Direct-push spectroscopic and imaging based sensor systems for characterization of Vadose Zone hydrologic conditions and contaminant distributions

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Problem

- The distribution and transport of subsurface contaminants may be controlled by small-scale variations in subsurface soil properties
- Variations, such as the presence of a thin layer of low permeability material, may be difficult to delineate with traditional soil sampling methods or other non-invasive techniques
- Without detailed knowledge of subsurface soil characteristics, it is unlikely that transport models will accurately predict the fate of subsurface chemical contaminants

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Proposed Solution

- Use direct push sensor systems capable of delineating small-scale variations in lithology and contaminant distributions

Outline

- Background
  - Describe direct push sensor systems that extend the capabilities of penetrometer based sensor systems
  - These optical based sensors build on the approach that was first used for *in situ* measurement of petroleum hydrocarbons via laser-induced fluorescence (LIF).
- Laser-Induced Break Spectroscopy (LIBS) metal sensor
- Soil Video Imaging System (GeoVIS)
  - Resolve small-scale changes in soil characteristics
  - Detect/delineate free phase NAPL (e.g., chlorinated solvents)
- Conclusions

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Background

- Traditional characterization techniques often rely on a limited set of samples to characterize subsurface environment
  - Problem is: Are these samples representative of the subsurface conditions?
  - Methods not suitable (not capable) of characterizing small-scale variations in subsurface properties
- We have often attempted to use “confirmation tools” as “exploration tools”
- Direct push optical methods offer capability for real-time high resolution (cm scale) resolution

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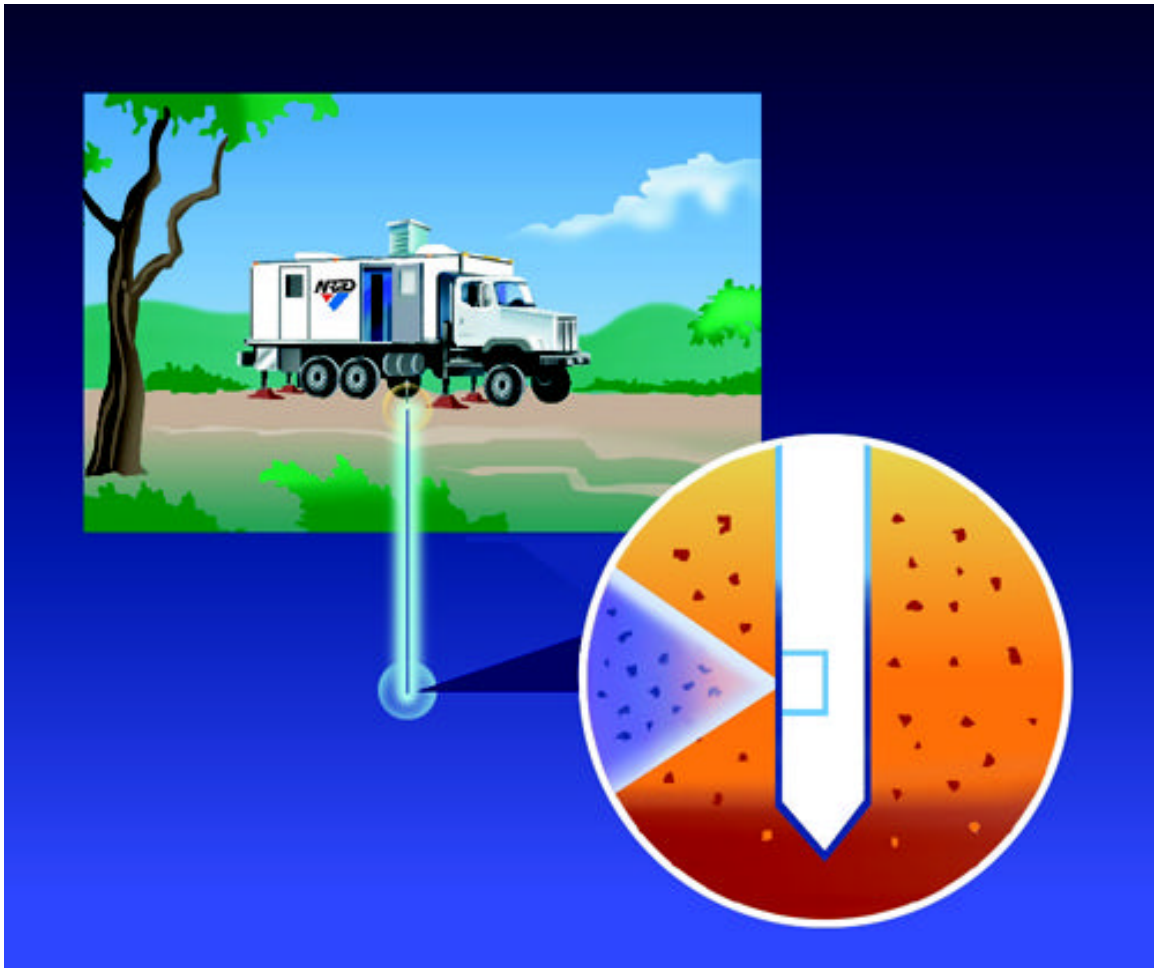
Integrate fiber optic-based chemical sensor with cone penetrometer probe equipped with sapphire window



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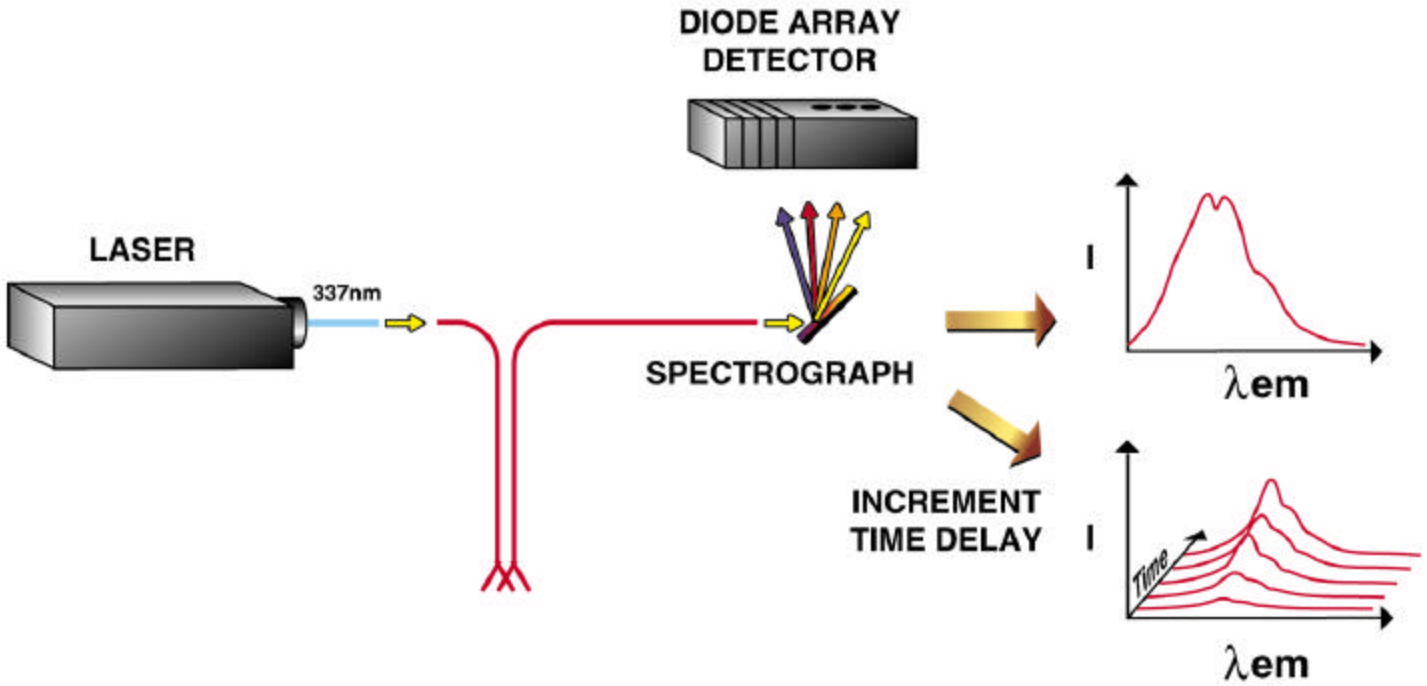
Laser-Induced Fluorescence (LIF) sensor for detection of petroleum hydrocarbons



