymetry for the area around the sediment-coring grid also indicated the area to be net depositional with as much as 2 to 6 cm sediment accumulation in some areas (Malcome Pirine, et al., 2005).

There was little evidence of biological processes at any of the stations that could produce the deep RPD layer depths observed at many of the sediment-coring grid stations. Oxidic voids, usually associated with feeding activity of infauna, observed at three stations did not appear to be biogenic in origin. The large amounts of detritus mixed into the sediments likely caused the voids within the apparently oxidic sediment layer. Small infaunal organisms were observed at about half of the stations. The small size of these organisms and leaf detritus made their confirmation difficult, but if they were infauna they would be consistent with the fauna known to occur within a kilometer of the sediment-coring grid. Grab samples collected in the summer of 2005 (Earth Tech, et al., 2005) indicated most of the species were small surface dwellers such as small tube-building spionid polychaetes like *Streblospio benedicti* and *Polydora* sp. and the amphipod *Gammarus* sp., or small subsurface burrowers such as a Naididae oligochaete, which was also the most abundant taxa. There were also several larger body-size subsurface dwelling species such as the burrowing isopod *Cyathura polita* and the burrowing polychaetes *Nereis succinea*, *Marenzelleria viridis*, and *Eteone* sp. in the grab samples. *Cyathura polita* and *Nereis* spp. were found to be major bioturbating species in Newark Bay (Diaz, 2005), but there was no evidence of these species in or around the sediment-coring grid. Similarly, Germano and Associates (2005) concluded that the brackish segment of the river was dominated by small, opportunistic and/or pollution-tolerant taxa based on the apparent successional Stage I designation of SPI.

Comparing the near channel station from the June 2005 SPI survey from transects T6 and T7, which were near the sediment-coring grid (Figure 12), with the December 2005 SPI survey, it can be seen that the sediments were similar in grain-size and color (Figure 13). Leaf detritus was present at many stations in June as were gas voids and sediment color layers (Germano and Associates, 2005). Germano and Associates (2005) classified benthic habitats at all stations on T6 and T7 as being layered silts with or without methane. This classification would fit most of

the stations in and around the sediment-coring grid. Other benthic habitat characteristics in common between the transects T6 and T7 stations and sediment-coring grid stations were the presence of soft, high water content sediments, organic detritus (typically decayed leaf litter) occurring in layers or mixed with silt-clay sediments, and sediment layering.

RPD layer depths at the selected T6 and T7 stations were shallower in June relative to December and most closely matched the appearance of the RPD layers of stations outside the sediment-coring grid. The RPD layers within the sediment-coring grid were deeper and more uniform in color and texture. The depth of RPD layer is an indication of how deeply sedimentary geochemical processes are primarily oxidative. The thickness of the RPD layer has long been associated with benthic habitat quality, in particular with regards to organic enrichment gradients (Pearson and Rosenberg, 1978) with habitat quality positively correlated with RPD layer depth (Rhoads and Germano, 1986; Nilsson and Rosenberg, 2000). Below the RPD layer, geochemical processes are primarily anaerobic or reducing (Fenchel and Riedl, 1970). In silt-clay sediments similar to those in the lower Passaic River, physical diffusion limits oxygen penetration to <1 cm (Jørgensen and Revsbech, 1985). It appeared that diffusion-limited RPD layers occurred at stations B1-North and D1-North in December and at SPI-128 in June (Figure 13). When the RPD layers in silt-clay sediments are >1 cm, it is bioturbation by infauna (Rhoads, 1974) or major resuspension/deposition events (Don Rhoads, personal communication) that are responsible for oxygenating sediments.

Given the uniform color and texture, and absence of bioturbating fauna in the SPI and grab samples, it is likely that the thick RPD layers observed within the sediment-coring grid in December are a result of a major resuspension/deposition event associated with the dredging which took place the week before the December SPI sampling. The occurrence of sediment color and grain-size layers outside the perimeter of the dredged area may also be related to deposition of sediments resuspended during the dredging. If all the sediment layers observed in SPI were associated with the dredging, as much as 10 to 14 cm of deposition occurred in the area immediately around the dredged area and the amount of sediment deposited within the dredged area was on the order of 4 to 10 cm, based on the assumption that the apparent oxidized sediments as measured by the RPD layer depth were dredging related (Table 4).

5. REFERENCES

- Aller, R.C. and J.Y. Aller. 1998. The effect of biogenic irrigation intensity and solute exchange on diagenetic reaction rates in marine sediments. *Journal of Marine Research* 56:905-936.
- Bonsdorff, E., R.J. Diaz, R. Rosenberg, A. Norkko and G.R. Cutter. 1996. Characterization of soft-bottom benthic habitats of the Åland Islands, northern Baltic Sea. *Marine Ecology Progress Series* 142:235-245.
- Diaz, R.J. 2005. Estimation of the biologically active zone, Newark Bay, New Jersey. Final Report, BBL Sciences, Annapolis, MD. 48 pp.
- Diaz, R.J. and L.C. Schaffner. 1988. Comparison of sediment landscapes in the Chesapeake Bay as seen by surface and profile imaging. p. 222-240. In: M. P. Lynch and E. C. Krome, eds. *Understanding the estuary; Advances in Chesapeake Bay research*. Chesapeake Res. Consort. Pub. 129, CBP/TRS 24/88.
- Diaz, R.J., G.R. Cutter, Jr. and D.M. Dauer. 2003. A comparison of two methods for estimating the status of benthic habitat quality in the Virginia Chesapeake Bay. *Journal of Experimental Marine Biology and Ecology* 285-286:371-381.
- Earth Tech, Malcolm Pirnie, Inc. and Aqua Survey Inc. 2005. Technical report, geophysical survey, lower Passaic River restoration project. Report to NJ Department of Transportation-OMR, Office of Maritime Resources, Trenton, NJ. 353 pp.
- Fenchel, T. 1969. The ecology of marine microbenthos. IV. Structure and function of the benthic ecosystem, its chemical and physical factors and microfauna communities with special reference to the ciliated Protozoa. *Ophelia* 6:1-182.
- Fenchel, T. M. and R.J. Riedl. 1970. The sulphide system: a new biotic community underneath the oxidized layer of marine sand bottoms. *Marine Biology* 7:255-268.
- Folk, R.L. 1974. *Petrology of sedimentary rocks*. Austin, Texas, Hemphill's. 170 pp.
- Germano and Associates, Inc. 2005. Sediment profile imaging survey of sediment and benthic habitat characteristics of the lower Passaic River. Final Report DS-ASI-01, Aqua Survey, Inc., Flemington, NJ. 129 pp.
- Jørgensen, N. and N.P. Revsbech. 1985. Diffusive boundary layers and the oxygen uptake of sediments and detritus. *Limnology and Oceanography* 30:111-122.
- Malcolm Pirnie, Inc., Battelle and HydroQual, Inc. 2005. Work plan lower Passaic River restoration project. Version: 2005/08/02. 151 pp.

- Nilsson, H.C. and R. Rosenberg. 2000. Succession in marine benthic habitats and fauna in response to oxygen deficiency: analyzed by sediment profile imaging and by grab samples. *Marine Ecology Progress Series* 197:139-194.
- Normandeau Associates and TRC Environmental. 2002. HubLine pipeline project soft substrate benthos first preconstruction sampling. Report to Duke Energy Gas Transmission.
- Odum, E.P. 1969. The strategy of ecosystem development. *Science* 164:262-270.
- Pearson, T.H. and R. Rosenberg. 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. *Oceanography and Marine Biology Annual Review* 16:229-311
- Rhoads, D.C. and S. Cande. 1971. Sediment profile camera for in situ study of organism-sediment relations. *Limnology and Oceanography* 16:110-114.
- Rhoads, D.C. 1974. Organism sediment relations on the muddy sea floor. *Oceanography and Marine Biology Annual Review* 12:263-300.
- Rhoads, D.C. and J.D. Germano. 1982. Characterization of organism-sediment relations using sediment profile imaging: an efficient method to remote ecological monitoring on the seafloor (REMOTS'system). *Marine Ecology Progress Series* 8:115-128.
- Rhoads, D.C. and J.D. Germano. 1986. Interpreting long-term changes in benthic community structure: a new protocol. *Hydrobiologia* 142:291-308.
- Rosenberg R., H.C. Nilsson and R.J. Diaz. 2001. Response of benthic fauna and changing sediment redox profiles over a hypoxic gradient. *Estuarine Coastal and Shelf Science* 53:343-350.
- Solan, M., B.J. Cardinale, A.L. Downing, K.A.M. Engelhardt, J.L. Ruesink and D.S. Srivastava. 2004. Extinction and ecosystem function in the marine benthos. *Science* 306:1177-1180.
- Snelgrove, P.V.R. and C.A. Butman. 1994. Animal-sediment relationships revisited: cause versus effect. *Oceanography and Marine Biology: an Annual Review* 32:111-177.
- Valente, R.M., D.C. Rhoads, J.D. Germano and V.J. Cabelli. 1992. Mapping of benthic enrichment patterns in Narragansett Bay, Rhode Island. *Estuaries* 15:1-17.
- Vismann, B. 1991. Sulfide tolerance: Physiological mechanisms and ecological implications. *Ophelia* 34:1-27.
- Werme, C.W. and C.D. Hunt. 2001. 2000 Outfall monitoring overview. Report ENQUAD 2001-10, Massachusetts Water Resources Authority, Boston, MA. 92 pp.

Table 1. Relationship of SPI parameters with apparent infaunal successional stage.

Parameter	Successional Stage		
	I	II	III
Average RPD (cm)	<1	1-3	>2
Max Depth RPD (cm)	<2	>2	>4
Small Tubes	+++	++	+
Large Tubes	-	++	+++
Burrows	-	++	+++
Feeding Voids	-	+	+++
Small Infauna	+++	++	+
Large Infauna	-	+	++
Epifauna	+	++	++

"-" = not associated with,

"+" = associated with,

"++" = moderately associated with, and

"+++ " = strongly associated with

Table 2. Parameters ranges and scores for calculation of OSI. Taken from Rhoads and Germano (1986).

Depth of the apparent color RPD:		Estimated successional stage:	
0 cm	0	Azoic	-4
>0 – 0.75	1	I	1
0.76 – 1.50	2	I-II	2
1.51 – 2.25	3	II	3
2.26 – 3.00	4	II-III	4
3.01 – 3.75	5	III	5
>3.75	6	I on III	5
		II on III	5

Other:	
Methane or gas voids present	-2
No/Low DO	-4

Table 3. Location of SPI stations, time of sampling, and depth at time of sampling.

Station	Easting	Northing	Lat.	Long.	Time	Depth (feet)
E1 EAST	594533.3	695506.4	40.742233	-74.130400	10:06:30	13.0
E3 EAST	594561.6	695360.8	40.741833	-74.130300	10:20:43	10.0
D1 NORTH	594418.2	695564.4	40.742394	-74.130814	10:30:17	15.0
B1 NORTH	594297.6	695539.1	40.742326	-74.131250	10:41:01	15.0
A1 WEST	594190.2	695470.1	40.742138	-74.131639	10:52:08	14.5
A3 WEST	594212.6	695324.7	40.741738	-74.131560	11:01:00	9.5
A1	594251.8	695456.7	40.742100	-74.131417	11:08:06	16.5
A2	594261.3	695396.0	40.741933	-74.131383	11:15:30	13.5
A3	594275.4	695329.3	40.741750	-74.131333	11:22:11	9.5
C1	594363.9	695487.9	40.742184	-74.131012	11:29:09	16.0
C2	594385.9	695408.7	40.741967	-74.130933	11:36:18	13.5
C3	594386.2	695341.9	40.741783	-74.130933	11:44:37	9.0
E1	594491.7	695506.3	40.742233	-74.130550	11:51:18	14.5
E2	594496.7	695421.3	40.742000	-74.130533	11:59:23	12.0
E3	594502.9	695354.5	40.741817	-74.130512	12:06:37	8.0

Table 4. Summary of SPI data from the 15 Lower Passaic River stations, December 2005.

Station	Prism			RPD (cm)	Voids				Void Comments	Tubes	Burrows	Stage	Succ. OSI
	Pene- tration (cm)	Bound. Rough. (cm)	Bound. Rough. Origin		Infauna Depth (cm)	Oxic Depth (cm)	Anaerobic Depth (cm)	Gas Depth (cm)					
A1	19.4	1.6	Physical	5.4	4.0	3.0	12.9	15.2	Voids not biogenic	0	0	I	6.3
A1 West	16.1	2.6	Physical	9.0	1.3		11.2	13.1		0	0	I	5.3
A2	17.7	0.8	Physical	7.3	1.7	4.1	15.8	4.7	Voids not biogenic	0	0	I	6.0
A3	20.4	1.5	Physical	4.6	8.1	13.8	20.4		Voids not biogenic	0	0	I	7.0
A3 West	22.3	2.0	Physical	10.4						0	0	I?	7.0
B1 North	14.0	1.0	Physical	0.7	2.3		6.7	12.3		0	0	I	1.0
C1	23.2	1.1	Physical	9.9						0	0	I?	7.0
C2	22.4	0.7	Physical	6.7	1.1		23.6	11.6	Many Gas Voids	0	0	I	5.7
C3	24.3	0.8	Physical	6.3						0	0	I?	7.0
D1 North	17.4	2.2	Physical	0.6			12.7	13.9		0	0	I?	0.7
E1	20.9	1.7	Physical	1.4				14.9	Many Gas Voids	0	0	I?	3.3
E1 East	19.8	1.6	Physical	2.4			5.1	8.0	Many Gas Voids	0	0	I?	2.7
E2	17.8	1.7	Physical	5.7			10.3	10.1		0	0	I?	5.3
E3	18.3	0.9	Physical	4.5	9.1		14.1			0	0	I	6.7
E3 East	29.3	3.1	Physical	6.7	7.3		12.1	23.9	Many Gas Voids	0	0	I	6.3

Station	Grain Size		Fluff of Fines	Detritus	Layer 1		Layer 2		Layer 3	
	Modal	Max.			Thickness (cm)	Description	Thickness (cm)	Description	Thickness (cm)	Description
A1	>4	>4	Yes	Yes						
A1 West	>4	3-2	Yes	Yes	4.0	Lighter gray siltclay	3.8	Fine sand	2.4	Lighter gray siltclay
A2	>4	>4	Yes	Yes						
A3	>4	>4	Yes	Yes						
A3 West	>4	>4	Yes	Yes						
B1 North	>4	>4	Yes	Yes	10.4	Lighter gray siltclay				
C1	>4	>4	Yes	Yes						
C2	>4	>4	Yes	Yes						
C3	>4	>4	Yes	Yes						
D1 North	>4	>4	Yes	Yes	9.7	Darker gray siltclay	4.7	Lighter gray siltclay		
E1	>4	>4	Yes	Yes						
E1 East	>4	1-0	Yes	Yes	6.8	Medium coarse sand	3.1	Darker gray detritus		
E2	>4	>4	Yes	Yes						
E3	>4	>4	Yes	Yes						
E3 East	>4	>4	Yes	Yes	14.3	Darker gray siltclay				

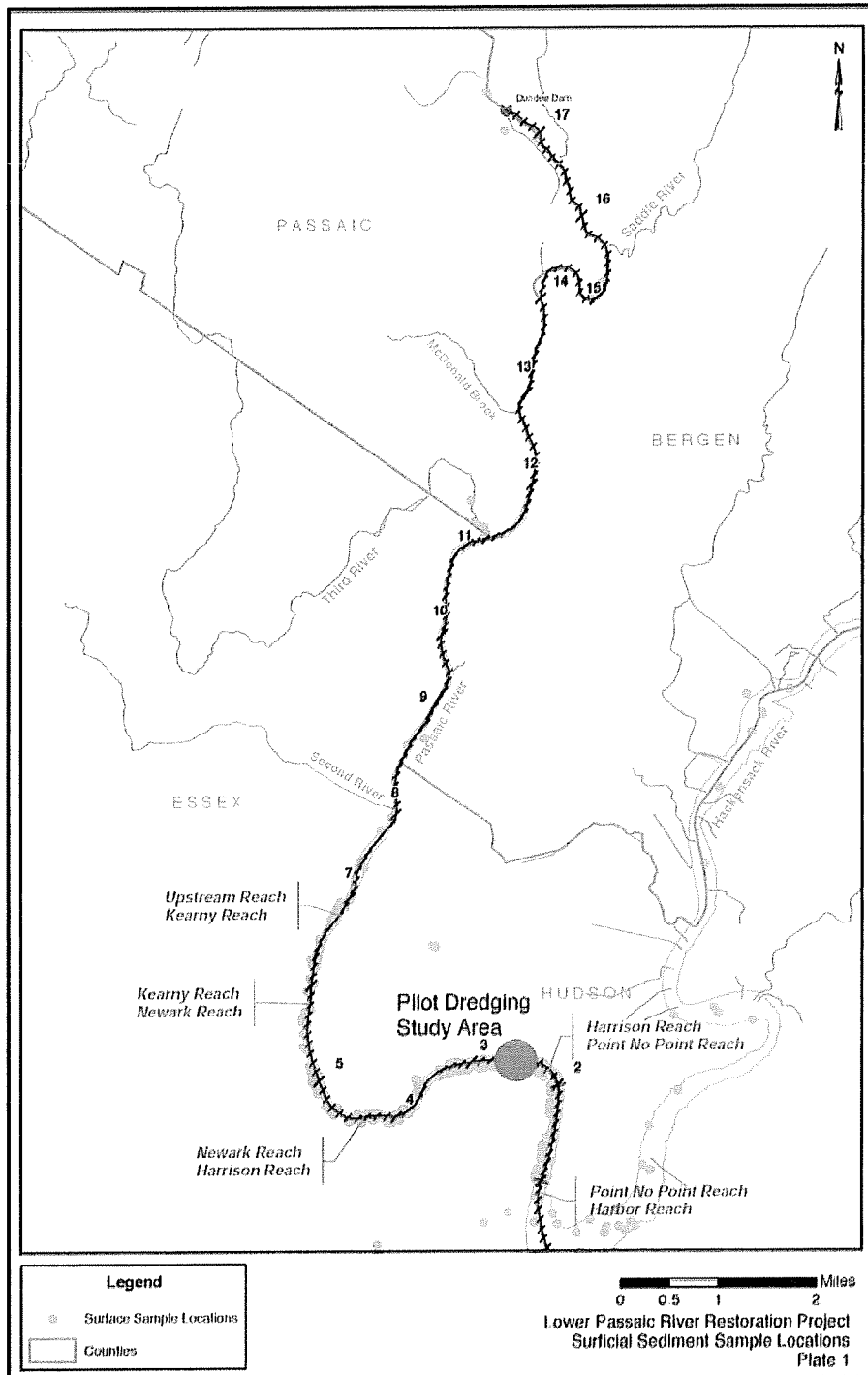


Figure 1. Location of the LPRRP pilot dredging study area in the Passaic River. Modified from Malcome Pirine et al. (2005).

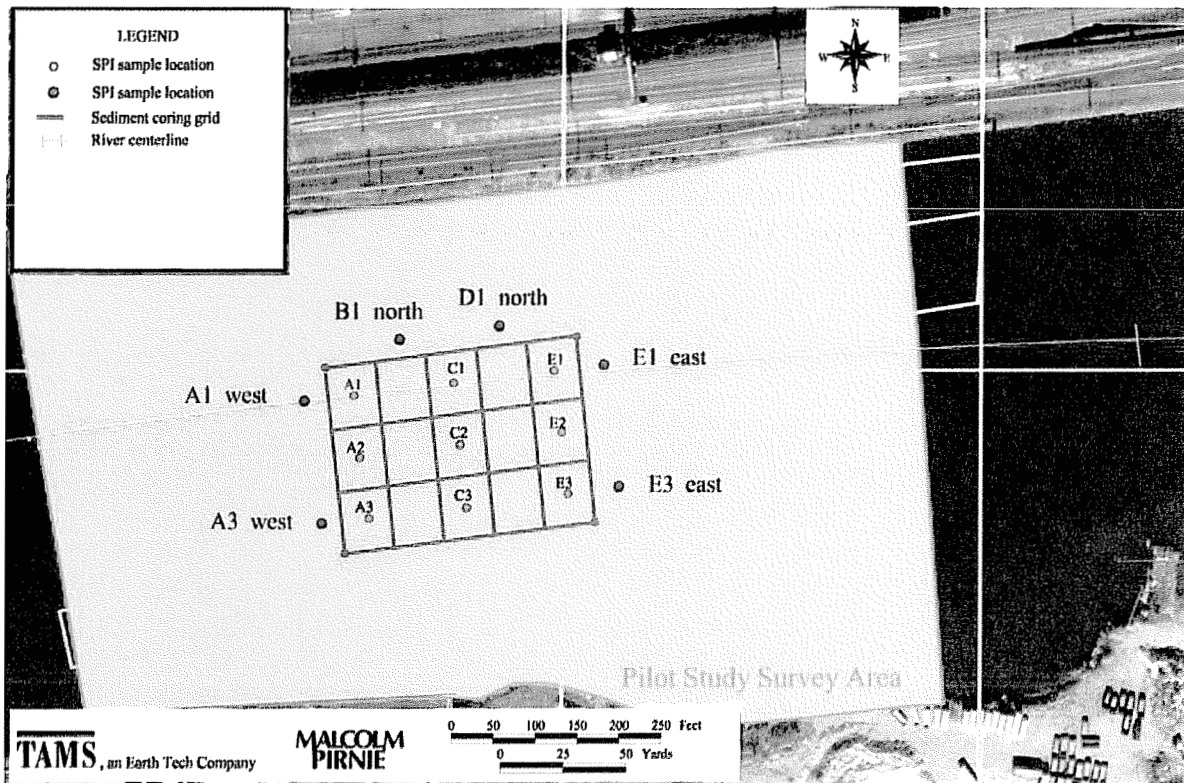


Figure 2. Location of SPI stations within the sediment-coring grid established around the pilot dredged area.

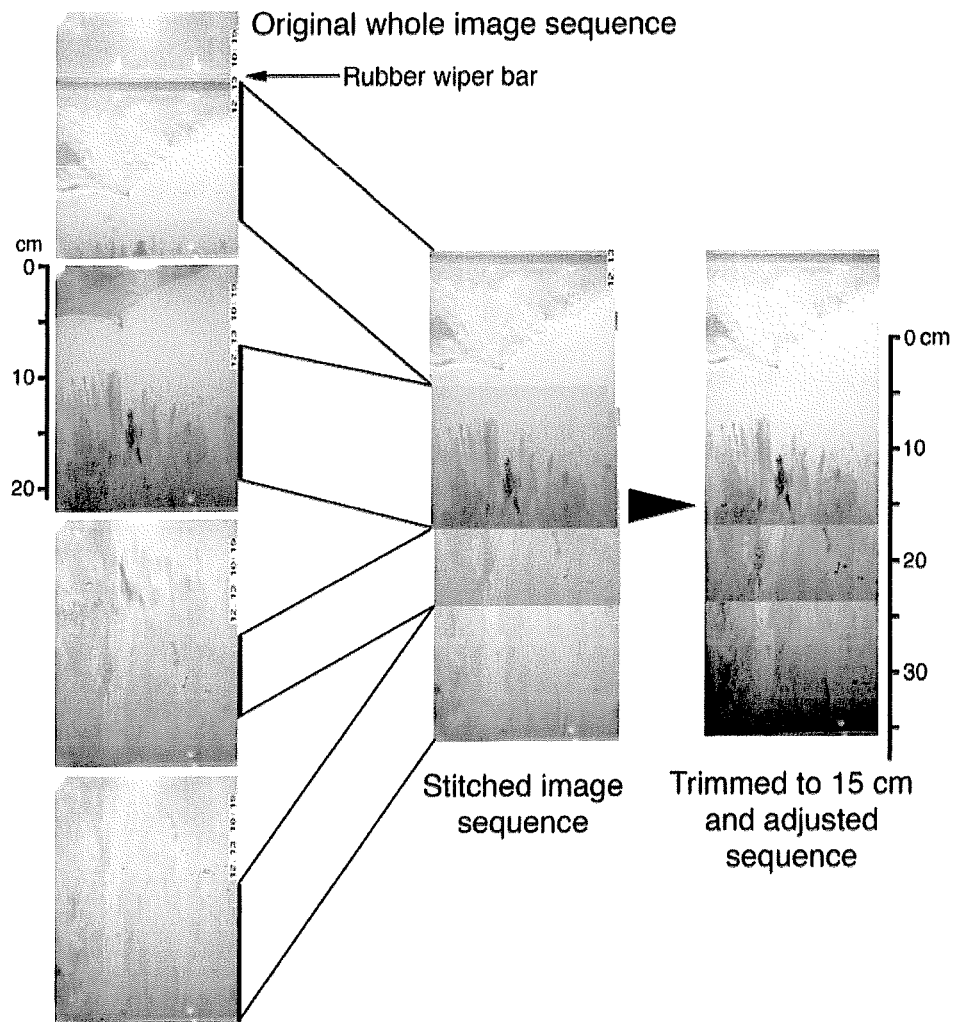


Figure 3. Example of image stitching used to combine original sequence of images into a single SPI.

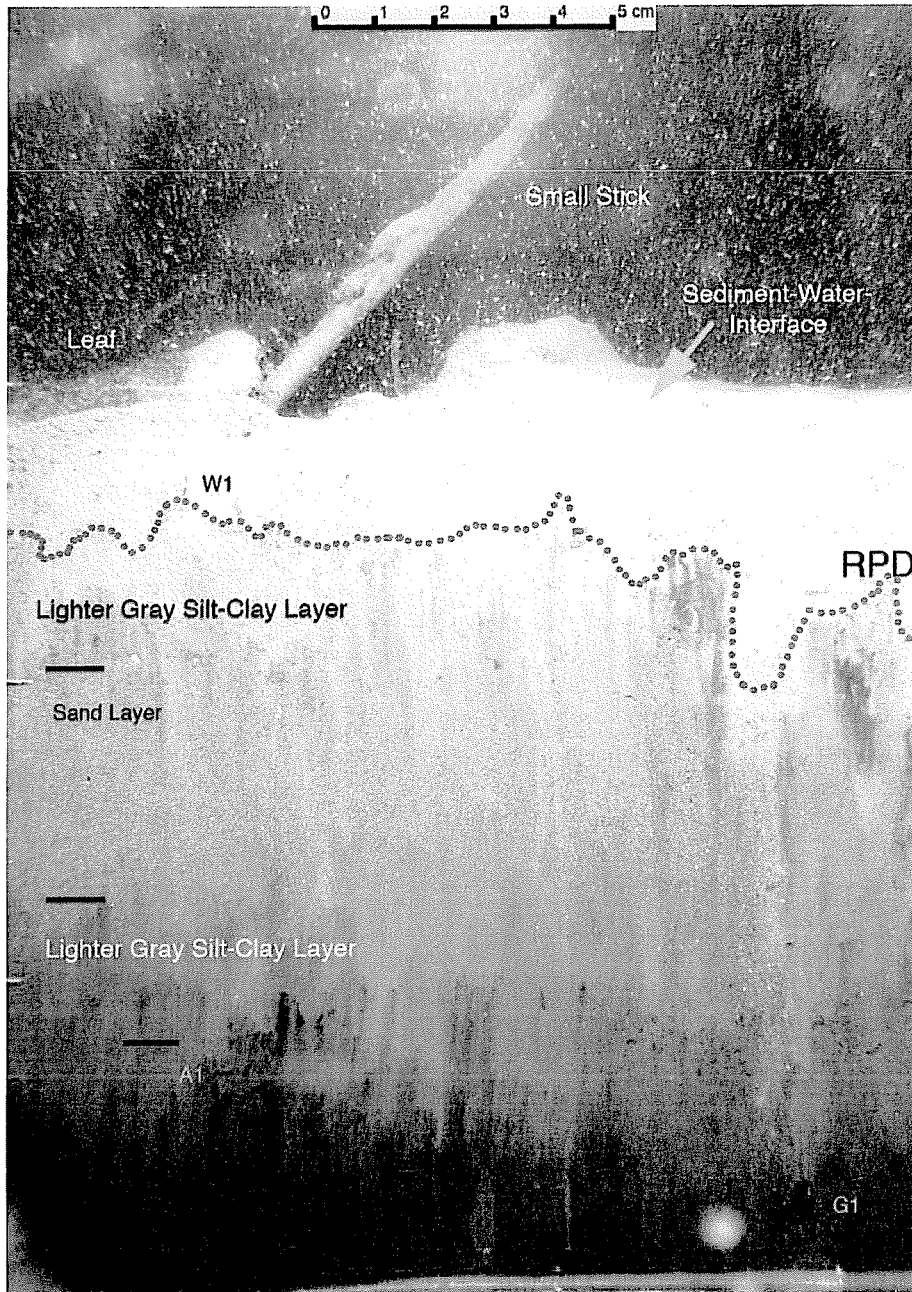


Figure 4. SPI from station A1-West, replicate 1 with labeled features. Light brown oxidized sediments at the surface had a thin layer of lighter gray sediments underneath than a fine-sand layer and another lighter gray layer. Sediment at the bottom of the image was darker gray. Red dotted line is the approximate location of the apparent color RPD layer. A1 is an anaerobic void and G1 is a gas-filled void. W1 appears to be a worm.

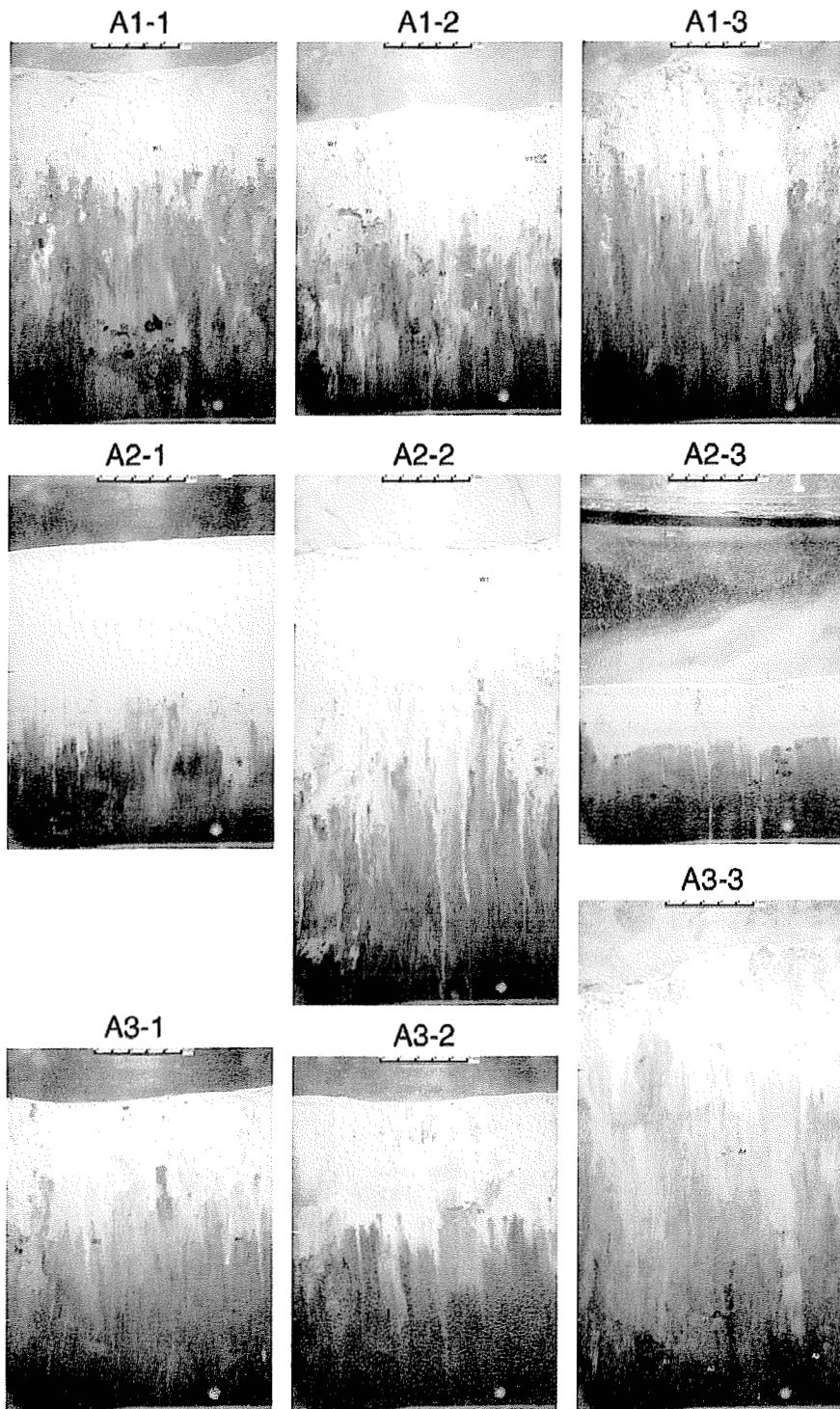


Figure 5. SPI replicates from stations A1, A2, and A3. A is anaerobic void, G is gas void, V is oxic void, and W is worm.

