TETRA TECH

SITE CHARACTERIZATION

Part 2. Intrusive Investigation Technologies

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SITE CHARACTERIZATION
INTRUSIVE TECHNOLOGIES

- Defining the Objectives of the Investigation
- Risk and Risk Mitigation
- Test Pits and Trenches
- Direct Push
- Hollow Stem Augers
- Mud Rotary Drilling
- Air Rotary Drilling
  - Percussion
  - Casing Drivers
- Cable Tool Drilling
- Coring
- Soil Sampling Devices
- Sonic Drilling
- Downhole Geophysical Logging

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OBJECTIVES OF USING INTRUSIVE SITE INVESTIGATION TECHNOLOGIES

- To better define site subsurface geologic structures, stratigraphy, lithology, and hydrogeology
- To define geologic and hydraulic controls of groundwater and contaminant flow
- To more definitively delineate the extent of contamination
- To provide more definitive measurements of the hydraulic properties of the subsurface materials

RISKS OF INTRUSIVE INVESTIGATIONS

- Increased possibility of cross-contamination of vertically separated zones
- Potential to mobilize NAPL
- Failure to adequately interpret the data, especially where subsurface conditions are highly heterogeneous and/or complex

MITIGATION OF RISK FOR INTRUSIVE INVESTIGATIONS

- Avoid drilling in areas where NAPL or contaminant source areas may be present
- Minimize the length of hole which is open at any time
- Use test pits judiciously
- Use multiple cased bores when contamination is expected in vertically separated water-bearing zones

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TEST PITS AND TRENCHES

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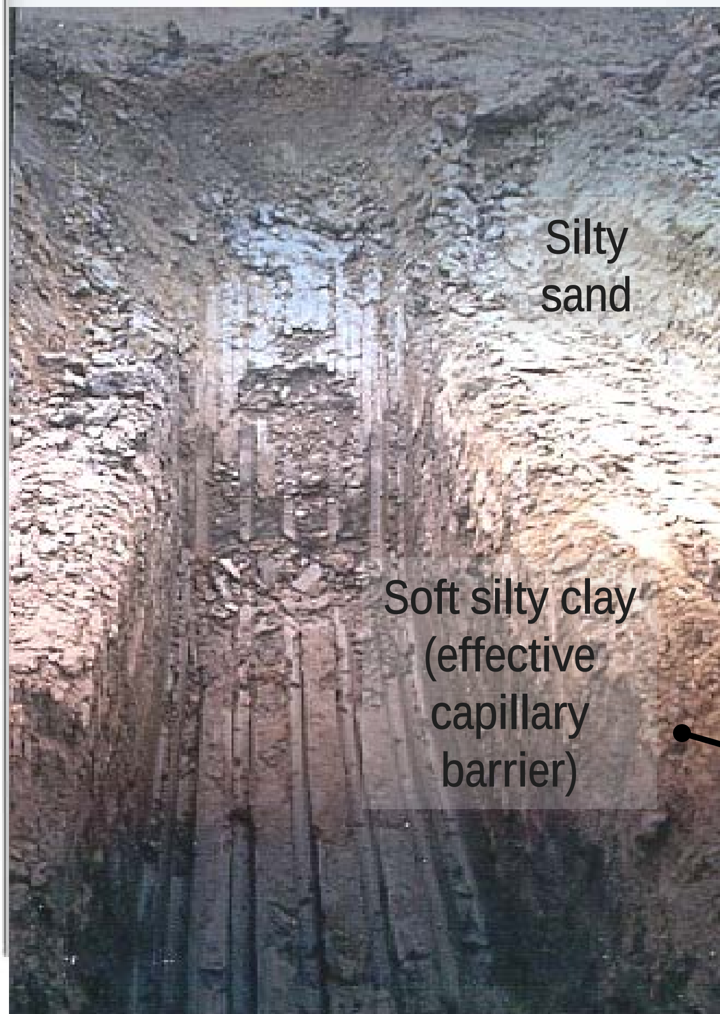
APPLICATIONS OF TEST PITS AND TRENCHES IN SITE CHARACTERIZATION

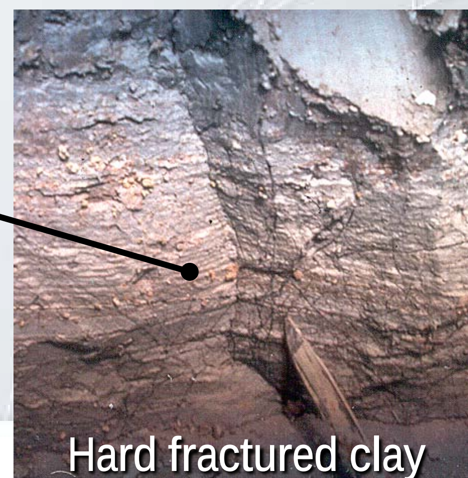
- Physical characterization of shallow subsurface conditions
- Identify depth to the water table
- Locate and define the limits of buried waste
- Better enables interpretation of geologic heterogeneity than other methods of investigation
- Identify preferential pathways
- Identify if and where NAPL is present
- Permits sampling for chemical and physical analyses

TESTS PITS

- Used to define shallow soil stratigraphy, structure, and NAPL distribution



Love Canal site, Niagara Falls, NY



DISADVANTAGES OF TEST PITS AND TRENCHES

- May mobilize contaminants, especially if left open for long duration
- May disrupt day-to-day facility operations
- May pose a safety hazard

DIRECT-PUSH SAMPLING TECHNOLOGIES

BENEFITS OF DIRECT-PUSH SAMPLING

- Rapid stratigraphic logging and contaminant detection using a variety of sampling and/or sensor systems
- Rapid, depth-discrete sampling of soil, soil gas, and water
- No drill cuttings, little IDW
- Minimally invasive; effective grouting and sealing capabilities
- Reduced potential for contaminant drag-down
- Standard methods
  - Direct push soil sampling (ASTM D-6282)
  - Direct push groundwater sampling (ASTM D-6001)
  - Cone penetration testing (ASTM D-3441)

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Geoprobe® and Cone Penetration Tools

- Soil gas sampler
- Soil sampler
- Groundwater sampler
- CPT – stratigraphy
- Soil moisture probe
- Electrical conductivity/resistivity
- Fluorescence detector
- Downhole camera
- MIP and thermal desorption VOC sampler
- Aquifer testing
- Grouting module

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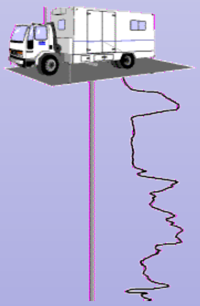
Comparison of Direct Push Methods

Technique	Advantage	Limitation
Percussion Probing (Geoprobe®) 	▪ Less expensive ▪ More mobile and available ▪ Well-developed sampling tools ▪ Availability of certain sensors	▪ Difficult to penetrate hard/dense soils ▪ Depth limitation
Cone Penetration 	▪ Greater depth penetration ▪ Certain sensors better-developed (LIF, tip resistance, sleeve friction, etc.)	▪ More expensive ▪ Less available ▪ Less maneuverable

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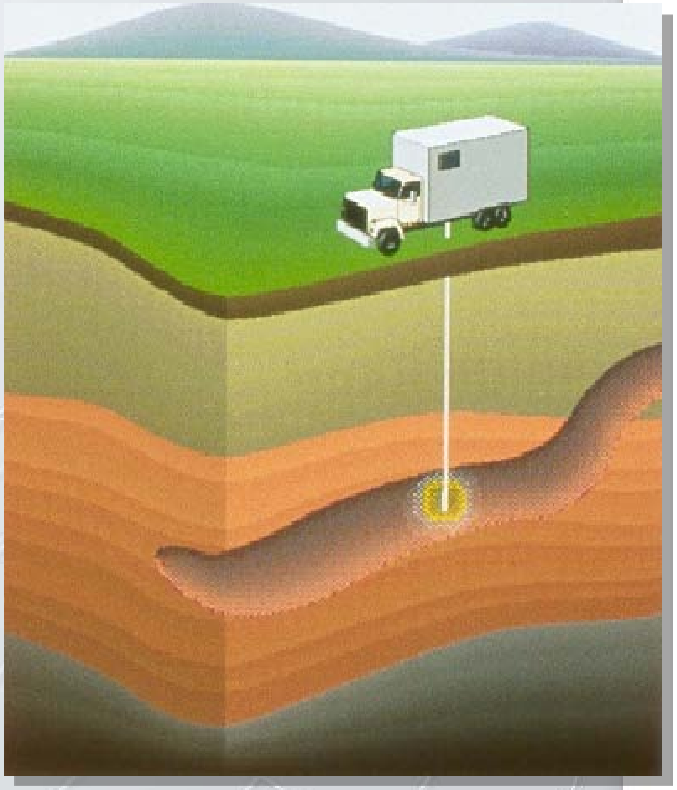
CONE PENETROMETER TECHNOLOGY / LASER INDUCED FLUORESCENCE (CPT/LIF)

- CPT uses strain gauges to measure soil behavior properties (tip and sleeve resistance) to provide real-time, in situ stratigraphic identification
- LIF provides real-time logging of fluorescent contaminants
- Probe continuously advanced smoothly at ~1 meter/min in accord with ASTM Standard D-3441
- CPT rigs vary from 20 to >35 tons in truck and ATV format



Source: Fugro, 1999

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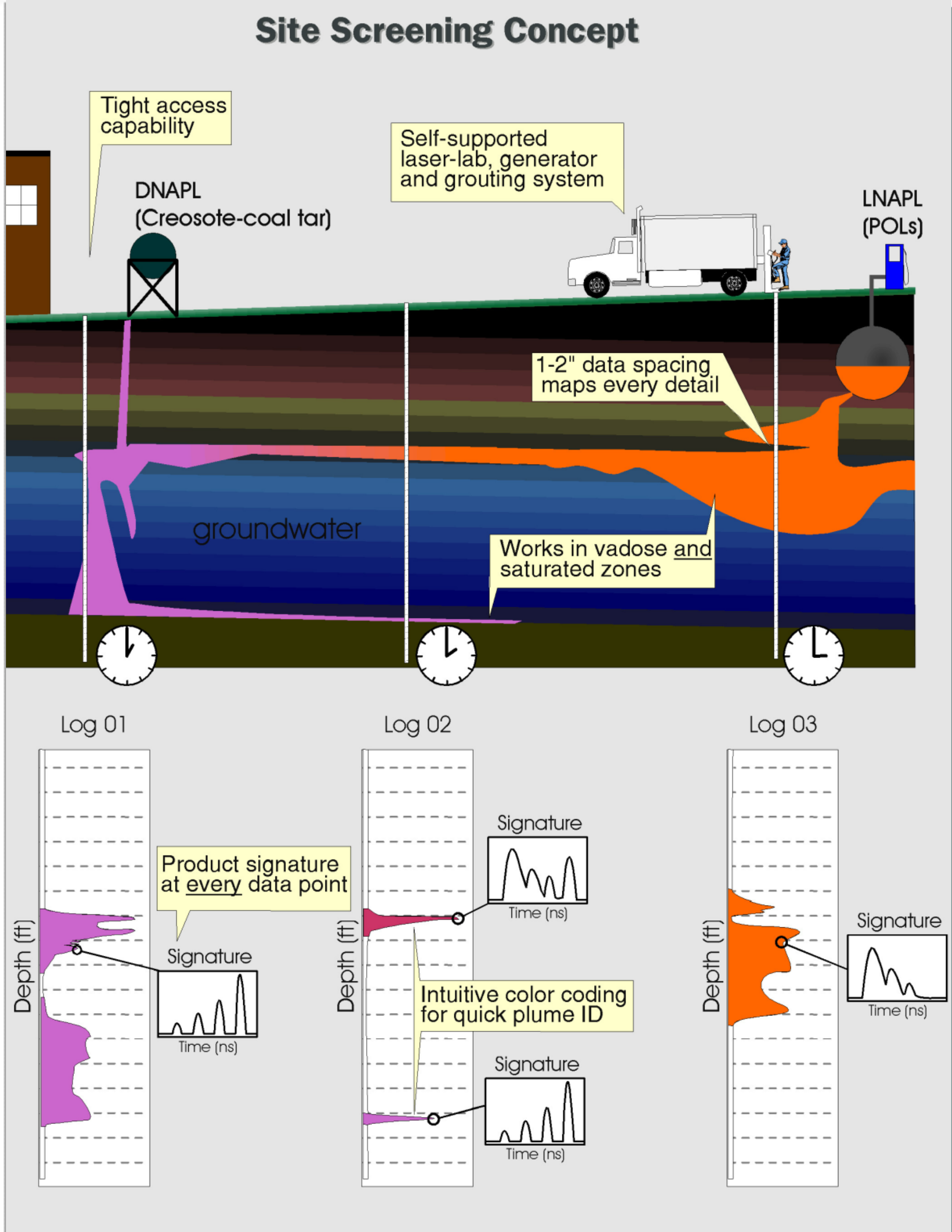
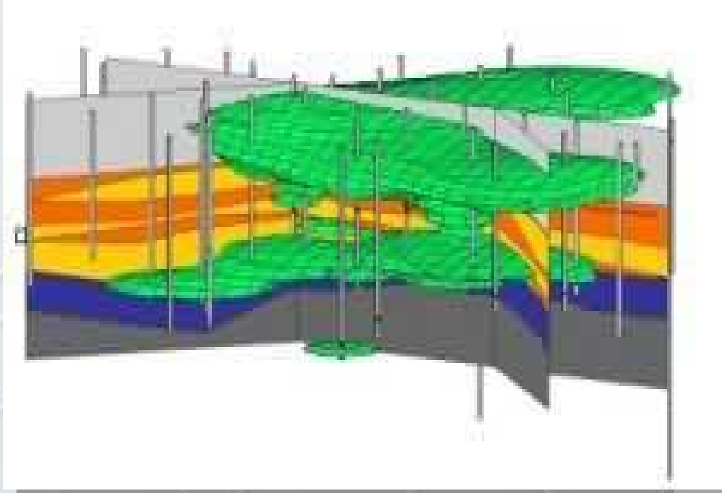


