SEDIMENT PROFILE IMAGING:
A Rapid Seafloor Impact Assessment Tool for Oil Spills

by

Joseph D. Germano[1]
Germano & Associates, Inc.
12100 SE 46th Place
Bellevue, WA 98006
USA

ABSTRACT:

Sediment Profile Imaging (SPI) was developed more than a decade ago as a rapid reconnaissance tool for characterizing physical, chemical, and biological seafloor processes and has been used in numerous sediment quality surveys throughout the United States, Pacific Rim, and in Europe. While it has revolutionized the approach to monitoring programs for ocean disposal of dredged material, its potential for oil spill environmental assessment has been largely untapped.

The camera quickly acquires cross-sectional images of the upper 20 cm of the seafloor that can be analyzed rapidly and incorporates an innovative design where water turbidity is never a limiting factor. Because the sediment column is a superb time-integrator of short- and long-term perturbations in the water column or the seafloor, this state-of-the-art technology allows investigators to deduce dynamics from imaged structures using the same inverse methods approach that paleoecologists and sedimentologists use to reconstruct past environmental conditions. However, the technology's greatest asset is the production of a visual image from environments that normally can never be viewed. Given the environmental controversy that typically surrounds most ocean disposal projects, the camera's greatest asset in the recent past has been as a powerful communication tool to inform non-scientific audiences about environmental conditions following disturbances through visual images that are easily understood. With the highly-charged atmosphere following oil spills or Natural Resource Damage Assessment claims, a monitoring tool such as this would be invaluable in communicating accurately the areal extent of the initial impact on the seafloor immediately following a spill or the status of ecosystem recovery for both short- and long-term post-impact environmental assessments.

INTRODUCTION

After an oil spill occurs, a rapid, efficient response is essential for minimizing environmental damage. While most of the concern and effort with environmental

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[1] FROM: Proceedings of the Eighteenth Arctic and Marine Oilspill Program (AMOP) Technical Seminar, June 14-16, 1995, Edmonton, Alberta, pp 1271-1279

damage following an oil spill is concentrated on surface waters and shoreline impacts, the heavier crude oils and fractions of crude oils will weather and may settle to the bottom. Determining which areas of the seafloor are high energy erosional environments or low energy depositional environments play a key role in identifying subtidal areas at risk following crude oil spills. Delineating the areal extent of impacts to the seafloor following spills is an important part of natural resource damage assessment.

The traditional approach for assessing impacts to benthic (bottom-dwelling) communities using dredges, grabs, or box cores has many drawbacks. These techniques, developed more than 100 years ago, are costly, labor intensive, and the data return is slow. It is not unusual to get the results of benthic biology surveys 6-12 months following the completion of the field sampling effort. The collection and processing of samples using dredges and grabs destroys the *in-situ* organism-sediment relationships, making data interpretation in an ecological context quite difficult; high costs coupled with the time lag on data return using traditional methods limit their usefulness for making active management decisions

Sediment Profile Imaging (SPI) was developed and matured as benthic monitoring tool during the last decade (Rhoads and Germano, 1982, 1986, 1990; Revelas *et al*., 1987; Valente *et al*., 1992). This innovative technology was designed to overcome the shortcomings associated with traditional techniques, and it has been used extensively for monitoring the impacts of open-water dredged material disposal (e.g., Germano *et al*., 1989, 1994; Fredette *et al*., 1992). Images can be collected rapidly (more than 100 per day) and analyzed quickly (initial results can be provided to clients within 24 hours of completion of field work). The camera's rugged design and ease of operation makes it very amenable to be included as part of the monitoring protocols in the initial environmental response for crude oil spills, and the ecological insights that can be gained during post-impact recovery monitoring efforts because of the preservation of organism-sediment relationships are unmatched by traditional sampling techniques.