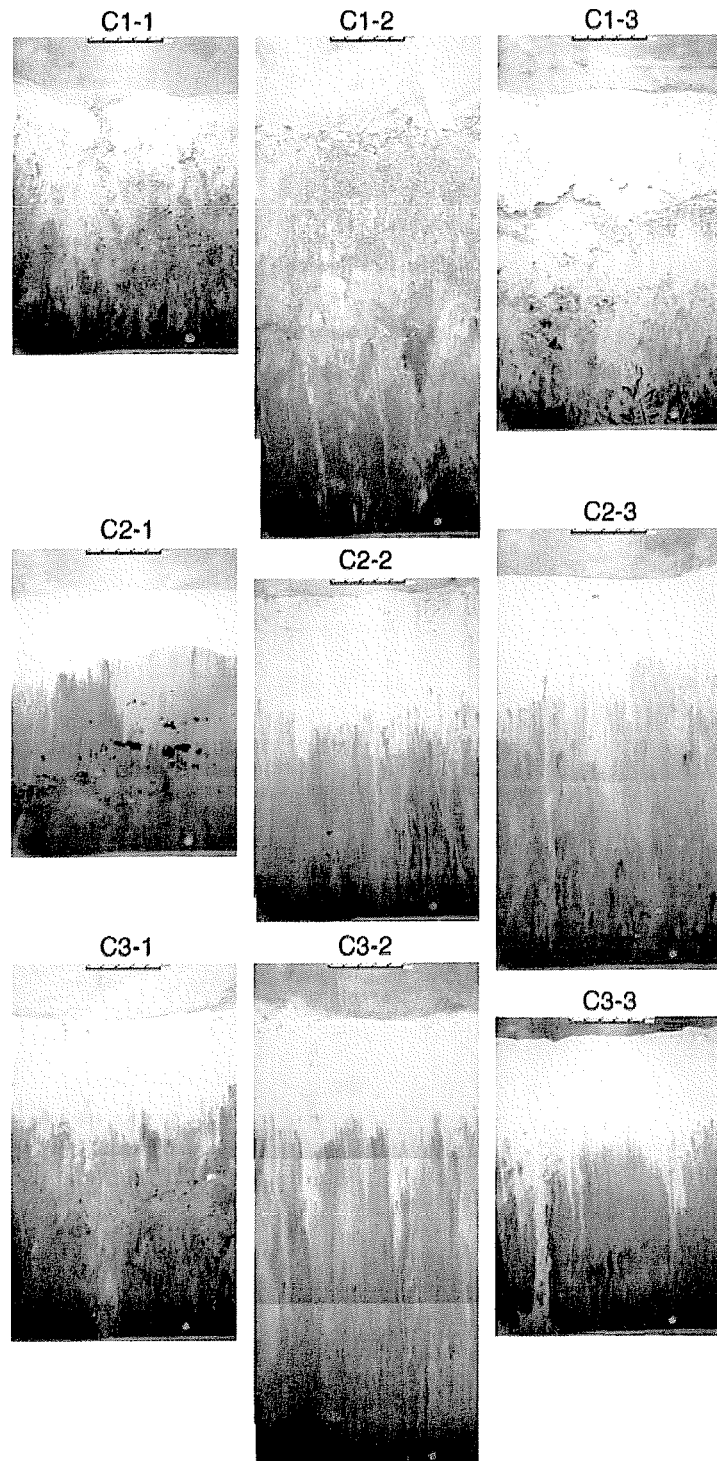


Figure 6. SPI replicates from stations C1, C2, and C3. A is anaerobic void, G is gas void, V is oxic void, and W is worm.

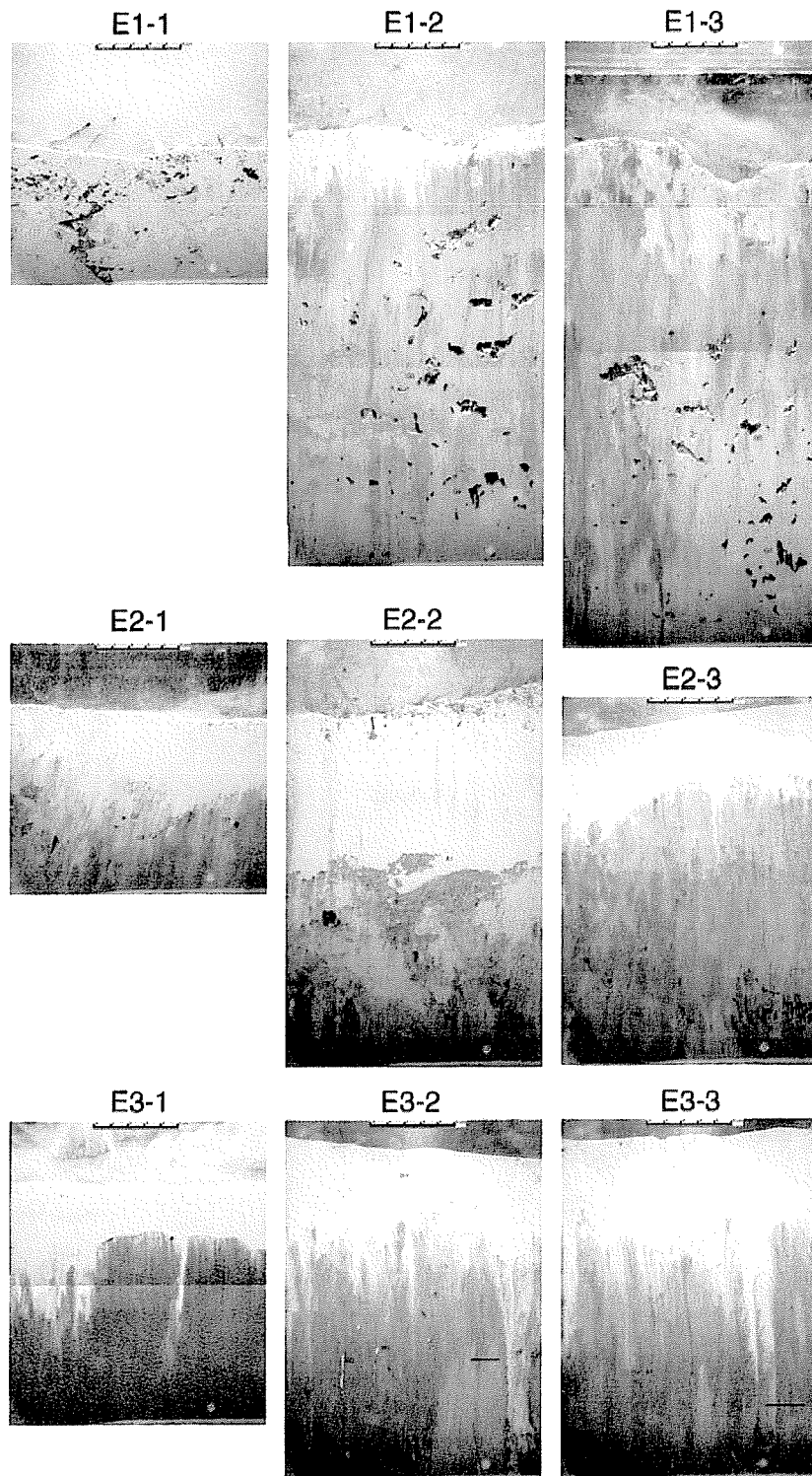


Figure 7. SPI replicates from stations E1, E2, and E3. A is anaerobic void, G is gas void, V is oxic void, and W is worm.

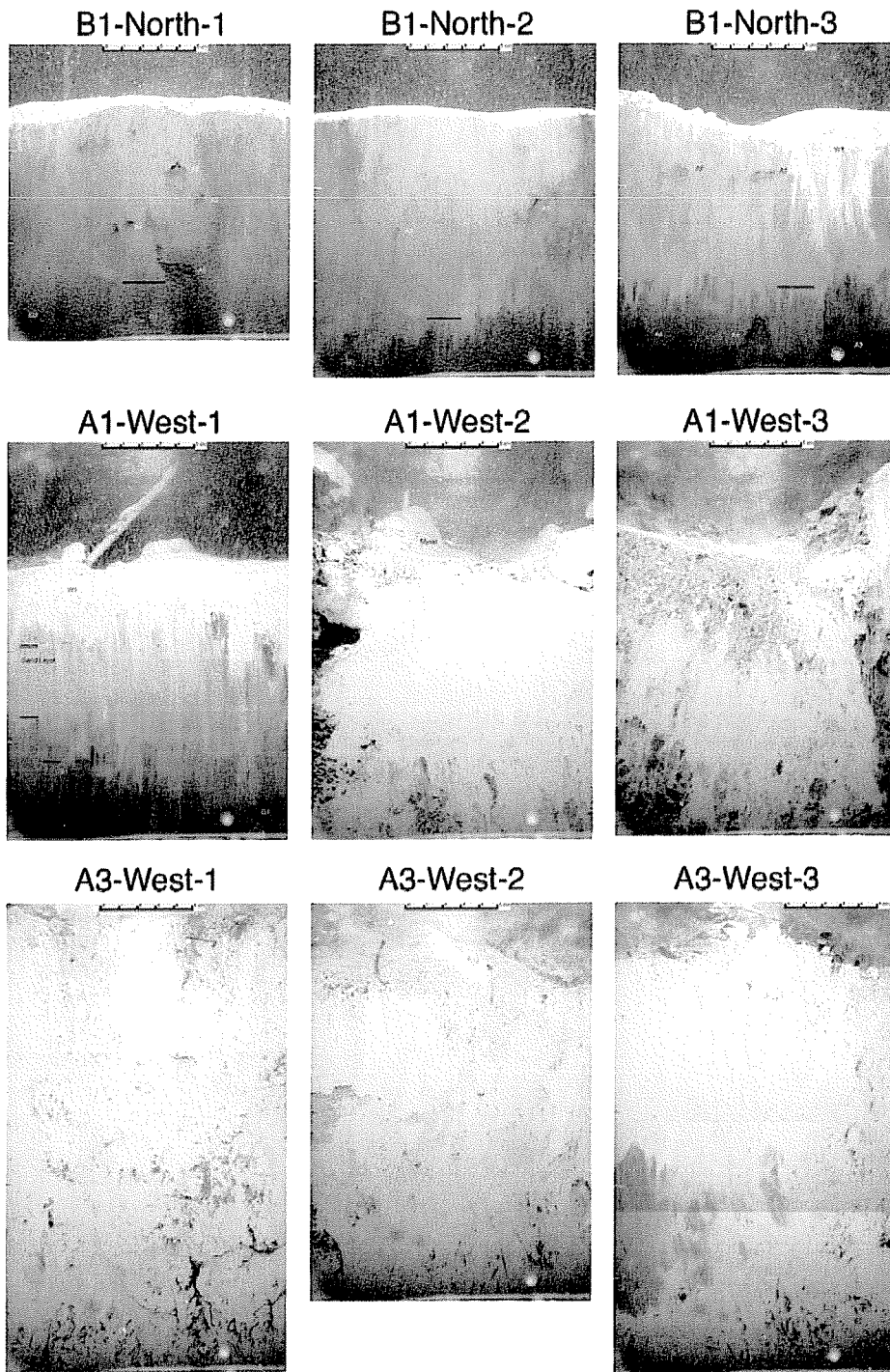


Figure 8. SPI replicates from stations B1-North, A1-West, and A3-West. A is anaerobic void, G is gas void, V is oxic void, and W is worm.

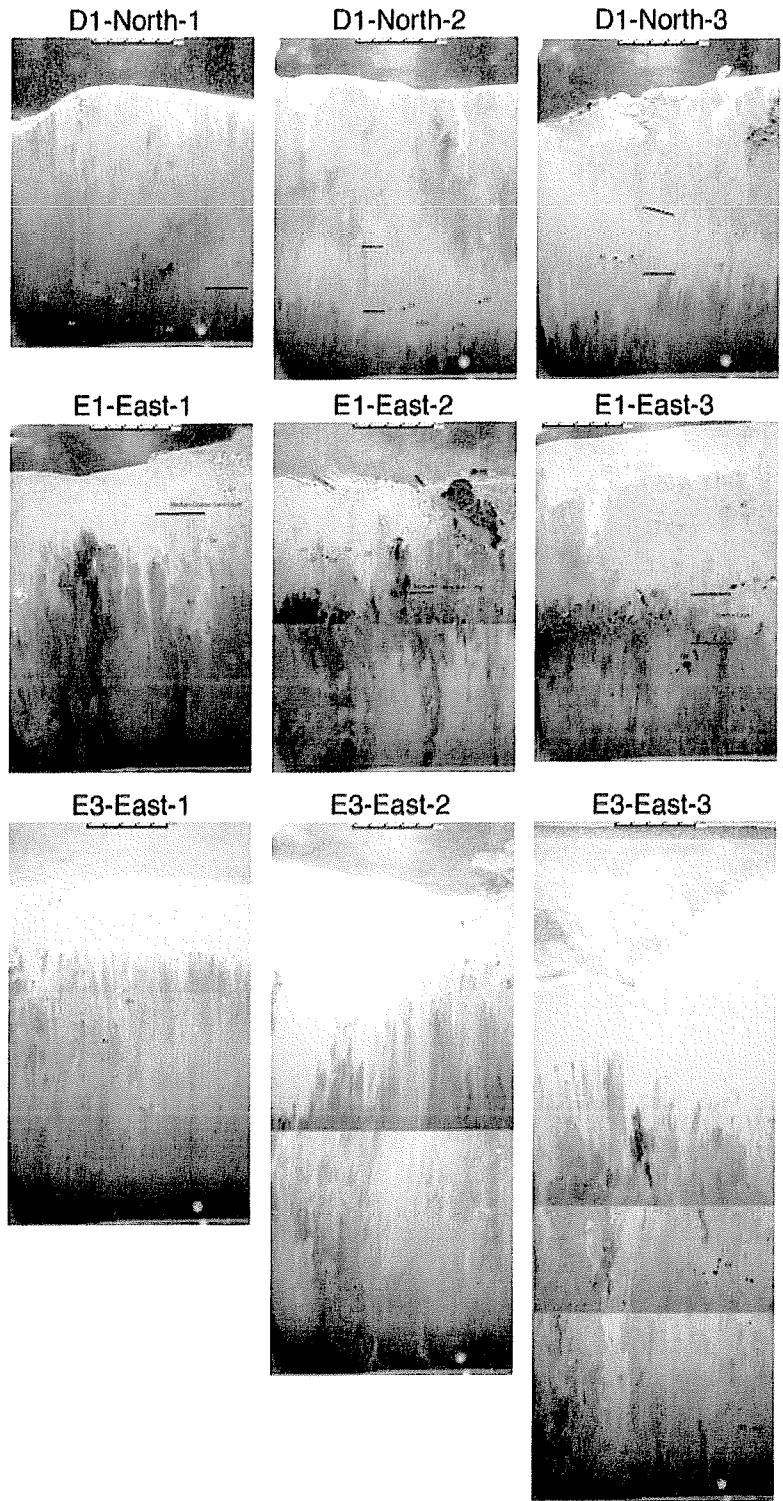


Figure 9. SPI replicates from stations D1-North, E1-East, and E3-East. A is anaerobic void, G is gas void, V is oxic void, and W is worm.

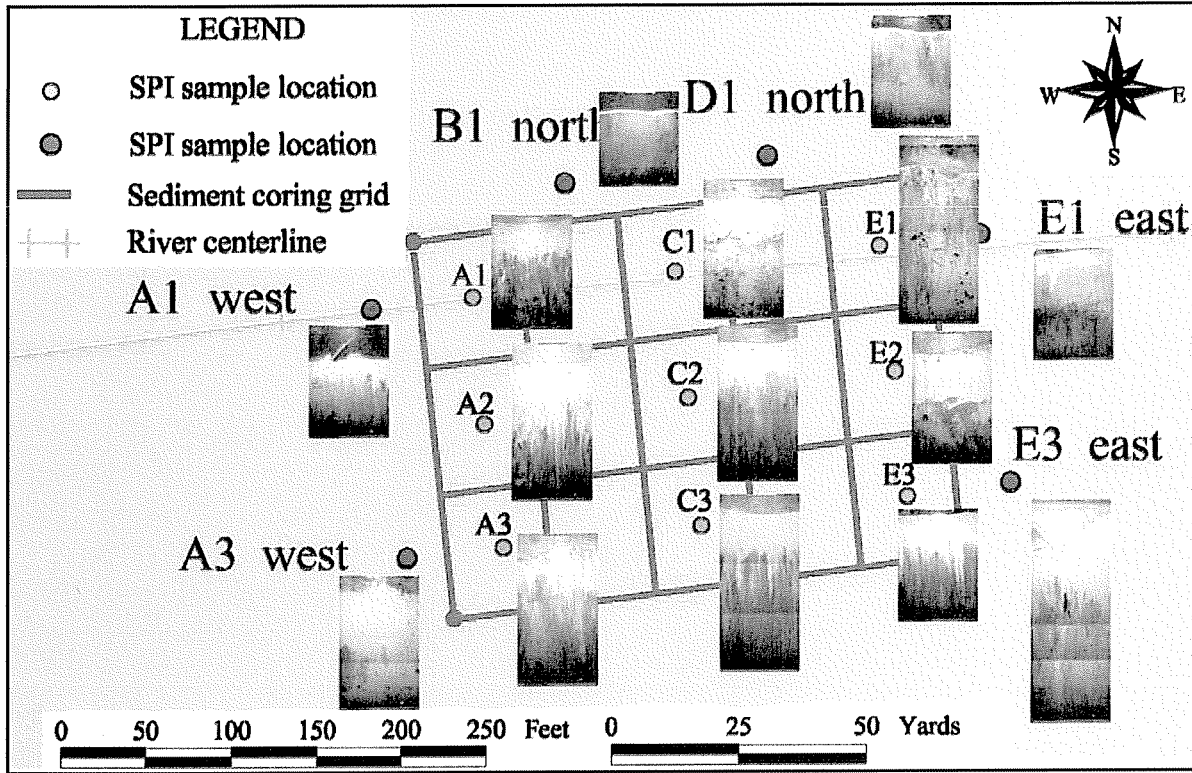


Figure 10. Mosaic of selected SPI arranged over the sediment-coring grid. Scale at top of images is 5 cm.

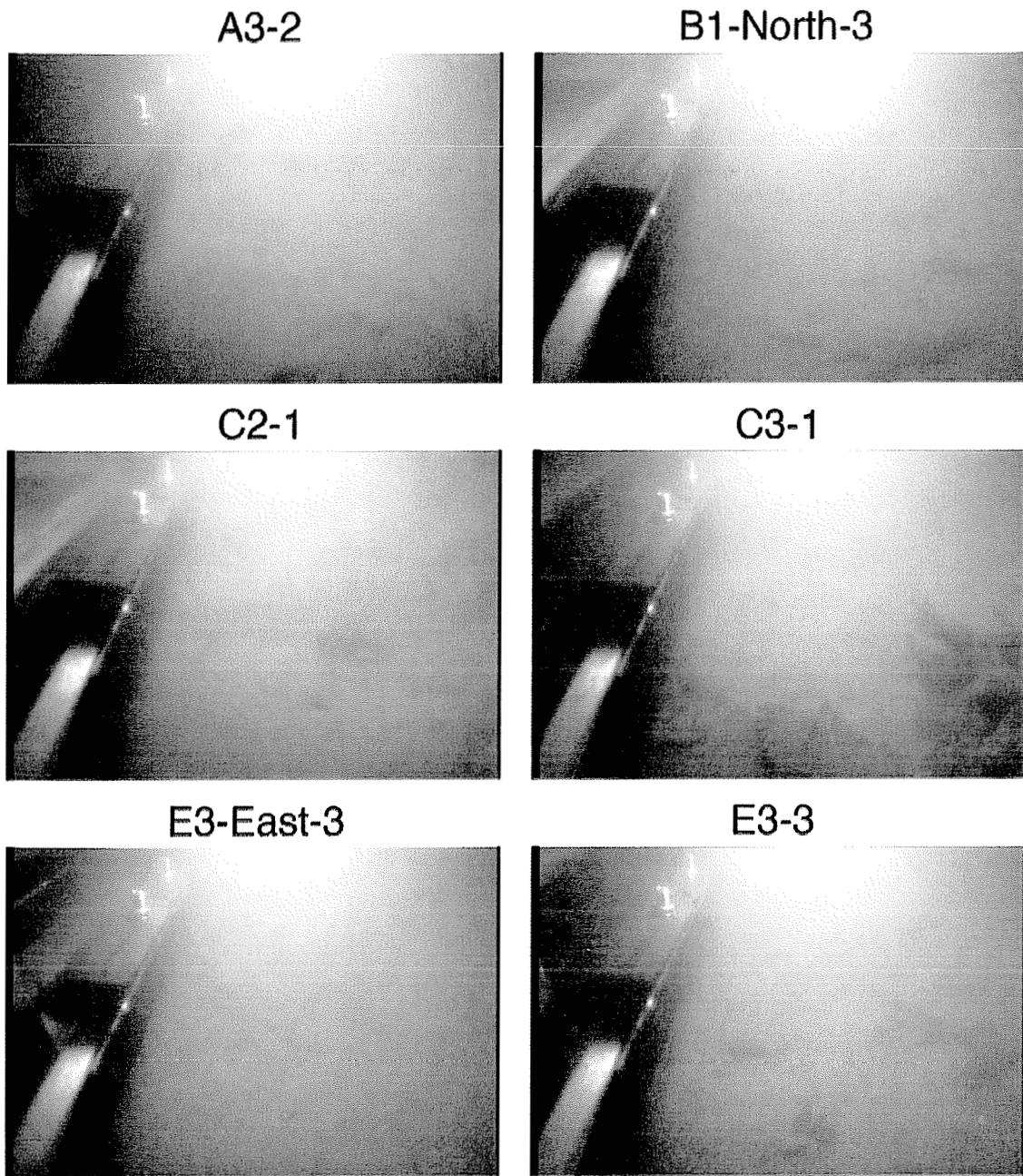


Figure 11. Frames extracted from the surface video showing the sediment surface in front of the profile camera prism. Sediment surfaces are unconsolidated with many leaves. Top of image is about 40 cm wide and bottom about 30. The prism wiper bar is to the left.

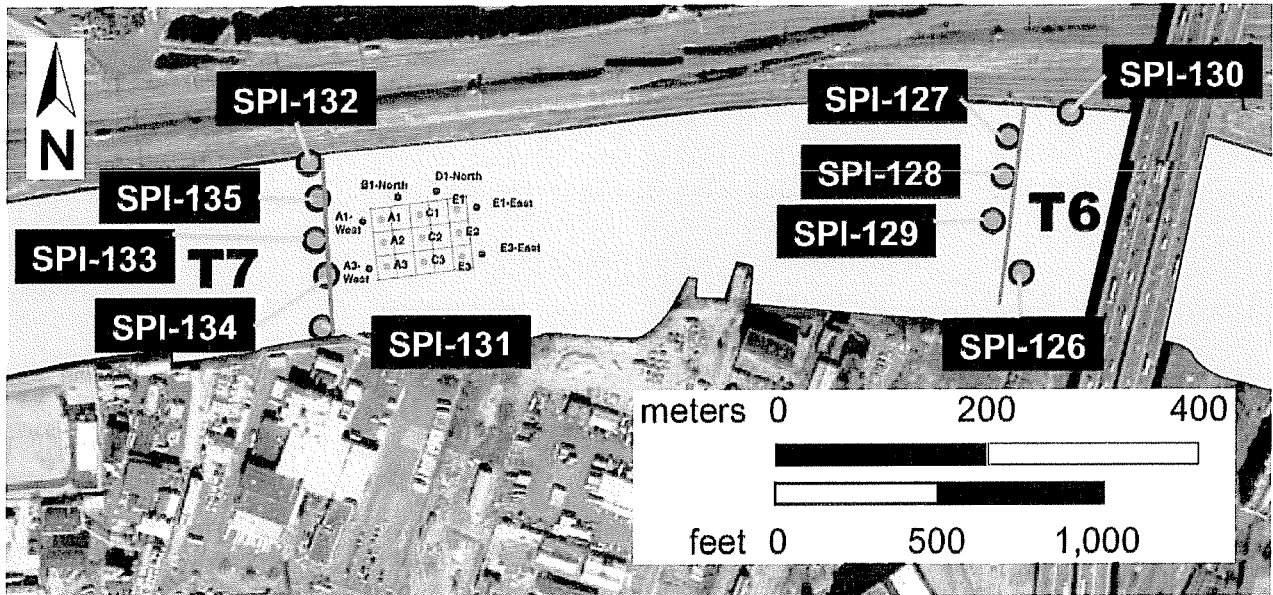


Figure 12. Location of the sediment-coring grid relative to SPI transects sampled in June 2005. Modified from Germano and Associates (2005).

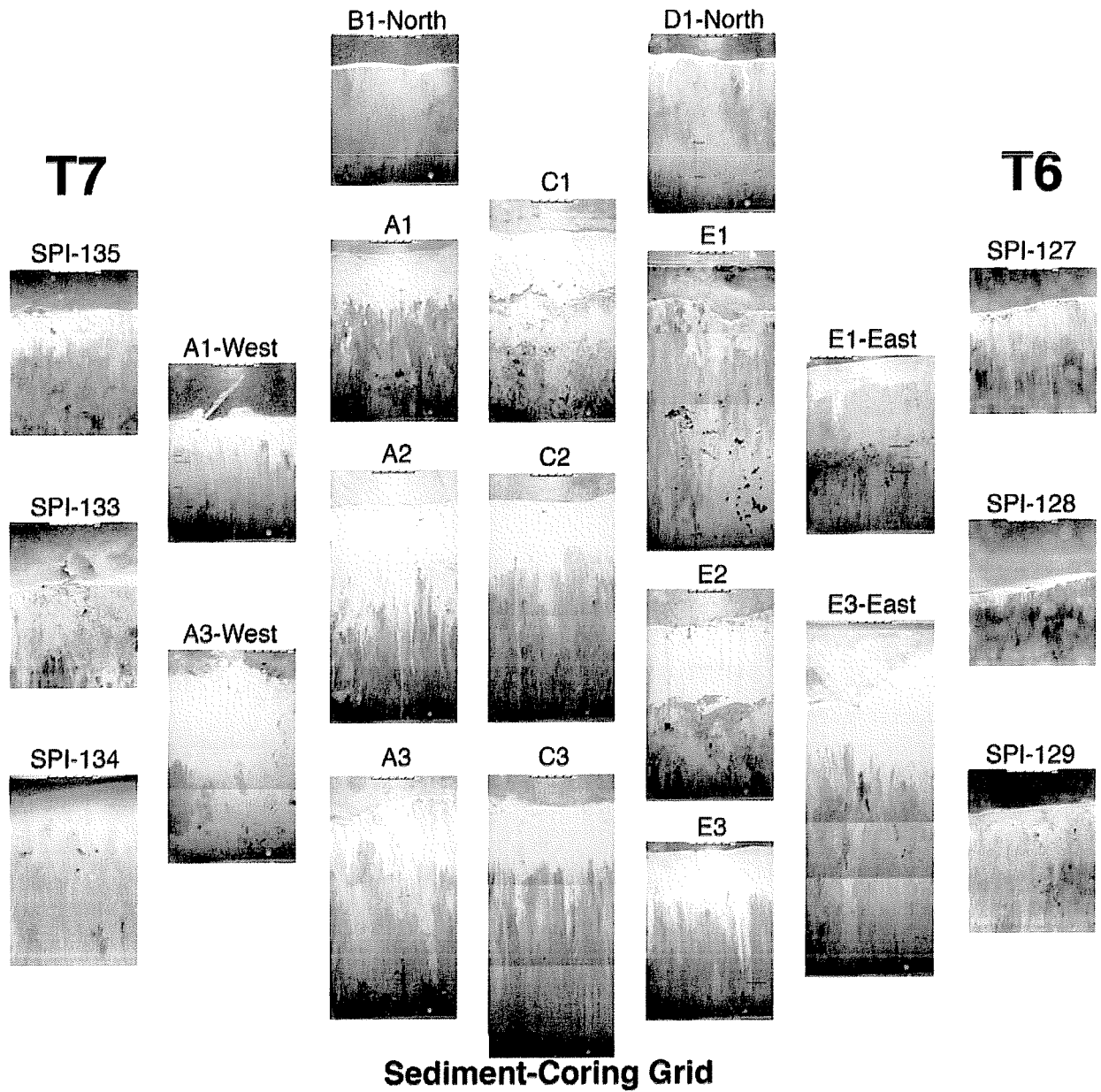


Figure 13. Mosaic of SPI from sediment-coring grid, December 2005, and nearby lower Passaic River transects, June 2005 (Germano and Associates, 2005). Figure 11 shows the actual location of stations. Scale at top of images is 5 cm.