CPT/LIF CONCEPT

Detailed characterization of stratigraphy and contamination in real time



Source: Dakota Technologies, Inc.

LIF/FFD APPLICATIONS

- Polycyclic aromatic hydrocarbons (PAHs) in petroleum products, coal tar, and creosote
- Double-ring (naphthalene) and single-ring aromatic hydrocarbons (BTEX compounds) at lower excitation wavelengths
- Chlorinated solvents (e.g., PCE, TCE) and other NAPLs mixed with fluorescent impurities can produce strong fluorescent signals
- LIF has mainly been used to delineate petroleum (at POL sites) and coal tar contamination (at wood-treating and MGP sites) at relatively shallow depths.

DOWNHOLE FLUORESCENCE

Advantages

- Real-time delineation of stratigraphy and fluorescent contamination
- Typical daily productivity of 100 to 300 meters at 10 to 15 locations
- LIF waveforms offer product identification/verification and rejection of non-contaminant fluorescence
- Reduced IDW and exposure to site contaminants
- Potential cost savings

Limitations

- Primarily applicable to PAHs
- Subject to interferences
- NAPL has to be adjacent to sapphire window
- Limited availability

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GROUNDWATER QUALITY PROFILING USING DIRECT PUSH TOOLS

- Collect multiple discrete groundwater samples from <u>coarse sediments</u> at multiple depths in a single hole
  - Waterloo Profiler®
  - Geoprobe® Dual Tube and GW Profilers
  - VERTEK ConeSipper™
- Need to know stratigraphy to select sampling zones
  - Based on CPT log, EC log, K-test, geologic log . . .
- Combine with mobile lab for real-time measurement and dynamic site characterization

Geoprobe® DT21 Profiler

Source: Pitkin, 2002

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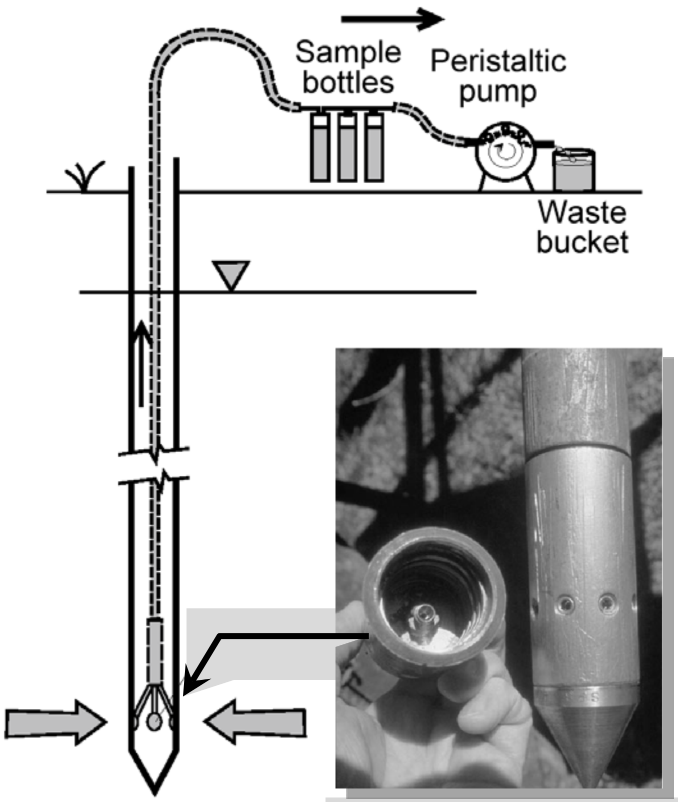
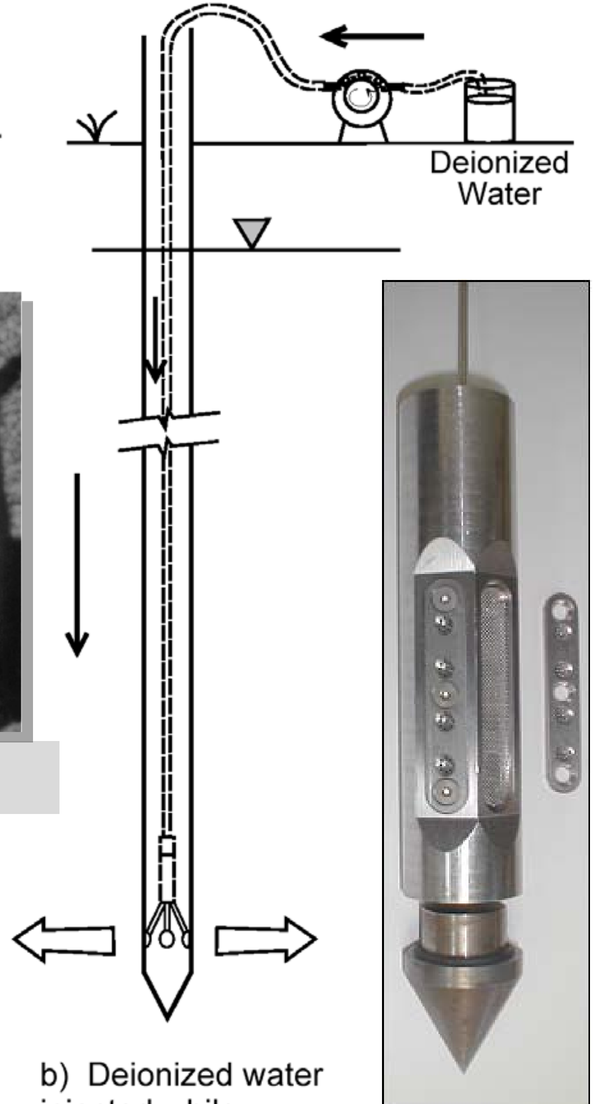
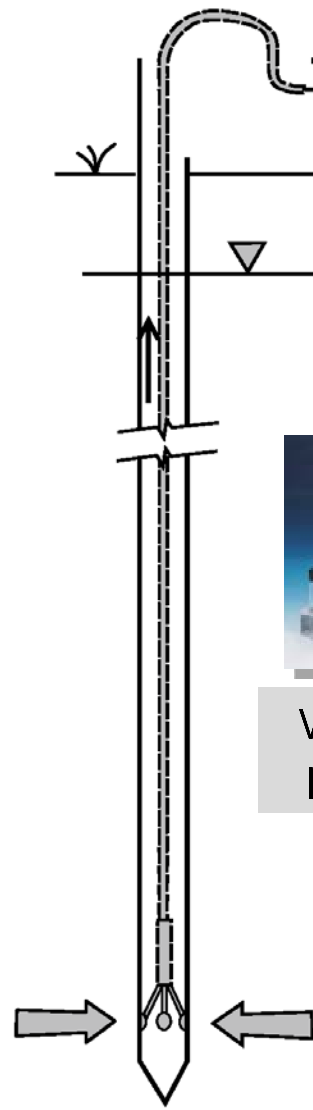


Sampling Port

a) Groundwater sample collected from first target zone with peristaltic pump.



b) Deionized water injected while advancing tool to prevent sampling ports from becoming plugged.



VOA Vial filler for peristaltic pump

c) Groundwater sample collected from second target zone with peristaltic pump.

Waterloo Profiler®

Sources: Precision Sampling, Inc.; Solinst Canada, Ltd.; Pitkin et al., 1999; and Stone Environmental, 2002

ADVANTAGES OF DP GROUNDWATER PROFILING

- No drill cuttings and little purge water
- Can pump clean water out through screen during advancement to minimize clogging and drag down of contaminants*
- Can collect multiple samples (at any spacing) with depth using peristaltic or pneumatic low-flow pumping methods*
- Can perform K tests*
- Can develop well screen*
- Holes can be grouted through rods
- Provides detailed concentration profiles that can be used for back-tracking to DNAPL source
- Rapid and cost-effective

* See specific products for availability

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LIMITATIONS OF DP GROUNDWATER PROFILING

- Limited by lithology (clogging, turbidity, and lack of yield problematic in fine-grained sediments) and depth (depending on drilling and sample collection methods)
- Only provides a snapshot in time of water quality
- Concentrations of metals and hydrophobic compounds likely to be biased due to sample turbidity
- Vertical hydraulic gradients can impact back tracking interpretation
- Due to heterogeneity and dilution effects, can still be difficult to define morphology of DNAPL sources
  - Concentration > effective solubility indicates NAPL in sample
  - Concentration < effective solubility requires interpretation