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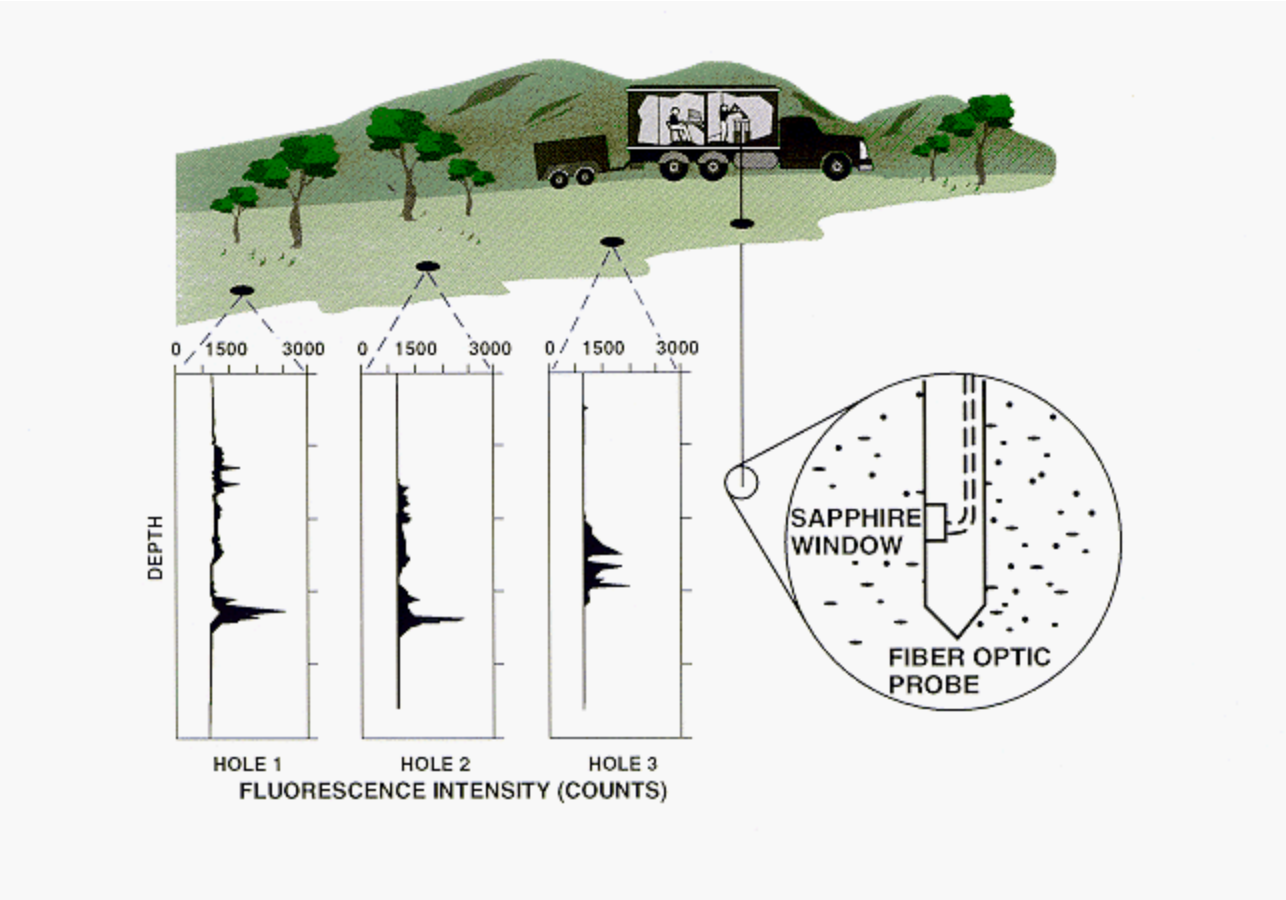
In Situ LIF measurements of petroleum hydrocarbons



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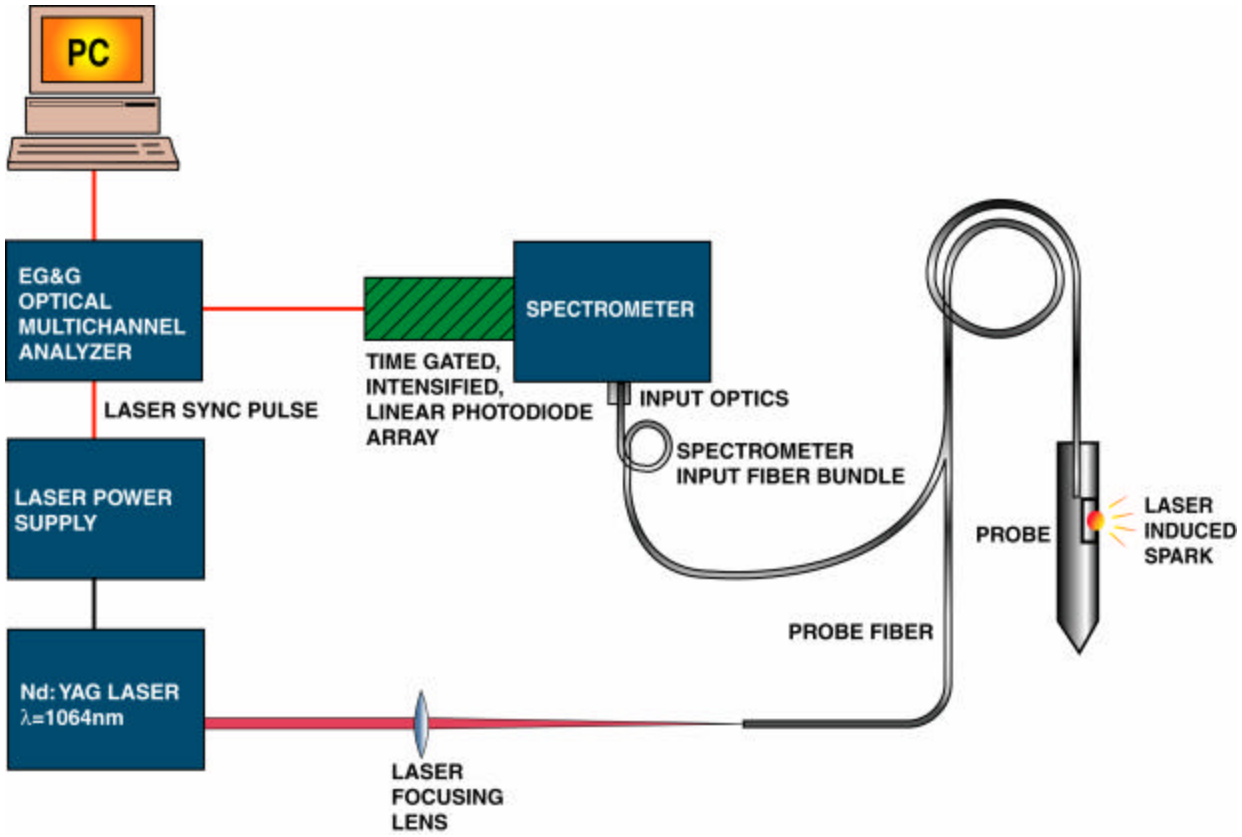
Fiber Optic-based Laser-Induced Breakdown Spectroscopy (FO-LIBS) Metals Sensor



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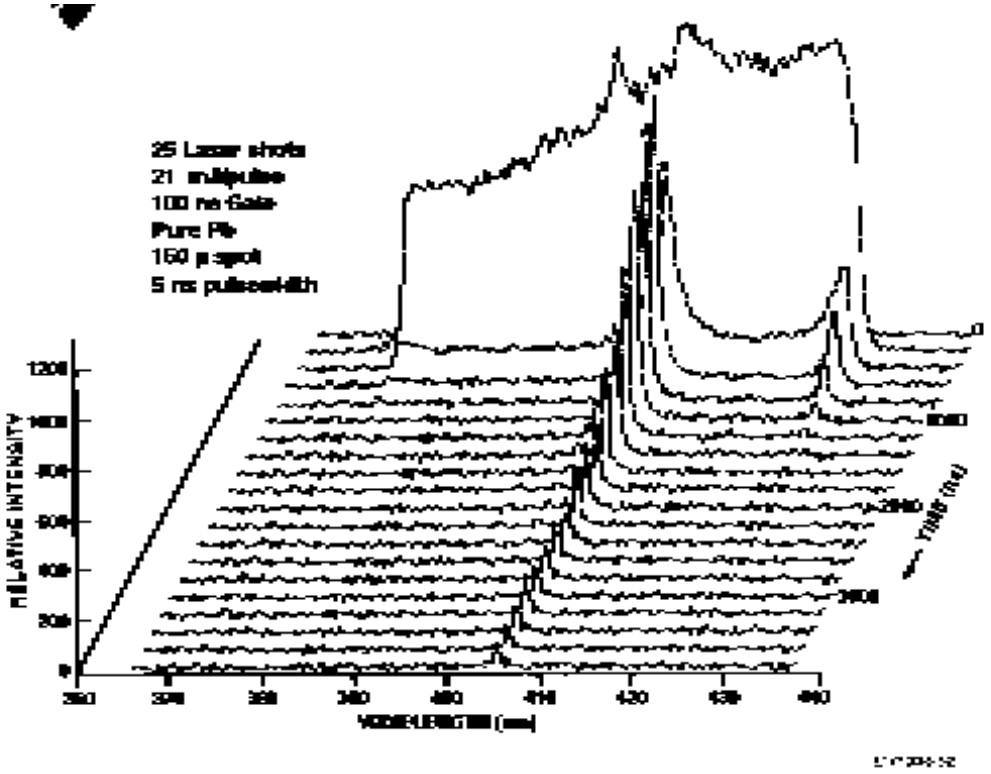
LIBS wavelength-time matrix

Emission signal from solid lead



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Transportable FO-LIBS System

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Photo of LIBS probe with enlarged window