Appendix A

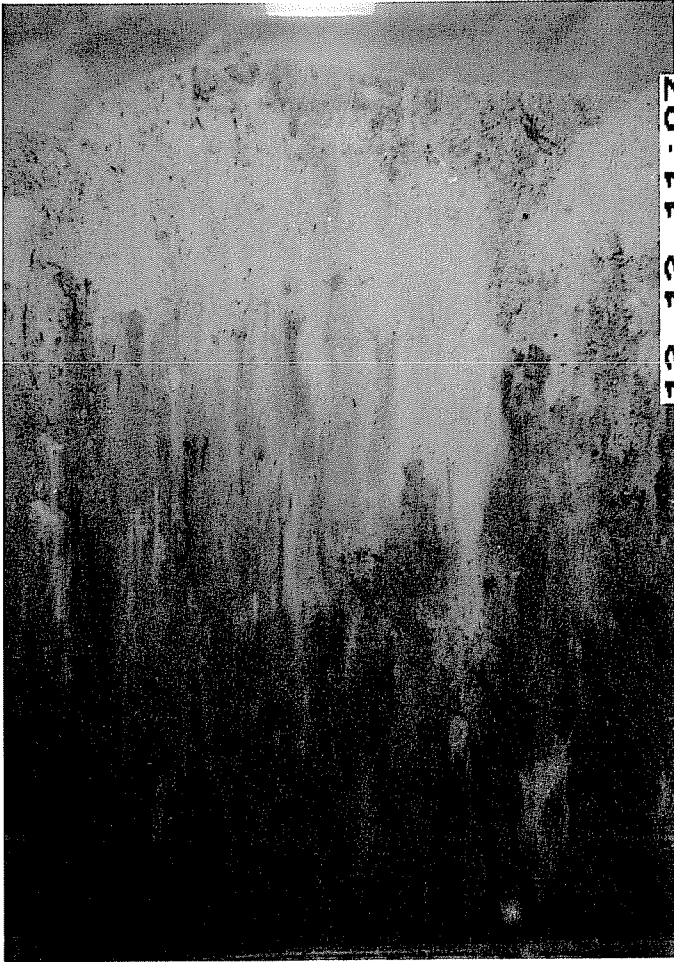
**Sediment Profile Image Data
December 2005**

Station	Replicate	Prism Penetration (cm)	Boundary Roughness (cm)	Type of Boundary Roughness	RPD Qualifier	RPD (cm)	Oxic Void Depth (cm)	Infauna Depth (cm)			Gas Void Depth (cm)					Anaerobic Void Depth (cm)					Comment		
								1	2	3	1	2	3	4	5	1	2	3	4	5			
A1	1	21.0	1.7	Physical		5.5		4.3	6.2		14.5	16.2	14.7	15.7	14.9	16.7							
A1	2	17.4	1.1	Physical		5.5	3.0	1.6								9.2							Oxic voids do not appear to be biogenic
A1	3	19.9	1.8	Physical		5.3																	
A1 WEST	1	14.9	0.3	Physical		2.2		1.3			13.1					11.2							
A1 WEST	2	15.9	2.0	Physical		13.1																	
A1 WEST	3	17.7	5.5	Physical		11.6																	
A2	1	17.7	0.7	Physical		9.8										15.8							
A2	2	26.3	0.9	Physical		9.0		1.7															
A2	3	9.3	0.6	Physical		3.2	4.1				3.8	4.4	5.1	5.6									Oxic void does not appear to be biogenic
A3	1	17.9	1.0	Physical		3.8		8.4	7.7														Translucent worms?
A3	2	17.9	0.8	Physical		5.3	3.3																Oxic void does not appear to be biogenic
A3	3	25.3	2.8	Physical		4.7	24.2									22.3	24.0	23.7	11.5				Oxic void does not appear to be biogenic
A3 WEST	1	25.0	0.9	Physical	>	25.0																	
A3 WEST	2	18.0	1.9	Physical	>	18.0																	Trash at surface
A3 WEST	3	23.9	3.2	Physical		10.4																	
B1 NORTH	1	13.1	0.5	Physical		0.5					12.0	11.3				2.6	3.9	5.4	7.1	9.3			
B1 NORTH	2	14.4	0.4	Physical		0.4					13.4					12.8	6.6	5.3	0.7	2.1			
B1 NORTH	3	14.5	2.0	Physical		1.1	2.3									2.6	3.3	13.0	11.8	13.2			
C1	1	18.0	1.4	Physical		6.4																	
C1	2	28.7	1.2	Physical	Indeterminant																		
C1	3	23.0	0.5	Physical		13.3																	
C2	1	17.7	0.5	Physical		4.4					7.4	9.1	10.4	12.5	14.2								>30 Gas voids
C2	2	22.5	0.9	Physical		7.5					16.0												
C2	3	26.9	0.5	Physical		8.2	1.1									24.4	22.8						
C3	1	22.0	0.9	Physical		5.7																	
C3	2	30.3	0.6	Physical		6.4																	
C3	3	20.5	0.9	Physical		6.6																	
D1 NORTH	1	15.5	2.3	Physical		0.5					11.7					11.3	12.5	13.5	13.5	15.3			
D1 NORTH	2	18.8	1.0	Physical		0.7					14.1	13.7	14.8	15.2									
D1 NORTH	3	17.8	3.2	Physical		0.5										10.1							
E1	1	7.9	1.0	Physical	>	7.9																	
E1	2	25.5	1.4	Physical		1.6					1.8	5.3	13.8	20.6	25.3								>50 Gas voids
E1	3	29.2	2.8	Physical		1.1					3.6	13.8	15.1	23.6	26.5								>50 Gas voids
E1 EAST	1	20.2	2.8	Physical		2.4					3.0	5.8	4.5	6.9	9.7								>10 Gas voids
E1 EAST	2	18.3	0.6	Physical		2.8					4.5	4.6	4.7	4.4	4.4								
E1 EAST	3	20.9	1.4	Physical		1.9					10.0	10.4	12.1	15.2	19.6	5.1							>30 Gas voids
E2	1	10.8	1.3	Physical		3.0					5.2	6.3	6.1	7.3	9.1								
E2	2	21.9	2.0	Physical		9.8										9.3	11.3						
E2	3	20.6	1.9	Physical		4.2					18.4	18.1											
E3	1	14.1	0.6	Physical		3.4																	
E3	2	19.9	1.4	Physical		4.5	1.7	13.3	12.3														
E3	3	20.7	0.7	Physical		5.5										14.1							
E3 EAST	1	21.5	0.1	Physical		4.0	7.3									10.1	14.2						
E3 EAST	2	31.0	2.7	Physical		8.7																	
E3 EAST	3	35.6	6.5	Physical		7.3					12.3	21.3	20.8	33.3	31.7								>20 Gas voids

Station	Modal Grain Size	Minimum Grain Size	Maximum Grain Size	Surface Sediment Description	Layer 1		Layer 2		Layer 3		Fluff of Fines	Detritus	Worm Tubes	Burrows	Epifauna	Successional Stage	OSI
					Thickness (cm)	Description	Thickness (cm)	Description	Thickness (cm)	Description							
A1	>4	>4	>4	Uniform light brownish with small gray inclusions							Yes	Yes	0	0		1	5
A1	>4	>4	>4	Uniform light brownish with small gray inclusions							Yes	Yes	0	0		1	7
A1	>4	>4	>4	Light brownish with small gray inclusions							Yes	Yes	0	0		1?	7
A1 WEST	>4	>4	3-2	Uniform light brownish	4.0	Lighter gray siltclay	3.8	Fine sand	2.4	Lighter gray siltclay	Yes	Yes	0	0		1	2
A1 WEST	>4	>4	>4	Uniform light brownish							Yes	Yes	0	0	Mysid	1	7
A1 WEST	>4	>4	>4	Uniform light brownish with small gray inclusions							Yes	Yes	0	0		1?	7
A2	>4	>4	>4	Uniform light brownish							Yes	Yes	0	0		1?	7
A2	>4	>4	>4	Uniform light brownish							Yes	Yes	0	0		1	7
A2	>4	>4	>4	Uniform light brownish							Yes	Yes	0	0		1?	4
A3	>4	>4	>4	Uniform light brownish with small gray inclusions							Yes	Yes	0	0		1	7
A3	>4	>4	>4	Uniform light brownish with small gray inclusions							Yes	Yes	0	0		1?	7
A3	>4	>4	>4	Uniform light brownish with small gray inclusions							Yes	Yes	0	0		1?	7
A3 WEST	>4	>4	>4	Uniform light brownish with small gray inclusions							Yes	Yes	0	0		1?	7
A3 WEST	>4	>4	>4	Uniform light brownish with small gray inclusions							Yes	Yes	0	0		1?	7
A3 WEST	>4	>4	>4	Uniform light brownish							Yes	Yes	0	0		1?	7
B1 NORTH	>4	>4	>4	Thin brownish layer	9.8	Lighter gray siltclay					Yes	Yes	0	0		1?	0
B1 NORTH	>4	>4	>4	Thin brownish layer	11.8	Lighter gray siltclay					Yes	Yes	0	0		1?	0
B1 NORTH	>4	>4	>4	Thin brownish layer	9.6	Lighter gray siltclay					Yes	Yes	0	0		1	3
C1	>4	>4	>4	Uniform light brownish with small gray inclusions							Yes	Yes	0	0		1?	7
C1	>4	>4	>4	Uniform light brownish with small gray inclusions							Yes	Yes	0	0		1?	7
C1	>4	>4	>4	Uniform light brownish with small gray inclusions							Yes	Yes	0	0		1?	7
C2	>4	>4	>4	Uniform light brownish							Yes	Yes	0	0		1?	5
C2	>4	>4	>4	Uniform light brownish							Yes	Yes	0	0		1?	5
C2	>4	>4	>4	Uniform light brownish							Yes	Yes	0	0		1	7
C3	>4	>4	>4	Uniform light brownish							Yes	Yes	0	0		1?	7
C3	>4	>4	>4	Uniform light brownish							Yes	Yes	0	0		1?	7
C3	>4	>4	>4	Uniform light brownish							Yes	Yes	0	0		1?	7
D1 NORTH	>4	>4	>4	Thin brownish layer	11.6	Lighter gray siltclay					Yes	Yes	0	0		1?	0
D1 NORTH	>4	>4	>4	Thin brownish layer	10.2	Darker gray siltclay	5.6	Lighter gray siltclay			Yes	Yes	0	0		1?	0
D1 NORTH	>4	>4	>4	Thin brownish layer	7.3	Darker gray siltclay	3.8	Lighter gray siltclay			Yes	Yes	0	0		1?	2
E1	>4	>4	>4	Uniform light brownish with small gray inclusions							Yes	Yes	0	0		1?	7
E1	>4	>4	>4	Uniform light brownish with small gray inclusions							Yes	Yes	0	0		1?	2
E1	>4	>4	>4	Uniform light brownish with small gray inclusions							Yes	Yes	0	0		1?	1
E1 EAST	>4	>4	1-0	Uniform light brownish	3.4	Medium coarse sand					Yes	Yes	0	0		1?	3
E1 EAST	>4	>4	1-0	Uniform light brownish with small gray inclusions	6.8	Medium coarse sand					Yes	Yes	0	0		1?	3
E1 EAST	>4	>4	>4	Uniform light brownish	10.1	Lighter gray	3.1	Darker gray detritus			Yes	Yes	0	0		1?	2
E2	>4	>4	>4	Uniform light brownish							Yes	Yes	0	0		1?	4
E2	>4	>4	>4	Uniform light brownish with small gray inclusions							Yes	Yes	0	0		1?	7
E2	>4	>4	>4	Uniform light brownish							Yes	Yes	0	0		1?	5
E3	>4	>4	>4	Uniform light brownish							Yes	Yes	0	0		1?	6
E3	>4	>4	>4	Uniform light brownish							Yes	Yes	0	0		1	7
E3	>4	>4	>4	Uniform light brownish							Yes	Yes	0	0		1?	7
E3 EAST	>4	>4	>4	Uniform light brownish with small gray inclusions							Yes	Yes	0	0		1	7
E3 EAST	>4	>4	>4	Uniform light brownish with small gray inclusions	12.2	Darker gray siltclay					Yes	Yes	0	0		1?	7
E3 EAST	>4	>4	>4	Uniform light brownish	16.5	Darker gray siltclay					Yes	Yes	0	0		1?	5