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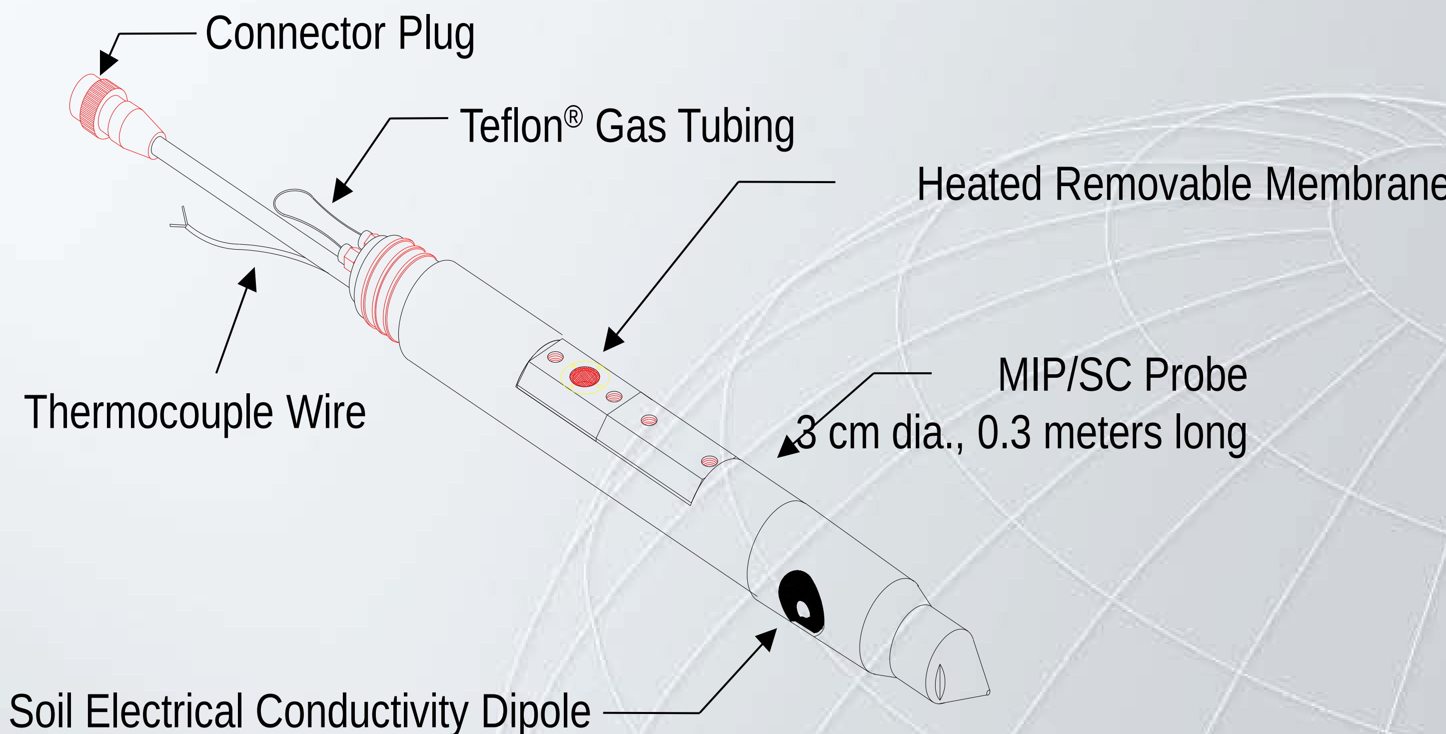
GEOPROBE® MEMBRANE INTERFACE PROBE (MIP) AND SOIL CONDUCTIVITY (SC) SYSTEM

A direct-push logging tool that records continuous relative VOC concentrations (MIP sensor) and electrical conductivity (SC sensor) with depth in soil. Provides rapid, real-time, detailed characterization of stratigraphy and VOC contamination.



Source: Geoprobe® Systems

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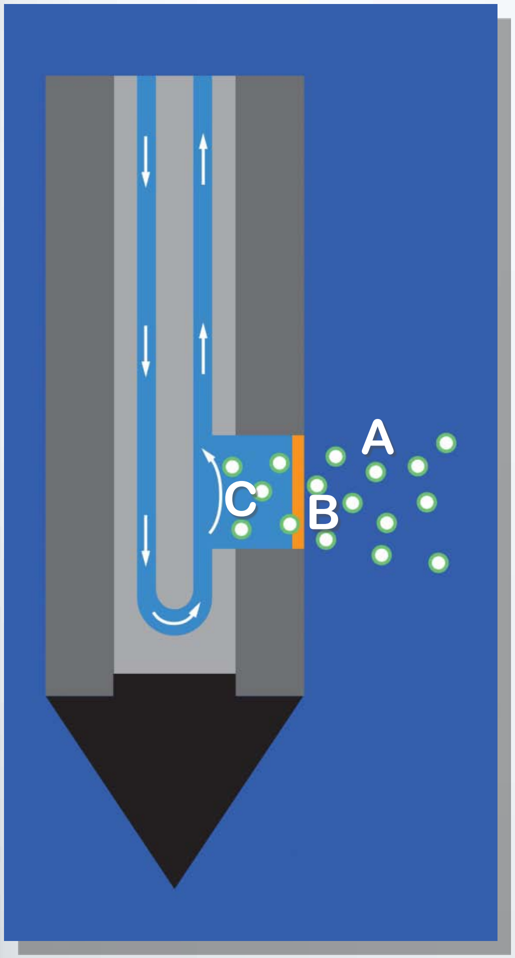
MIP THEORY OF OPERATION



Source: Geoprobe® Systems

- VOCs in subsurface region (A) come into contact with a thin film Teflon® membrane (B) set in a heating block, which is heated to 120°C.
- Chemicals are volatilized and diffuse across the membrane where they are swept by an inert carrier gas (C) to various detectors at the surface.
- Continuous voltage output from VOC detectors (ECD, PID, FID) are recorded versus depth.
- Bulk fluids do not travel across the membrane; thus the MIP can be used above or below the water table.

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GEOPROBE® MIP/SC PROBE

- MIP controller box is coupled to a field data logger, which records detector data, soil EC data, membrane temperature, and penetration speed.
- As the operator advances the MIP sensor into the subsurface a log is displayed onscreen by the field computer.

- For MIP use, the probe foot is anchored to the ground and the probe is driven 0.3 meters/min); typical operating depth to 20 meters; tool removed and hole can be grouted through rods.

Source: Geoprobe® Systems

THE MIP IS FOR VOCS

- Provides record of output voltage of the detector connected to the gas stream:
  - An electron capture detector (ECD) for chlorinated solvents
  - A photo-ionization detector (PID) for aromatic hydrocarbons
  - A flame-ionization detector (FID) for methane and petroleum hydrocarbons
- Gas samples can be analyzed by GC/MS; water and soil sampling can be guided using MIP data
- Given its relatively high detection limits, a good use of the MIP is to help delineate DNAPL zones

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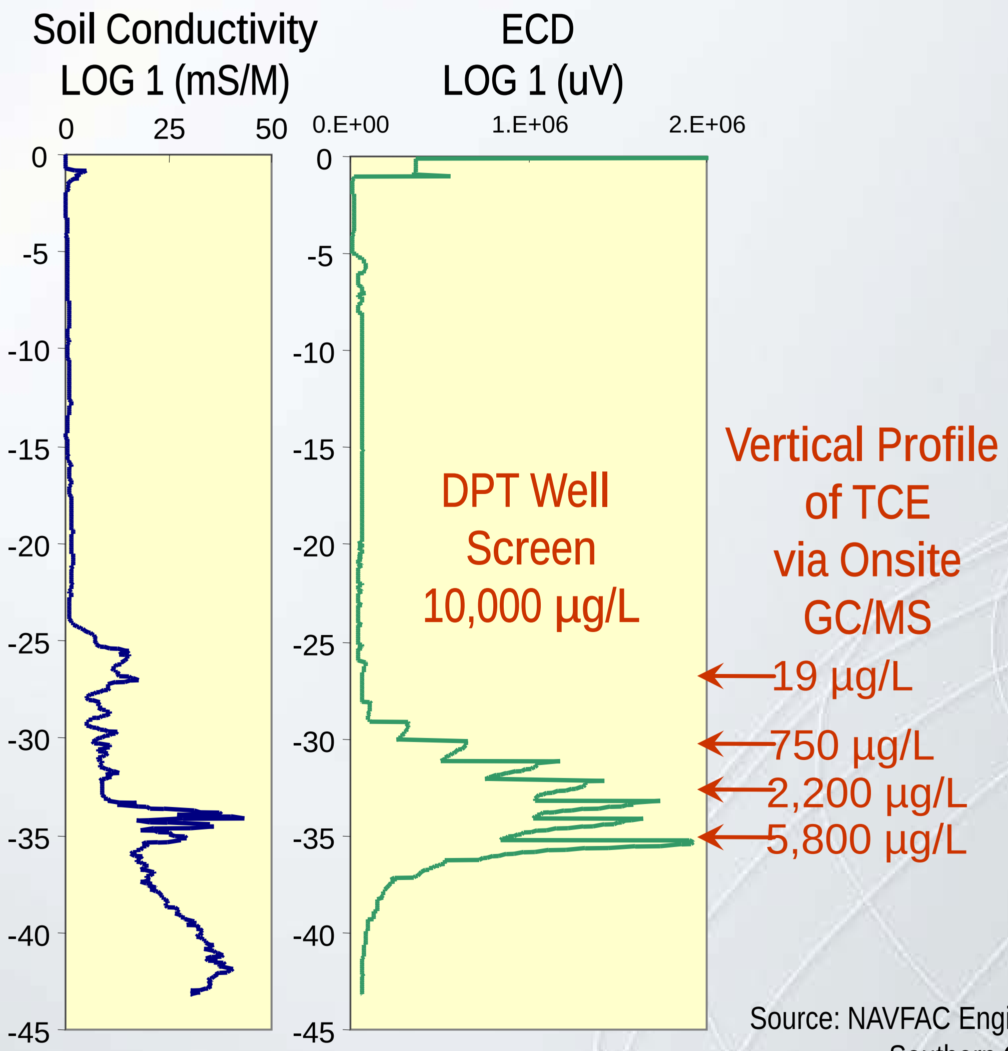
COMPARING MIP AND MOBILE LAB GCMS DATA

Charleston Naval Complex



Source: NAVFAC Engineering Division
Southern Command, 2001

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MEMBRANE INTERFACE PROBE

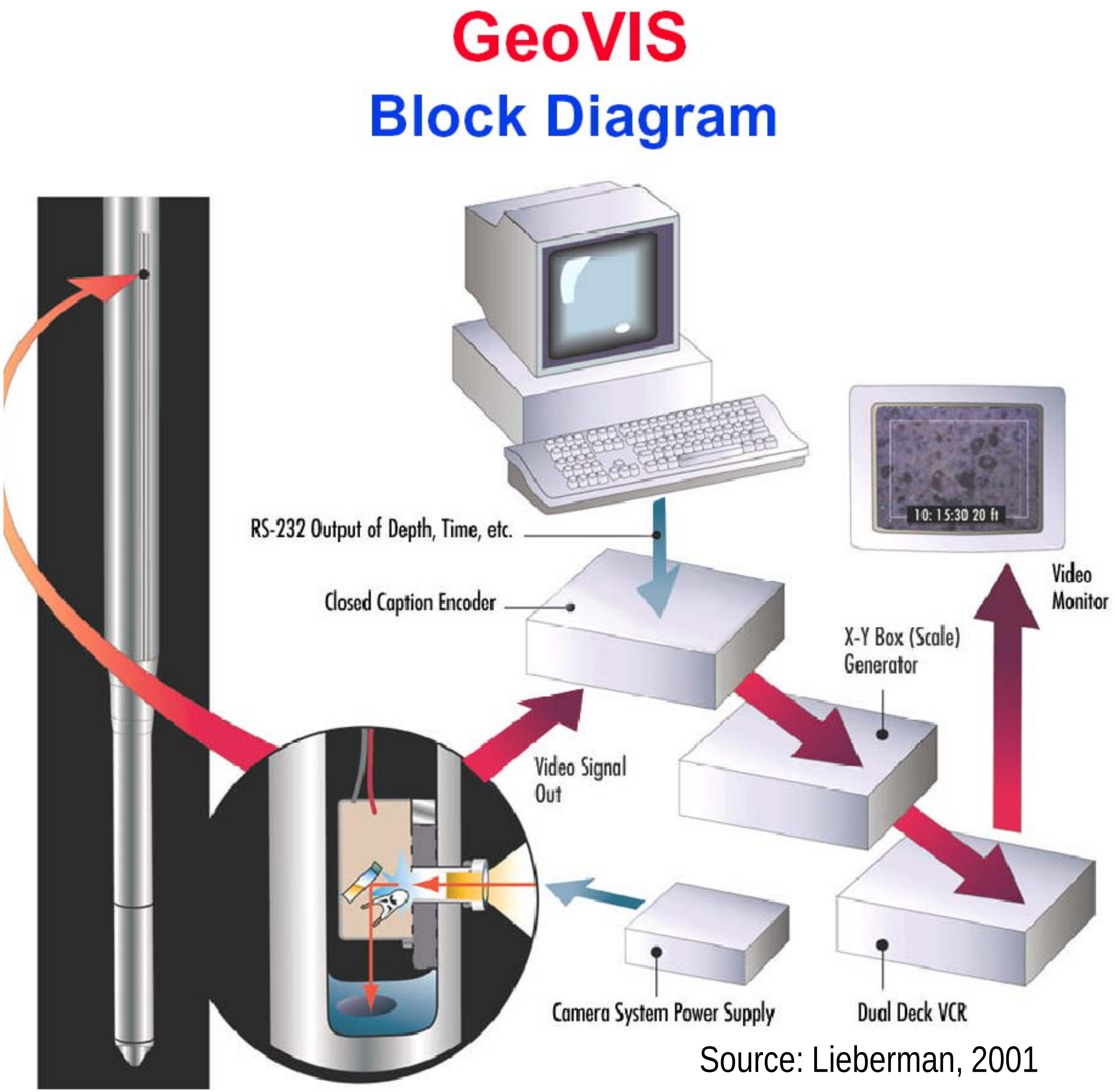
Advantages

- Widely available
- Simultaneous log of VOCs and soil conductivity
- Operates in vadose zone and saturated zones
- Useful for delineating NAPL source zones
- Rapid site screening (100s of meters per day)
- Cost savings