FIELD EQUIPMENT

The sediment profile camera (Figure 1) works like an inverted periscope. A 35mm camera is mounted horizontally on top of a wedge-shaped prism (Inset, Figure 1). The prism has a Plexiglas® faceplate at the front with a mirror placed at a 45° angle at the back. The camera lens looks down at the mirror which is reflecting the image from the faceplate. The prism has an internal strobe mounted inside at the back of the wedge to provide illumination for the image; this chamber is filled with distilled water, so the camera always has an optically clear path to shoot through. This wedge assembly is mounted on a moveable carriage within a stainless steel frame. The frame is lowered to the seafloor on a winch wire, and the tension on the wire keeps the prism in its "up" position. When the frame comes to rest on the seafloor, the winch wire goes slack (Figure 2), and the camera prism descends into the sediment at a slow, controlled rate by the dampening action of a hydraulic piston so as not to disturb the sediment-water interface. On the way down, it trips a trigger that activates a time-delay circuit to allow the camera to reach maximum penetration

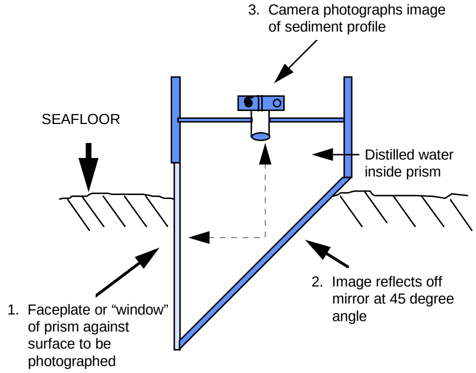


Figure 1. The sediment profile camera (right) is depth rated to 4,000 meters; the inset schematic (left) shows how the seafloor is photographed in cross-section.