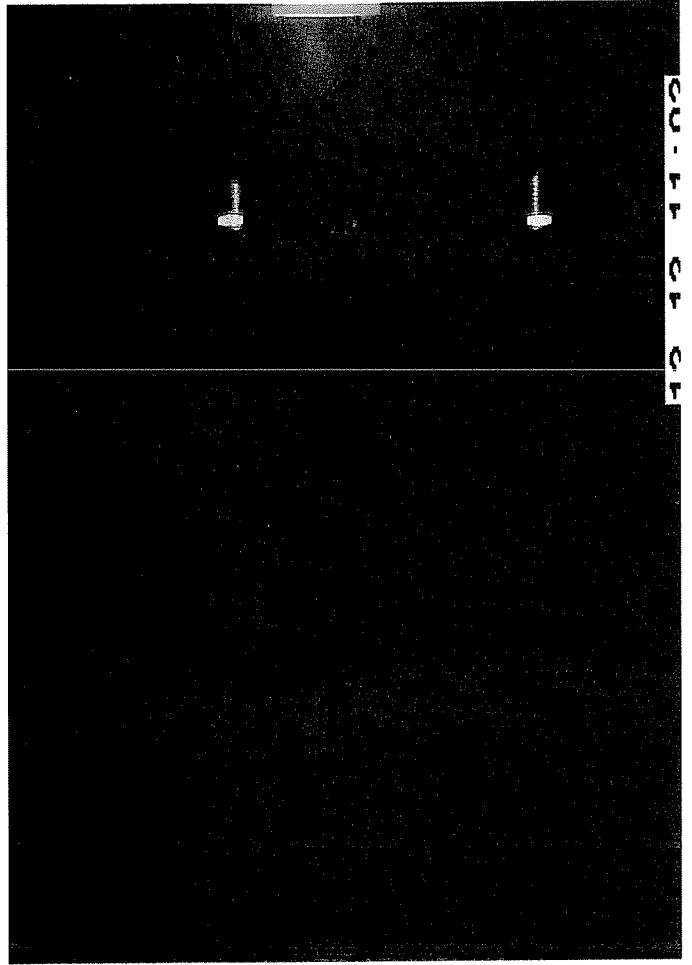
Appendix B

Original Sediment Profile Images



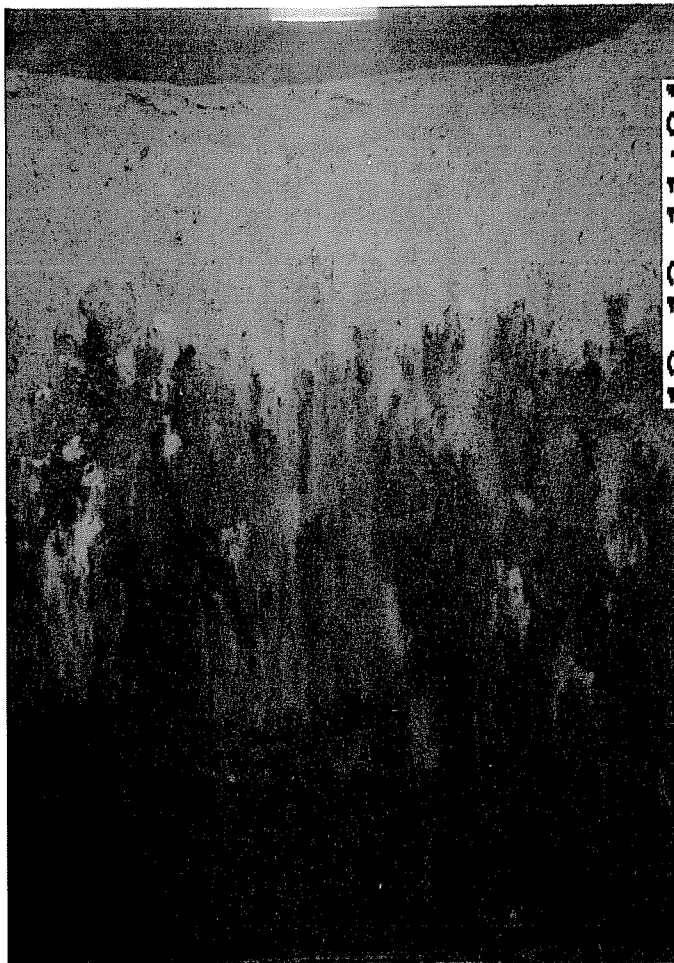
10 10 11 07

A1-3-2



10 10 11 09

A1 1-1



10 10 11 08

A1 1-2



10 10 11 08

A1 2



10 10 11 00

AI 3-1



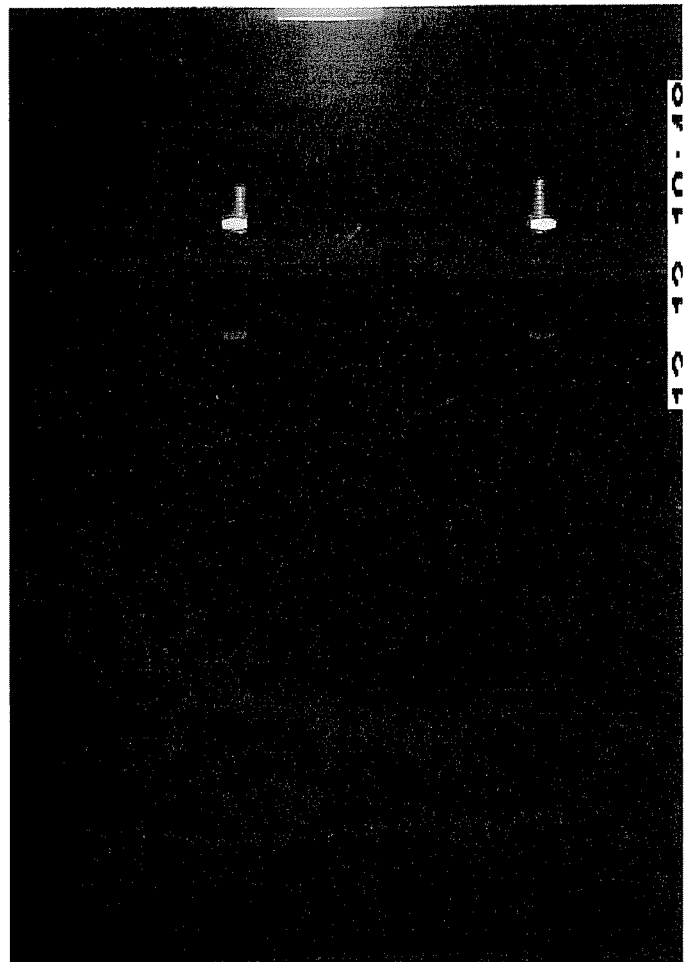
10 10 10 47

AI WEST 1-1



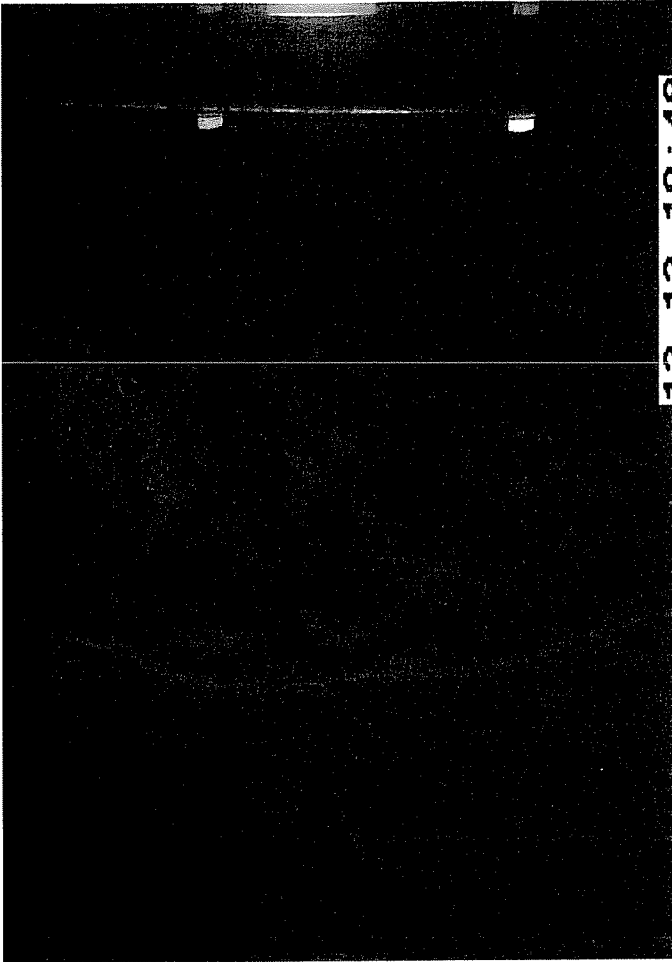
10 10 10 47

AI WEST 1-2



10 10 10 40

AI WEST 2-1



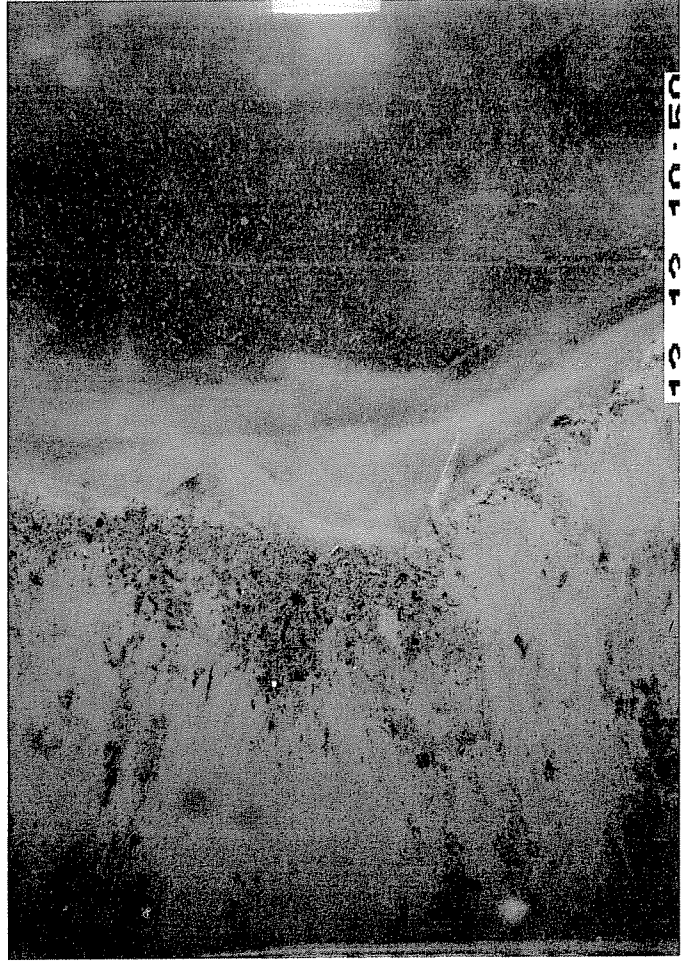
AI WEST 2-2



AI WEST 2-3



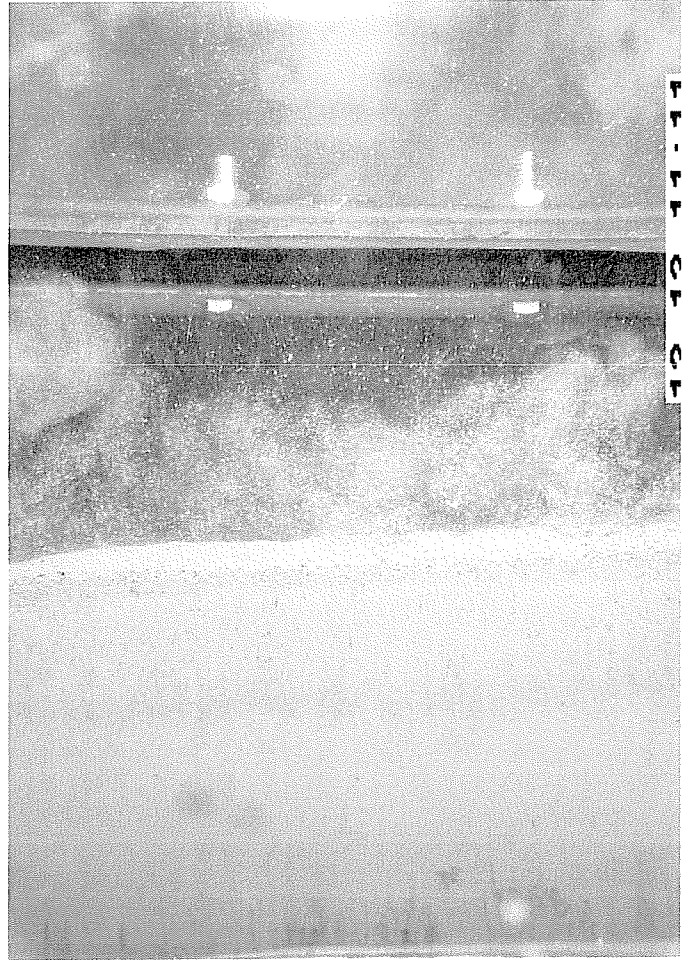
AI WEST 3-1



AI WEST 3-2



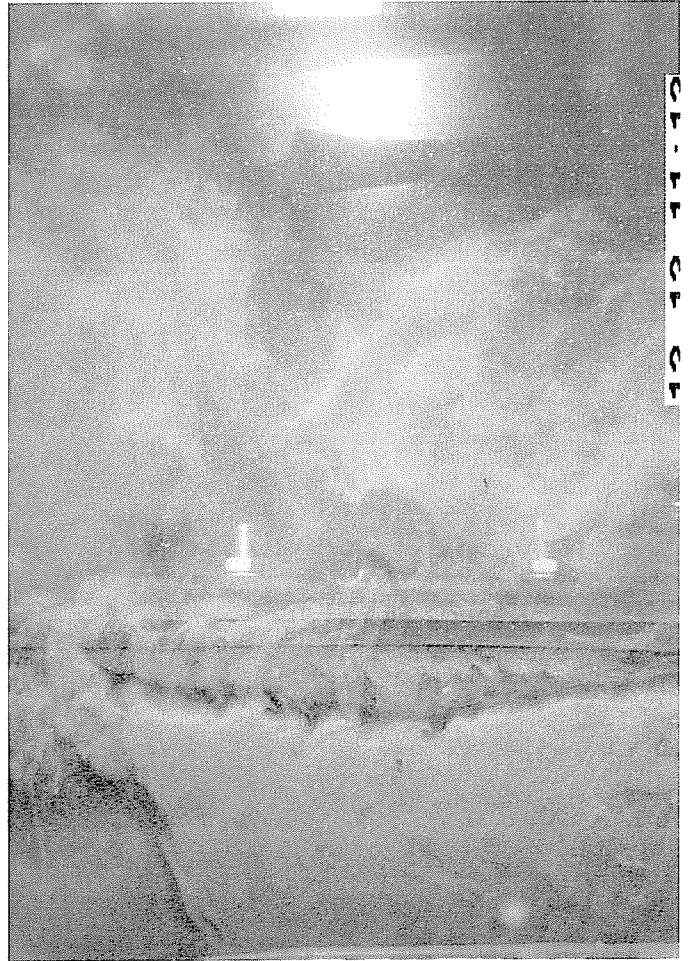
A1 WEST 3-3



A2 1-1



A2 1-2



A2 2-1



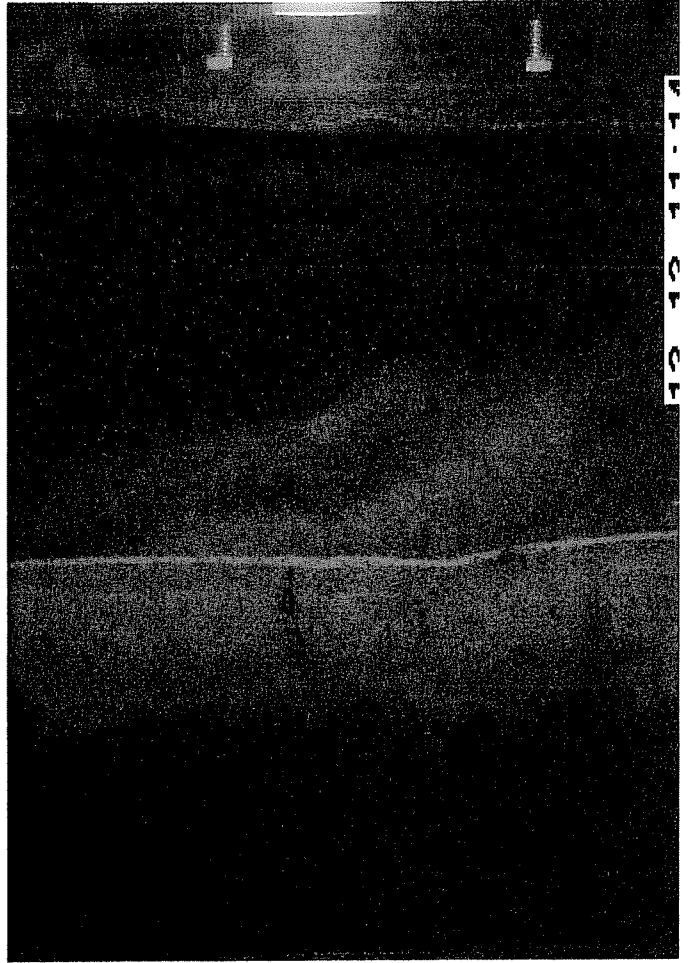
A2 2-2



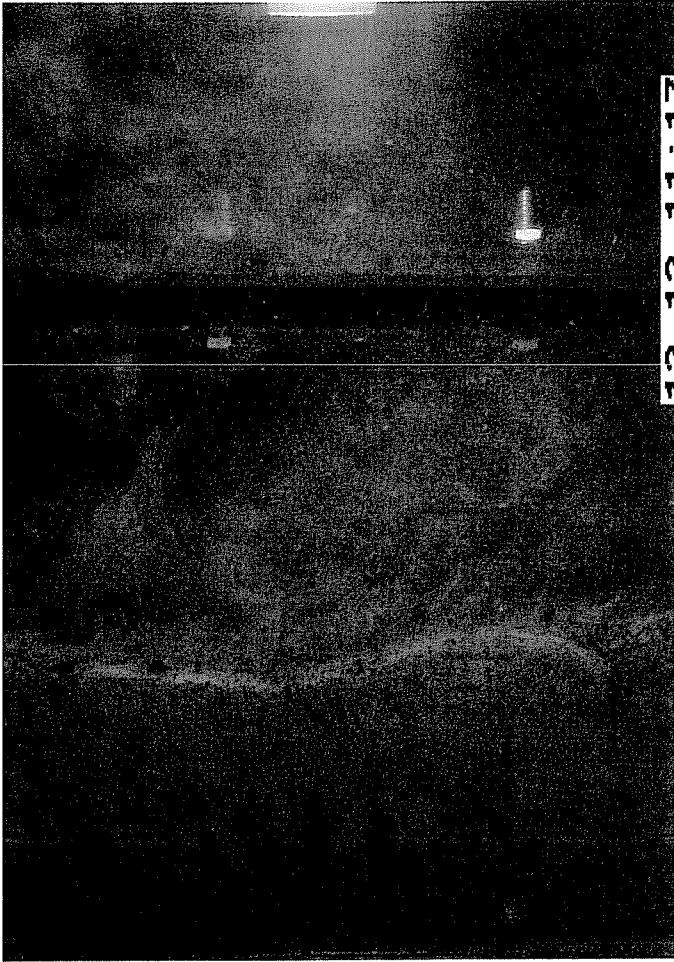
A2 2-3



A2 3-1



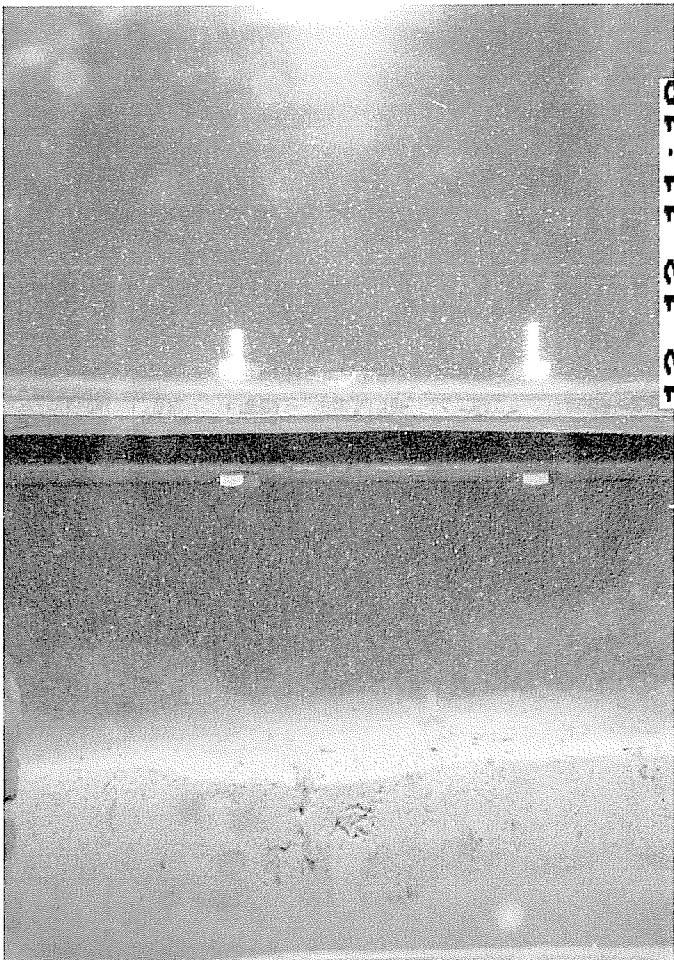
A2 3-2



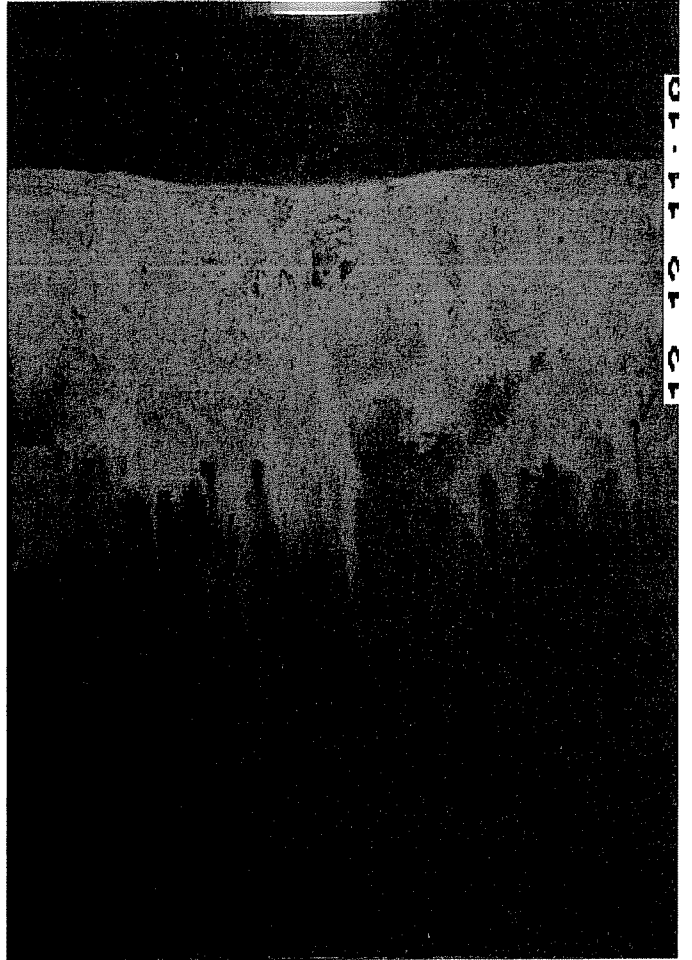
A3 1-1



A3 1-2



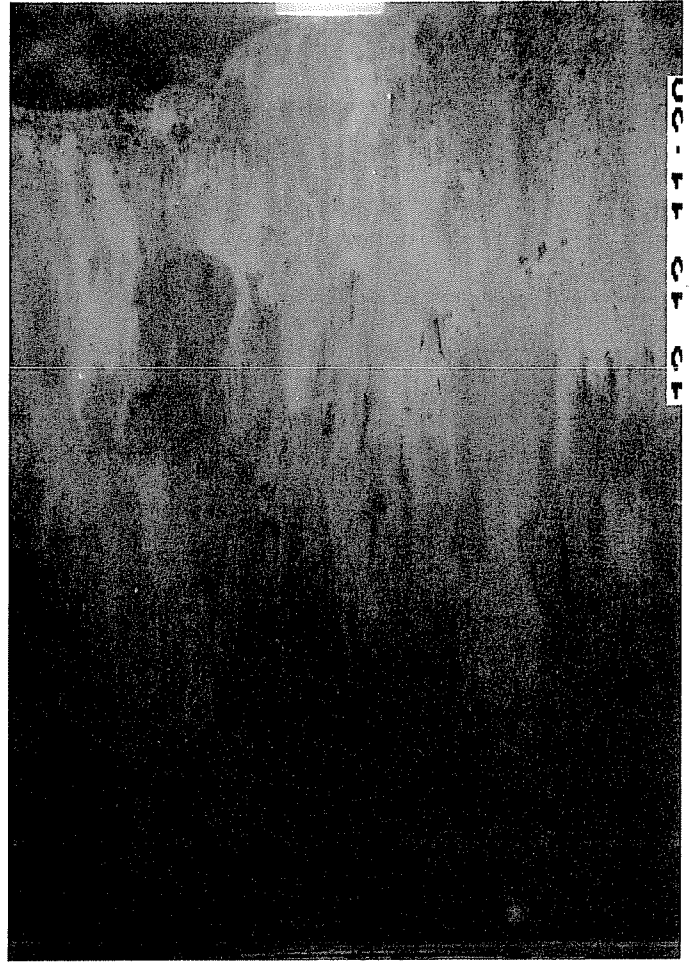
A3 2-1



A3 2-2



A3 3-1



A3 3-2



A3 3-3



A3 WEST 1-1



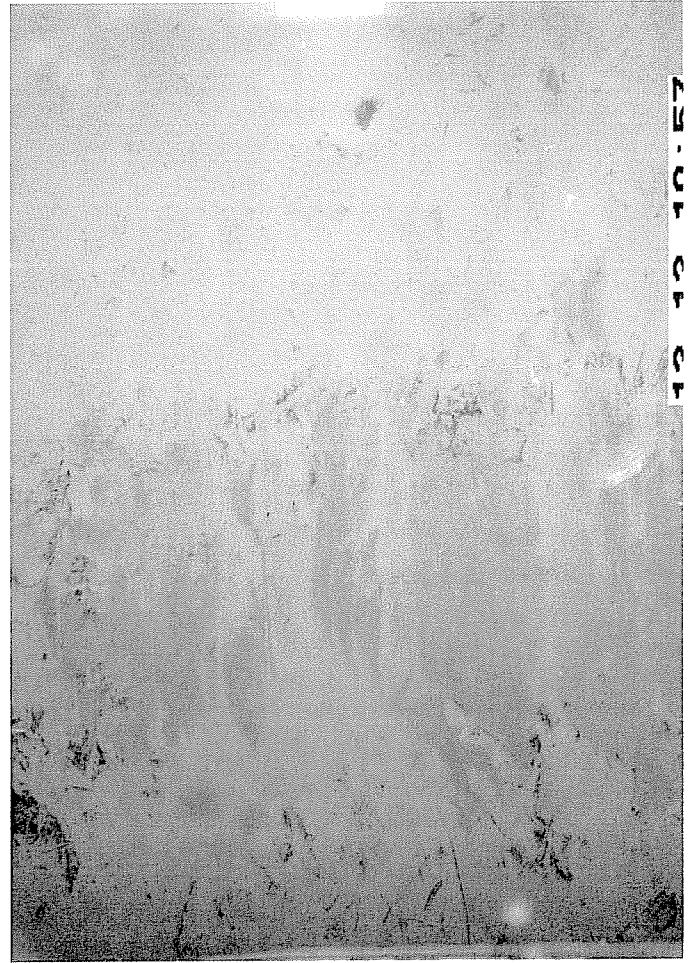
A3 WEST 1-2



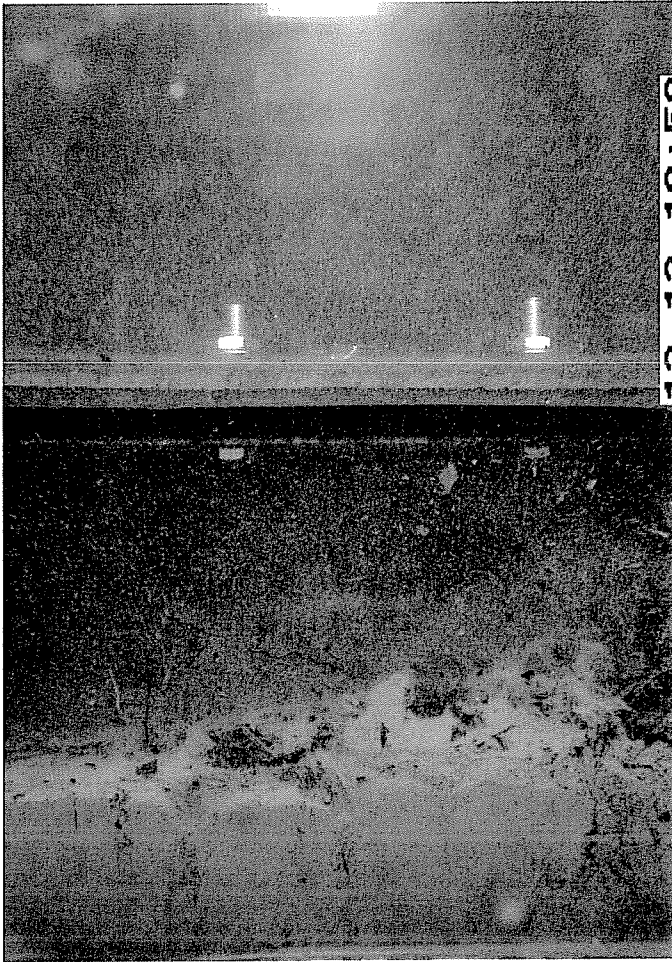
A3 WEST 2-1



A3 WEST 2-2

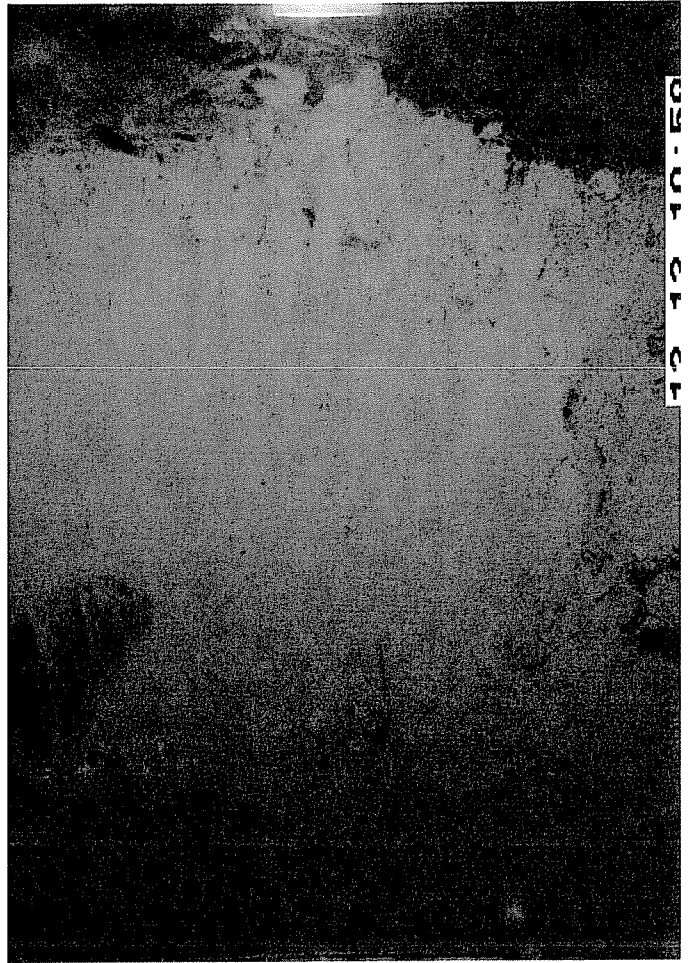


A3 WEST 2-3



10 10 10-EG

A3 WEST 3-1



10 10 10-EG

A3 WEST 3-2



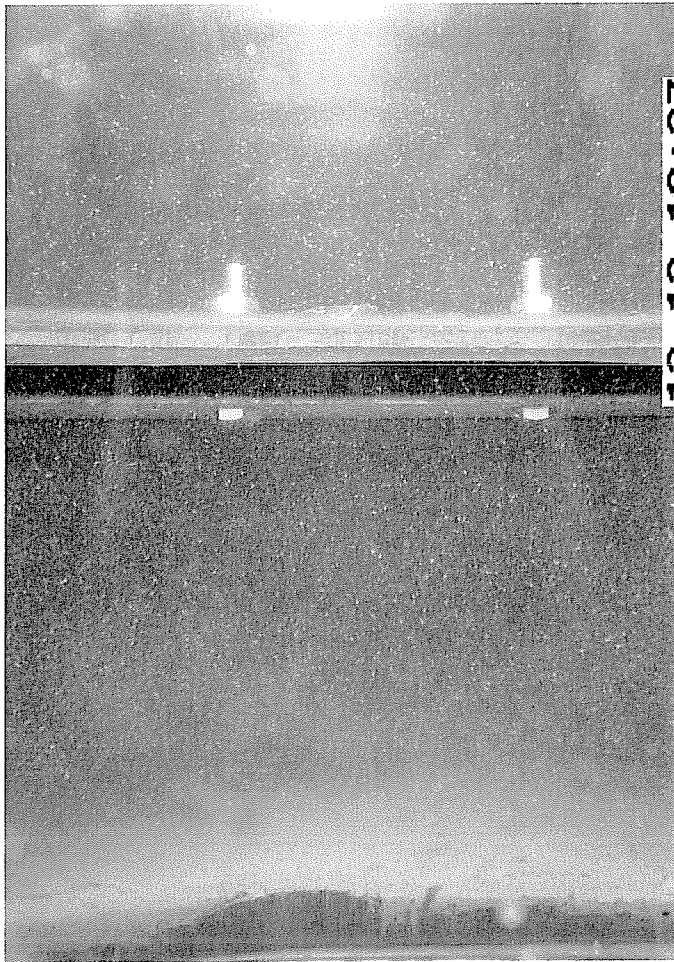
10 10 10-EG

A3 WEST 3-3

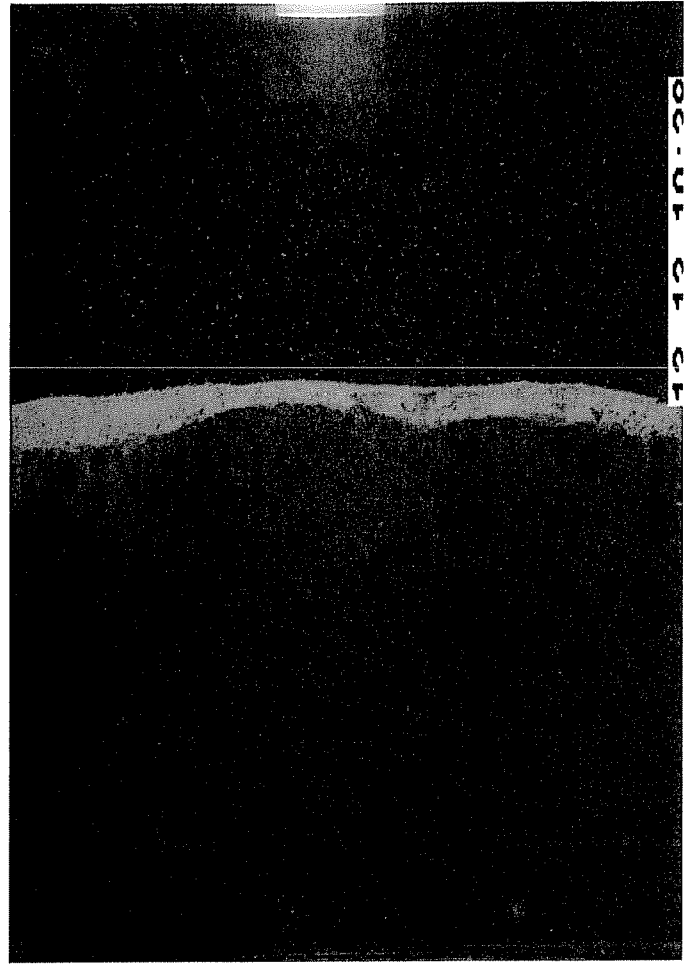


10 10 10-EG