Limitations

- High detection limits, qualitative analytical data
- Designed for volatile contaminants
- Contaminant carry over can be high
- Penetration resistance limitations

CPT - Video



Source: Lieberman, 2001

Navy's GeoVIS and ARA's Video Cone soil imaging systems for soil characterization and NAPL detection and/or confirmation

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HOLLOW-STEM AUGERS

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APPLICATION AND ADVANTAGES OF HOLLOW-STEM AUGERS FOR SITE CHARACTERIZATION

- Cost effective for soil sampling and monitoring well installations in over burden to depths up to 50 meters
- Permits soil sampling with split-spoon and thin-wall tube samplers
- Permits groundwater sampling during drilling
- Does not require drilling fluid
- Augers act to stabilize borehole
- Excellent mobility and small rigs can be used in confined spaces

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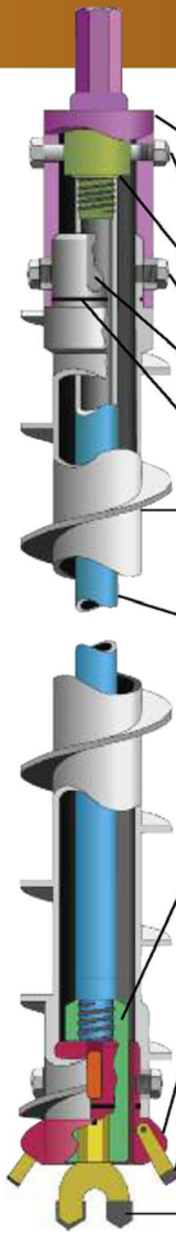
Hollow Stem Auger Assembly



Drive cap - The CME hollow auger drive cap has a shank to fit the drill spindle adaptor assembly and a keyed auger box coupling that fits over a hollow auger pin coupling.

Drive cap bolt and nut - Connects drive cap to rod-to-cap adaptor.

Rod-to-cap adaptor - Connects top center rod to drive cap.

Auger connector bolt - Secures each hollow auger connection.

Key-way - Allows augers to be rotated in forward or reverse under full rotary power while applying down pressure or retract forces to the auger column.

Patented O-ring seal - O-ring seal installed in groove on auger pin helps prevent contaminates from leaking into the auger column and drilling fluids from leaking out.

Hollow stem auger section - Auger flighting diameters and pitch are designed for maximum conveyance of soil cuttings with minimum drilling torque. Entire length of flighting is hardsurfaced for long-term abrasive wear resistance.

Drill rods - Threaded drill rods connect rod-to-cap adaptor to pilot assembly with center head.

Pilot assembly - Includes center head and connects to first center rod.

Auger head - Multi-use hollow auger head with replaceable forged steel, tungsten carbide tipped teeth.

Replaceable carbide insert tooth - Easily changeable forged steel, tungsten carbide tipped teeth are designed with the ultimate combination of hardness, durability and size for optimum cutting efficiency and long life.

Center head - Center heads used with 2 1/4" (5.7 cm) through 3 3/4" (9.5 cm) ID hollow augers are completely replaceable. Center heads used with 4 1/4" (10.8 cm) ID hollow augers can be either completely replaceable or have replaceable teeth. Center heads used with larger hollow augers have replaceable teeth.

Completely replaceable center head

Center head with replaceable teeth

Source: CME Product Catalog

LIMITATIONS OF HOLLOW-STEM AUGERS FOR SITE CHARACTERIZATION

- Not suitable for drilling in unconsolidated formations where large cobbles and boulders may be present
- May permit cross-contamination
- Ineffective for penetrating consolidated formations or “hard streaks”
- Limited depth capabilities (generally about 50 meters)

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MUD ROTARY DRILLING

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APPLICATION AND ADVANTAGES OF MUD ROTARY DRILLING

- Can rapidly drill through most unconsolidated to depths in excess of 500 meters
- Split-spoon and thin-wall tube sampling can be performed in unconsolidated materials
- Permits drilling and coring of rock formations
- Permits convenient use of most borehole geophysical devices
- In reverse circulation mode, water or less viscous muds can be used – rapid cutting recovery

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REVERSE CIRCULATING MUD ROTARY DRILLING

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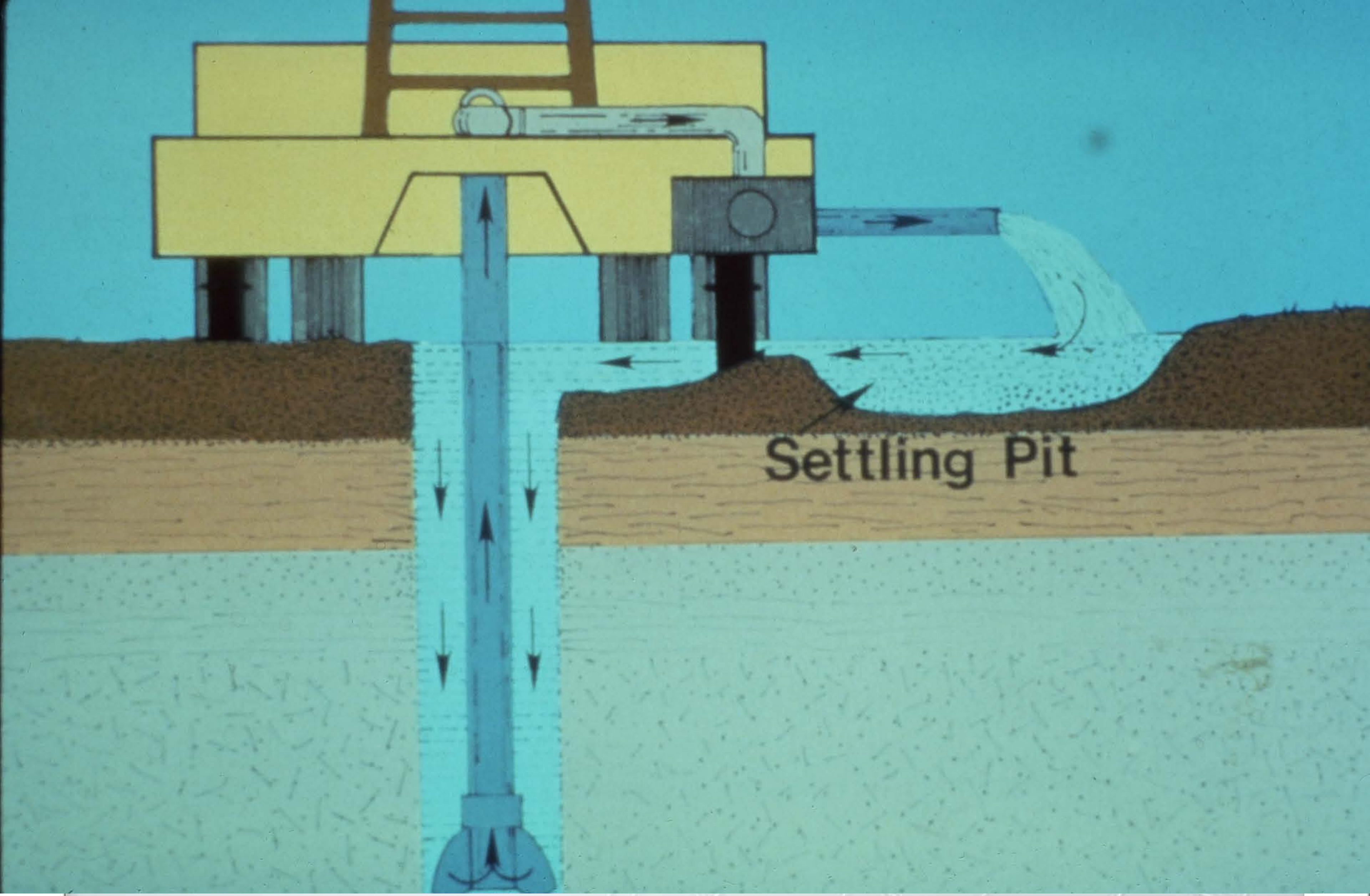
Settling Pit

LIMITATIONS OF ROTARY DRILLING

- Difficult to remove drilling mud from formations
- Some mud additives may influence the quality of groundwater samples
- Permits a potential for cross-contamination
- Difficult to decontaminate fluid handling equipment, e.g. mud pumps, hoses, etc.

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AIR ROTARY DRILLING FOR SITE CHARACTERIZATION

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APPLICATION AND ADVANATAGES OF AIR ROTARY DRILLING

- Rapid drilling of consolidated rock to depths in excess of 500 meters
- Acceptable well cutting recovery
- Allows for coring rock
- Reasonably good identification of water bearing zone
- Flexibility of hole diameter permits larger diameter monitoring wells

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LIMITATIONS OF AIR ROTARY DRILLING

- Surface casing required to stabilize the borehole through unconsolidated formations
- Small cuttings may hinder formation identification
- Air stream requires contaminant filtration
- Potential for vertical cross-contamination