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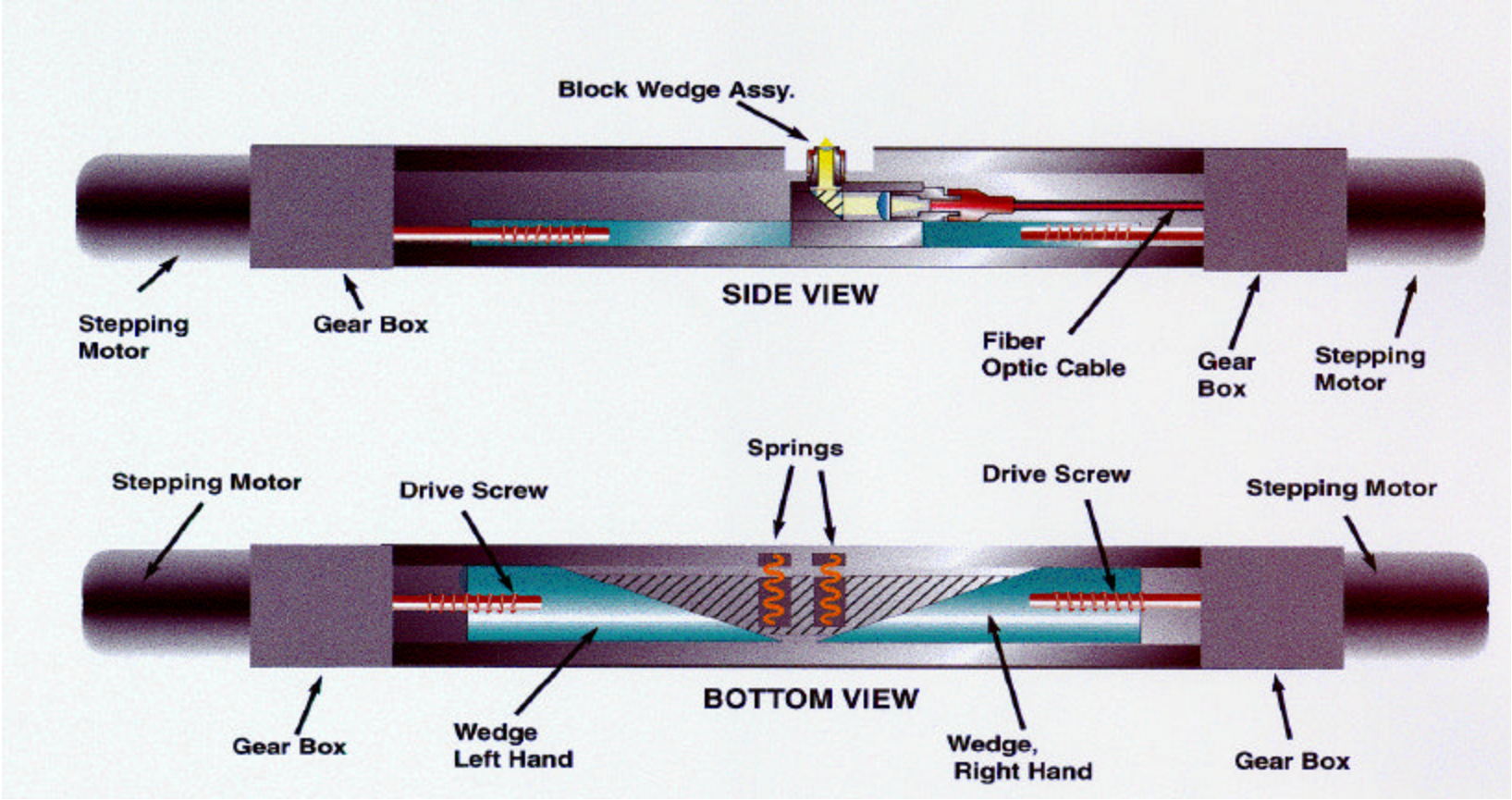
FO-LIBS
Optical Scanning Assembly



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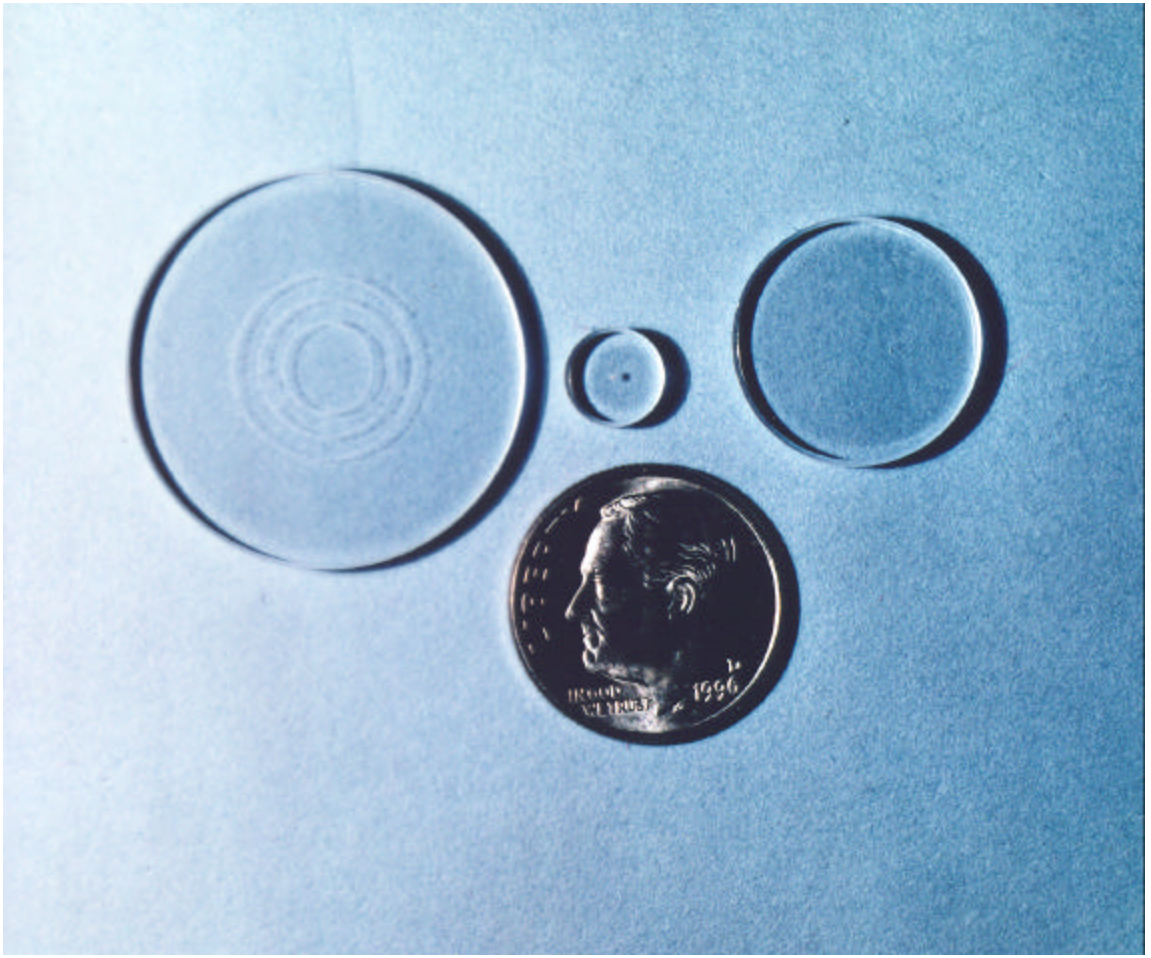
FO-LIBS
Photo showing plasma ablation of sapphire window



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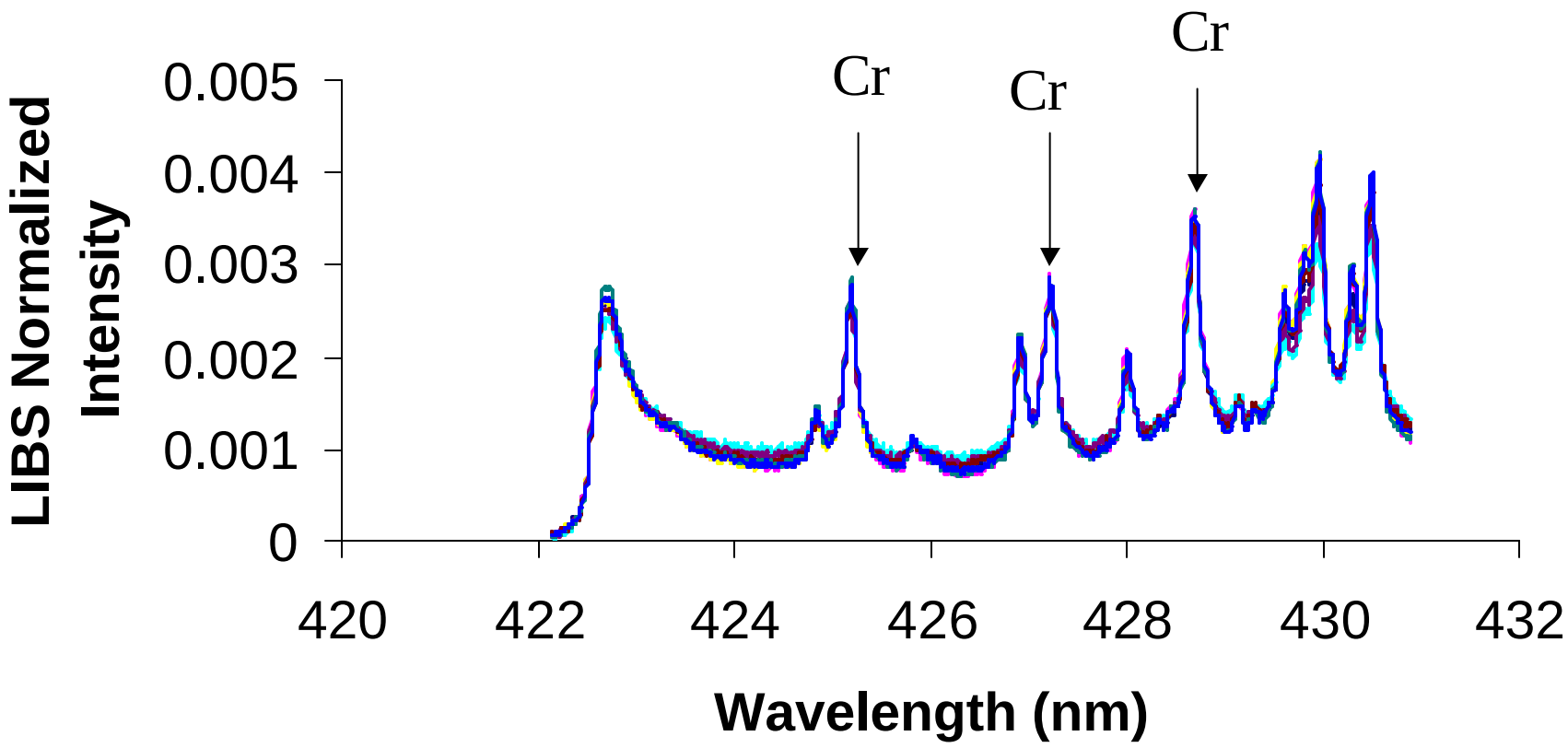
North Island Hole 1