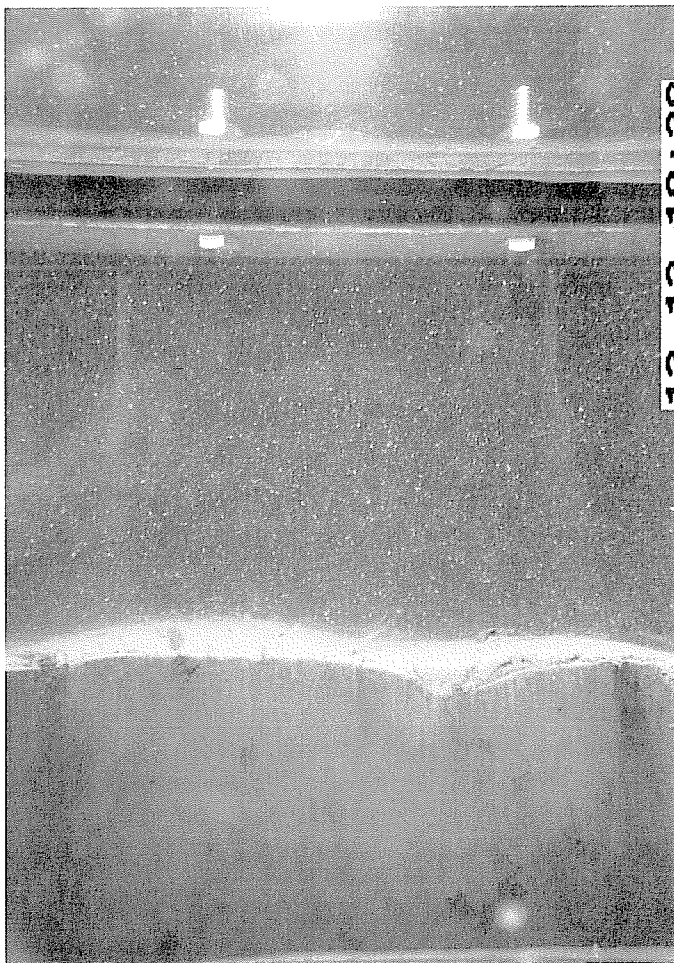
A3 WEST 3-4



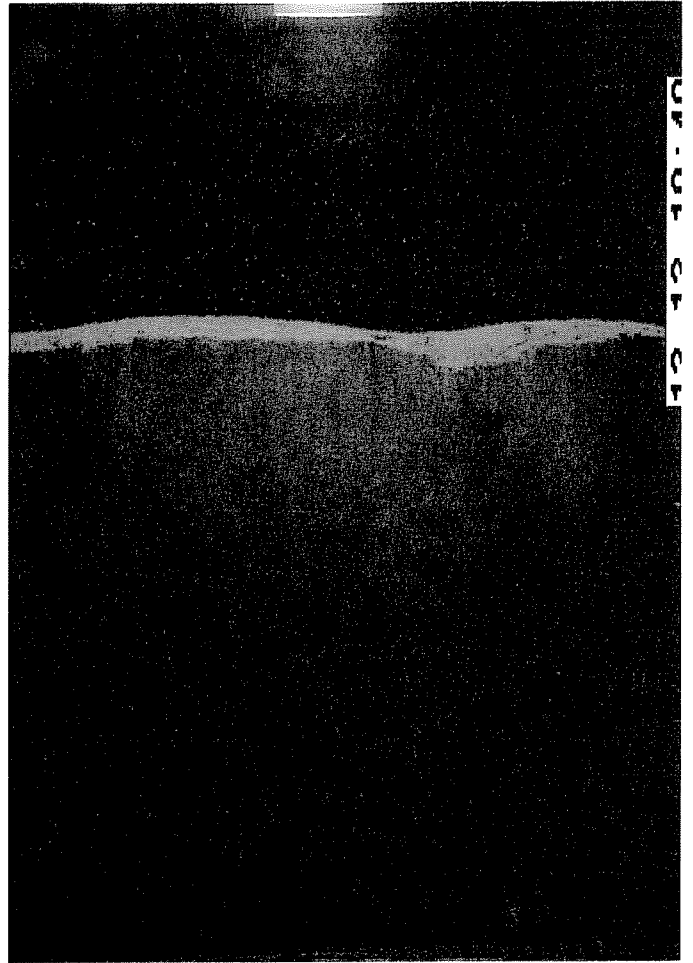
BI NORTH 1-1



BI NORTH 1-2



BI NORTH 2-1

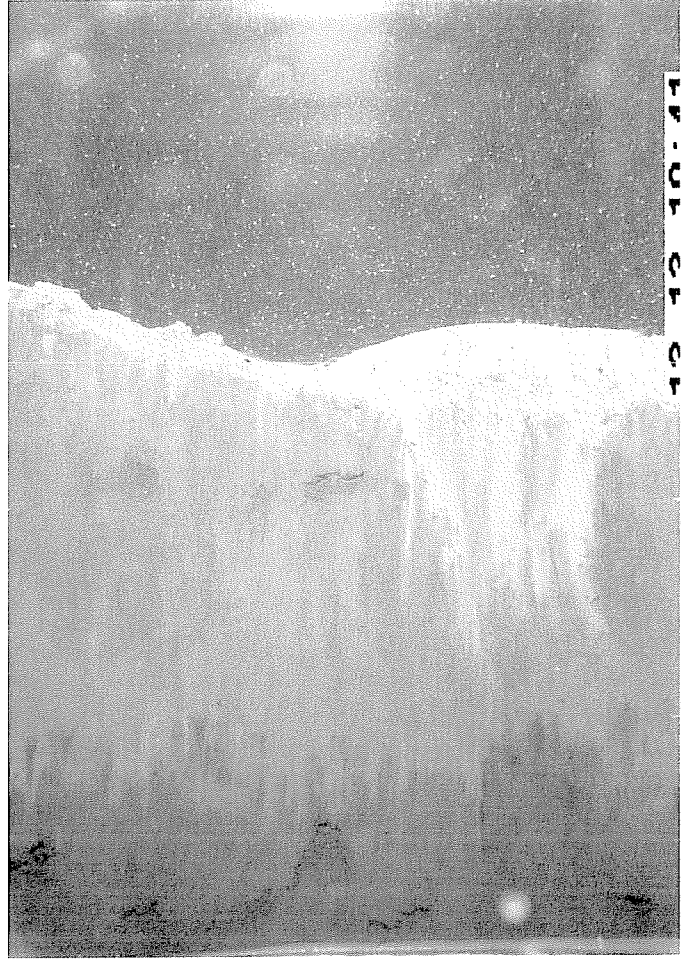


BI NORTH 2-2



10 10 10-11

BI NORTH 3-1



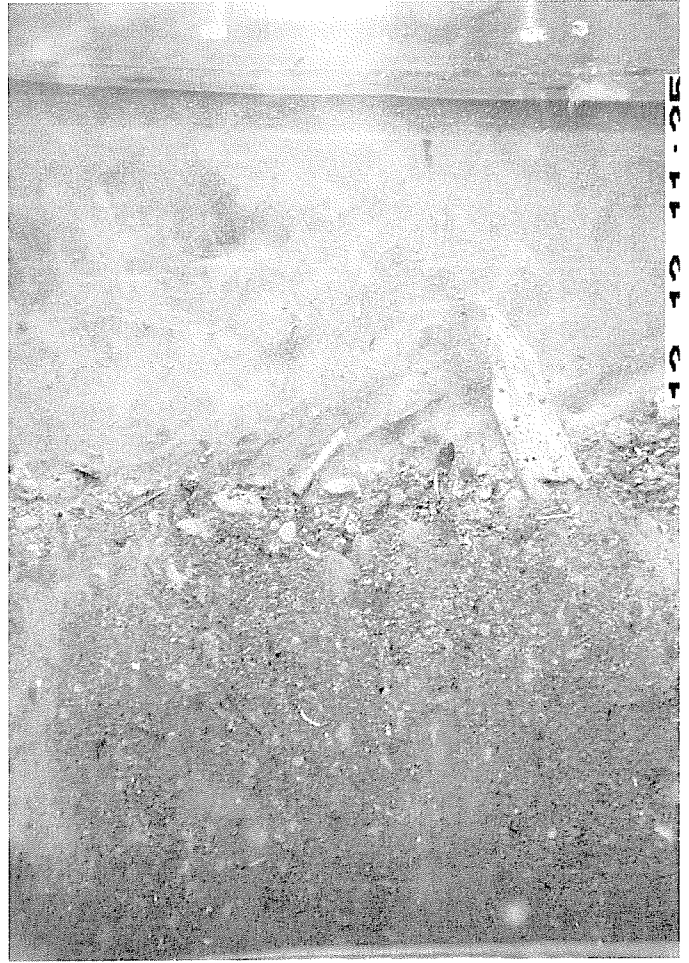
10 10 10-11

BI NORTH 3-2



10 10 11-08

CI 1



10 10 11-08

CI 2-1



10 10 11 06

CI 2-2



10 10 11 06

CI 2-3



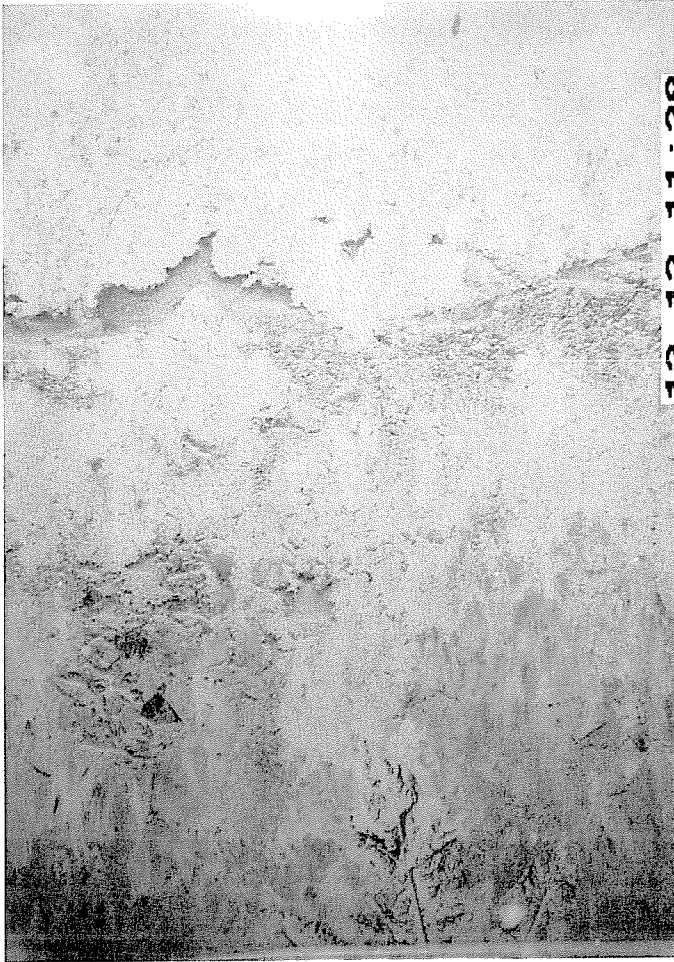
10 10 11 07

CI 2-4

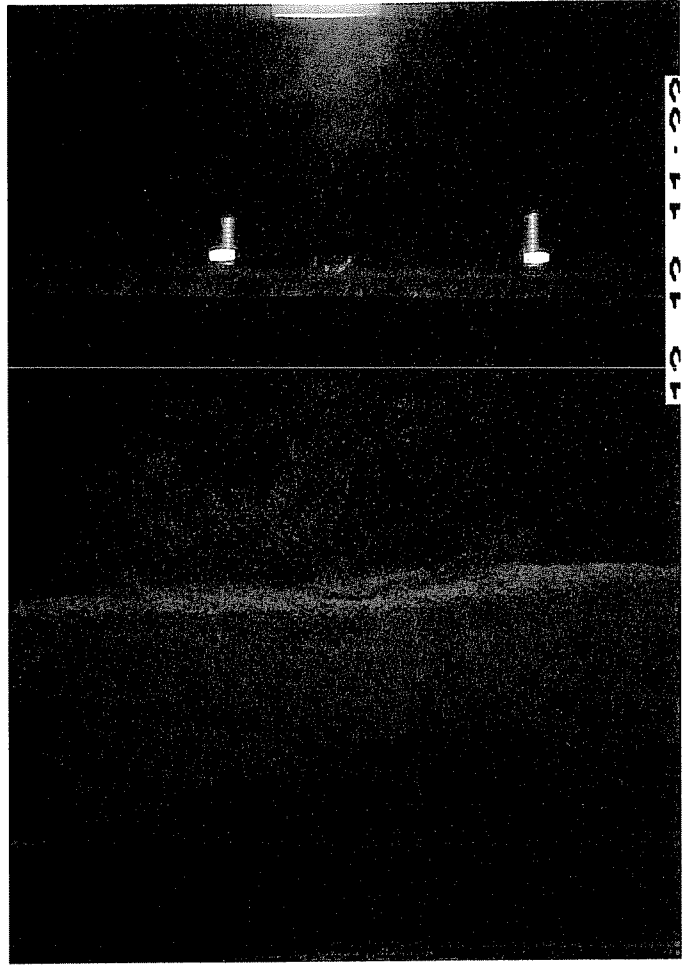


10 10 11 07

CI 3-1



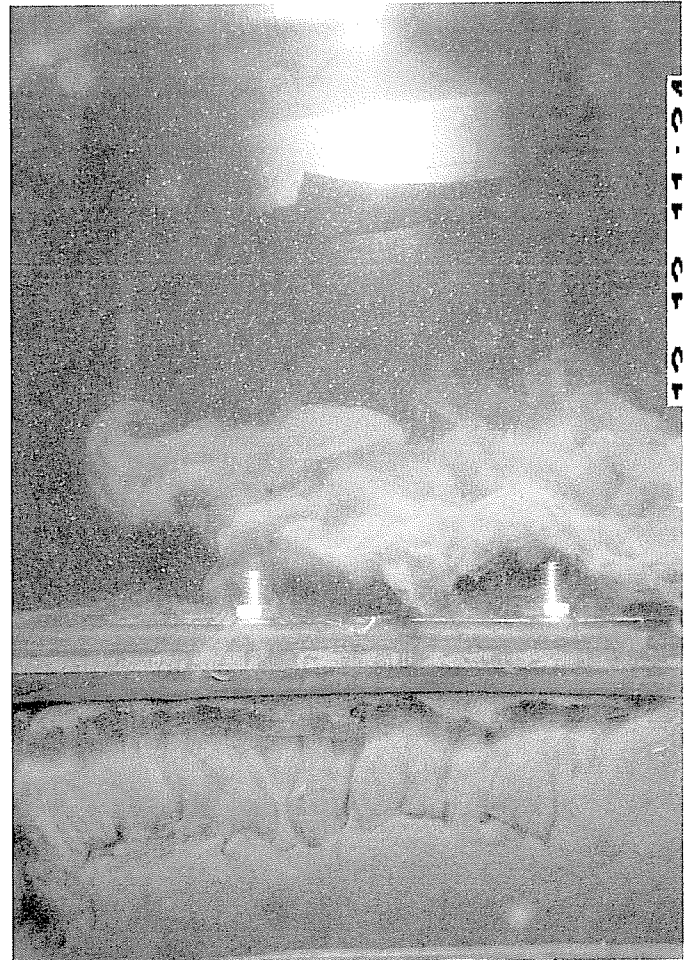
C1 3-2



C2 1-1



C2 1-2



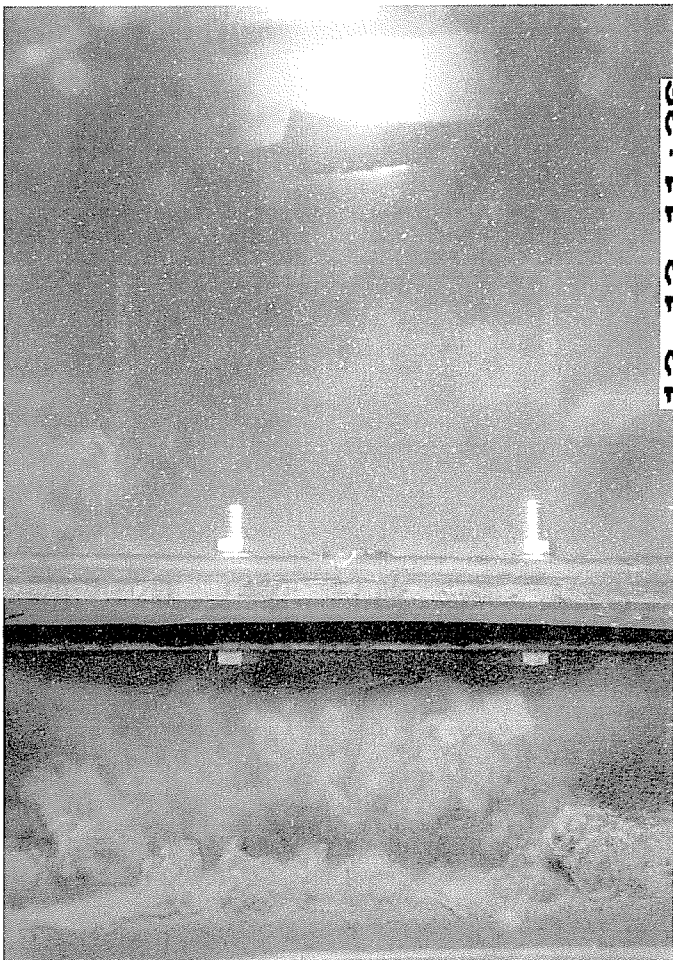
C2 2-1



C2 2-2



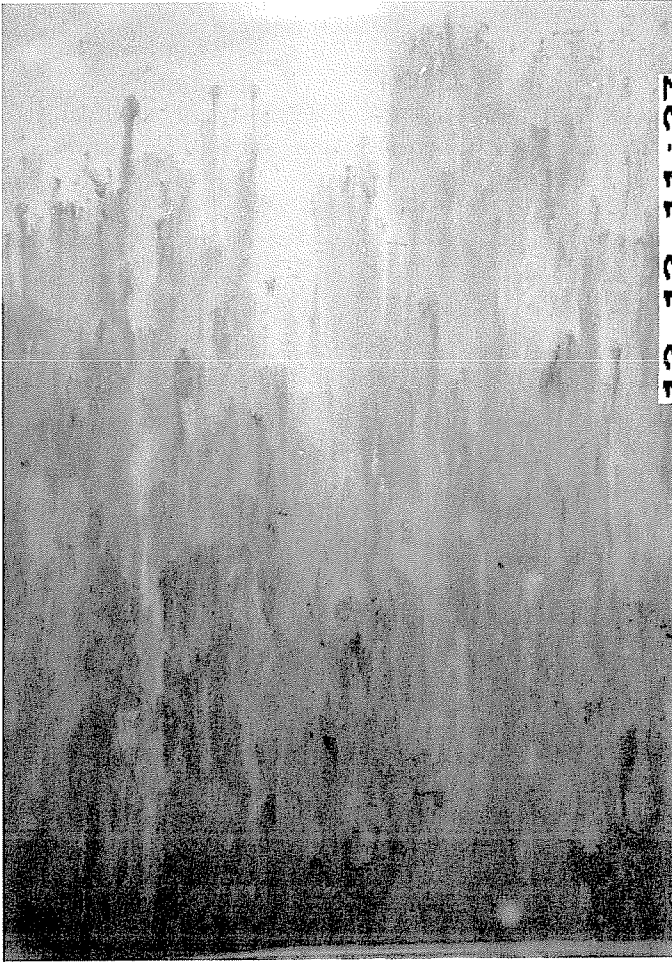
C2 2-3



C2 3-1

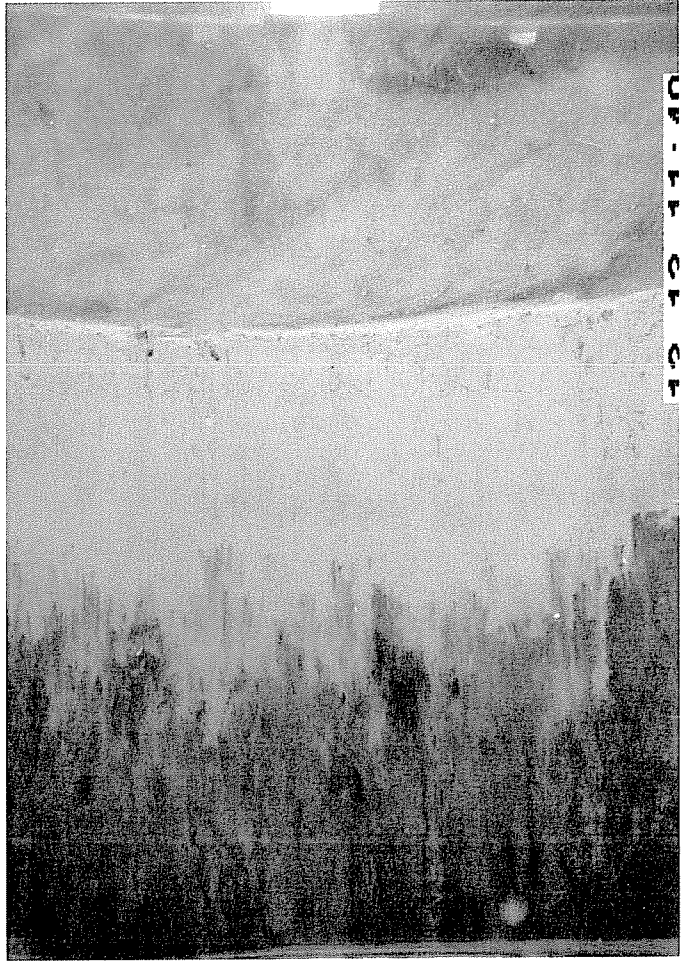


C2 3-2



10 10 11 07

C2 3-3



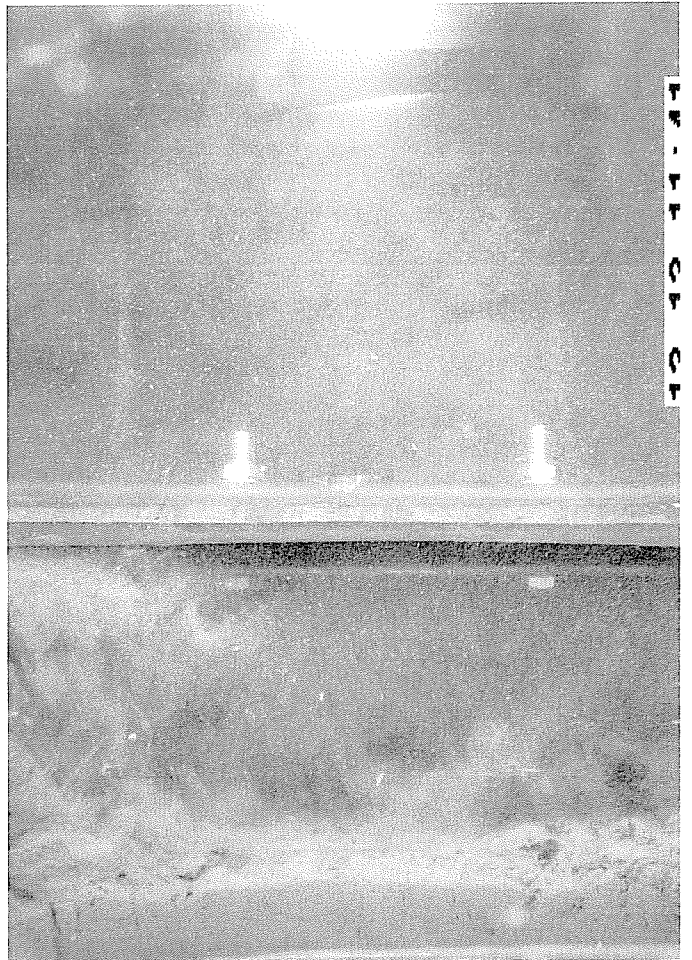
10 10 11 10

C3 1-1



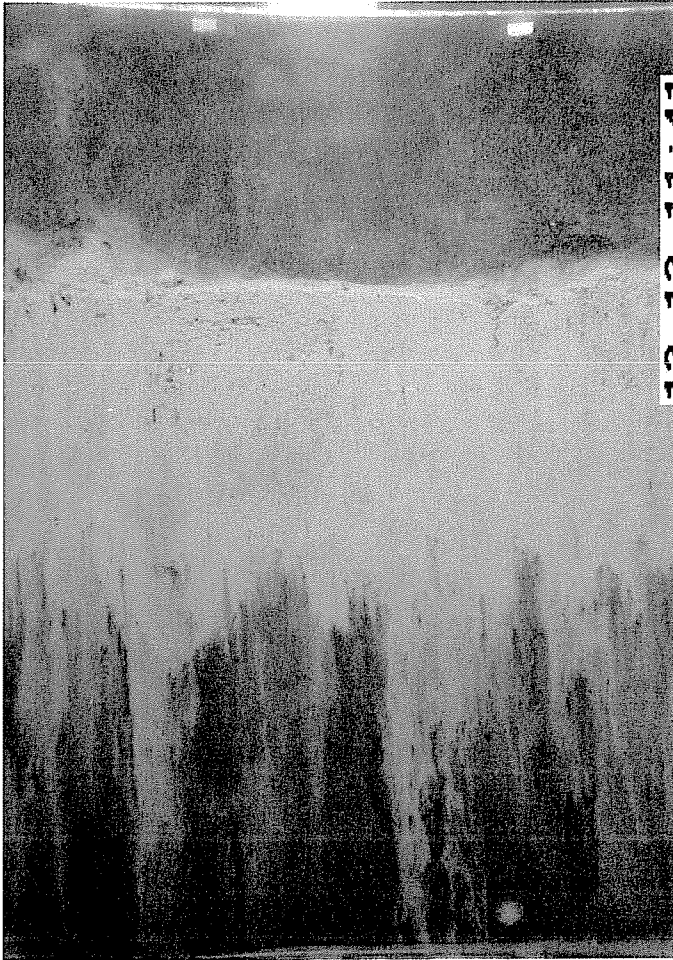
10 10 11 10

C3 1-2



10 10 11 11

C3 2-1



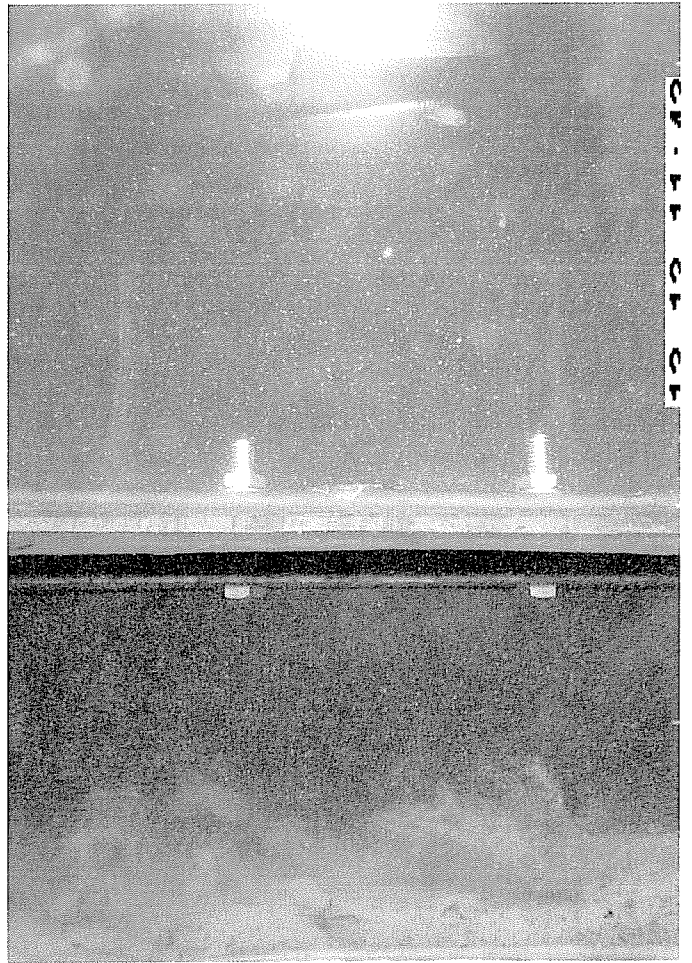
C3 2-2



C3 2-3



C3 2-4

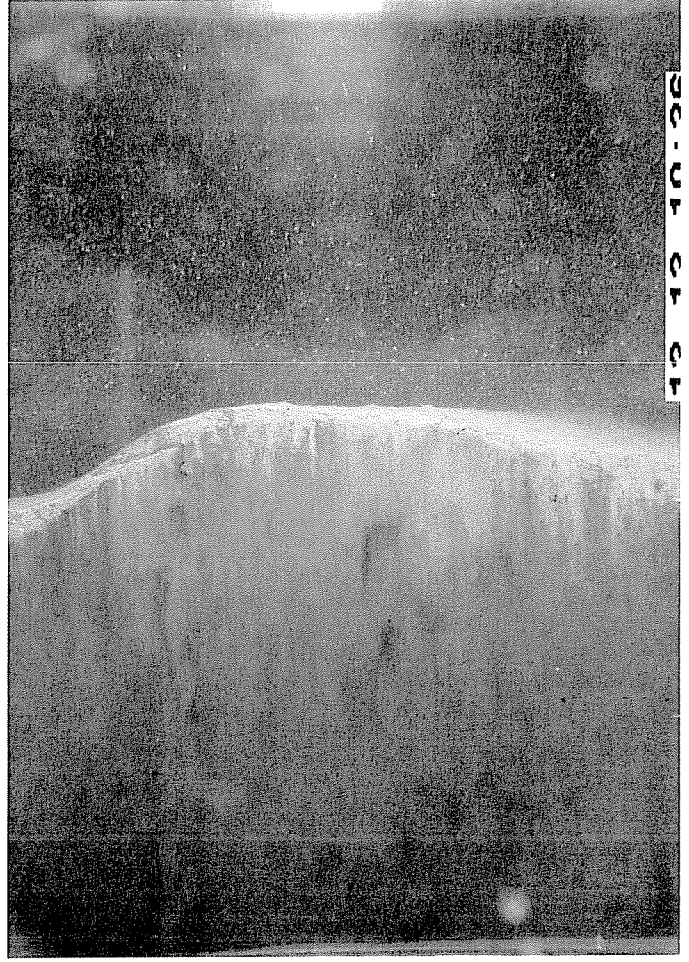


C3 3-1



13 10 11 10

C3 3-2



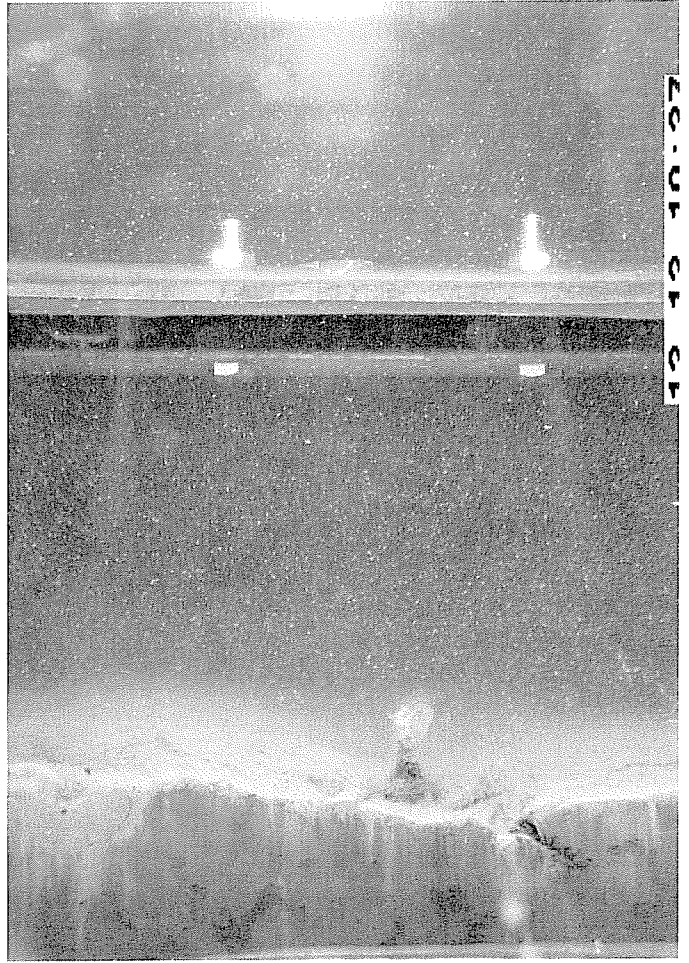
13 10 10 06

DI NORTH 1-1



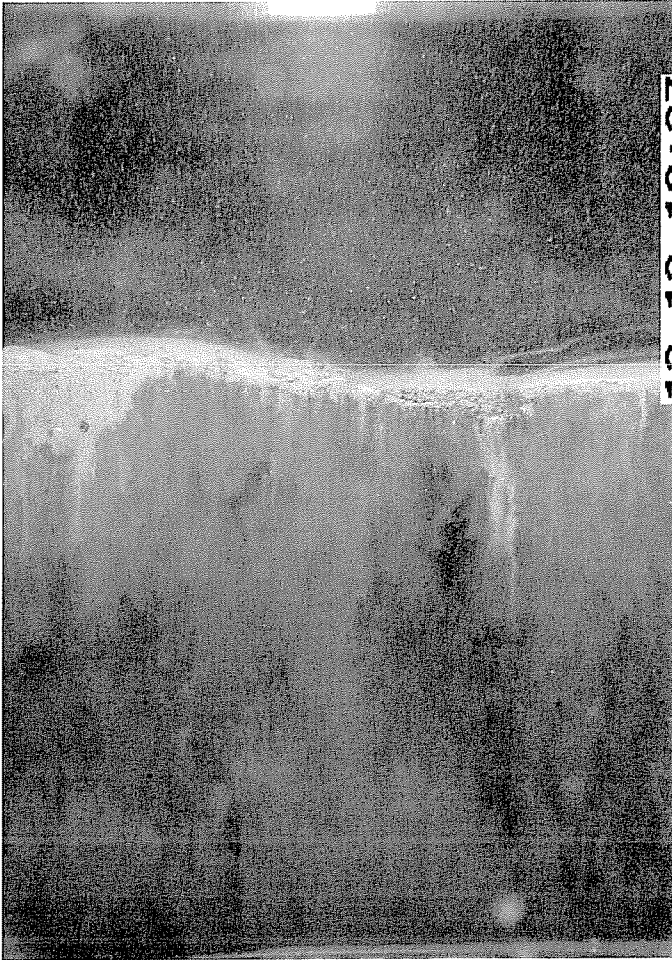
13 10 10 06

DI NORTH 1-2

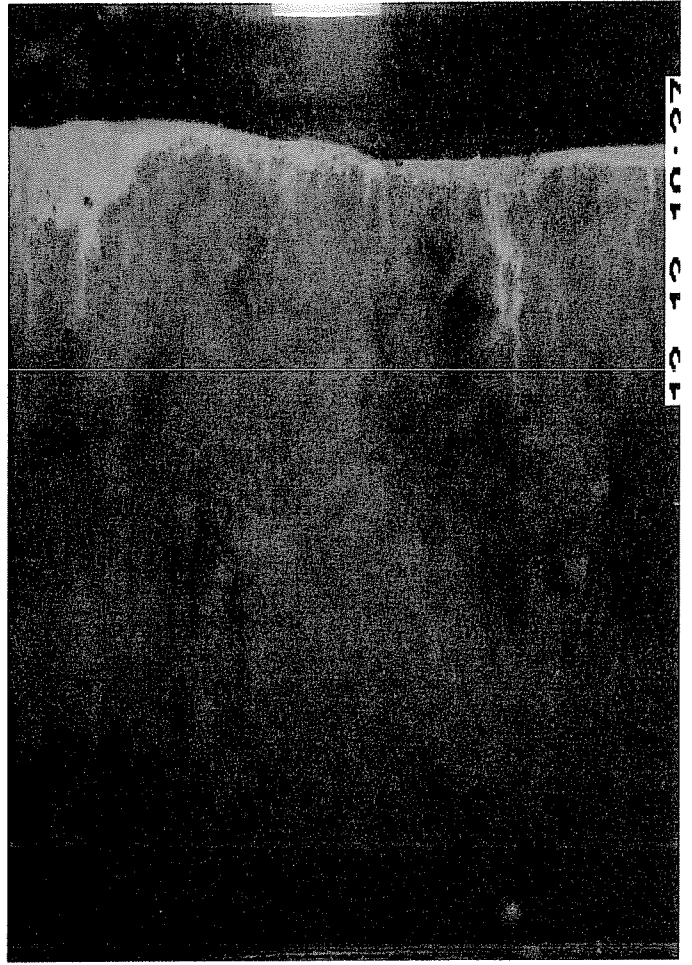


13 10 10 07

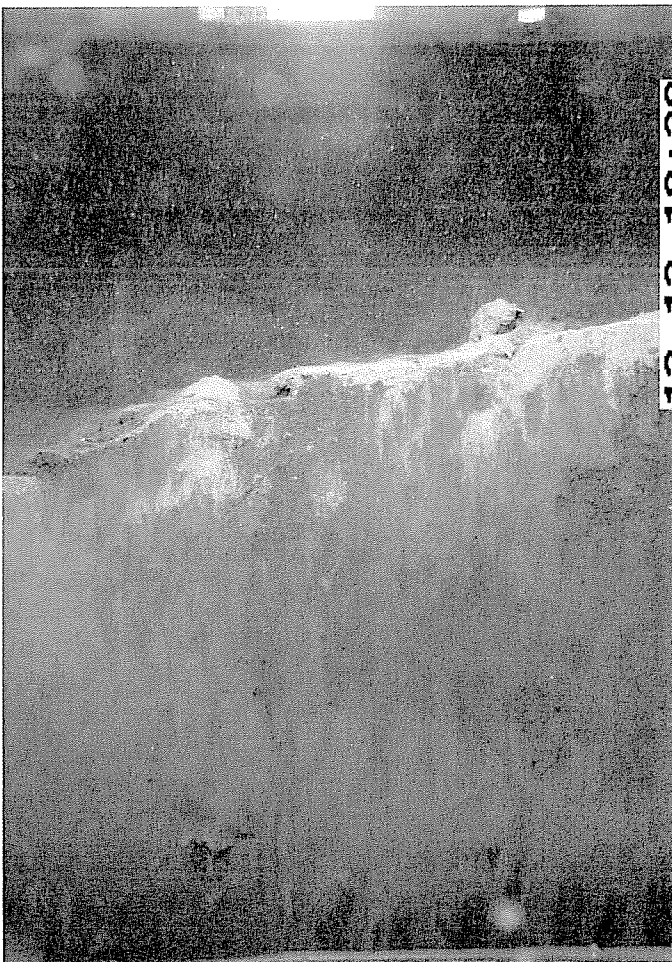