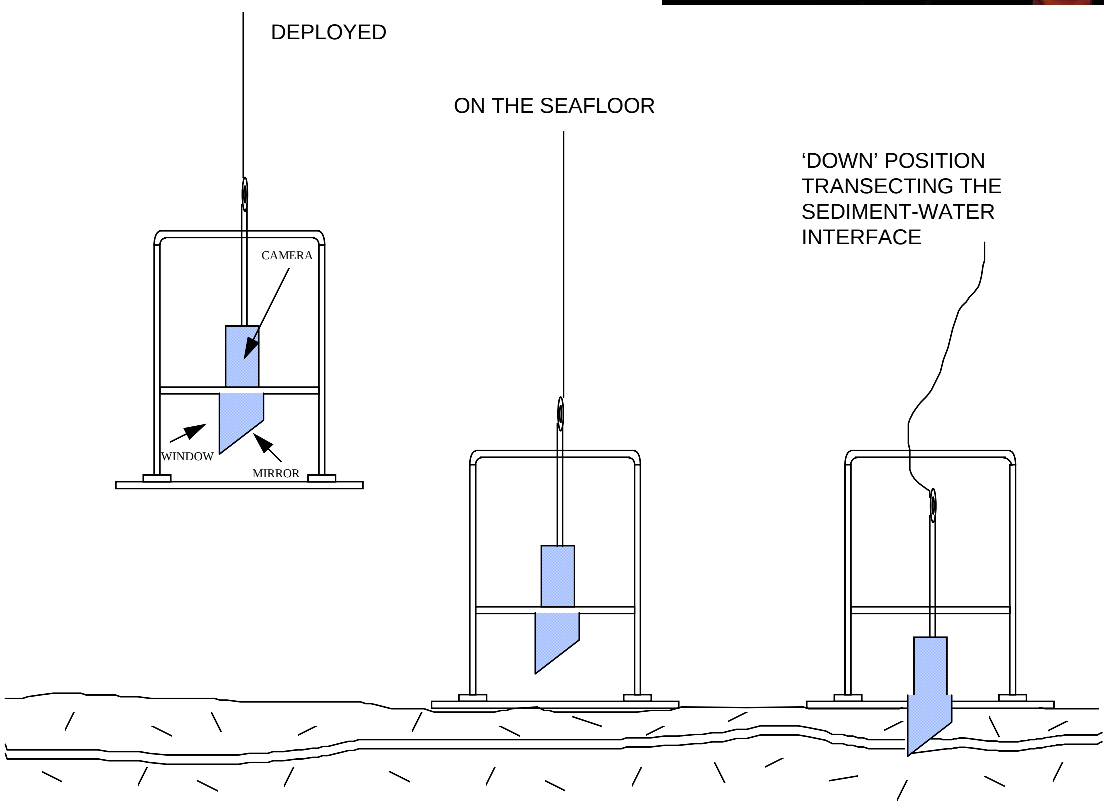


Figure 2. The central cradle of the camera is held in the "up" position by tension on the winch wire as it is being lowered to the seafloor (left); once the frame base hits the bottom (center), the prism is then free to penetrate the bottom (right) and take the photograph.

into the seafloor before the picture is taken. The knife-sharp edge of the prism transects the sediment and the prism penetrates the bottom. The strobe is discharged to obtain a cross-sectional image of the upper 20 cm of the sediment column; then the camera is raised up about 2-3 meters off the bottom while an internal motor drive advances the film. The strobe recharges within 5 seconds, and the camera is ready to be lowered again for another image. Surveys can be accomplished rapidly by "pogo-sticking" the camera across an area of seafloor while recording positional fixes on the surface vessel. The resulting images (Figure 3) gives the viewer the same perspective as looking through the side of an aquarium half-filled with sediment.

Figure 3. A typical sediment profile image from a healthy, fine-grained bottom showing a mature benthic community. The void in the lower half of the sediment is caused by the foraging activity of deposit-feeding invertebrates.

IMAGE ANALYSIS

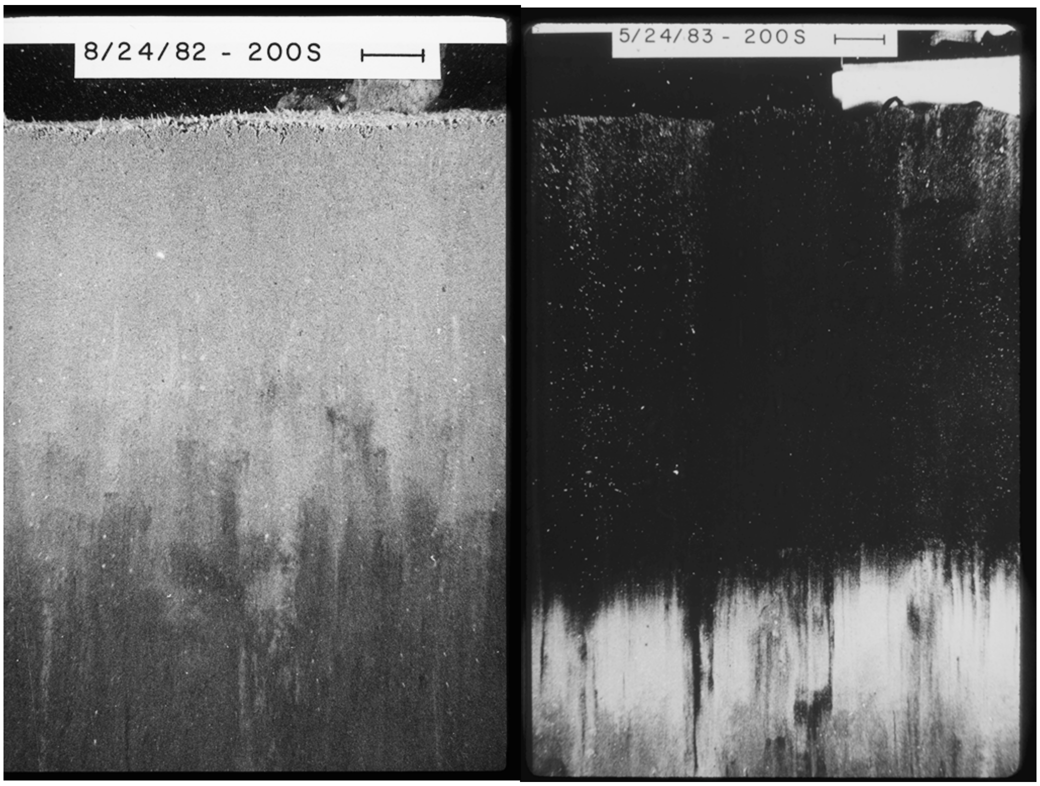
For a detailed description of the theory on which the interpretation of the profile images is based, the reader should see Rhoads and Germano (1982, 1986). While many of the parameters can be estimated visually in the field for a rapid initial assessment of field conditions (draft results and letter report to clients within 24 hours of field sampling), a thorough interpretive analysis of more than 20 different measurements is performed back in the laboratory using a computer image analysis system. Some of the typical parameters measured include:

- Presence and thickness of any depositional or crude oil layers
- Evidence of excess organic loading
- Subsurface methane gas pockets (evidence of high Sediment Oxygen Demand)
- Grain-size major mode and range (gravel, sand, silt, clay)
- Small scale surface boundary roughness
- Presence and thickness of any depositional or crude oil layers
- Depth of the apparent RPD (Redox Potential Discontinuity)
- Erosional and depositional events, such as bedforms, mudclasts, and recently deposited sedimentary intervals, allowing identification of high and low kinetic energy areas
- Epifauna
- Surface microbial aggregations
- Infaunal Successional Stage
- Calculation of the Organism-Sediment Index (Revelas *et al.*, 1987), allowing rapid identification and mapping of disturbance gradients in surveyed areas

The full color image analysis system can discriminate up to 16.7 million different shades of color, so subtle features can be accurately digitized and measured. The software allows for the measurement and data storage of each different variable measured for every SPI image obtained. Automatic disk storage of all parameters measured allows data from any variables of interest to be compiled, sorted, displayed graphically on a Geographic Information System (GIS), contoured (if appropriate, depending on station density/location), or compared statistically. A comprehensive, final interpretive report can be prepared in a matter of weeks.

CASE STUDY

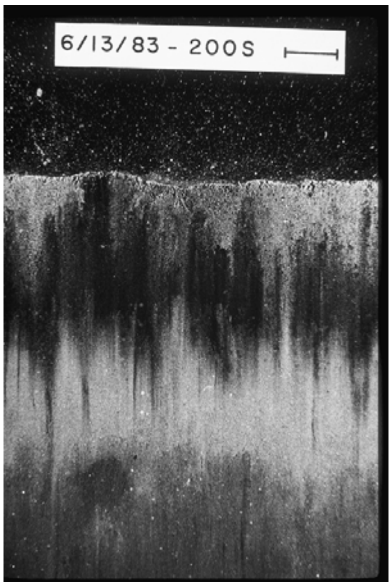
One of the best illustrations of the utility of this technology for oil spill environmental assessment is demonstrated from an analagous study of a controversial ocean-disposal project where 50,000 m^3 of highly-fluid (greater than 60% water content), anoxic, contaminated muds were to be placed at a dredged material disposal site in 20 meters of water. After all the material was deposited, a post-operational precision bathymetric survey revealed a discrete mound about 2.5 meters high and about 150 meters in diameter (Rhoads and Germano, 1990). Because the volume calculated from the bathymetric results only accounted for about half of the material deposited, a SPI survey was carried out to determine the total areal extent of the deposit. Results from the comprehensive SPI survey revealed that the thin apron of the deposit actually extended out about 1.5 km in diameter from the disposal point; approximately 45% of this previously undetected volume of disposed material was contained in this thin apron layer. Figure 4 shows sediment profile images taken before and immediately after the disposal event at a station 200 meters south of the disposal point. The depositional layer of anoxic, fluid mud that was too small to be detected by acoustic techniques shows up quite distinctly in the profile image.