Depth 6”-12” Normalized



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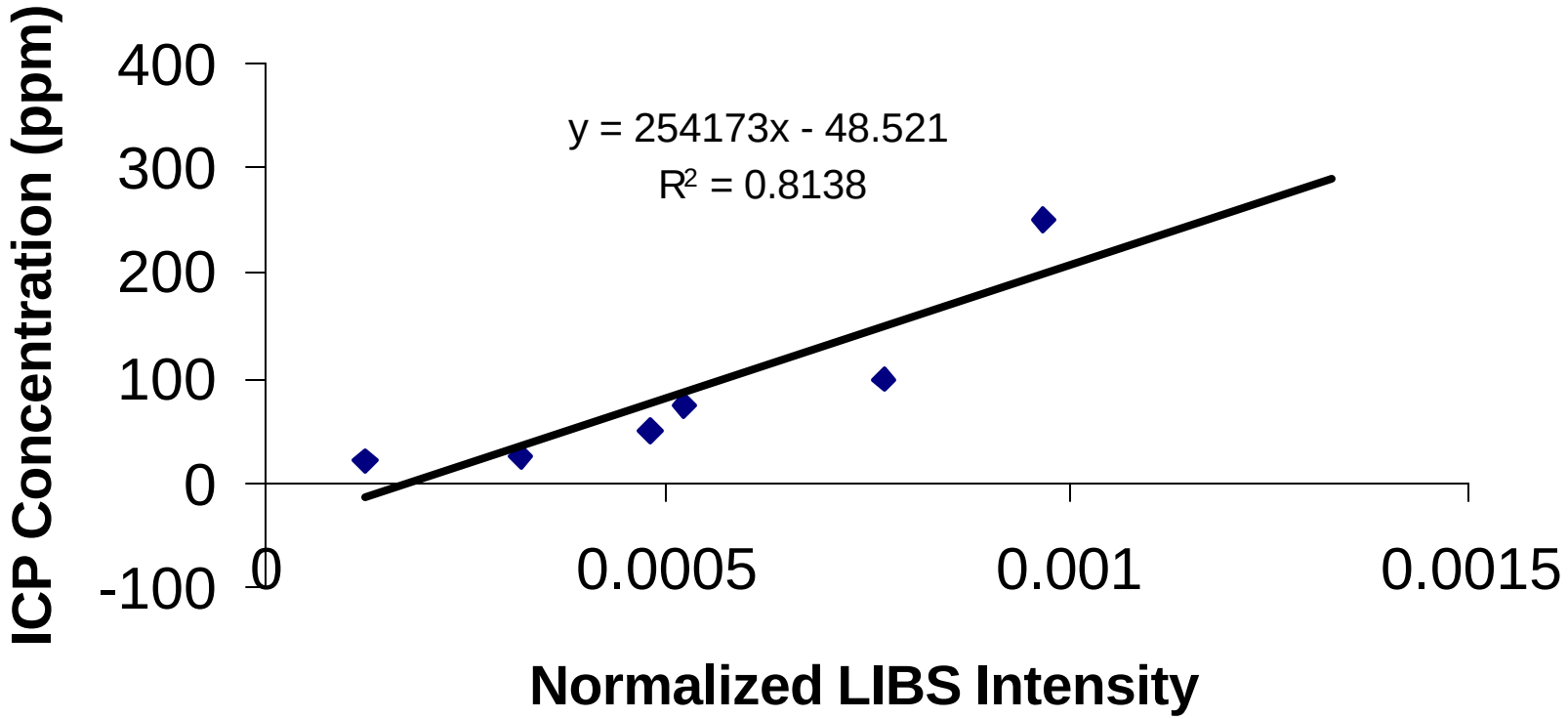
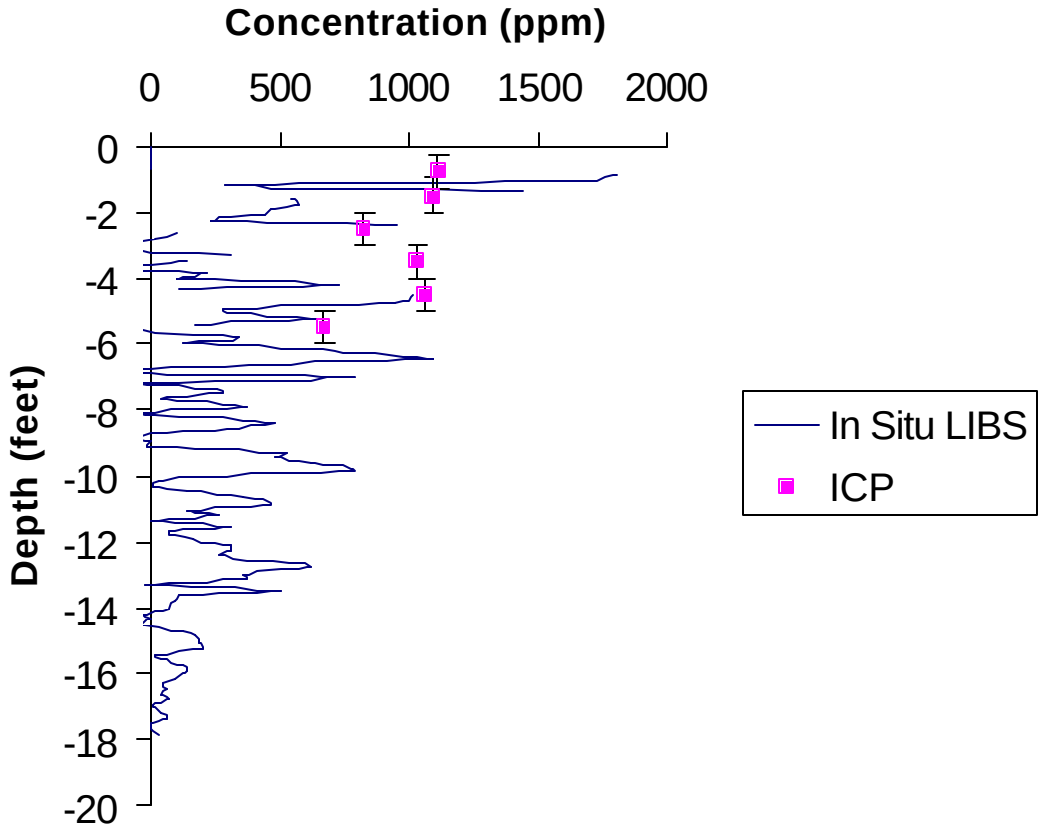
North Island FOLIBS Cr Calibration
(Linear Region)