DI NORTH 2-1



DI NORTH 2-2



DI NORTH 2-3



DI NORTH 3-1



DI NORTH 3-2



E1 1



E1 2-1



E1 2-2



E1 2-3



10 10 11 50

EI 3-1



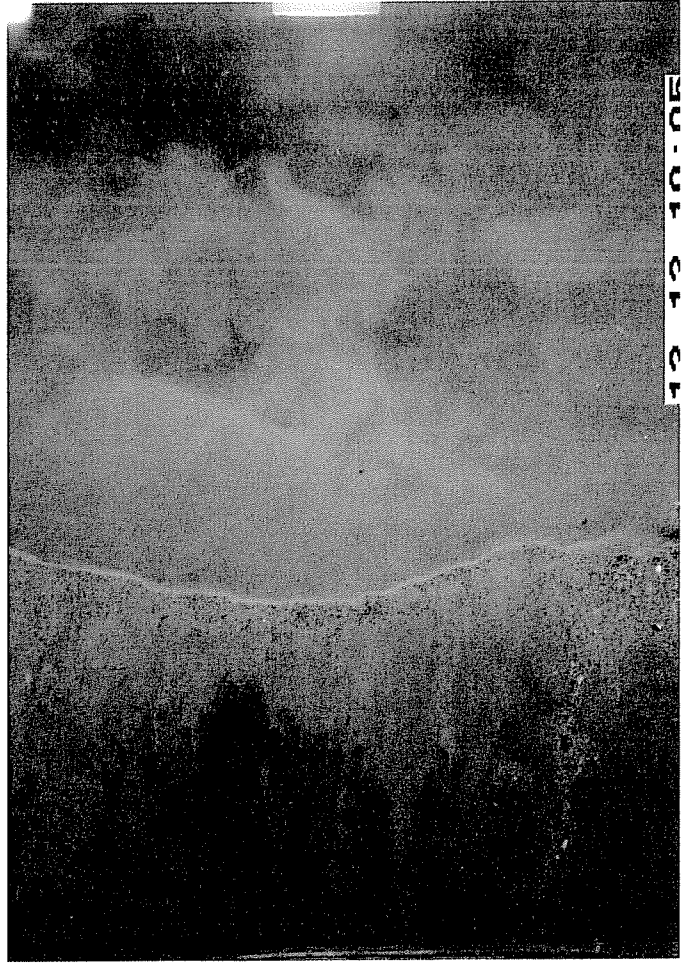
10 10 11 50

EI 3-2



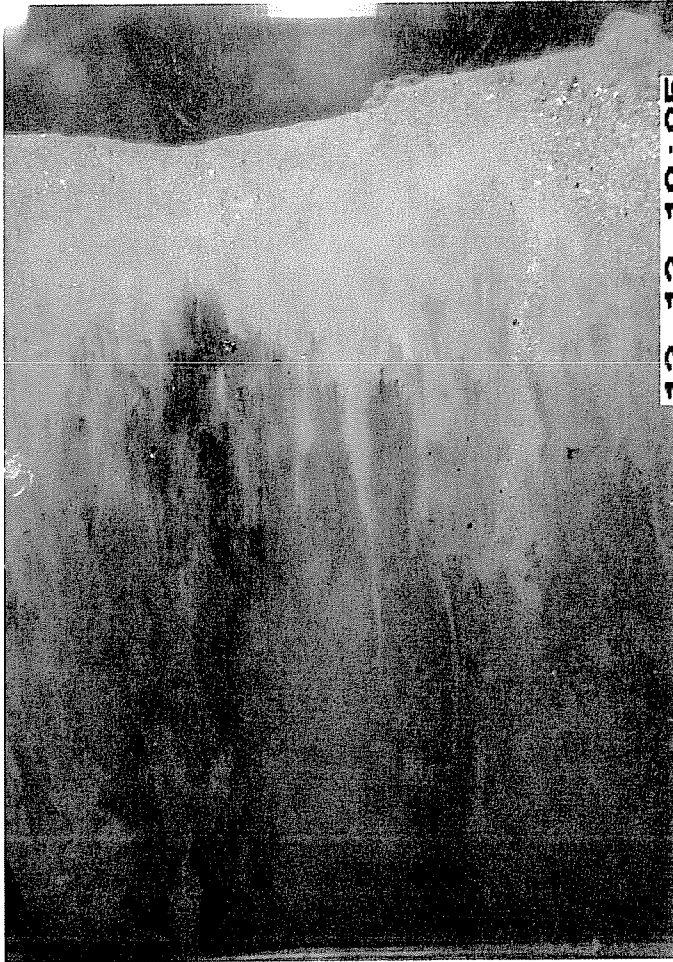
10 10 11 51

EI 3-3



10 10 10 05

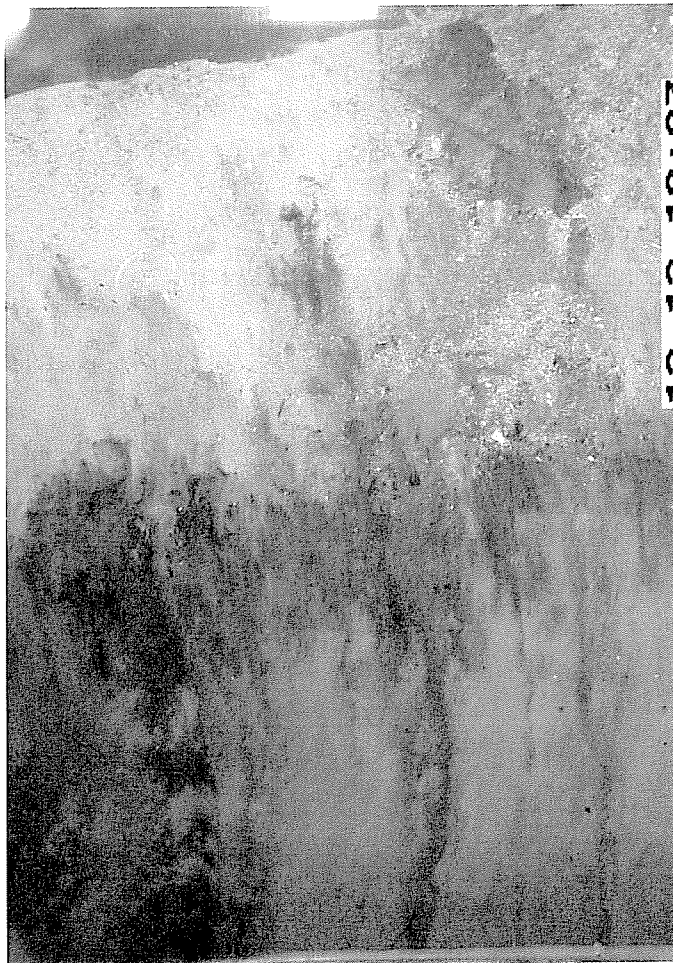
EI EAST



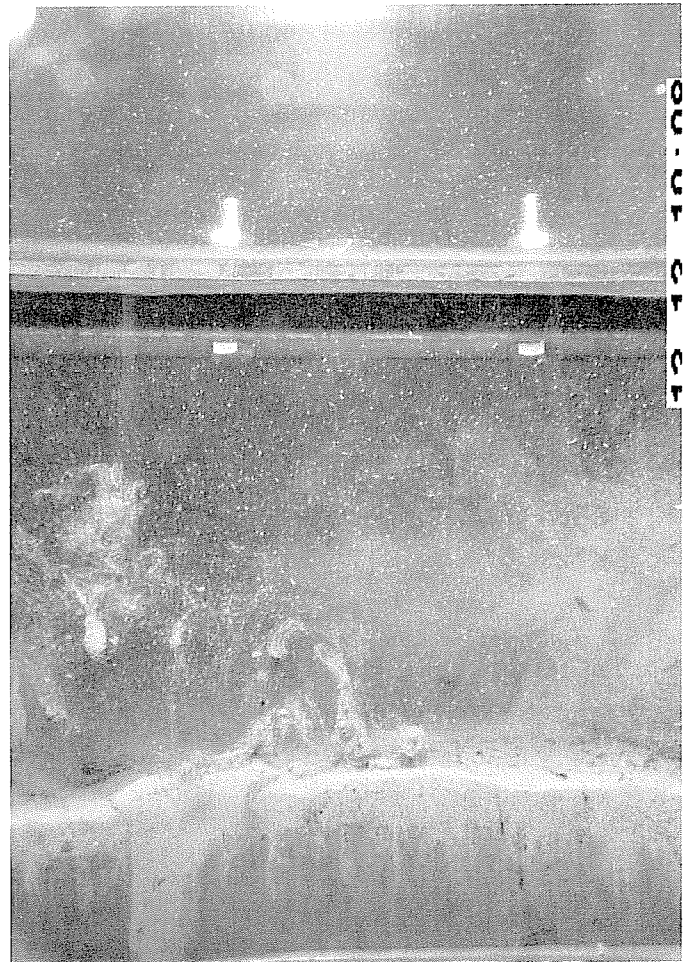
E1 EAST 1



E1 EAST 2-1



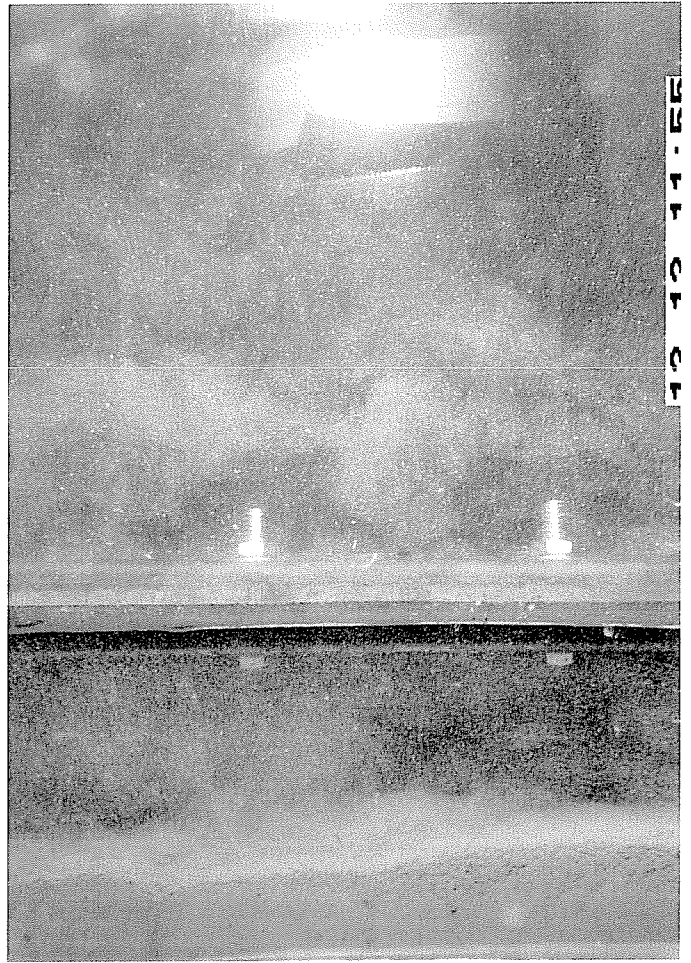
E1 EAST 2-2



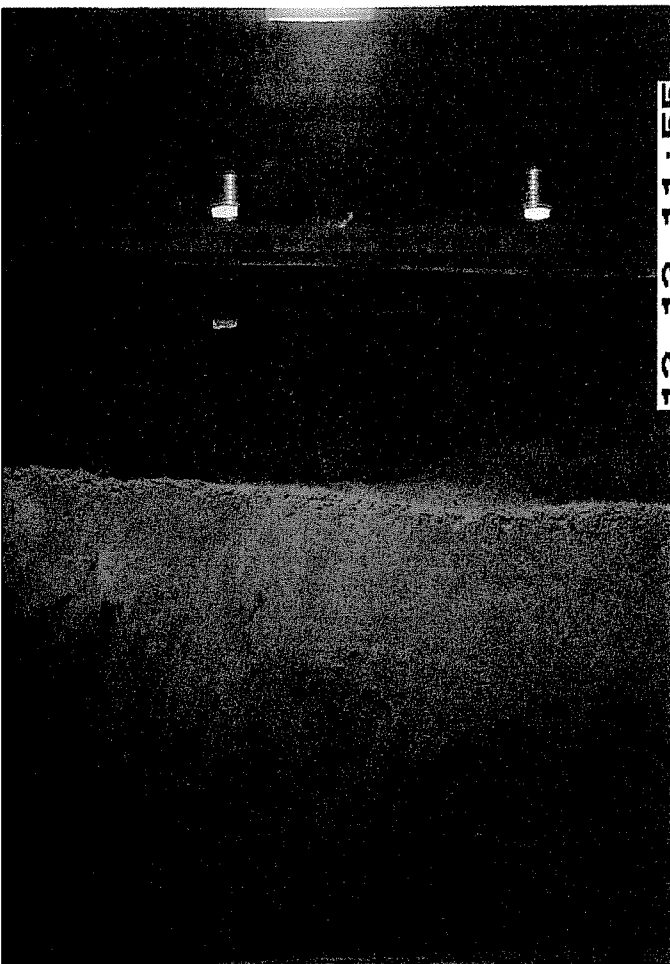
E1 EAST 3-1



E1 EAST 3-2



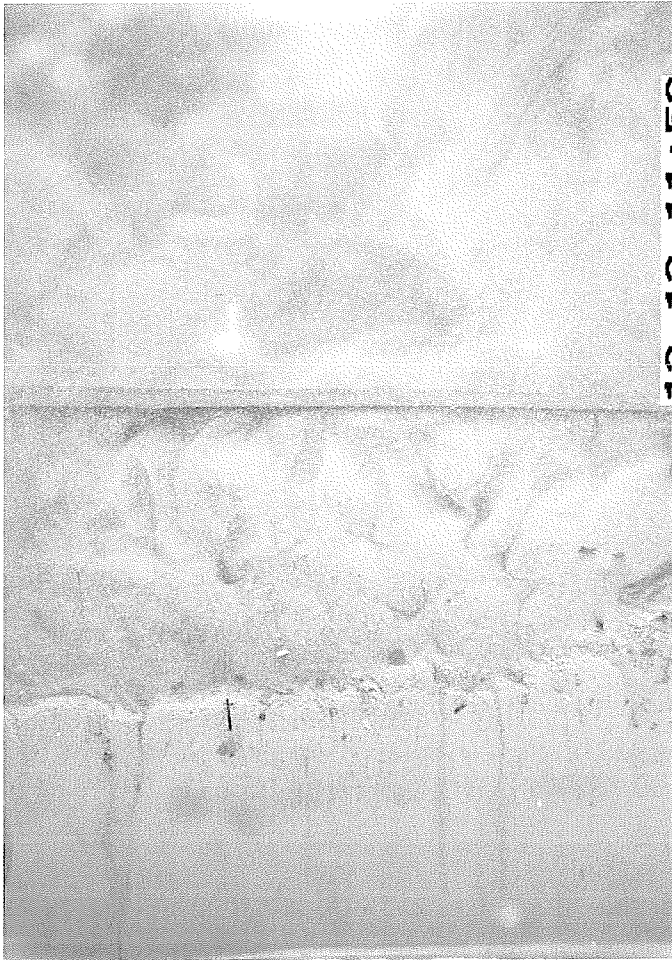
E2 1-1



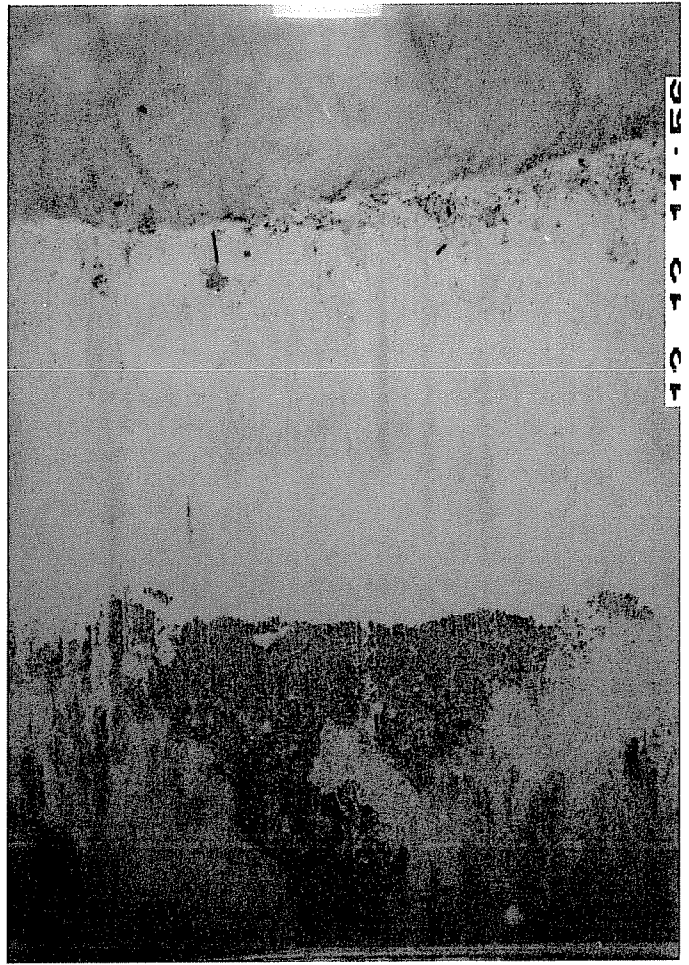
E2 1-2



E2 1-3



E2 2-1



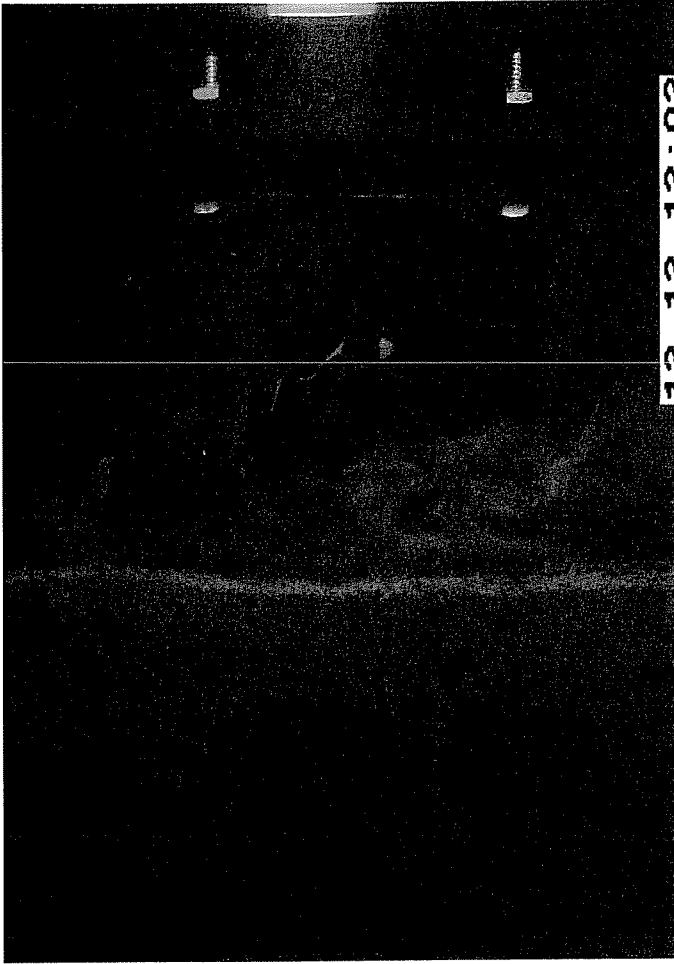
E2 2-2



E2 2-3

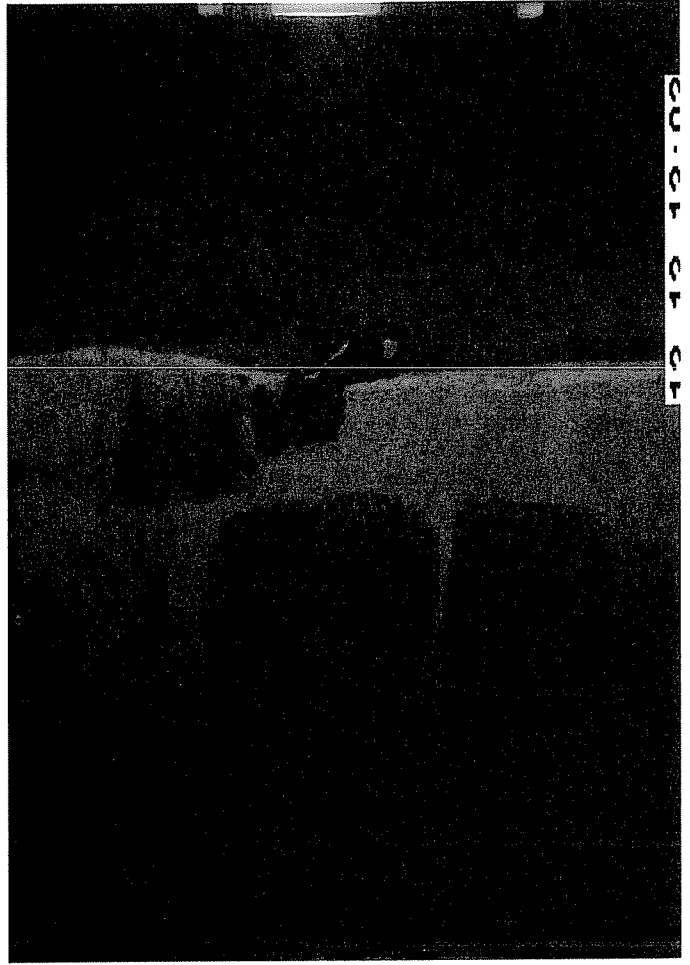


E2 3



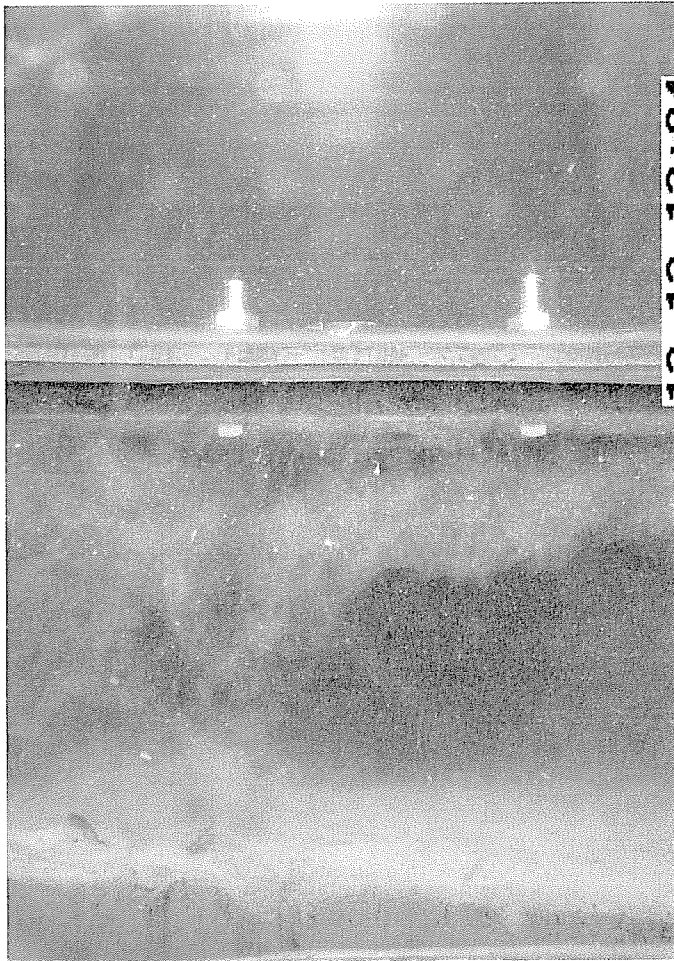
10 10 10-00

E3 1-1



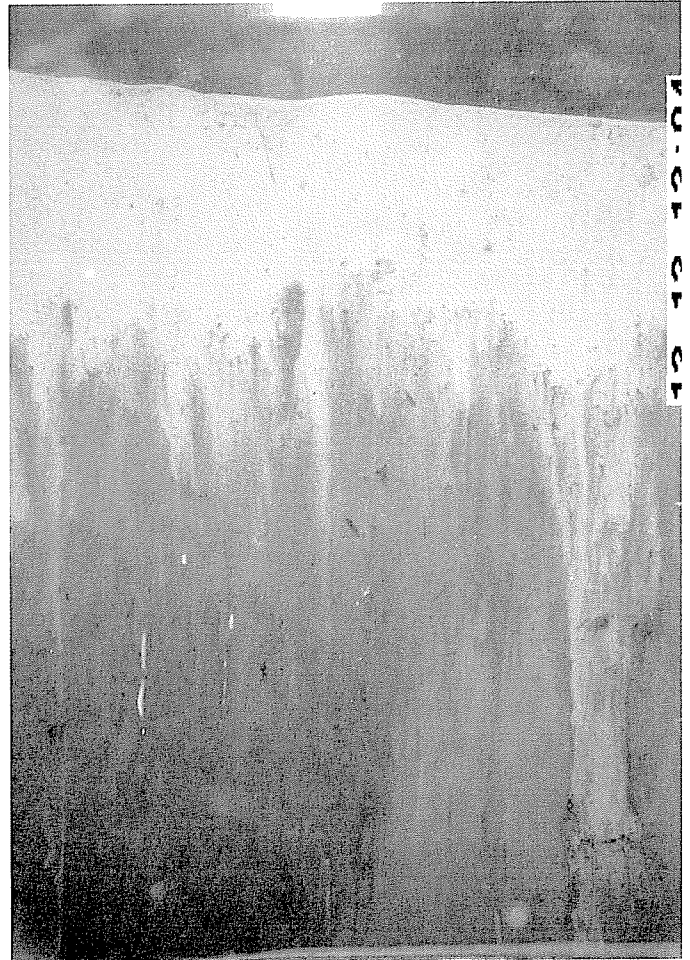
10 10 10-00

E3 1-2



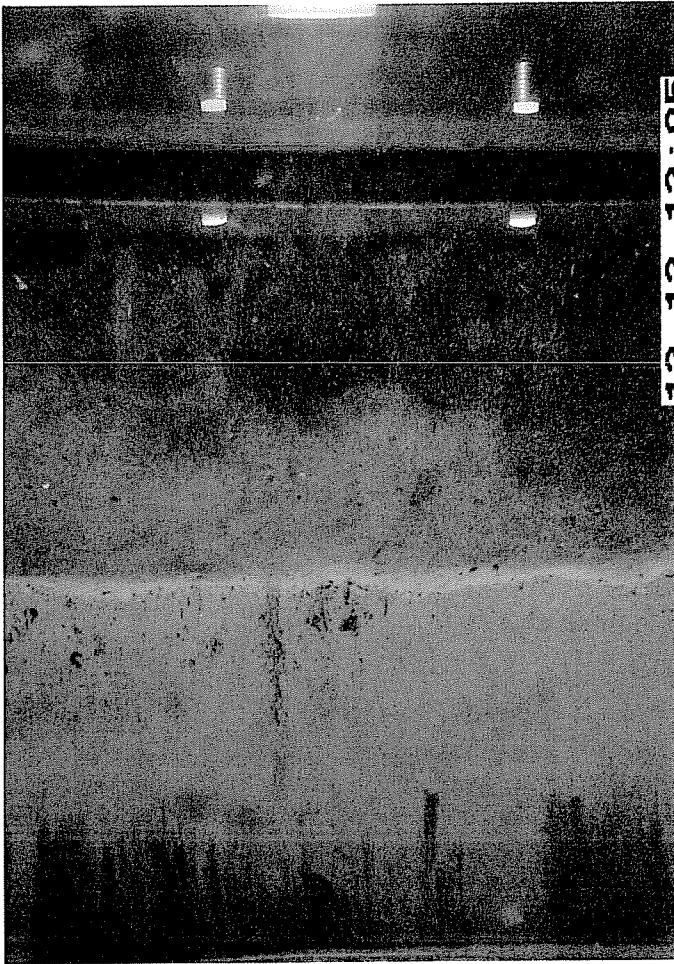
10 10 10-04

E3 2-1



10 10 10-04

E3 2-2



E3 3-1



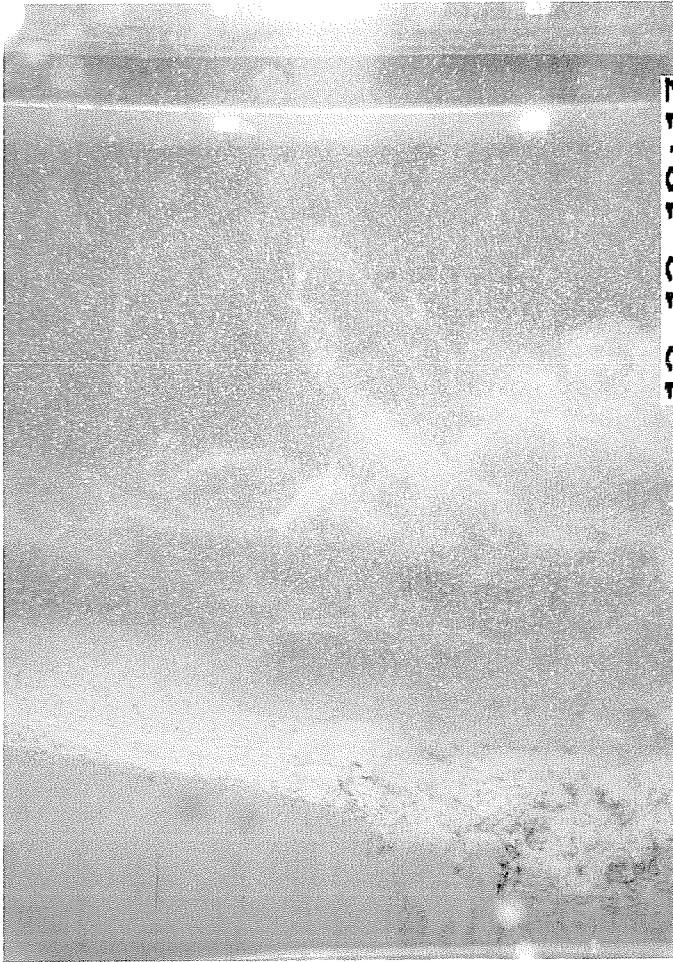
E3 3-2



E3 EAST 1-1

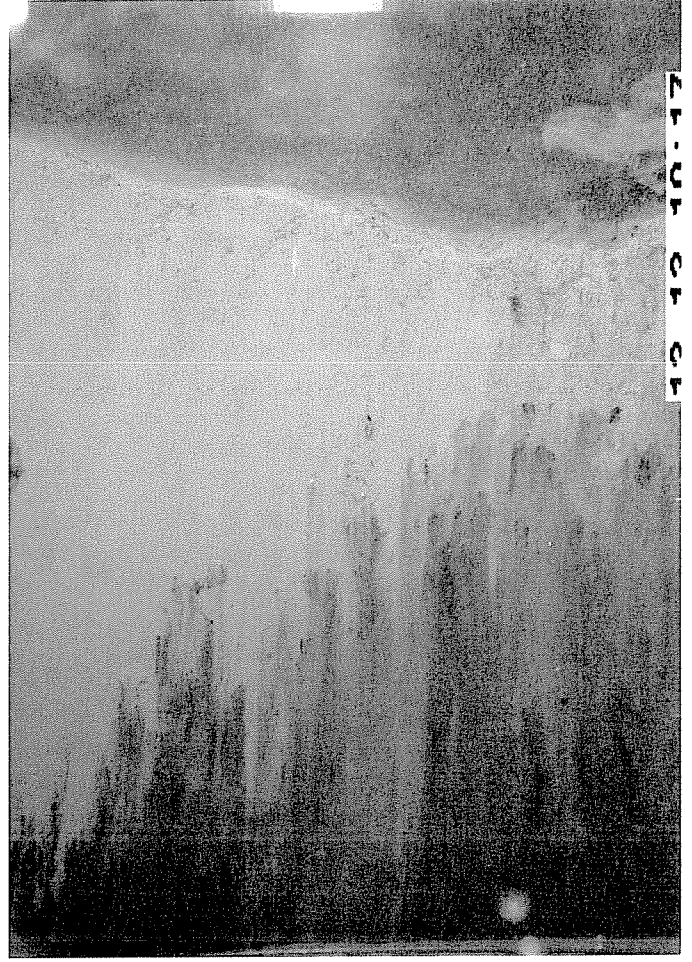


E3 EAST 1-2



10 10 10-17

E3 EAST 2-1



10 10 10-17

E3 EAST 2-2



10 10 10-17

E3 EAST 2-3



10 10 10-10

E3 EAST 2-4



E3 EAST 3-1



E3 EAST 3-2



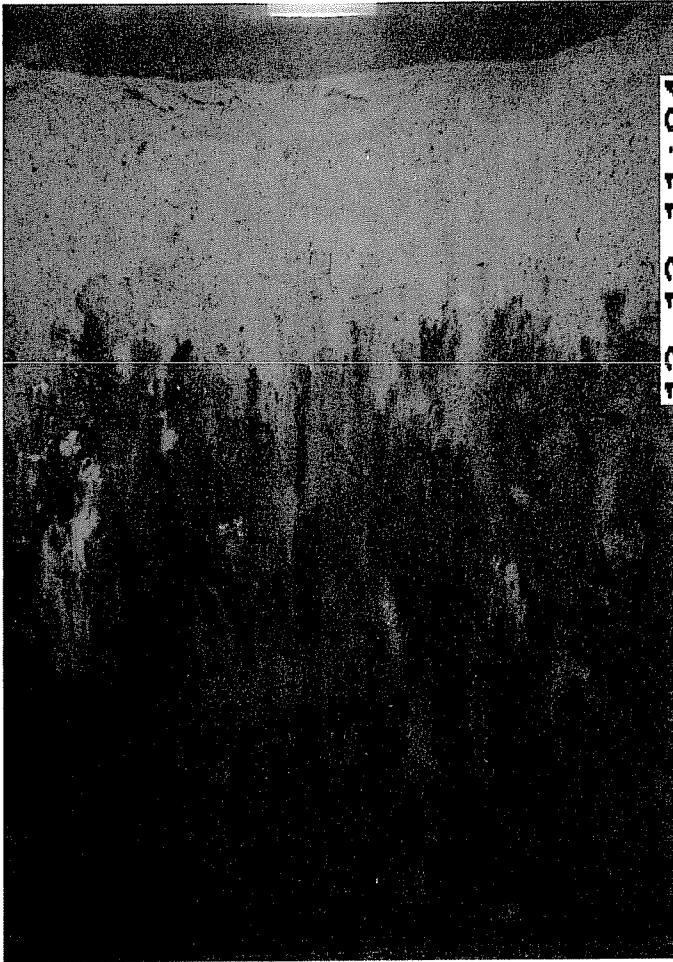
E3 EAST 3-3



E3 EAST 3-4

Appendix C