AIR ROTARY WITH DOWN HOLE PERCUSSION TOOL

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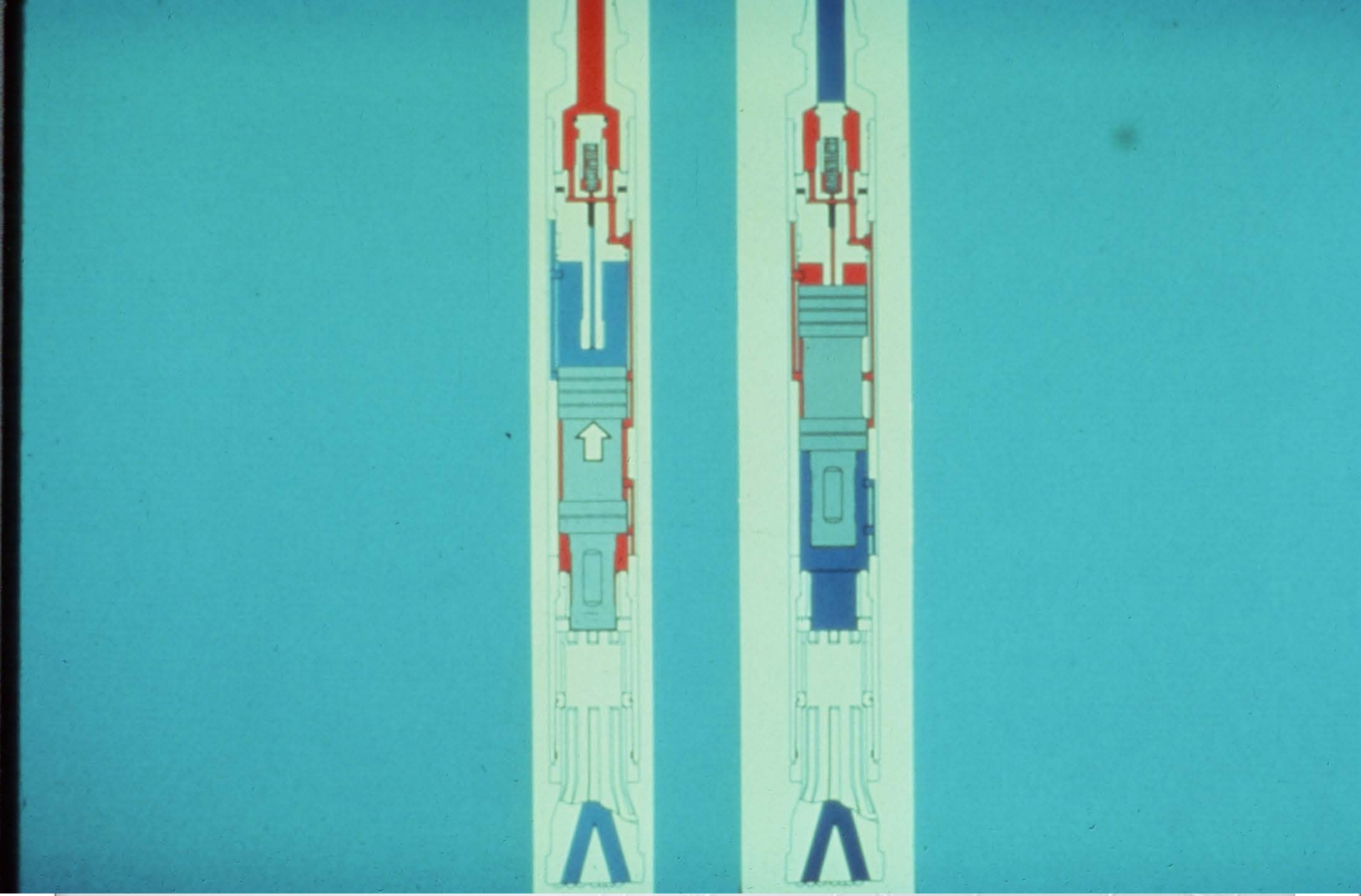

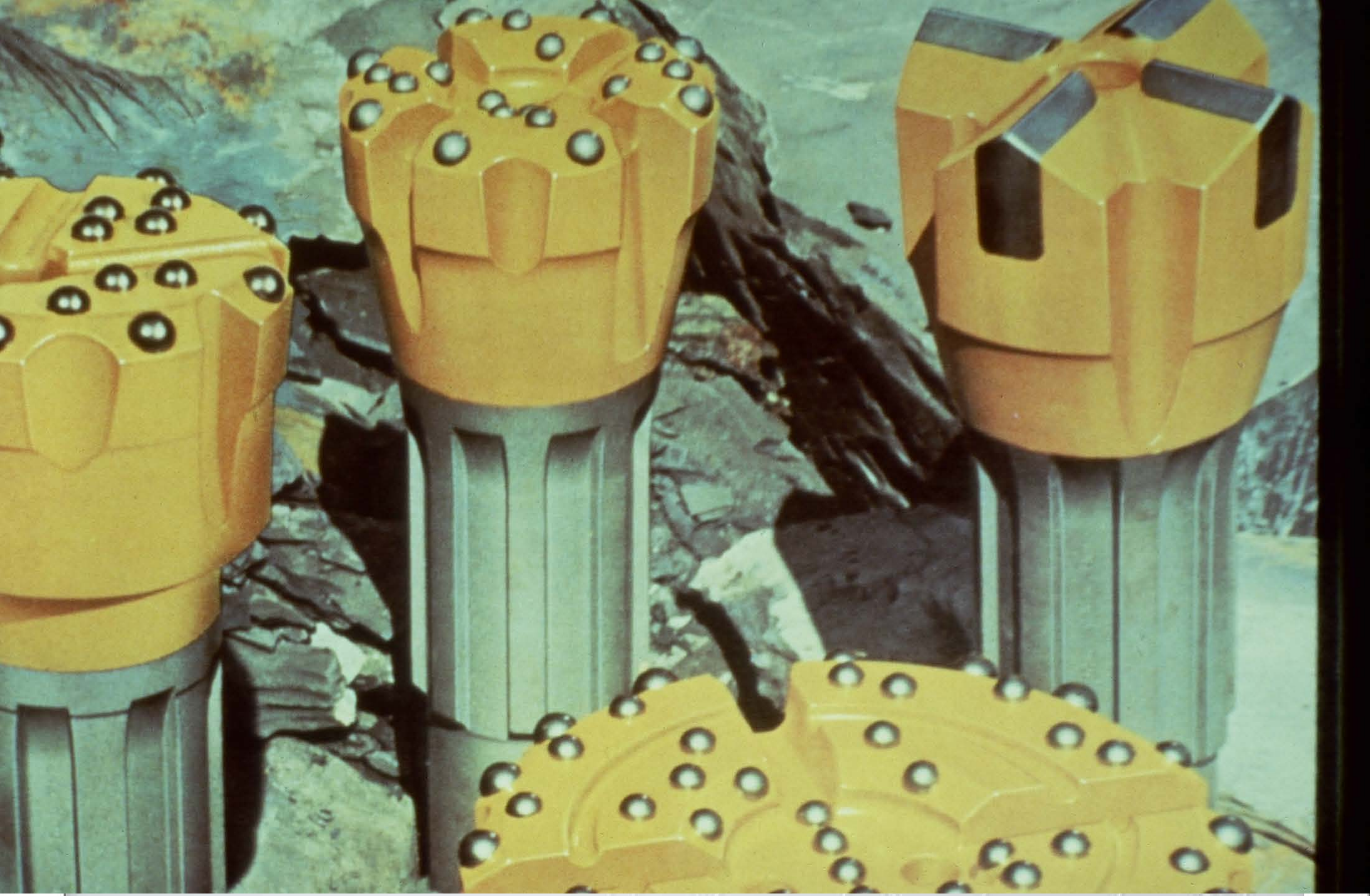

AIR ROTARY WITH CASING DRIVER

APPLICATIONS AND ADVANTAGES OF AIR ROTARY WITH CASING DRIVERS

- Rapid drilling through unconsolidated unstable formations, including formations with cobbles and boulders
- Casing supports the borehole and reduces potential for cross-contamination
- Good sample cutting recovery
- Permits larger diameter well completions
- Less potential to damage water producing zones

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LIMITATIONS OF AIR ROTARY DRILLING WITH CASING DRIVER

- Thin water bearing zones
- More expensive than other rotary drilling methods
- Air may have to be filtered for contaminants

DUAL WALL REVERSE ROTARY DRILLING FOR SITE CHARACTERIZATION

- Can use air or water
- Fluids flow down the annulus between the outer drill string and the inner drill string

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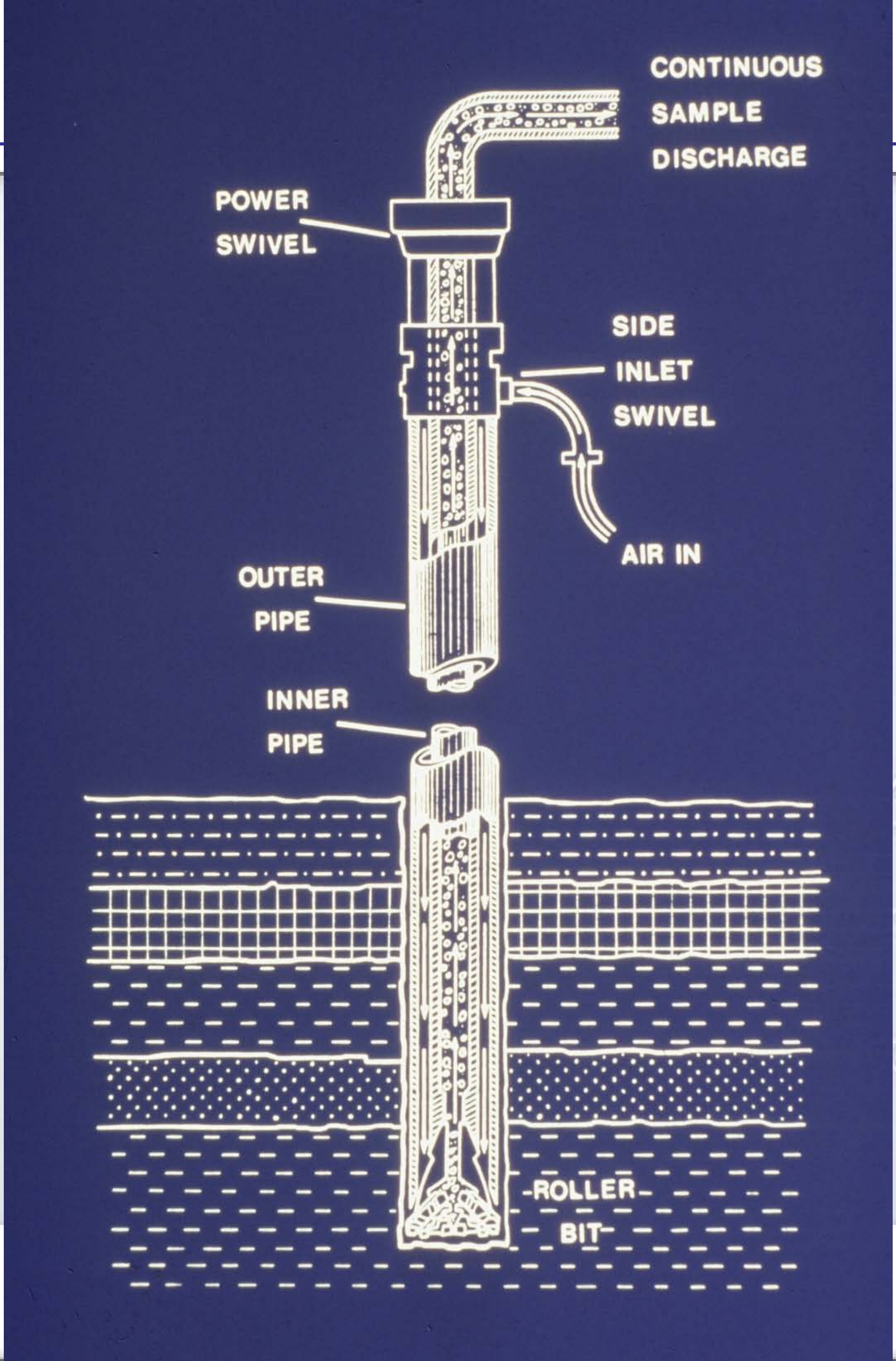
CONTINUOUS
SAMPLE
DISCHARGE
POWER
SWIVEL
SIDE
INLET
SWIVEL
AIR IN
OUTER
PIPE
INNER
PIPE
ROLLER
BIT

APPLICATIONS AND ADVANTAGES OF DUAL- WALL REVERSE CIRCULATED DRILLING

- Very rapid penetration through consolidated and unconsolidated materials
- Good representative samples of formations or formation fluids can be obtained
- Permits rock coring
- Facilitates completion of wells

LIMITATIONS OF DUAL-WALL REVERSE ROTARY DRILLING

- Well diameters are generally limited to 15 cm
- Availability of equipment may be limited in some parts of the country