Detection Limit 30 ppm



North Island In-Situ Cr Results Push 1



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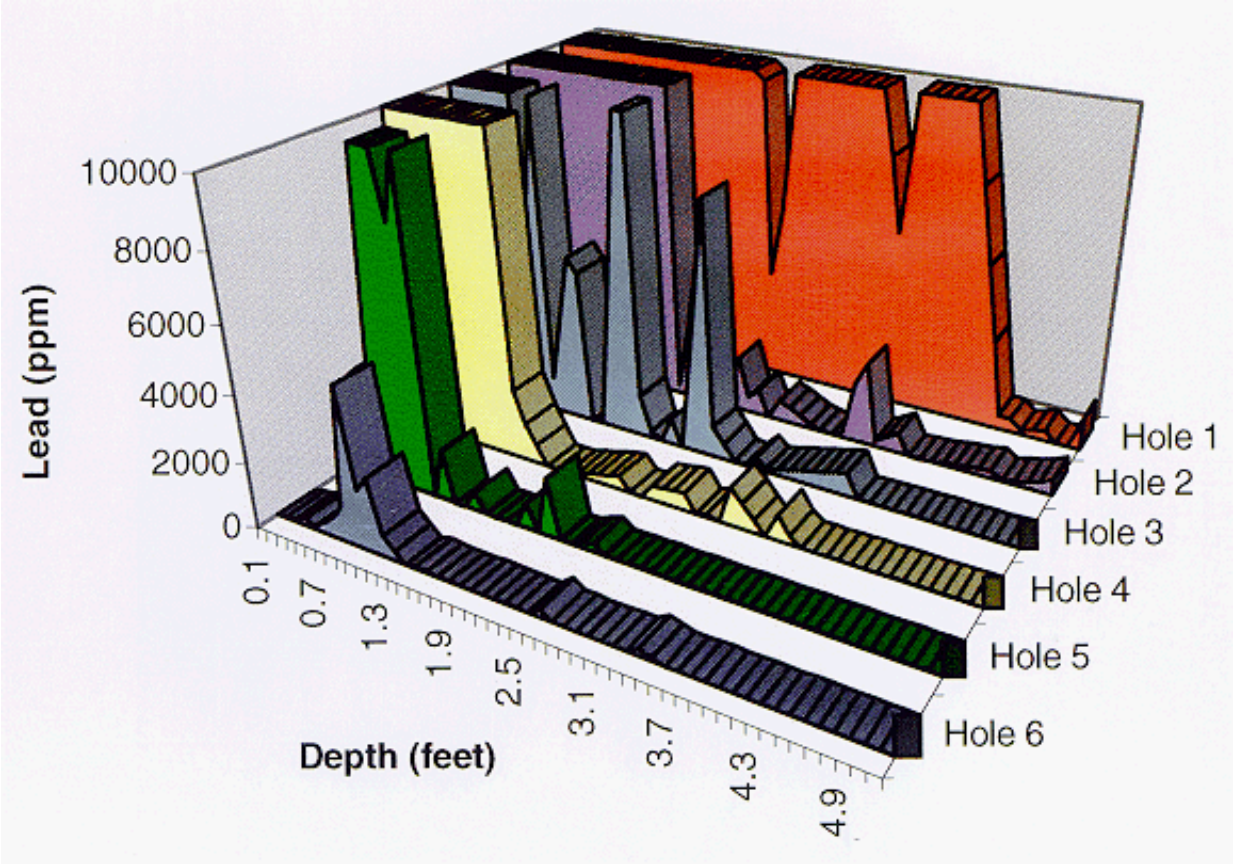
LIBS metal data from Pb contaminated site

Mare Island Naval Shipyard
Hole spacing 1 foot



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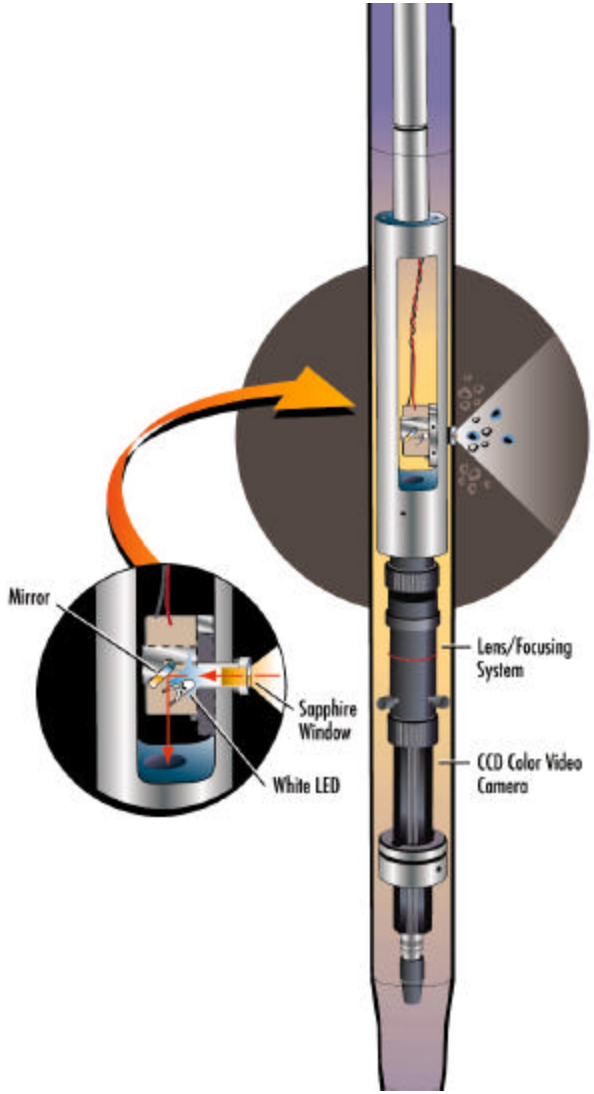
GeoVIS
Probe Schematic



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GeoVIS
Block Diagram

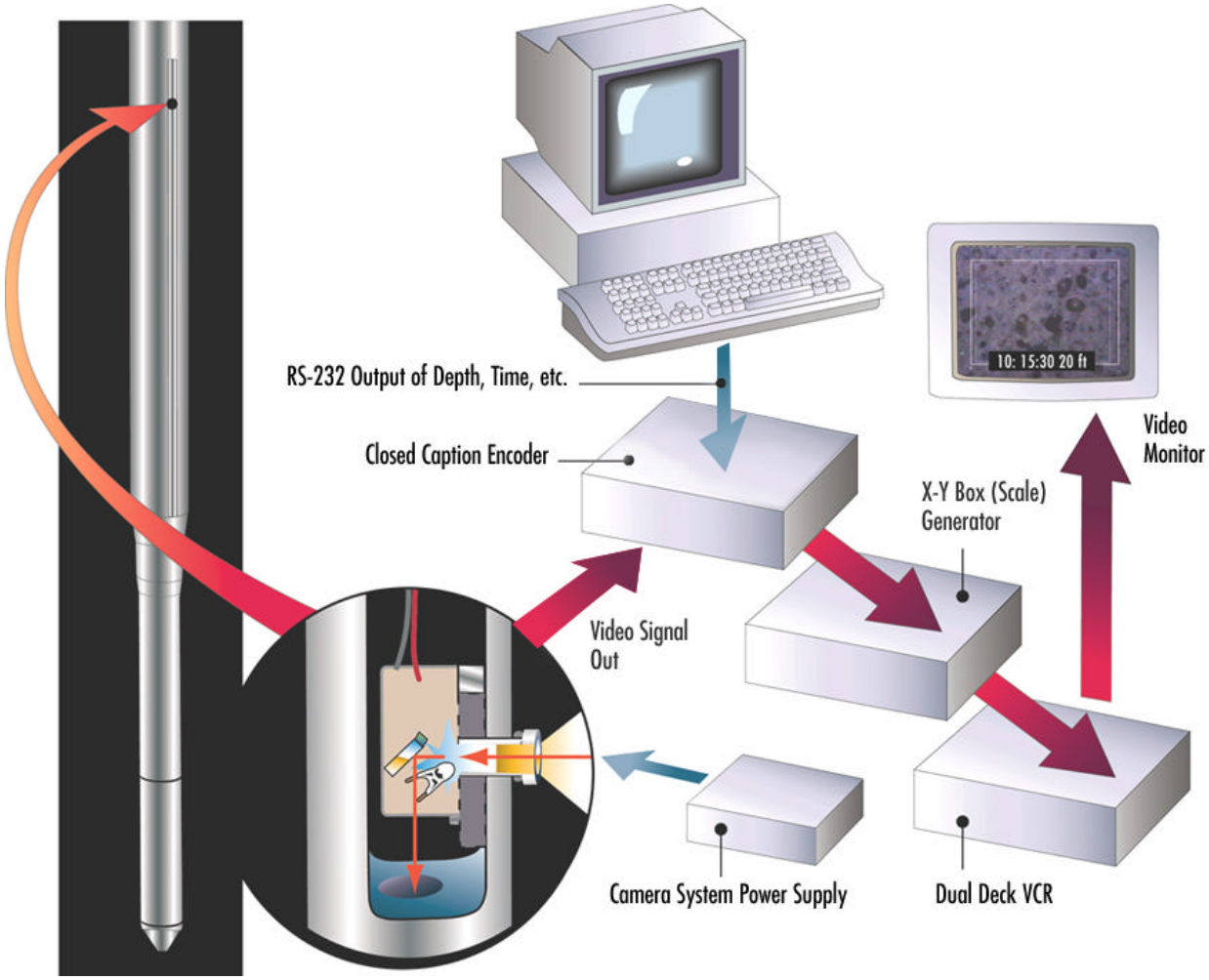

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Photo of GeoVIS Probe

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Exploded View of GeoVIS Probe