Stitched Sediment Profile Images



A1 1



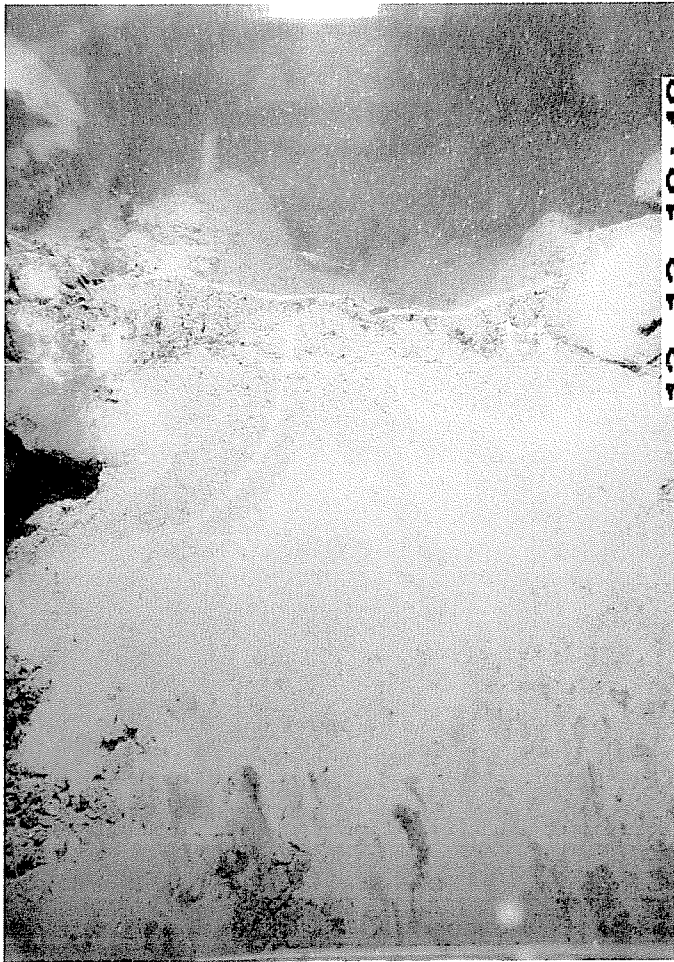
A1 2



A1 3



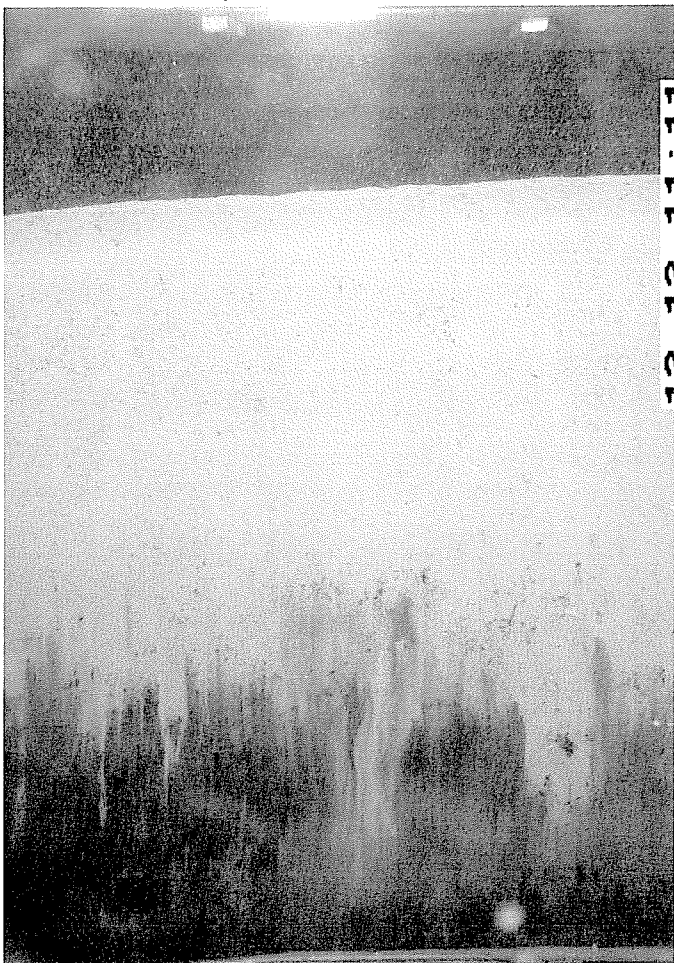
A1 WEST 1



A1 WEST 2



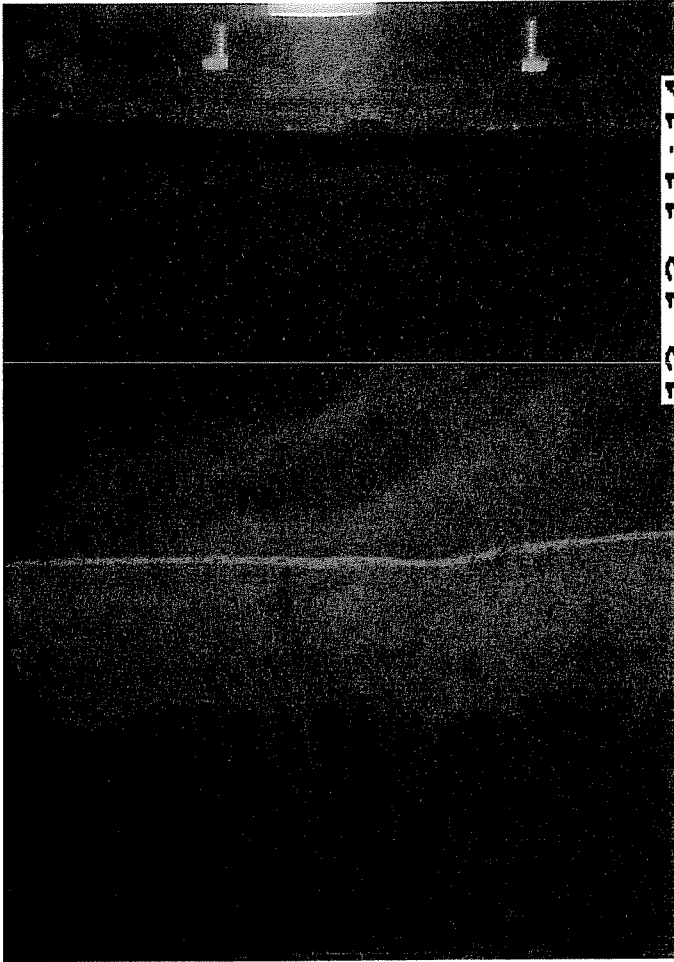
A1 WEST 3



A2 1



A2 2



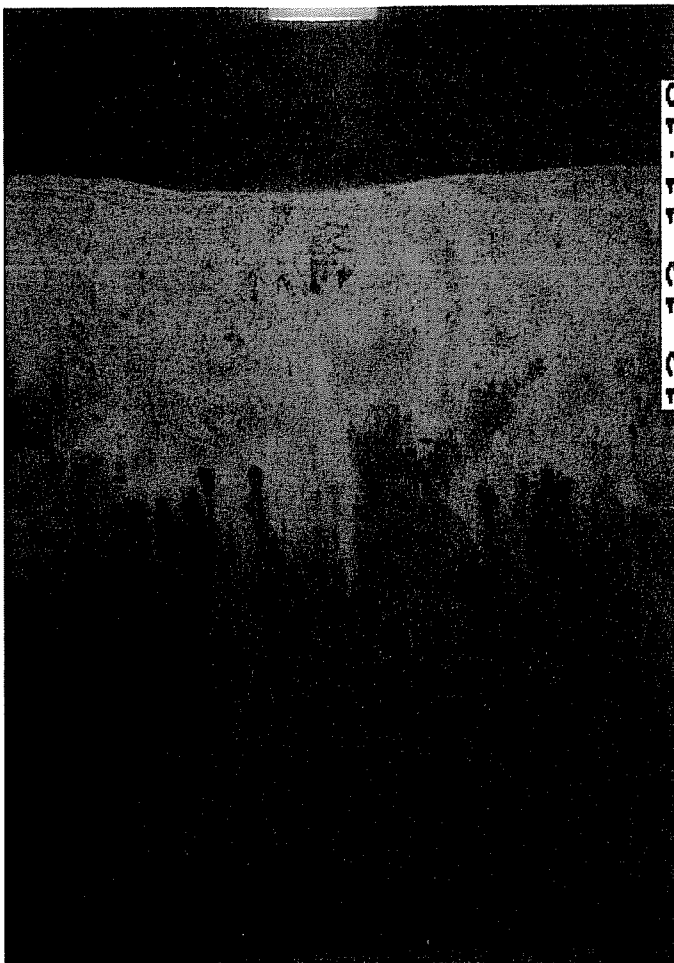
10 10 11 11

A2 3



10 10 11 10

A3 1



10 10 11 10

A3 2



12. 13

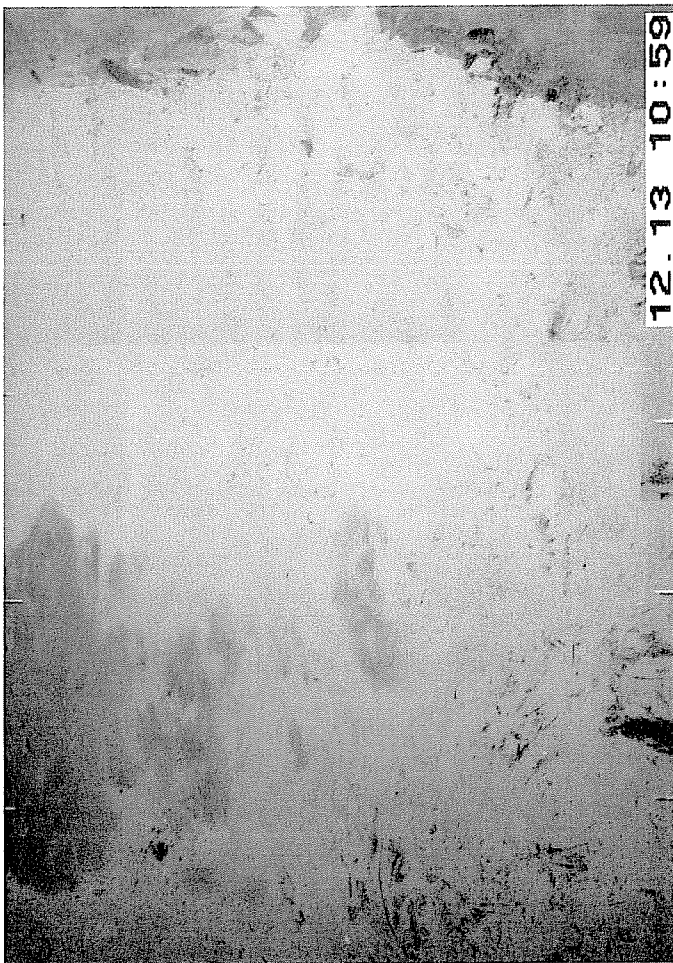
A3 3



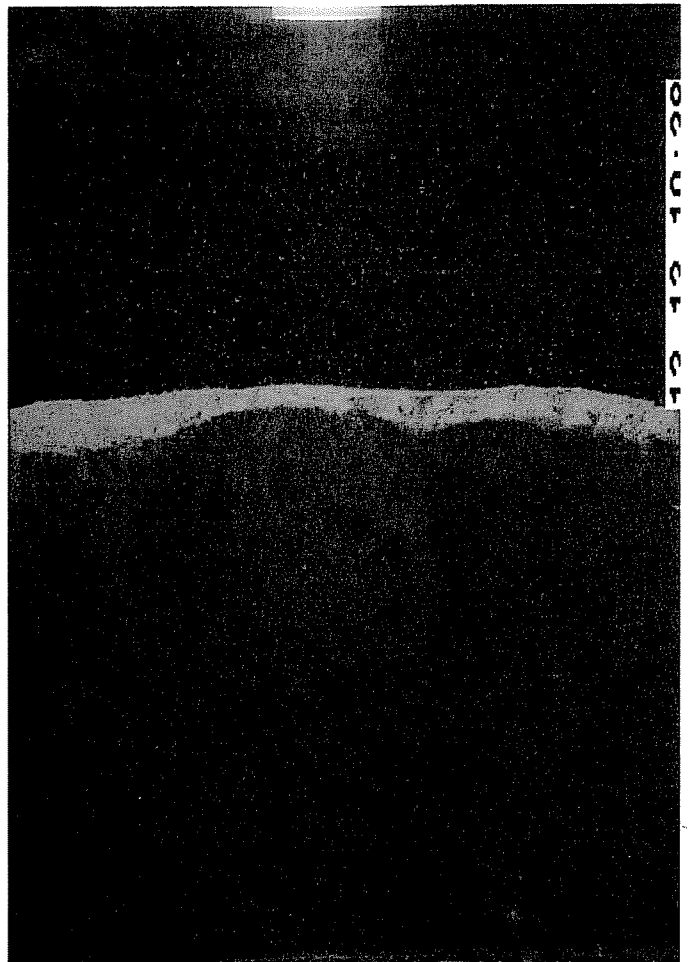
A3 WEST 1



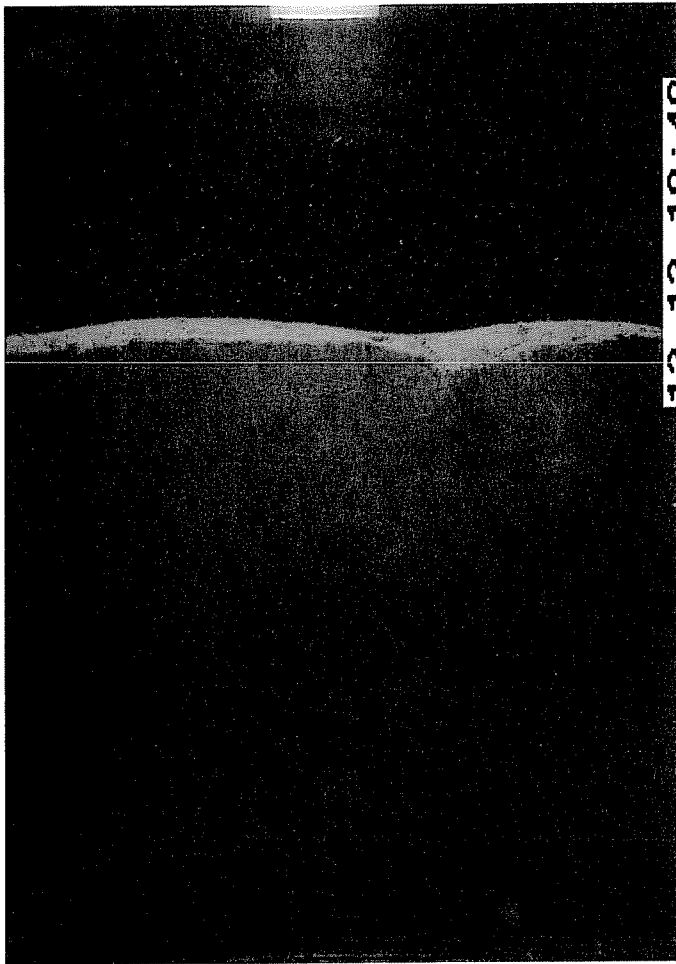
A3 WEST 2



A3 WEST 3

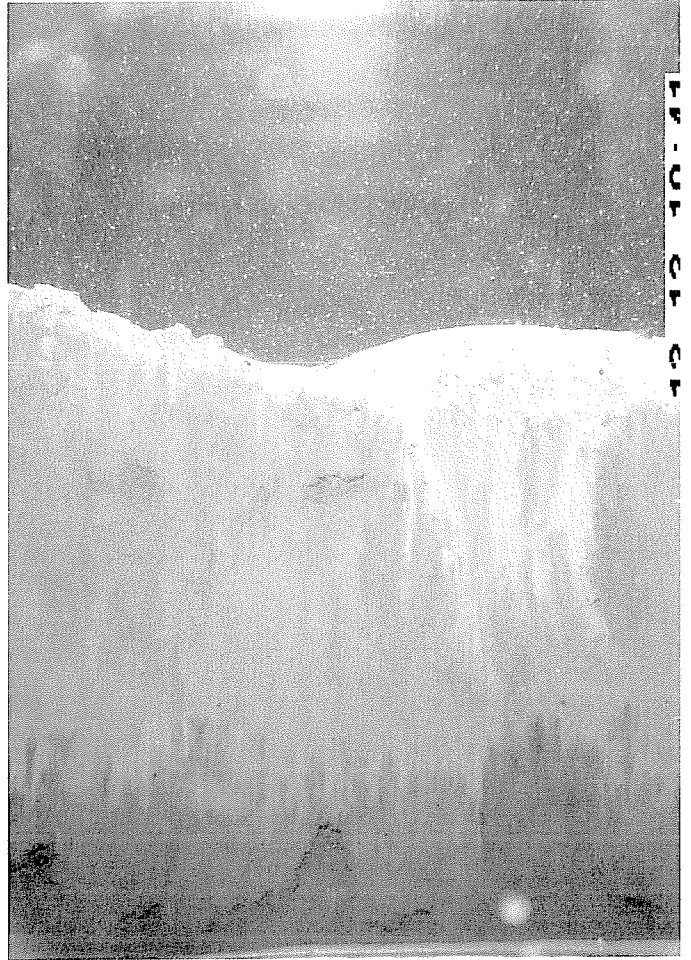


B1 NORTH 1



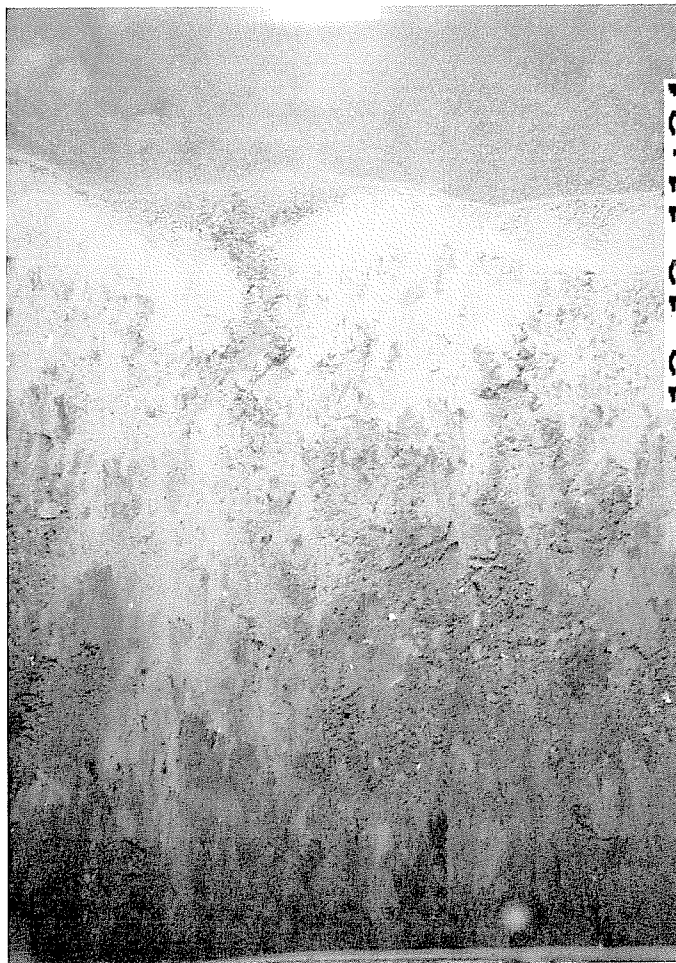
10 10 10-40

BI NORTH 2



10 10 10-41

BI NORTH 3

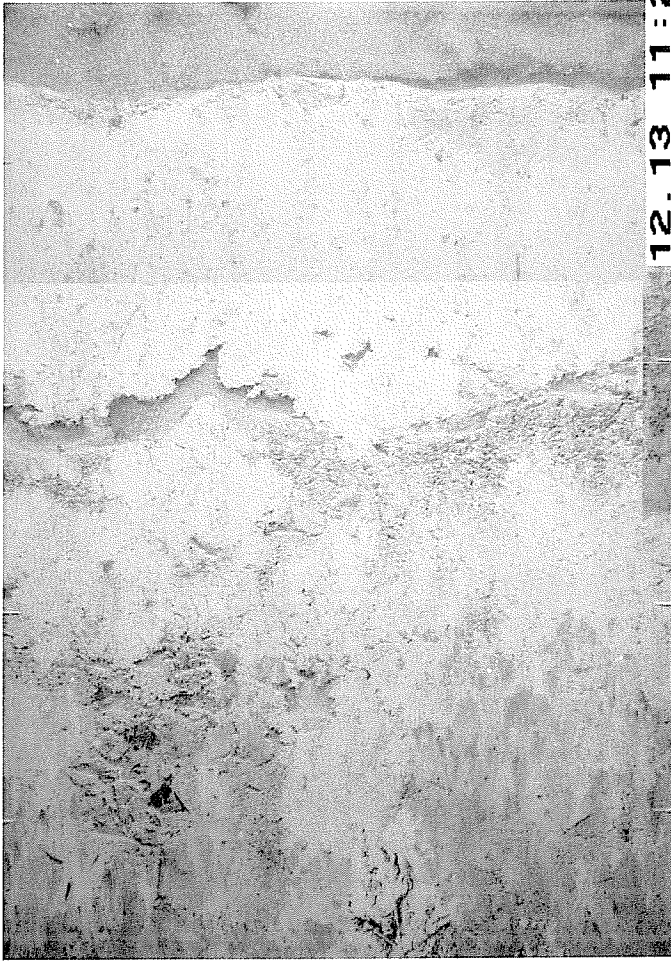


10 10 11-01

C11



C12



12.13 11:33

C13



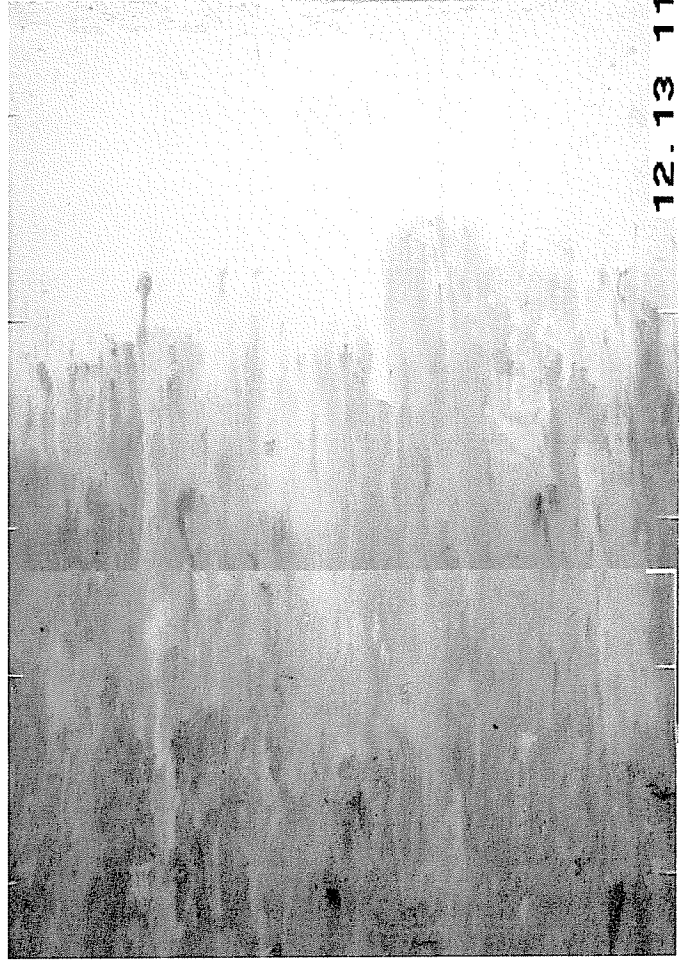
12.13 11:33

C21



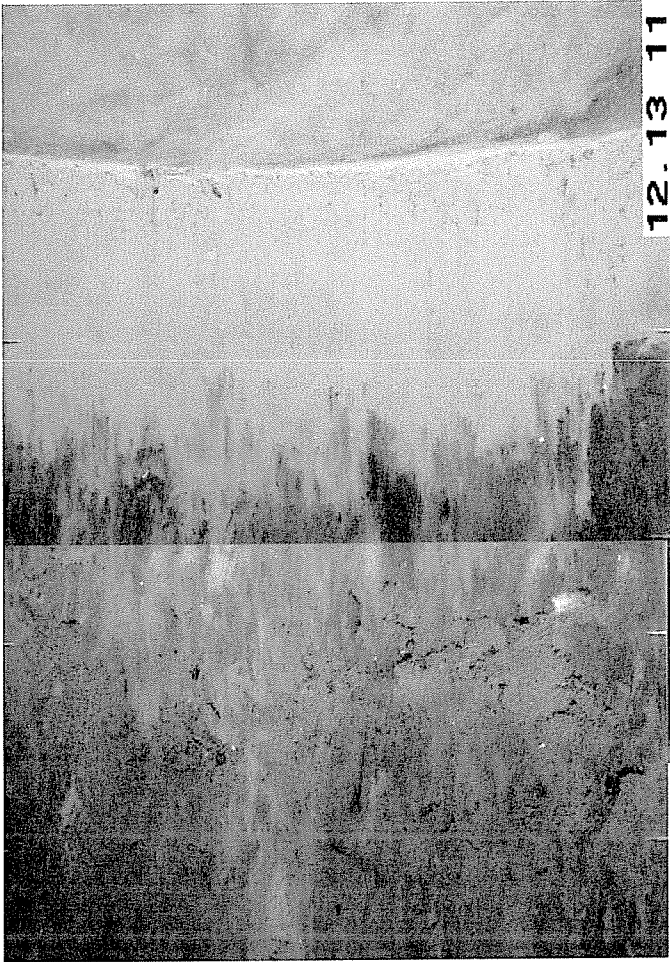
12.13 11:34

C22

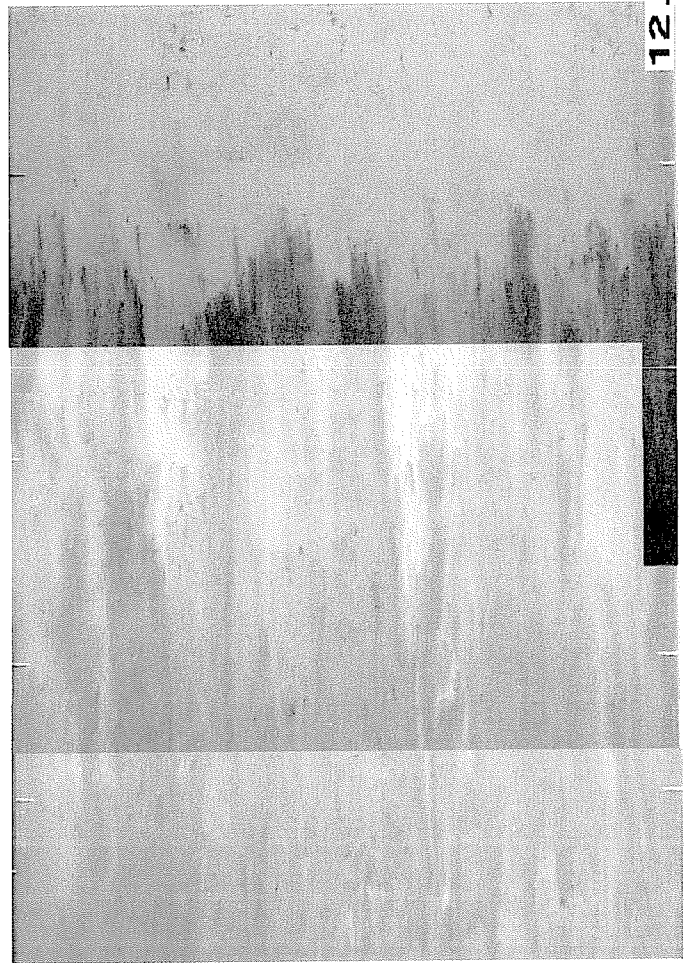


12.13 11

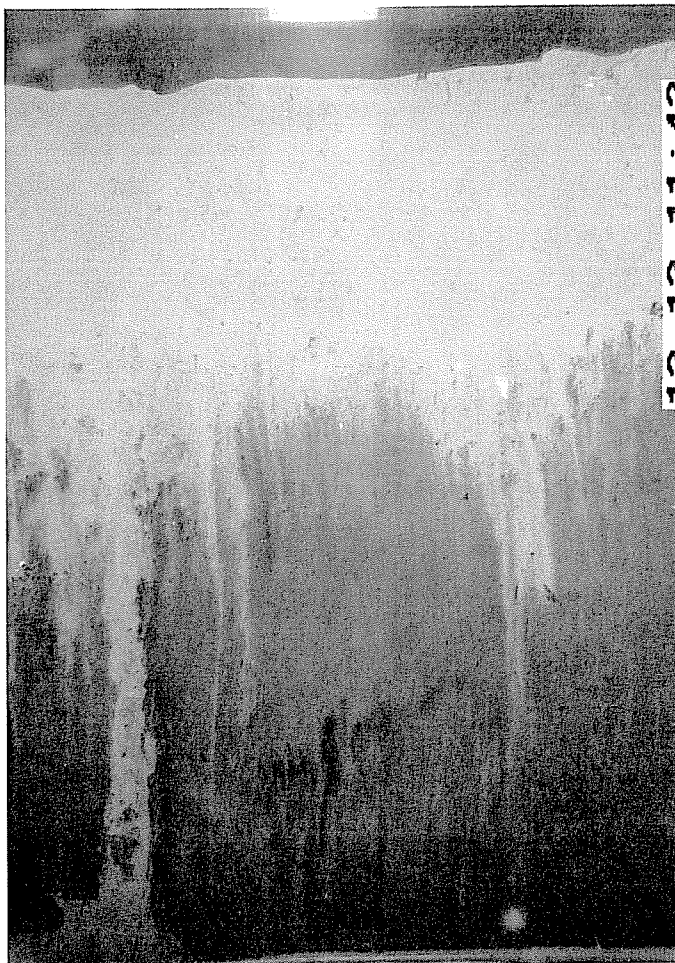
C23



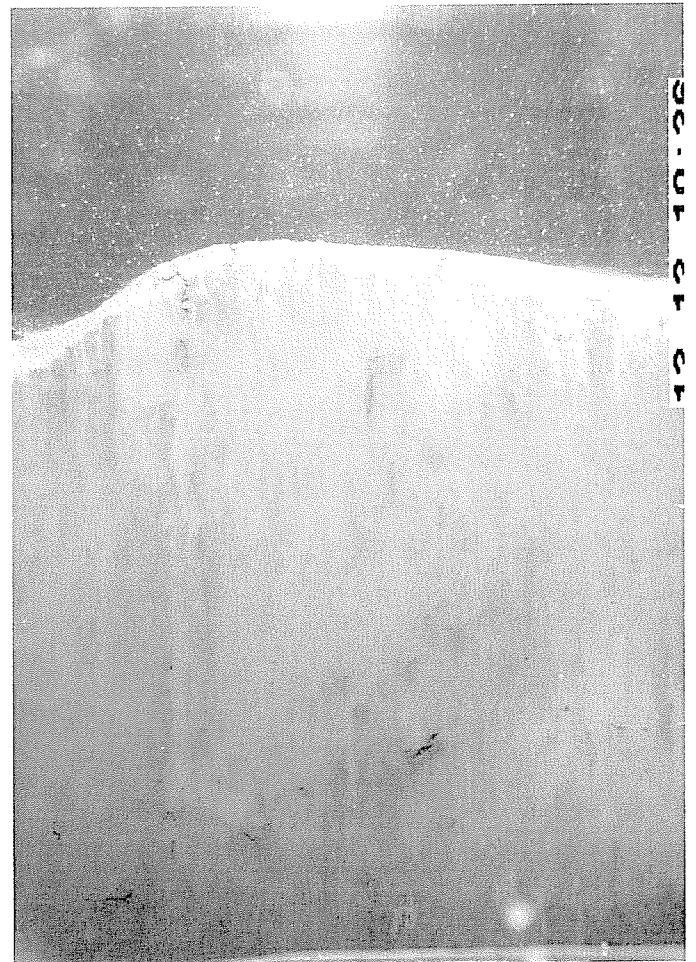
C3 1



C3 2



C3 3



DI NORTH 1



DI NORTH 2



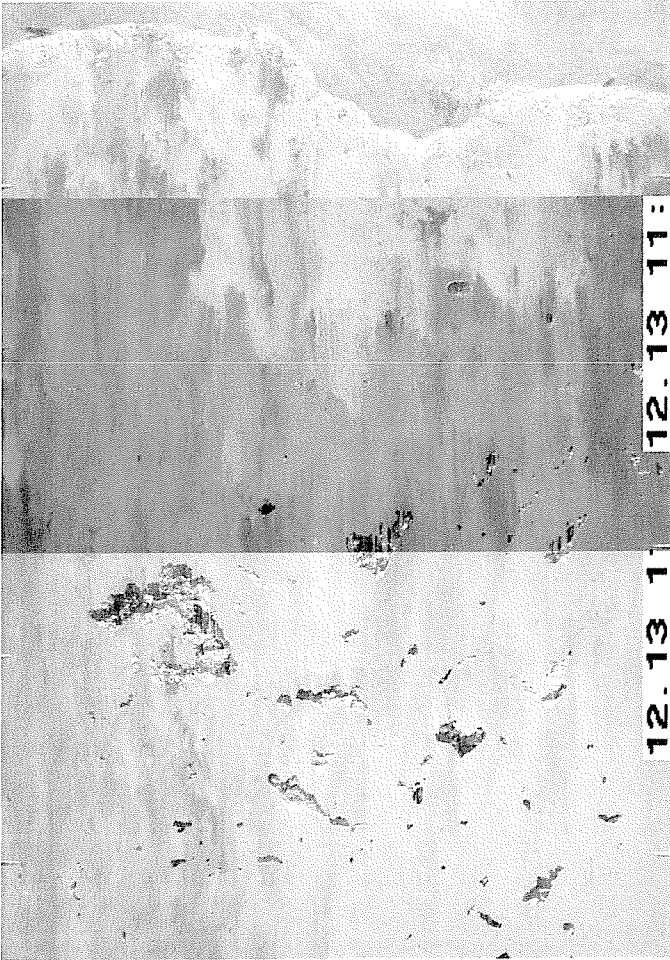
DI NORTH 3



EI 1



EI 2



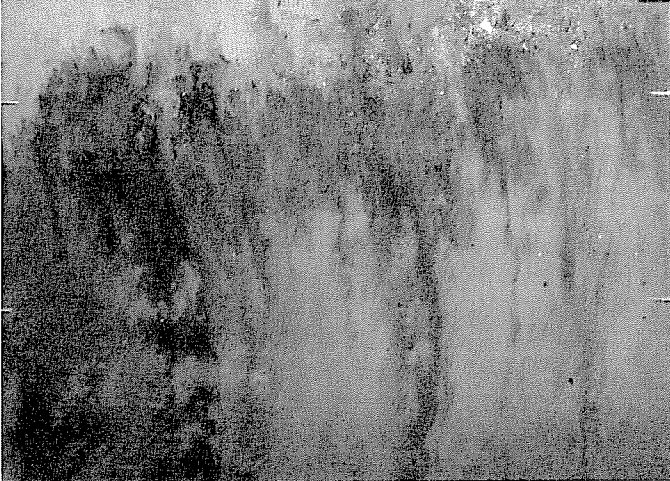
EI 3



EI EAST 1

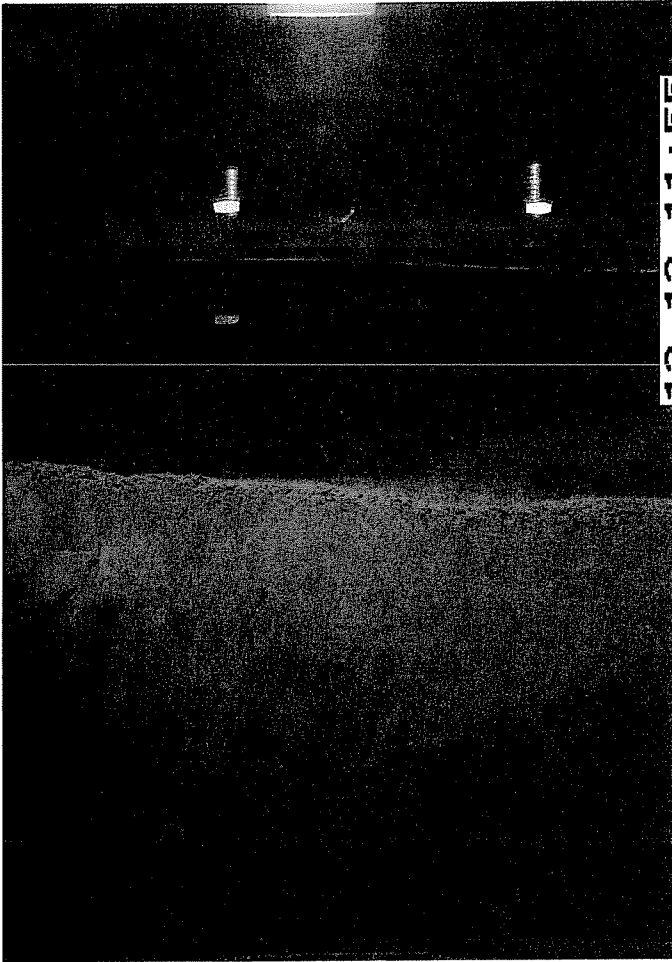


EI EAST 2

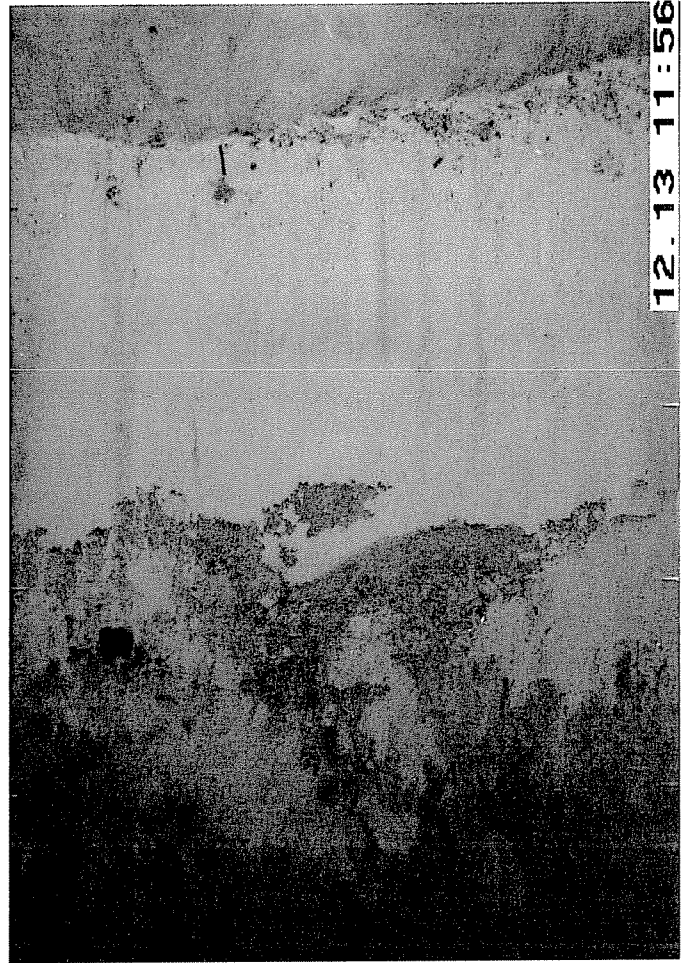


EI EAST 3