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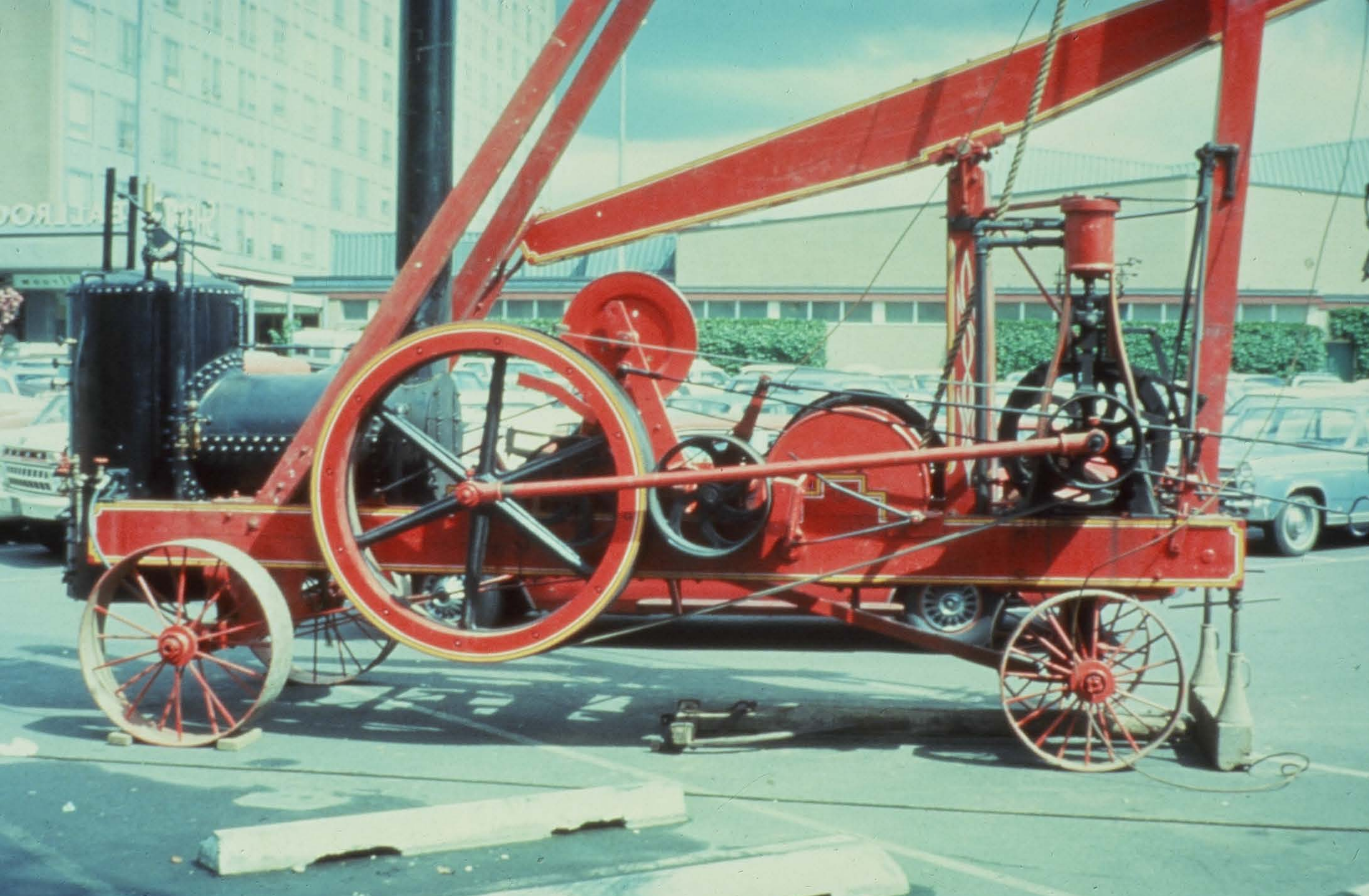
CABLE TOOL DRILLING FOR SITE CHARACTERIZATION



APPLICATION AND ADVANTAGES OF CABLE TOOL DRILLING

- Capability to drill through most types of formations
- Excellent depth and hole diameter ranges
- Casing facilitates monitoring well installation
- Easier to develop wells
- Potential for vertical cross-contamination is reduced
- Permits multiple cased wells

LIMITATIONS OF CABLE TOOL DRILLING

- Drilling is slow
- Heaving of unconsolidated materials must be controlled

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ROCK CORING FOR SITE CHARACTERIZATION

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APPLICATIONS AND ADVANTAGES OF ROCK CORING

- Provides high quality samples of stiff clays and consolidated formations
- Can detect the location and nature of rock fractures
- Permits the use of a variety of borehole geophysical logs
- Variety of core hole diameters permits up to 5 cm diameter wells
- Specific intervals can be tested for water quality and hydraulic parameters

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LIMITATIONS OF ROCK CORING

- Expensive
- Slow penetration rate
- Potential for vertical cross-contamination

SOIL SAMPLING DEVICES

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SPLIT-SPOON SAMPLERS

- Allows for standard penetration test procedures (STP) while obtaining a representative sample
- Driven by 140 lb weight dropped 30-inches
- The STP is a measurement of the number of blows to drive a 6-inch sample interval

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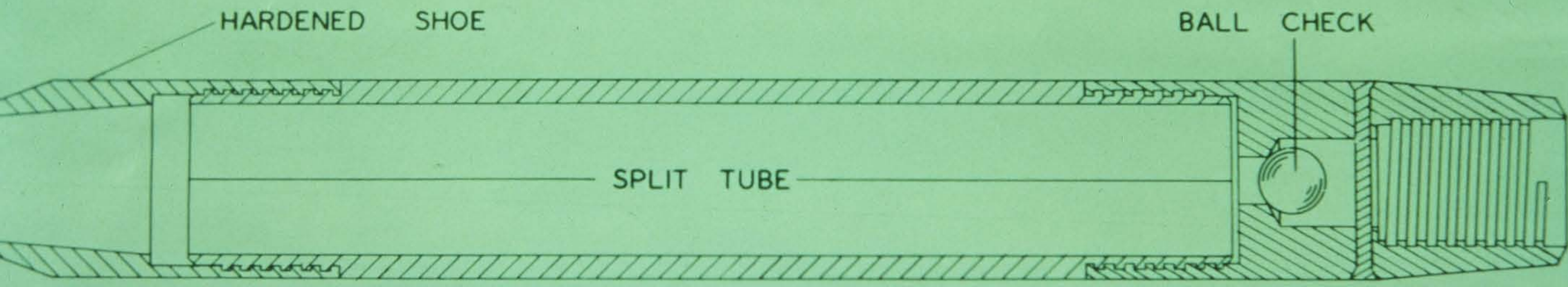
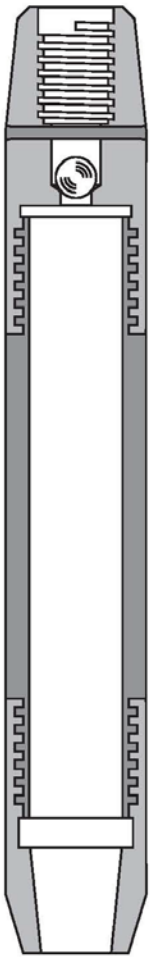

HARDENED SHOE
BALL CHECK
SPLIT TUBE



SPLIT SPOON SAMPLER STANDARD, 2" OD

Part No.	Conn	Description
34121	AW	Split spoon sampler, std, 2" x 18"
34124	AW	Split spoon sampler, std, 2" x 24"
34122	AWJ	Split spoon sampler, std, 2" x 18"
34125	AWJ	Split spoon sampler, std, 2" x 24"
34184	AW	Split spoon sampler head assembly
34185	AWJ	Split spoon sampler head assembly
34161		Split barrel, std, 2" x 18"
34162		Split barrel, std, 2" x 24"
34144		Shoe, 2"
34350		Shoe, 2" sharp

NOTE: 1) All samplers are 8 T.P.I
2) Also available in stainless steel

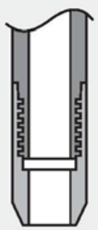
SPLIT SPOON SAMPLER STANDARD, 2.5" OD

Part No.	Conn	Description
34127	AW	Split spoon sampler, std, 2.5" x 18"
34130	AW	Split spoon sampler, std, 2.5" x 24"
34128	AWJ	Split spoon sampler, std, 2.5" x 18"
34131	AWJ	Split spoon sampler, std, 2.5" x 24"
34187	AW	Split spoon sampler head assembly
34188	AWJ	Split spoon sampler head assembly
34163		Split barrel, std, 2.5" x 18"
34164		Split barrel, std, 2.5" x 24"
34145		Shoe, 2.5"

NOTE: 1) All samplers are 8 T.P.I.

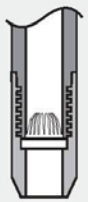
Central Mine Equipment Company
4215 Rider Trail North • Earth City, MO 63045 • Ph: 314.291.7700 • 800.325.8827 • Fax: 314.291.4880 • E-mail: info@cmeco.com

HEAT - TREATED SHOES SPLIT SPOON SAMPLER



Blunt			Sharp		
Size	TPI	Part No.	Size	TPI	Part No.
2″	4 Thread	34366	2″	4 Thread	34148
2″	8 Thread	34144	2″	8 Thread	34350
2.5″	8 Thread	34145	2.5″	8 Thread	N/A
3″	8 Thread	34146	3″	8 Thread	N/A

NOTE: 2.5″ & 3″ Shoes available in 4 TPI



SPRING TYPE SAMPLE RETAINERS

For 2" O.D. Samplers

Size	Springs	Adapter
2″	34201	34202

BASKET RETAINER FOR USE IN SPLIT SPOON SAMPLER

Steel Spring Type		Plastic Type	
Size	Part No.	Size	Part No.
2″	34203	2″	34208
2.5″	34204	2.5″	N/A
3″	34205	3″	34372

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ADVANTAGES OF SPLIT-SPOON SAMPLERS

- Provides samples that can be evaluated for contamination, lithologic characteristics, and physical and chemical properties
- Steel, brass, or plastic liners can be used to protect samples to be sent directly to a laboratory
- Relatively inexpensive

LIMITATIONS OF SPLIT-SPOON SAMPLES

- Hammering creates a stress that can alter the physical characteristics of a sample
- Difficulty in retention of loosely consolidated samples
- Sample handling may result in a loss of VOCs
- Cannot penetrate cobbles and some gravels

THIN-WALL (SHELBY) TUBE SAMPLERS

- Consists of an open tube with a thin wall 30 to 36 inches (approximately a meter) long and with diameters typically between 5-8 cm (2 to 3 inches)
- Sampler is pushed into underlying undisturbed soil
- Recently a 1-1.5 meter-long continuous sampler has been developed which permits wire-line recovery

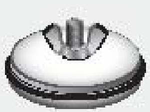
THIN WALL "SHELBY" TUBES AND ACCESSORIES

Part No.	Description
34253	Tube, steel, 2" x 30"
34254	Tube, galvanized, 2" x 30"
34456	Tube, steel, 3" x 24"
34457	Tube, galvanized, 3" x 24"
34256	Tube, steel, 3" x 30"
34257	Tube, galvanized, 3" x 30"
34266	Tube, galvanized, 3" x 36"
34327	Plastic cap 2"
34328	Plastic cap 3"
34417	Vinyl cap 2"
34418	Vinyl cap 3"
34325	Soil seal 3"
34410	Sealing wax, 10 pound

NOTE: Other sizes available on special order.