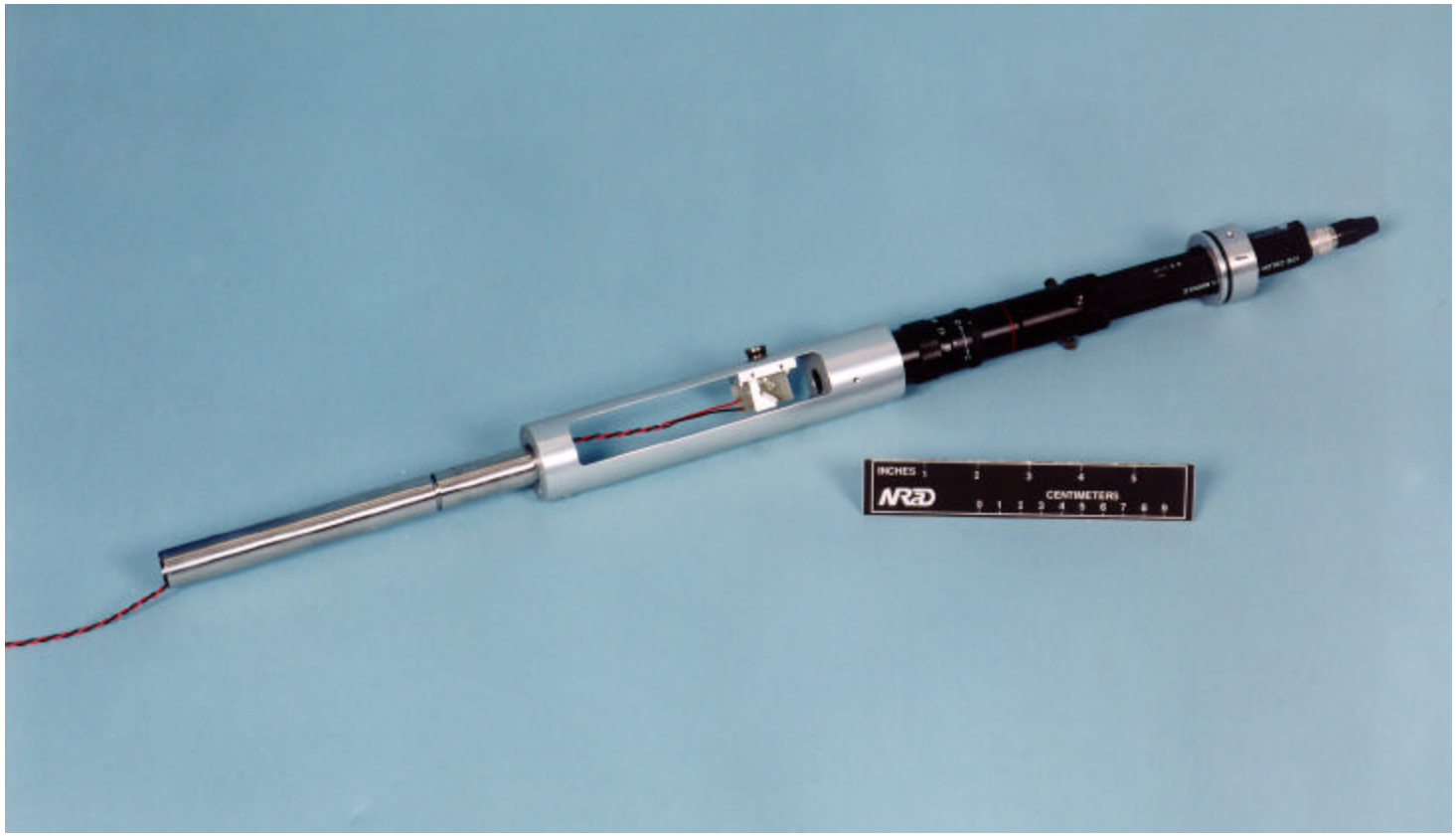

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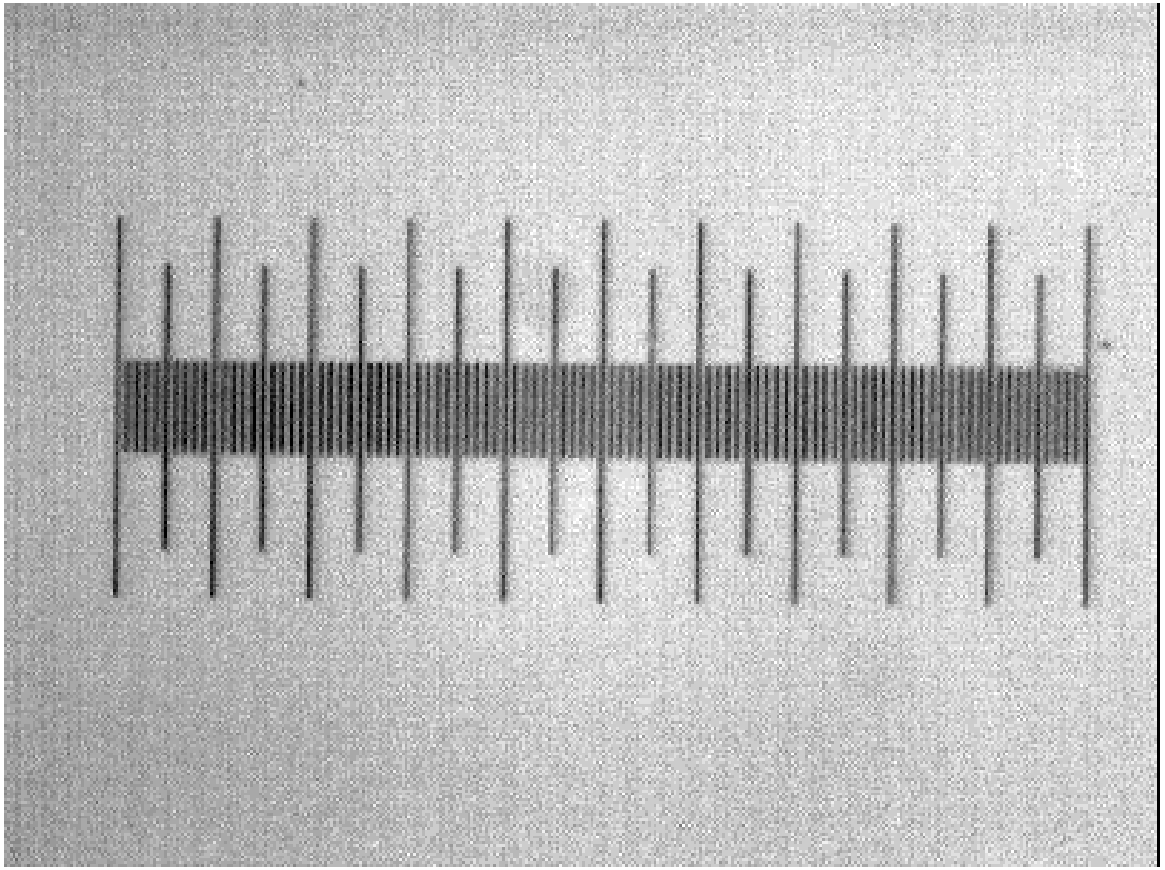
Image of 1 mm scale

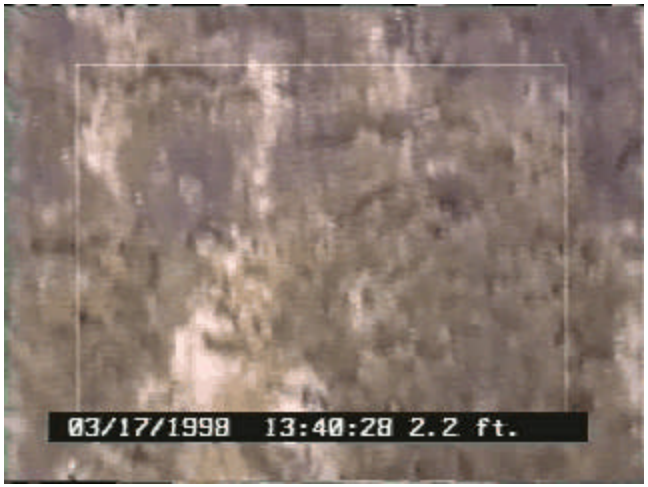


Video data from field deployment of soil video imaging system

- Conditions:
  - Push rate: ~ 10 cm/min
  - Image area: ~ 2x 2.5 mm
  - Frame rate: 30 frames/sec
  - Vertical spatial resolution: 0.05 mm/frame

Video Clip of soil root zone and vadose zone

Video clip of vadose zone showing changes in mineralogy



Video clip showing change in lithology from silty sand to silt

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Video clip showing change in color of soil

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Photo of cone penetrometer vehicle during LIF/GeoVIS characterization at NAS Alameda

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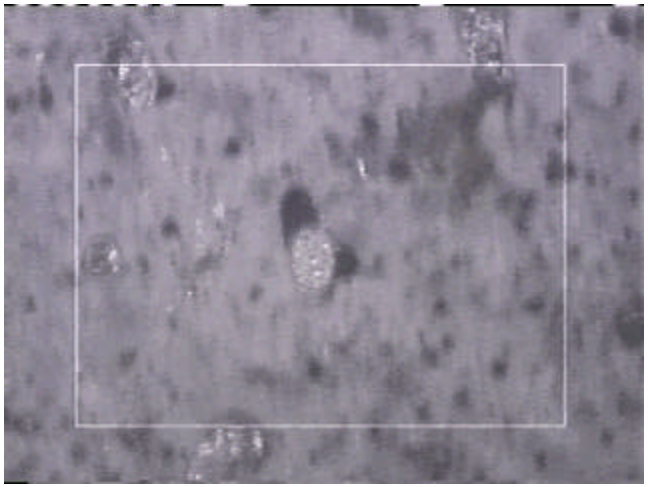
Video clip showing NAPL micro-globules