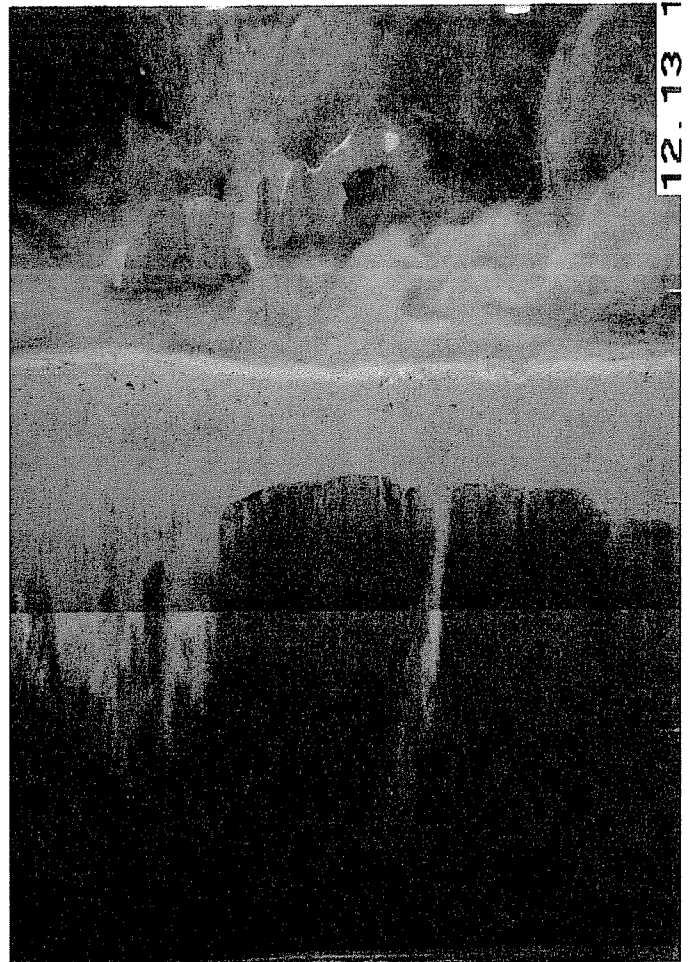
E2 1



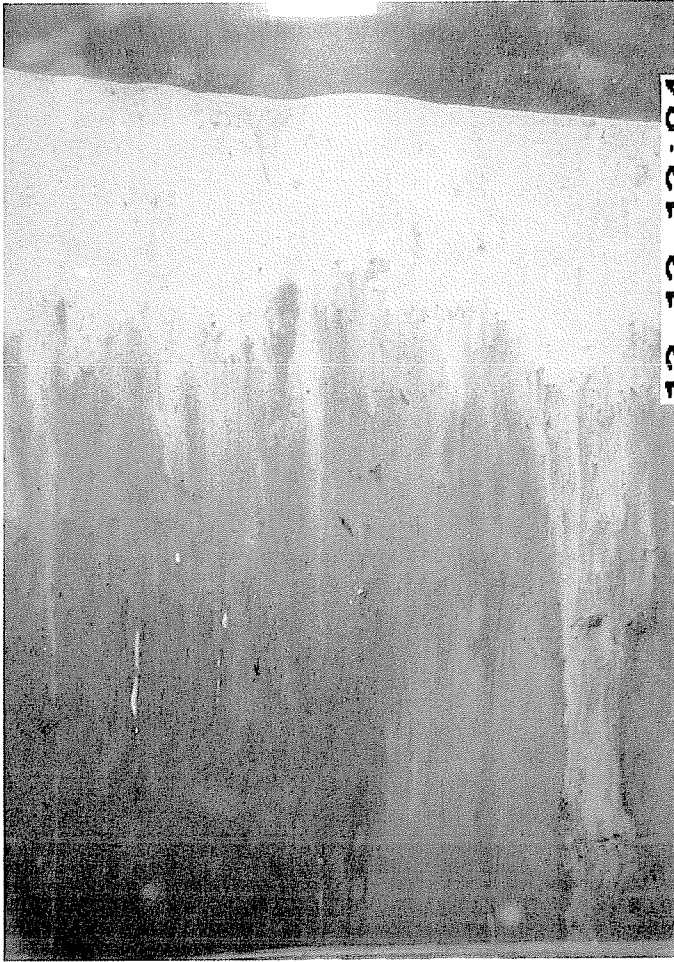
E2 2



E2 3



E3 1



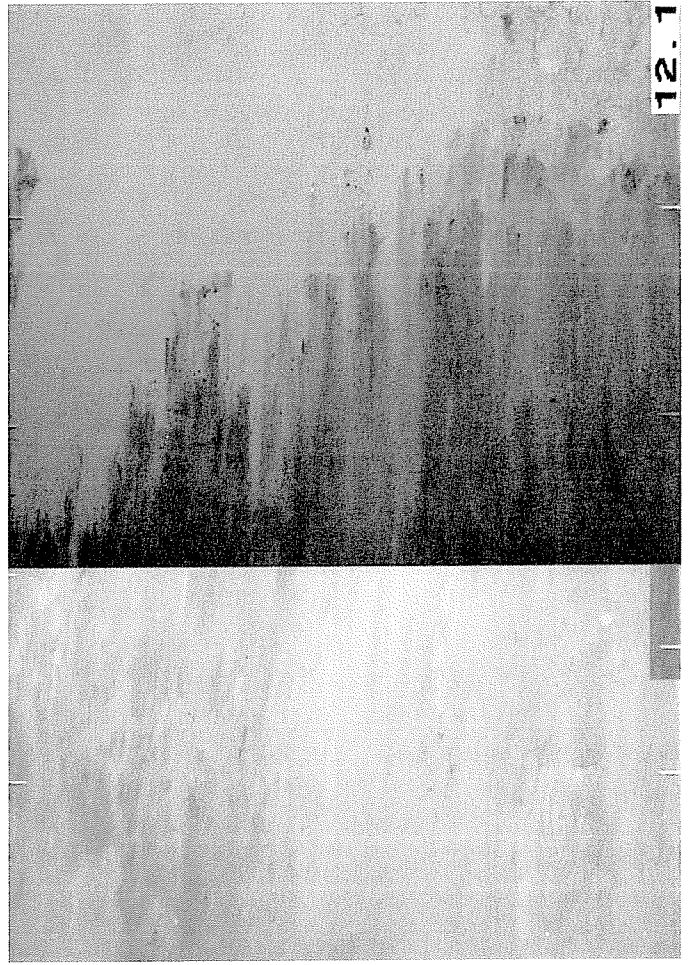
E3 2



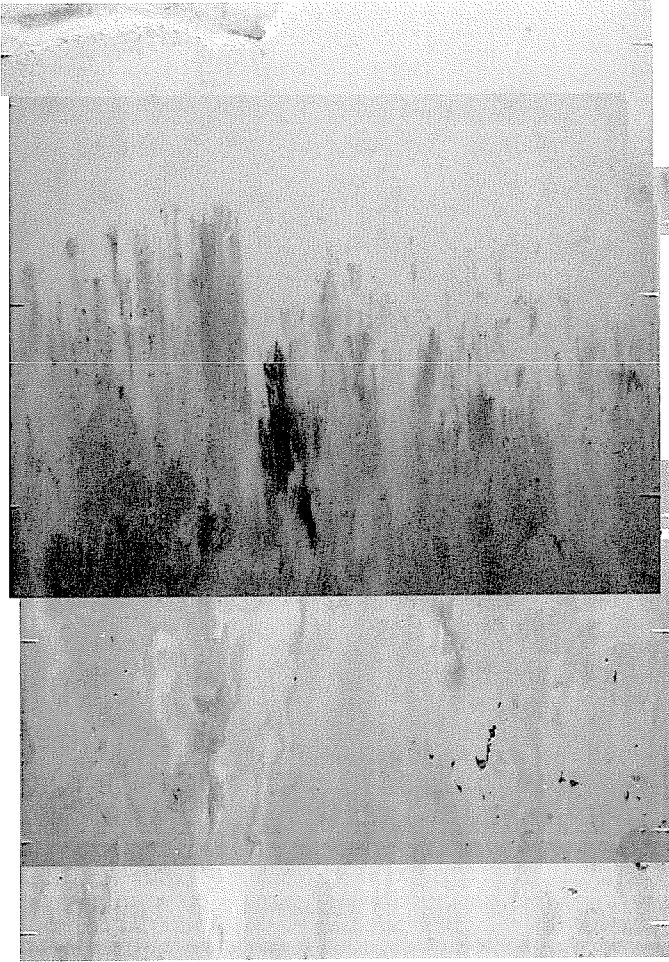
E3 3



E3 EAST 1



E3 EAST 2



E3 EAST 3

Appendix D

Adjusted and Labeled Sediment Profile Images



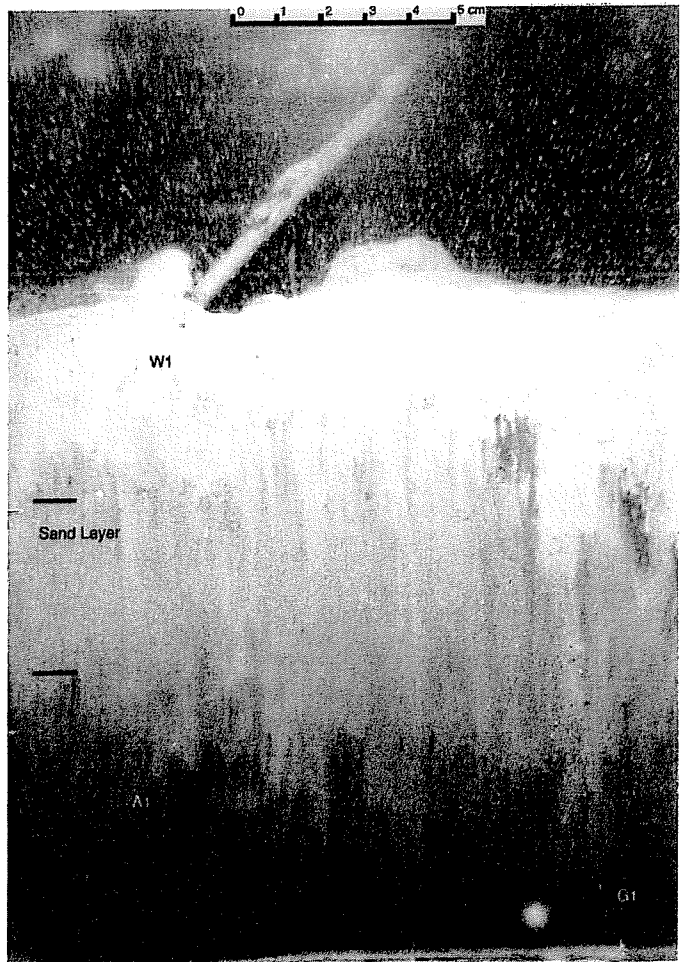
A1 1



A1 2



A1 3



A1 WEST 1



A1 WEST 2



A1 WEST 3



A2 1



A2 2



A2 3



A3 1



A3 2



A3 3



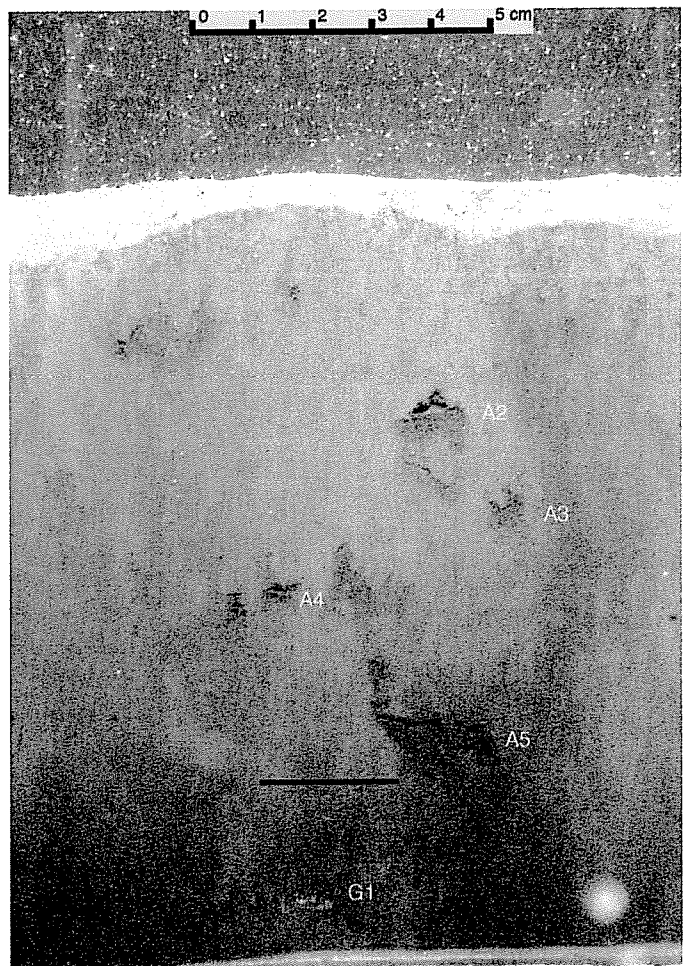
A3 WEST 1



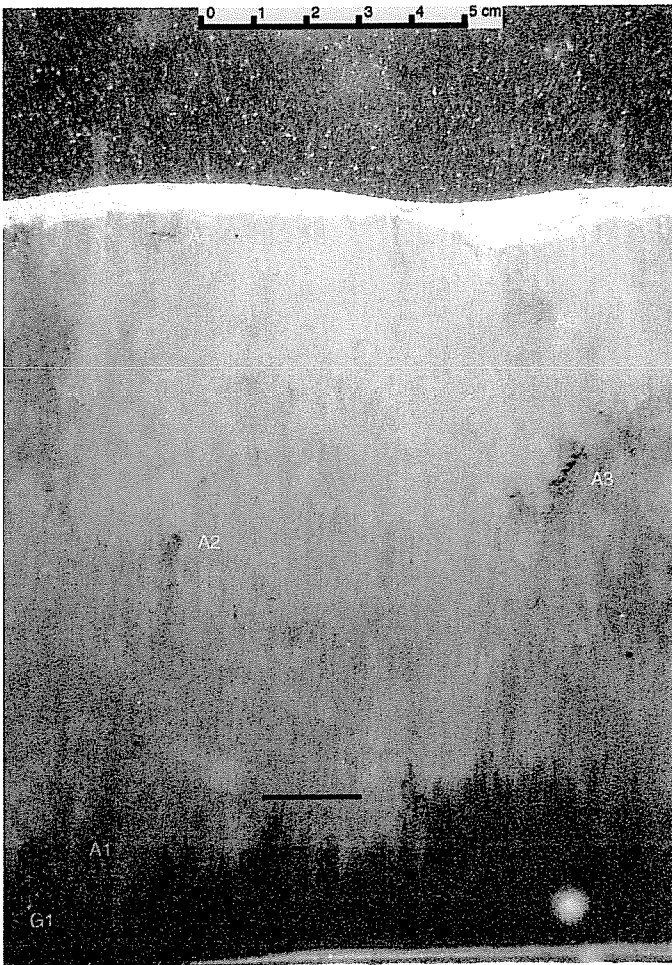
A3 WEST 2



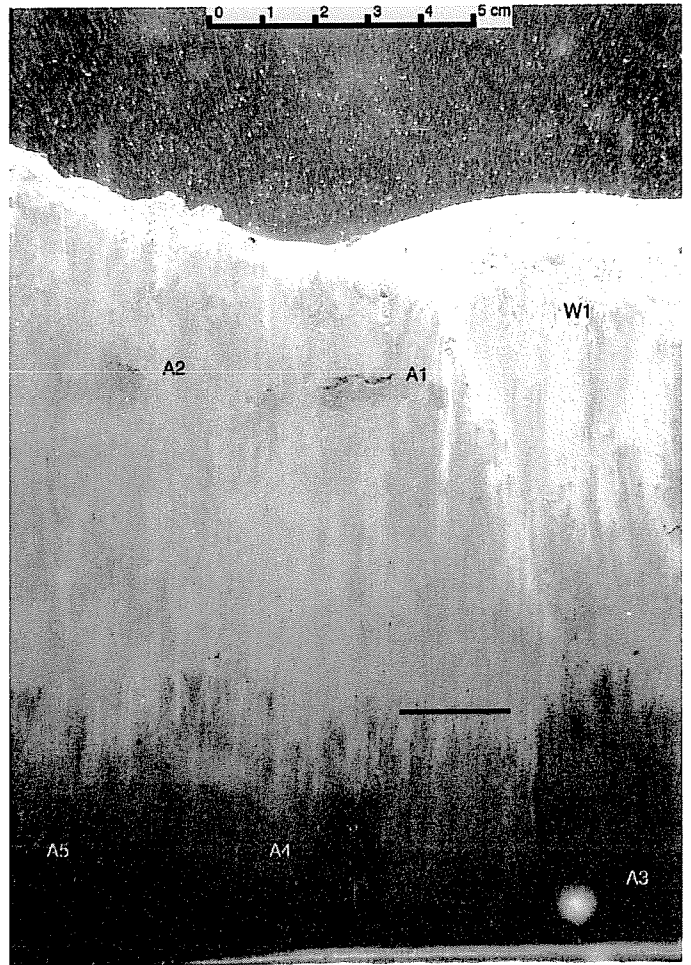
A3 WEST 3



B1 NORTH 1



Bi North 2



Bi North 3



C1 1



C1 2



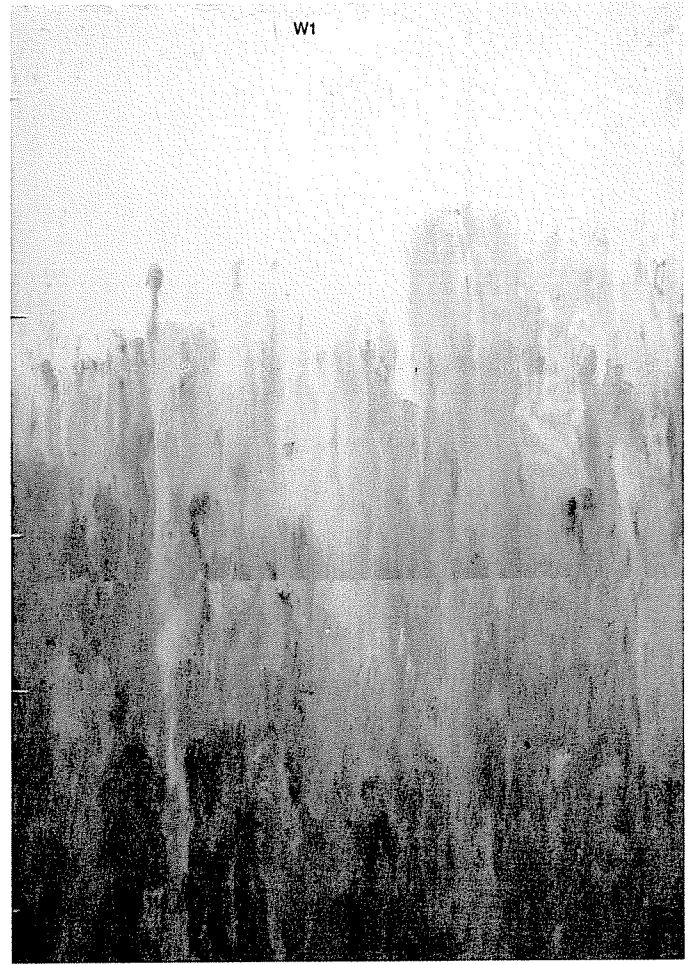
C13



C21



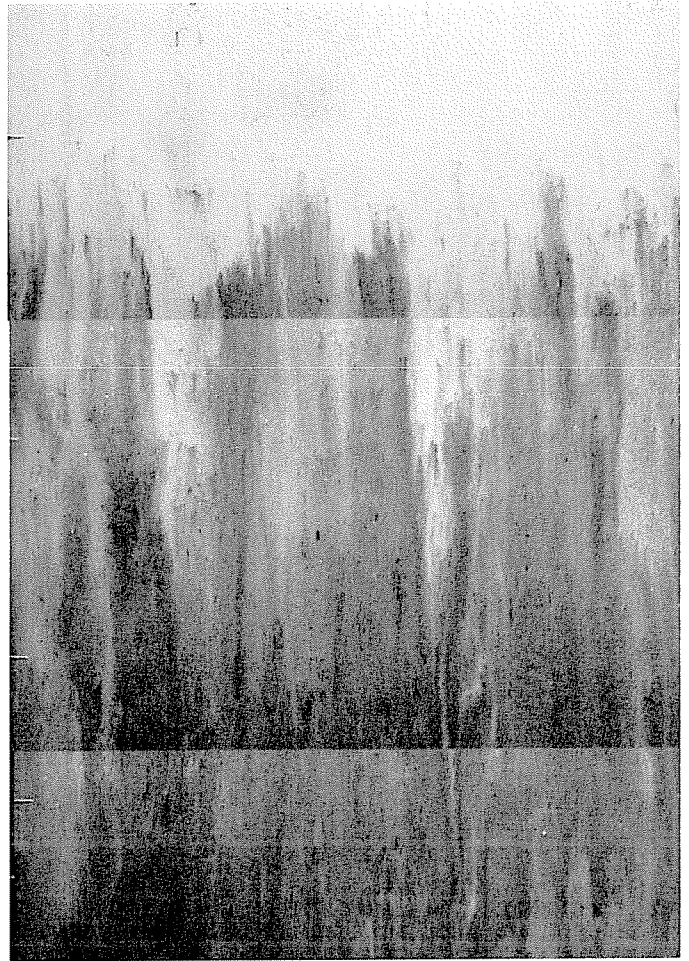
C22



C23



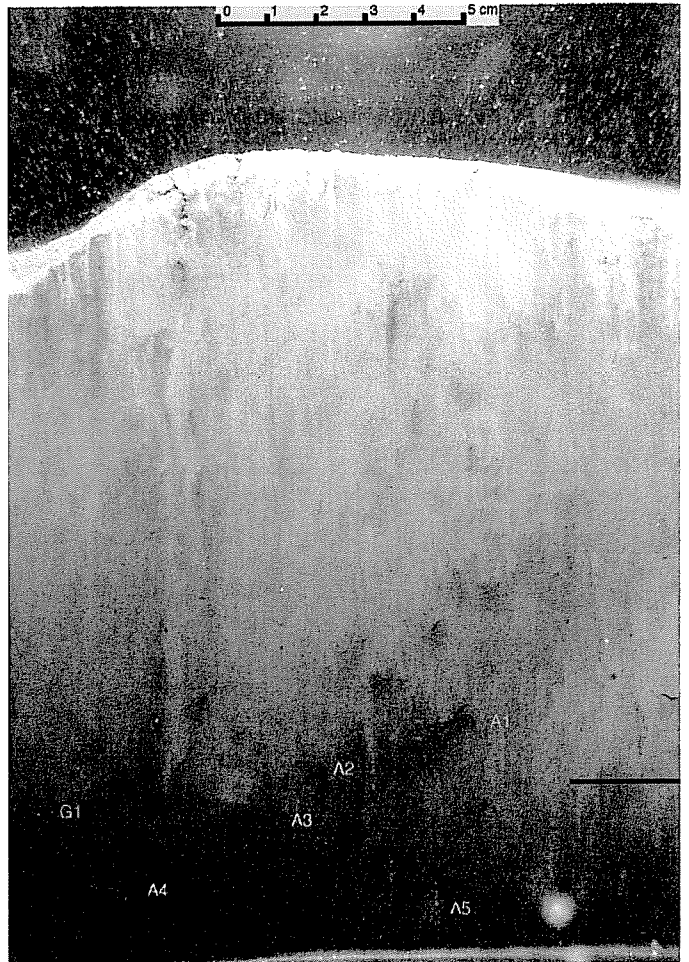
C3 1



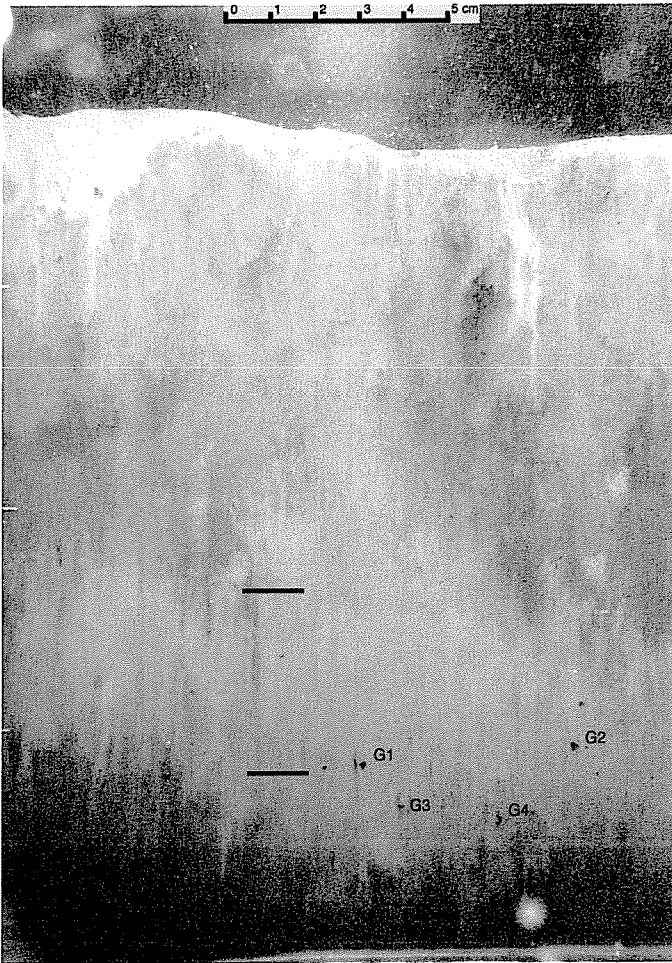
C3 2



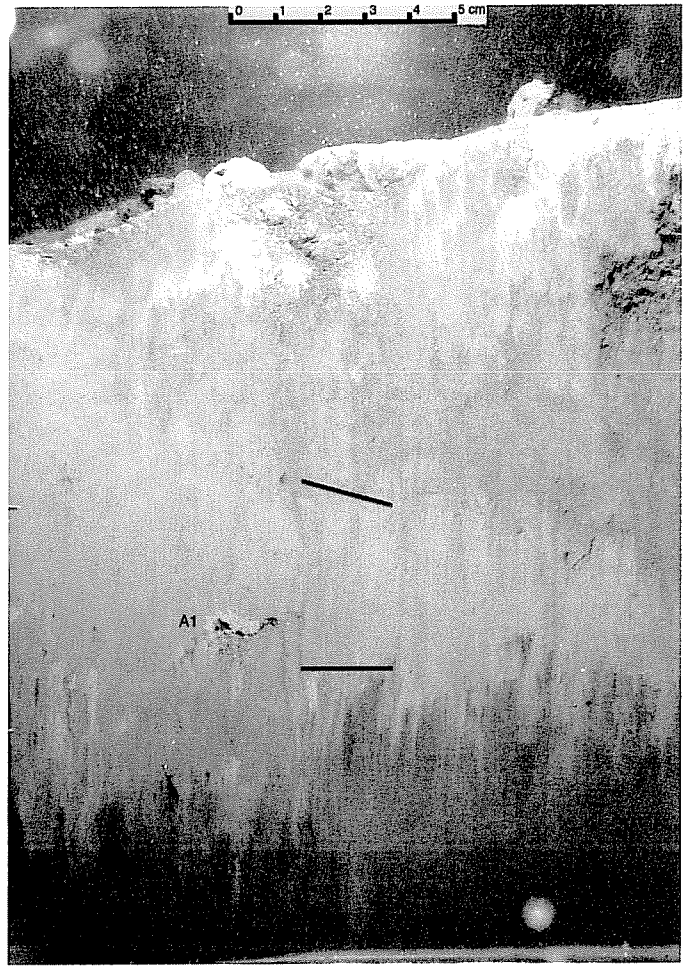
C3 3



DI NORTH 1



D1 NORTH 2



D1 NORTH 3



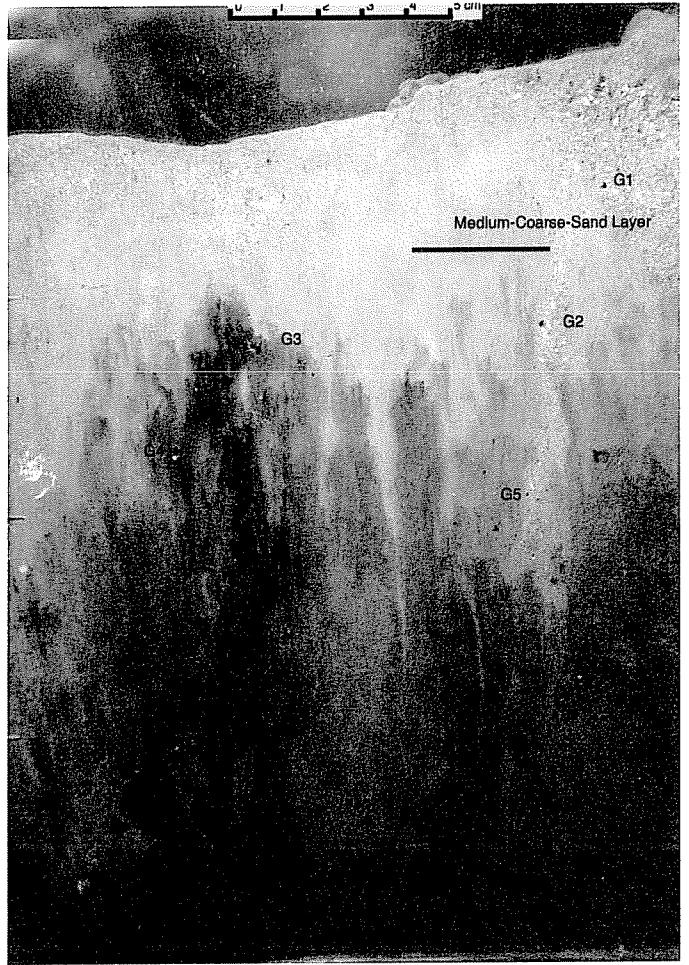
E11



E1 2



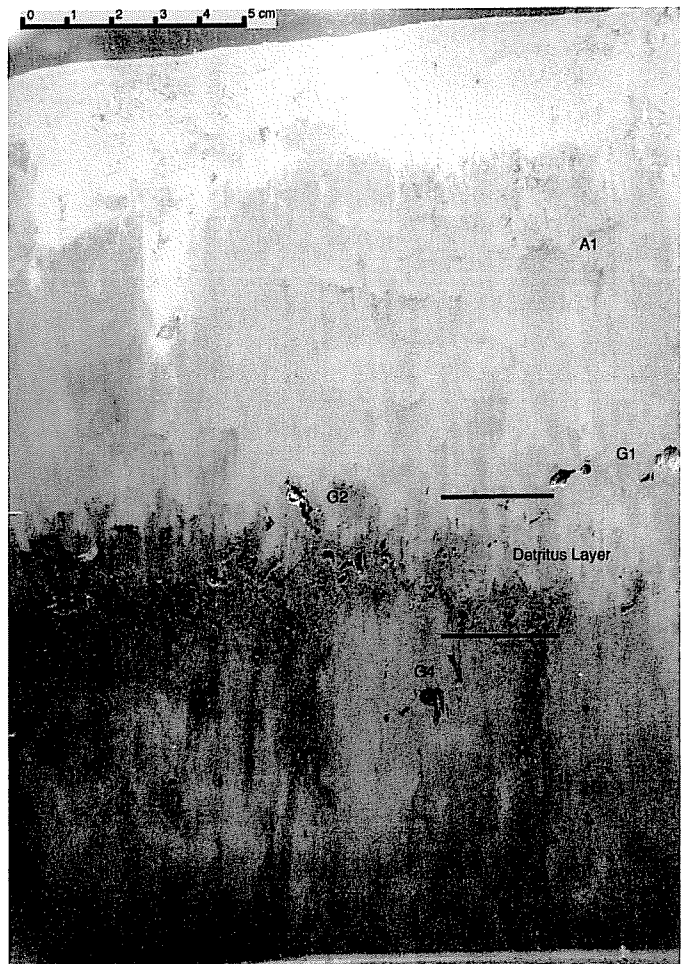
E1 3



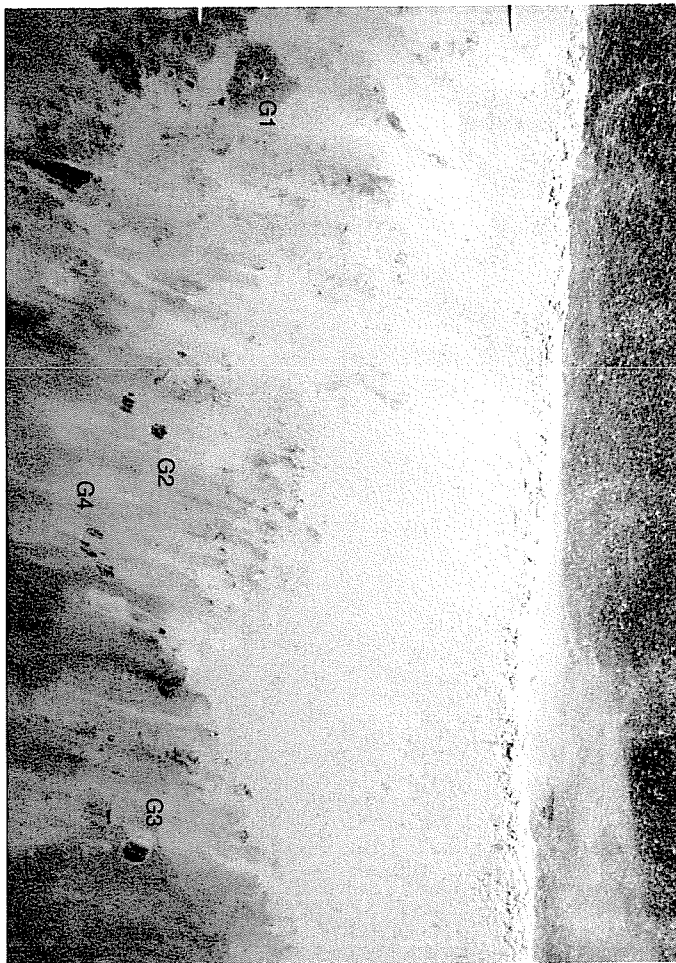
E1 EAST 1



E1 EAST 2



E1 EAST 3



E2 1



E2 2



E2 3



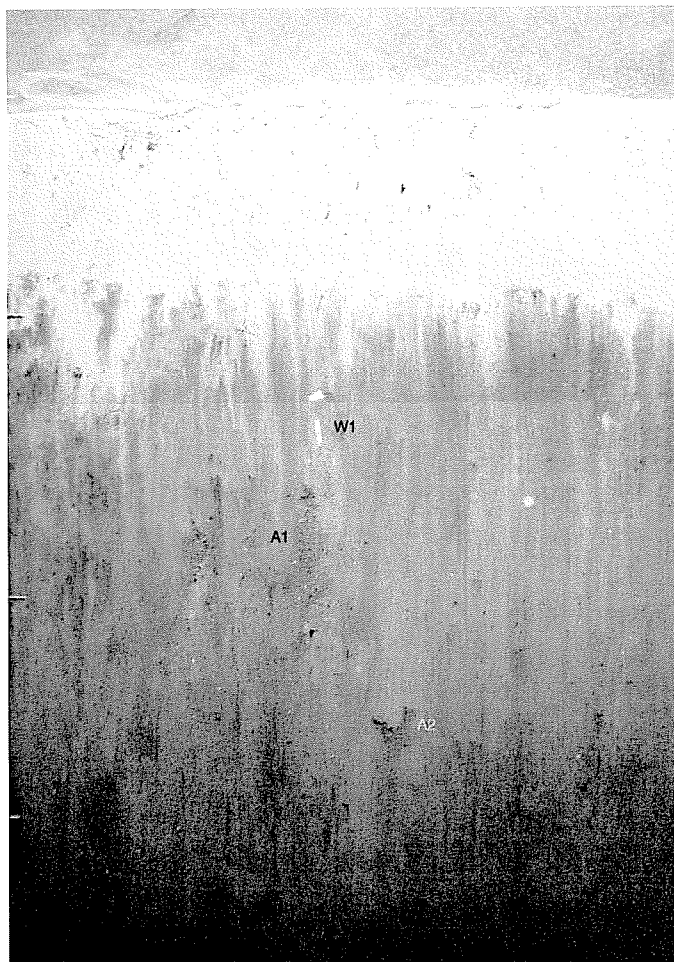
E3 1



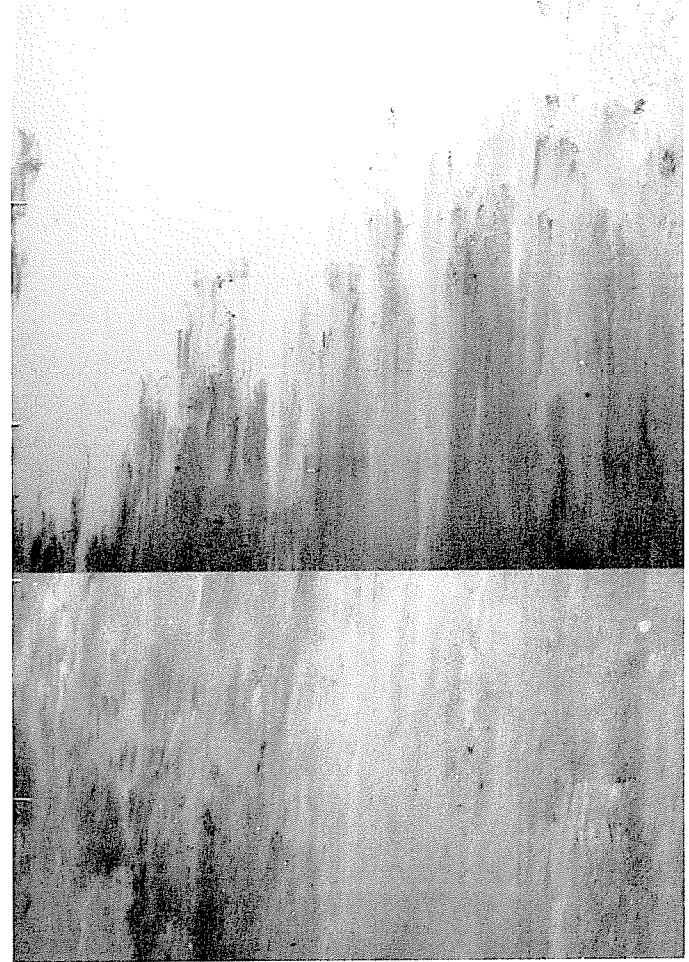
E3 2



E3 3



E3 EAST 1



E3 EAST 2



E3 EAST 3