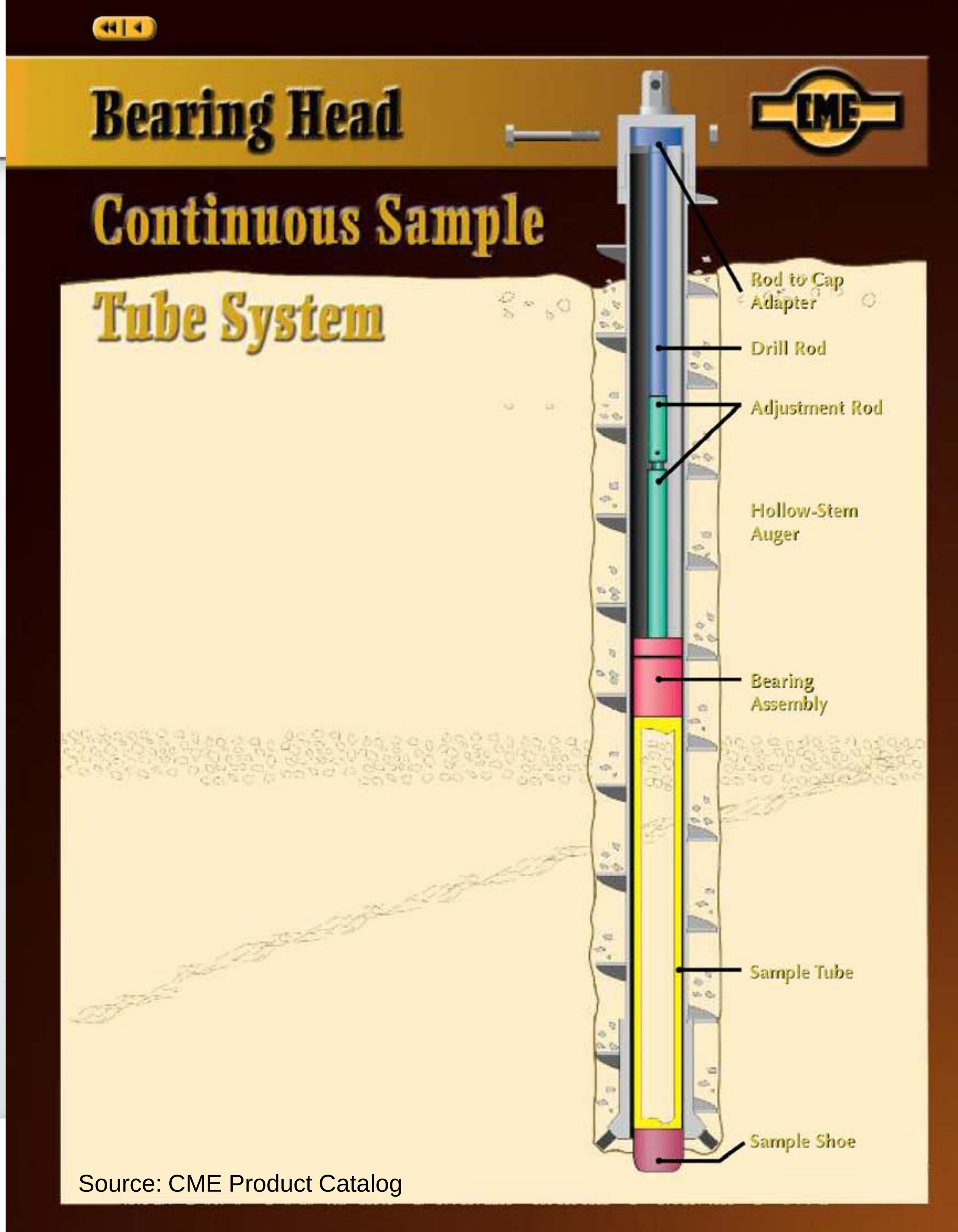
Plastic Caps

Soil Seal



Sealing Wax

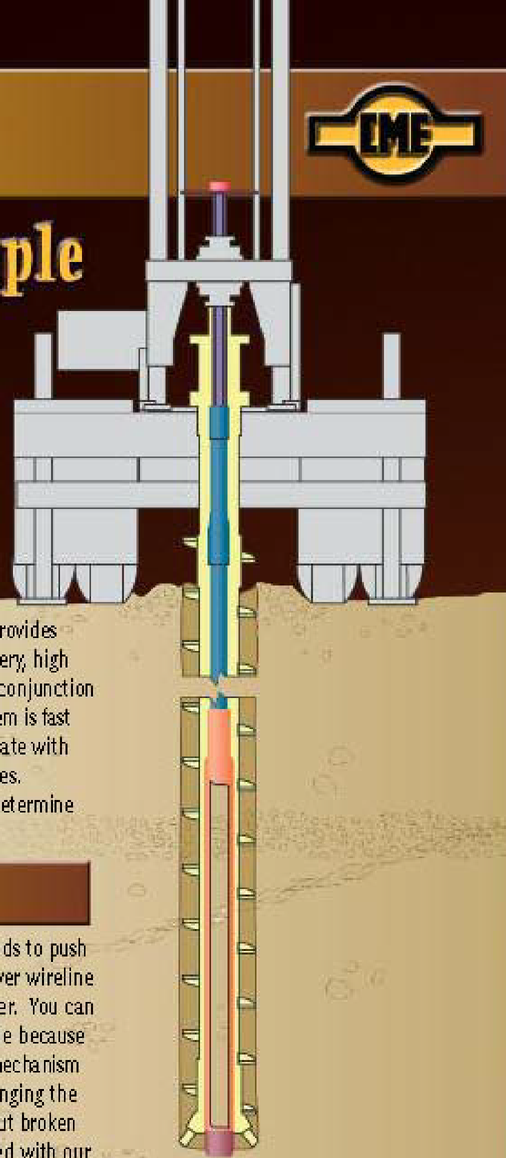
Central Mine Equipment Company
4215 Rider Trail North · Earth City, MO 63045 · Ph: 314.291.7700 · 800.325.8827 · Fax: 314.291.4880 · E-mail: info@cmeco.com



Source: CME Product Catalog

Stabilized

Continuous Sample Tube System



High Quality Samples

The patented CME Continuous Sample Tube System provides an extremely positive method for obtaining full recovery, high quality soil samples. Since sampling is performed in conjunction with the hollow stem auger drilling process, this system is fast and efficient. The sample tube positively does not rotate with the augers, so you get excellent, representative samples. You can even document the sample orientation and determine directional trends of fractures or contaminates.

Positive Sample Retrieval

The CME Continuous Sample Tube System uses hex rods to push and retrieve the sampler. It has several advantages over wireline sampling systems that use cable to retrieve the sampler. You can always tell the precise depth of the sampler in the hole because of the rigidity of the rods. Also, there's no latching mechanism to cause problems. And if you get in a bind while bringing the sampler out of the hole, you don't have to worry about broken cables and lost samples. The hex rods can also be used with our hollow stem auger, center hexagon drive system.

Effective in Difficult Formations

The CME Continuous Sample Tube System works well in many difficult formations such as glacial drift, hard clays and shales, lignite, peat, coal, mine tailings and loess.

Source: CME Product Catalog

TETRA TECH

ADVANTAGES OF THIN-WALL TUBE SAMPLES

- Provides undisturbed samples in cohesive soils, and representative samples in soft to moderately cohesive soils
- Permits direct testing of hydraulic characteristics of samples
- Widely available and relatively inexpensive

TETRA TECH

LIMITATIONS OF THIN-WALLED TUBE SAMPLES

- Cannot penetrate large gravel or cobbles
- Cannot easily be pushed into dense cohesive materials
- Not effective in cohesionless soils

SONIC DRILLING FOR SITE CHARACTERIZATION

- Provides continuous cores of representative samples of any consolidated or unconsolidated formation
- Core samples are extruded into clear plastic sleeves
- The drill stem and sample barrel are vibrated vertically at frequencies of 50 to 180 Hz
- No liquids are necessary

TETRA TECH


ENVIRONMENTAL DRILLING
SONIC
SONIC DRILLING LTD.
ADVANCED DRILLING TECHNOLOGY

CORE SAMPLING

- The Sonic Drill is outstanding in its ability to provide continuous, highly representative, relatively undisturbed core samples through any geological formation including boulders and bedrock.
- Coring in overburden is performed as a completely dry process, producing core samples that range from 3" to 8" in diameter. All core samples are large enough to provide duplicate samples.
- Core samples are extruded into clear plastic sleeves, minimizing the loss of volatile organic compounds and reducing the risk of operator exposure to in-ground contaminants. The clear plastic sleeves allow field screening devices to provide immediate soil chemistry information.
- Core samples can be subjected to a detailed visual examination and analysis, followed by sampling, photographing and archiving for a permanent record of existing soil conditions. This allows for the creation of an accurate description of the lithology and stratigraphy of the underlying geological setting.
- Holes are cased after coring to prevent cross-contamination and borehole collapse. Casing and rod sizes range from 3" to 12" in diameter, can be installed either completely dry or by water flushing, and are designed to nest together.
- Dense Non Aqueous Phase Liquids (DNAPL) investigations can be performed effectively by casing off contaminated zones.

Hole through granite boulder

Granite core samples

Coal tar contaminated sample

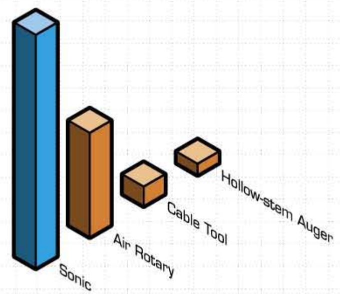
Field testing with a gas detector

Extruded core sample

TETRA TECH

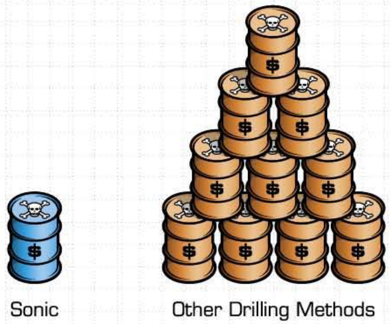
EFFICIENCY

- Sonic Drilling is up to five times faster than hollow stem auger and substantially faster than other drilling methods. The noticeably faster drilling rate is the result of the advanced ultra-efficient sonic drilling technique.
- The faster drilling rate translates to a much lower cost per foot on site as compared to other drilling methods.
- Overall project costs are also reduced due to minimization of the oversight cost of field personnel and supervisory staff.



RATE OF SONIC DRILLING VS. OTHER METHODS

Installing large diameter casing for a recovery well



WASTE GENERATED: SONIC DRILLING VS. OTHER METHODS

WASTE MANAGEMENT

- Sonic drilling generates considerably less waste than other drilling methods. Waste disposal and cleanup costs can be reduced by up to 80% less than auger, rotary and cable tool methods.

SONIC

TETRA TECH

ENVIRONMENTAL DRILLING

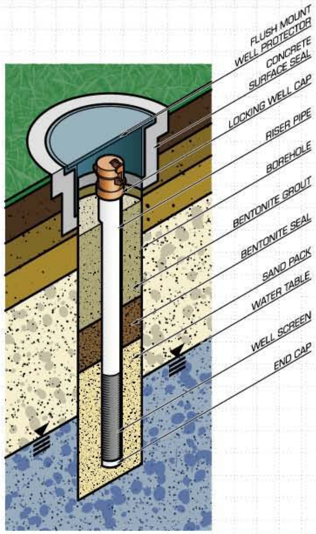
SONIC™

MONITORING WELLS

- Sonic Drilling utilizes a positive method of constructing monitoring wells by building the well inside the casing. The riser pipe, screen, bentonite seal and grout are inserted in the casing and the casing is then vibrated out of the ground, creating a perfect well installation. The vibrations help to center the well screen and riser pipe as well as eliminate bridging.
- Sonic drilling eliminates the concern of heaving sands and borehole collapses.
- Holes can be multi-cased with various casing sizes to seal off contamination zones.
- Multi-level wells can be constructed inside the casing, permitting isolated sampling of multiple aquifers.
- Well abandonment, when necessary, can be easily accomplished.

Flush mount and above ground monitoring well protectors

Well installation



TYPICAL MONITORING WELL CONSTRUCTION WITH THE SONIC DRILL

For more information, visit our website at **www.sonicdrilling.com** or contact us at Ph. **+1 604 588 6080** or Fax **+1 604 588 6090**.