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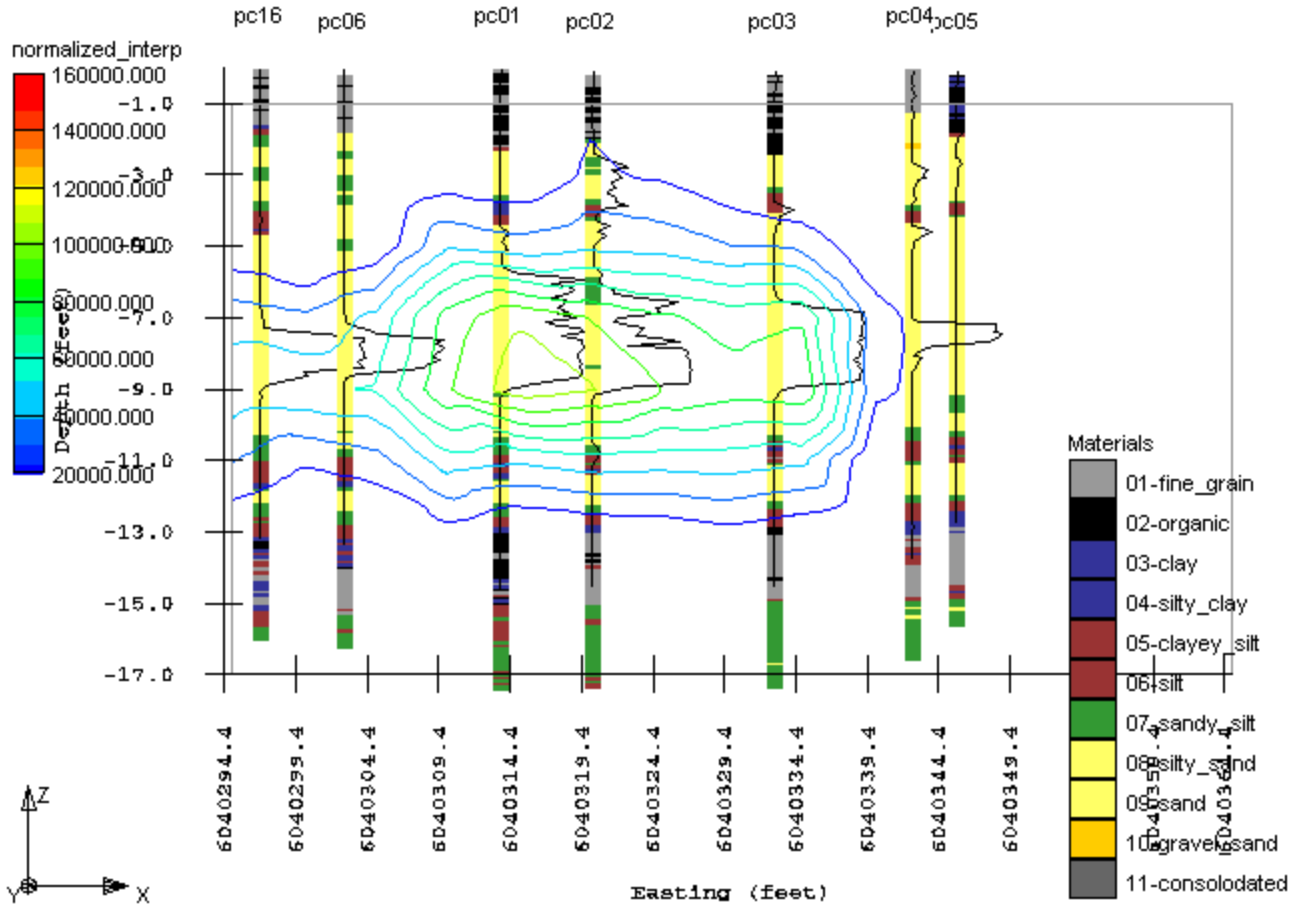
LIF - GeoVIS
North-South X-Section
Fluorescence & Lithology

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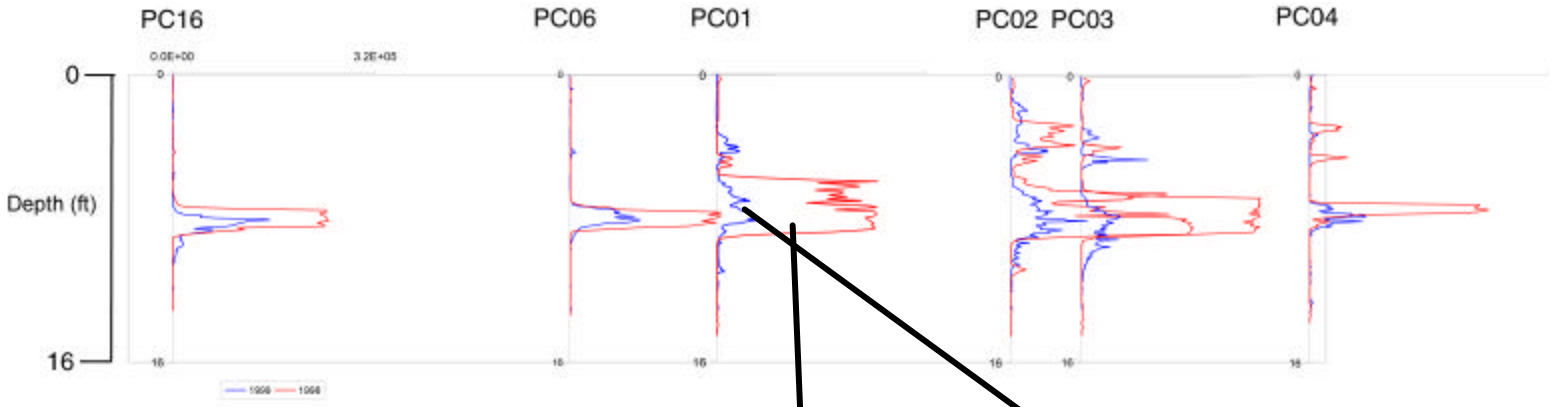
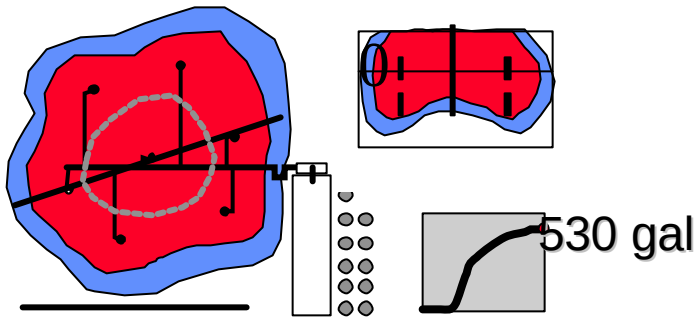
NAS Alameda

Evaluated effectiveness of Steam Enhanced Extraction after 65 Days of Steam Injection