A **B**

Figure 4. (A) Sediment profile image taken as part of the pre-disposal baseline survey shows a healthy bottom with a well-developed, oxygenated sediment surface layer .
(B). Profile image from the same location taken two days after ocean disposal of fluid muds; the former sediment surface can be seen as the bright discontinuity at the base of the photo.
Scale bar = 1 cm.

If the study had relied on traditional sampling techniques alone, the area of the seafloor affected by the deposit would have been underestimated by 95%. It is quite easy to envision the same type of results from delineating the areal extent of crude oil layers on the bottom or measuring the extent of drilling muds from an offshore platform with this technique. However, one of the most powerful applications for the camera is for monitoring the rate of ecosystem recovery after a disturbance. This same fluid mud deposit was monitored at monthly intervals for 12 months as part of a comprehensive monitoring program. As time passed, the animals that colonized this new sedimentary layer mixed the oxygen-rich overlying water into the sediment as a result of their burrowing activities (an activity known as bioturbation). Figure 5 shows a time series of profile images from this same location, and it is readily apparent why the concerns of regulatory groups initially opposed to this project were relieved once they saw this visual evidence of the normal successional recovery of the benthic community.



A

B

C

Figure 5.
(A). Sediment profile image at 1 month after disposal.
(B).Same location 2 months after disposal.
(C).Two years following disposal.

SUMMARY

SPI technology has become a routine tool for many of the more controversial ocean disposal projects (domestically and internationally) because it is a powerful medium for conveying environmental data in a convincing and easily understood manner to a lay audience or to other resource agency regulators who may not have a background in marine ecology or oceanography. In a number of environmental litigation cases concerning ocean disposal impacts where unsubstantiated claims were made about extensive environmental damage, SPI images provided the decisive evidence to show that impacts were transitory and a full ecosystem recovery had taken place.

By incorporating SPI technology as a standard monitoring tool to assess impacts from oil spills, the industry would benefit from the following advantages:

- **Allow parsimonious design of the most efficient sampling station strategy;** because traditional seafloor sampling techniques are expensive and time-consuming, SPI can be an enormous aid in determining the location of traditional sampling stations. By rapidly characterizing the variation in benthic sedimentary and community conditions, limited sampling resources can be allocated to the optimum sampling locations to accurately characterize the variance that exists in a particular area. All too often the results of monitoring programs show that a particular parameter of interest has either been over- or under-sampled as a result of "flying blind" initially and then sticking religiously with the initial station locations that were chosen arbitrarily from a nautical chart.

- **Collect and analyze data rapidly and cost-effectively**; not only can large areas of bottom be surveyed quickly and efficiently, but for many monitoring objectives, SPI technology can provide the necessary answers without the need to collect grab samples or repeatedly enumerate and identify individual invertebrates and assemble long species lists each time a sampling study is performed.

- **Delineate gradients between sampling locations accurately**; because of the camera's ability to obtain pictures rapidly and efficiently, it can supplement traditional sampling methods by "filling in the gaps" between traditional chemical and biological sampling locations. The camera can accurately delineate gradients in biological community type, organic loading, or sediment grain-size between fixed station locations.

- **Produce results that are easily understandable by a non-scientific audience;** many environmental programs have suffered because of their inability to convey results to regulators or a public audience who may not have a marine science background. Without a doubt, one of the camera's most powerful attributes is its ability to convey ecological information in a format that most people can understand quite easily: a picture.

Given the tremendous success this technology has achieved with monitoring the impacts of ocean disposal, there is no reason why it cannot be applied to oil spill monitoring programs with the same level of success. SPI is a powerful, cost-effective

reconnaissance monitoring tool that can supplement or sometimes entirely replace traditional sampling methods. There is no reason to continue to rely on sampling techniques that were used during the 19th century to monitor the seafloor. Given the ease of sampling, the speed of data return, the preservation of organism-sediment relationships, and the powerful communication tool it provides in the resulting images for non-scientific audiences, SPI technology is an innovative, versatile tool that would aid any oil spill monitoring program where concerns about seafloor impacts exist.

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