SONIC DRILLING LTD.
12055 – 102 AVENUE SURREY, BC, CANADA V3V 3C5

TETRA TECH

ADVANTAGES OF SONIC DRILLING

- Continuous core of consolidated and unconsolidated materials
- Plastic sleeves reduce the loss of VOCs, and can provide for visual examination
- Can sample groundwater at specific intervals
- Minimal waste generated during drilling

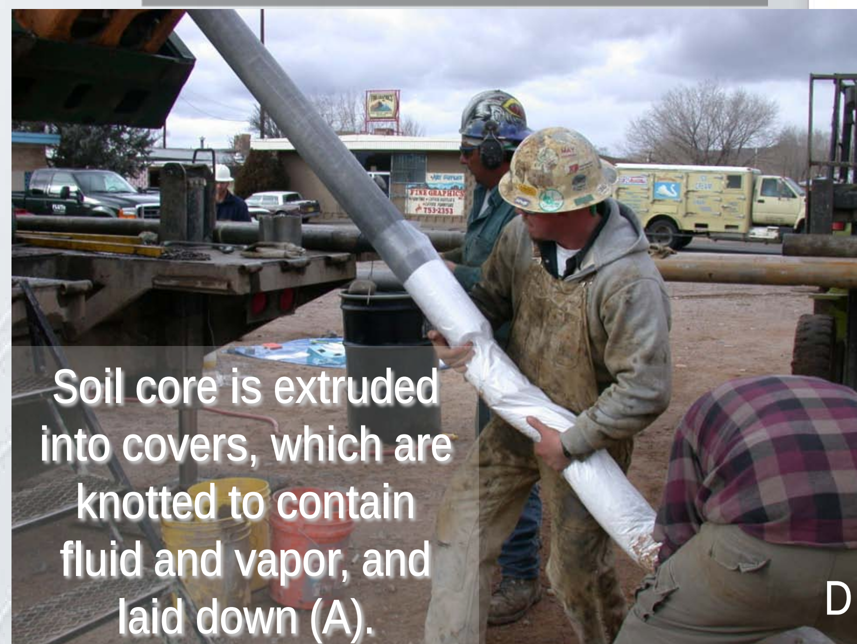
TETRA TECH

RNS USAGE

RNS tubular cover is pulled from reel, cut, inverted, and knotted.

RNS cover is slipped over the core barrel.

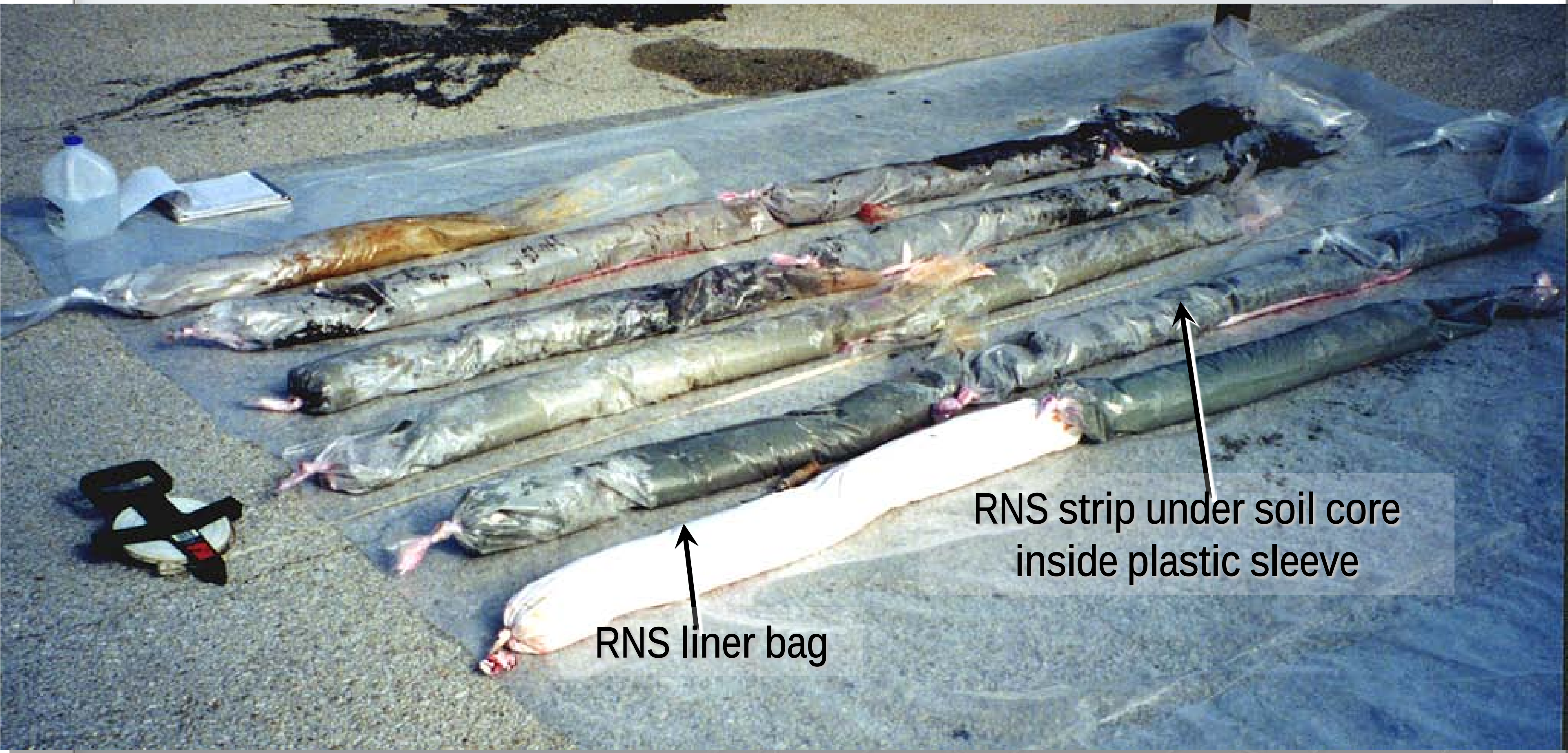
The basic tubular plastic core cover is slipped over RNS cover.



Soil core is extruded into covers, which are knotted to contain fluid and vapor, and laid down (A).

TETRA TECH

SOIL CORE WITH HYDROPHOBIC DYE STRIPS



Source: Griffin and Watson, 2002

TETRA TECH

LIMITATIONS OF SONIC DRILLING

- Expensive
- Limited Availability

TETRA TECH

DOWNHOLE GEOPHYSICAL LOGGING

- Some methods can produce continuous, high resolution measurements
- Instruments are able to measure formation characteristics from 0.3 to 3 meters beyond the borehole
- Some borehole geophysical logs can assess hydraulic properties of formations as well or better than traditional sampling and/or in-situ testing

TETRA TECH

NATURAL GAMMA LOGS

- Characterization of subsurface geology in cased and uncased holes, and in saturated and unsaturated conditions
- Provides a log of naturally emitted gamma particles found in rock and sediment
- Gamma emissions are typically higher in shales or clays, than quartz bearing sands and carbonate rocks

TETRA TECH

GAMMA – GAMMA (DENSITY) LOGS

- Measures the bulk density of rock or sediment
- Can be used in cased and uncased holes; above or below the water table
- Measures gamma counts per second, which is inversely proportional to formation density
- Relatively small radius of influence from the borehole (approx. 0.3 meters)

TETRA TECH

NEUTRON – NEUTRON (POROSITY) LOG

- Measures relative moisture content above the water table and porosity below the water table
- Can be used in cased and uncased holes
- Uses a radiation source and detector
- Radius of investigation is about 0.3 to 0.5 meters

TETRA TECH

INDUCTION LOG

- Measures electrical conductivity in open or PVC cased holes
- Works above and below the water table
- Measures electrical conductivity which is a function of rock type, porosity, and fluid in the pore spaces
- Can be used to identify and correlate stratigraphy
- Can be used to identify zones of organic and inorganic contamination
- Radius of investigation is up to 1 meter beyond the borehole

RESISTIVITY LOGS

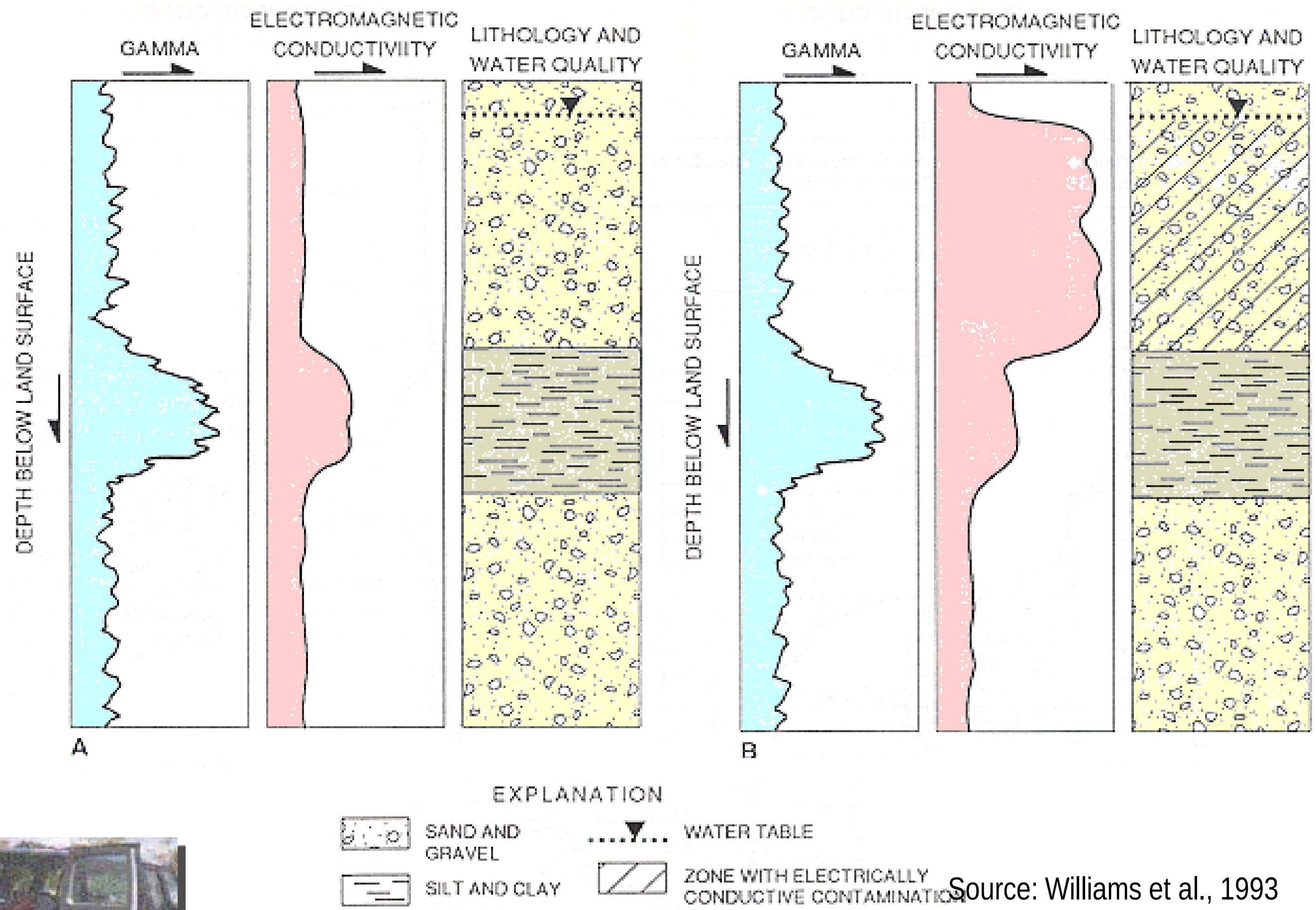
- Measures apparent resistivity in rock and soil within borehole
- Needs electrical contact with the borehole wall, therefore used in cased holes filled with water

SPONTANEOUS POTENTIAL LOGS

- Measures the natural potential between borehole fluid and surrounding materials
- Can only be used in uncased holes below the water table
- Provides measurements which facilitate interpretation of lithology, oxidation – reduction conditions, and fluid flow

TETRA TECH

Borehole Geophysics
Logging to Determine Stratigraphy



Source: Williams et al., 1993

Source: Geonics, 1999

TETRA TECH

QUESTIONS?