LIF Data Transect: Before and After Steam Enhanced Extraction



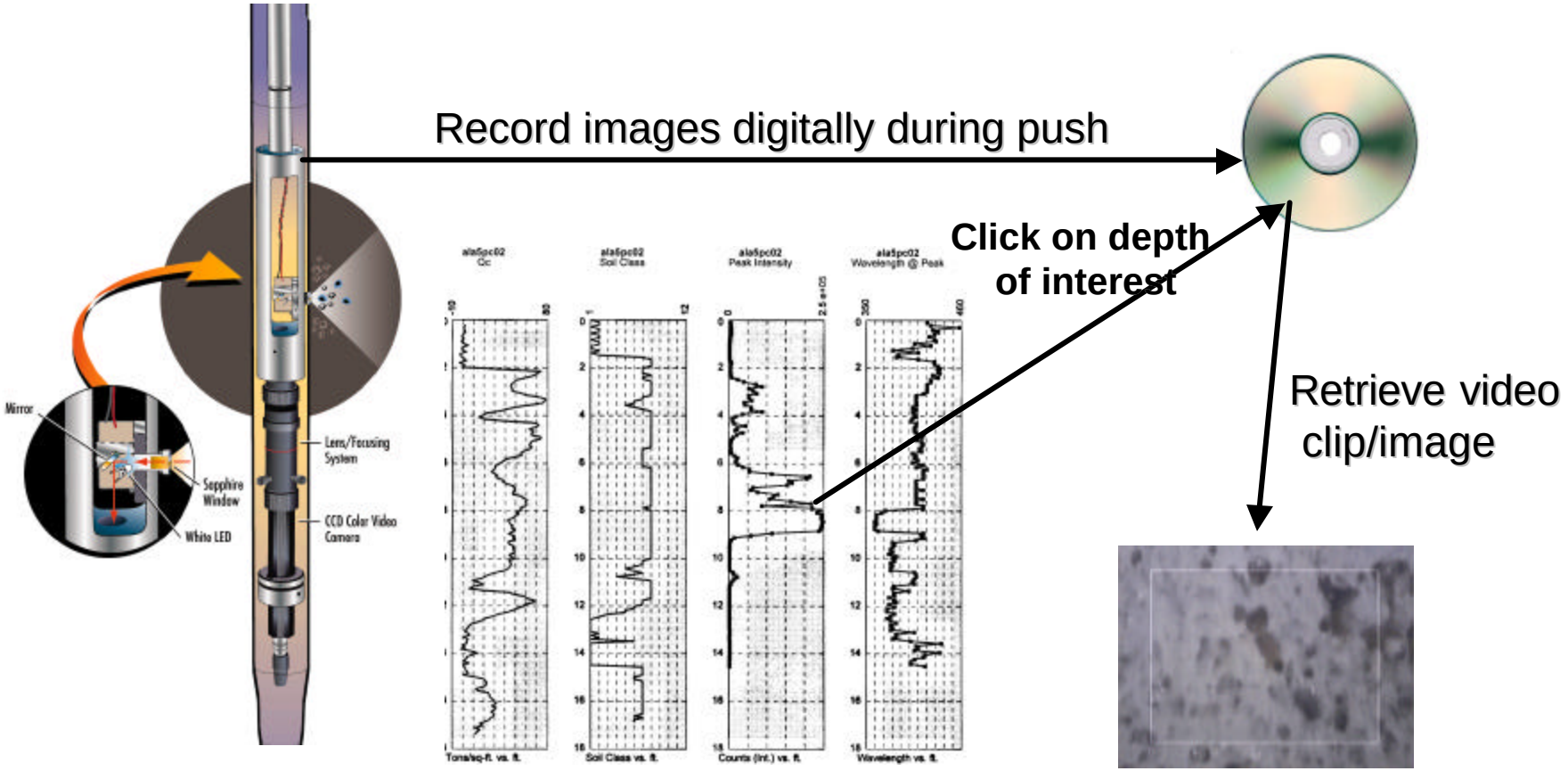


Before

After

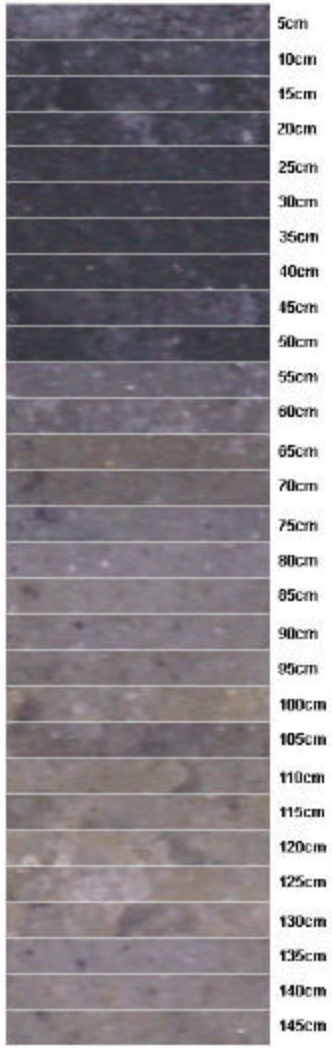
GeoVIS Data Handling

Images are now stored digitally and linked to other push data for convenient retrieval



GeoVIS Data Handling

Segments of images can be extracted from digital data file and "stacked" to generate Virtual Bore Log: useful for delineating changes in lithology



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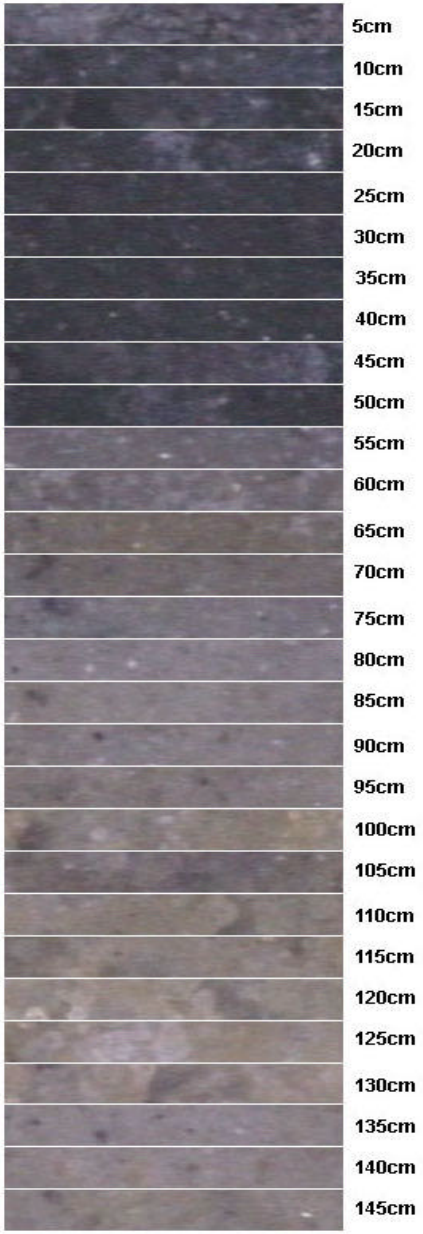
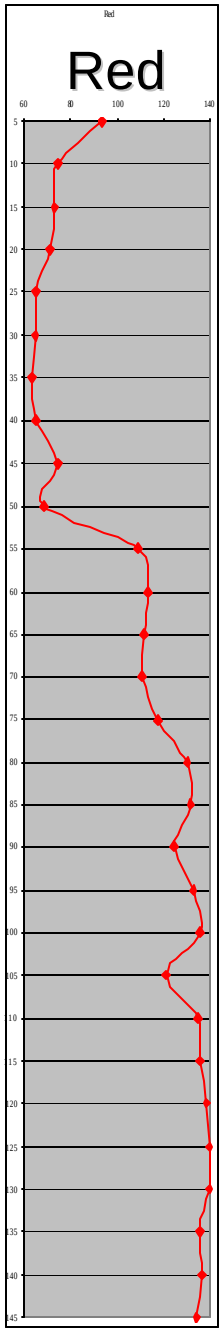
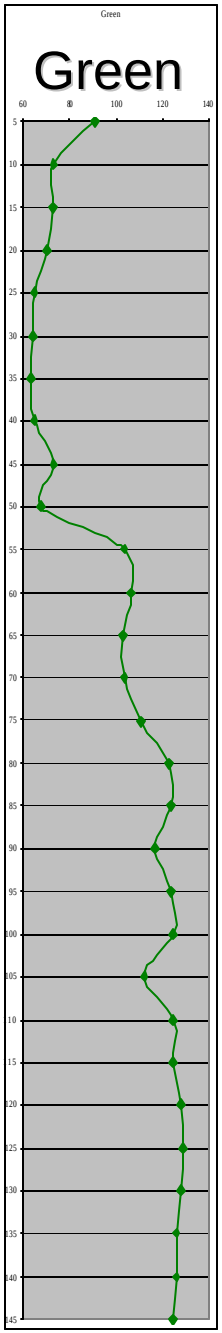
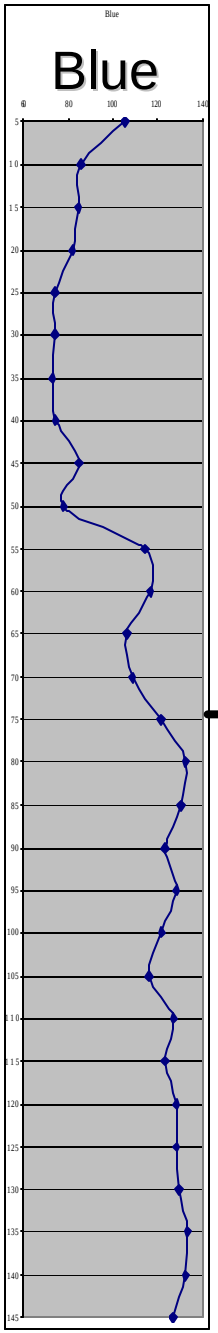
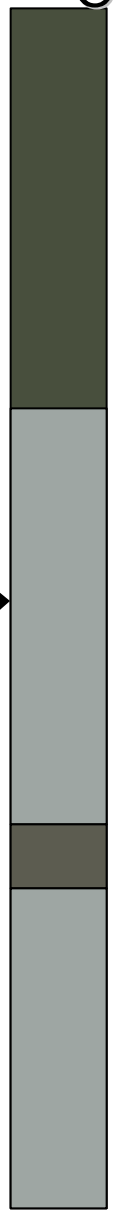








Munsell Color



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7.5YR 5/1

7.5YR 3/3

7.5YR 5/1

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Summary

- **LIBS Metal Sensor**
  - Provide high spatial resolution measurements of subsurface metal contamination
- ***In situ* Imaging System**
  - Provides high spatial resolution data on soil characteristics:
    - soil texture information, soil color, porosity, soil moisture (capillary fringe zone)
  - Imaging can be used to delineate DNAPL source zones
    - provides direct visual evidence of free phase product
    - suggests DNAPLs present at finely dispersed micro-globules rather than “pools”

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Current efforts

- LIBS
  - Conducting demonstrations/validations at multiple sites across US
- Current efforts are focusing on extracting useful information from images using automated imaging processing techniques
  - Textural information using wavelet analysis and color information using artificial neural net classification algorithm
  - Extent of DNAPL saturation using edge detection to identify micro-globules

Acknowledgments

Sponsors, etc.

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  - Naval Facilities Engineering Command
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- This technology may be covered by an invention disclosure assignable to the U.S. Government. Parties interested in licensing this technology may direct inquiries to: Harvey Fendelman, Legal Counsel for Patents, Code 0012, SPAWAR Systems Center, San Diego, (619) 553-3001.