THE TOOL BOX

Outline

Dynamic investigations -> Real-time data

– Sampling methods
– Analytical methods
– Investigation tools
  – Geology and hydrogeology
  – Source zone vs. Plume
SAMPLING METHODS

Soil gas probes
Auger drill
Direct push (GeoProbe)
Rotary Sonic
Hand drillings (auger)
SOIL GAS PROBES

- Depth 1 – 1.5 m bgl
- Site screening for source zones
- Volatile contaminants
SOIL GAS PROBES
Example Site screening (PID)

PROM chemical plant, DK
AUGER DRILLING

- Grab samples
- Permanent screens for water sampling
- Geology
- Small and large size rigs
- Max depth ~ 40 m bgl
- Dynamic???
DIRECT PUSH - GEOPROBE

- Variety of probes for in situ investigations and
- Sampling – soil, soil gas, groundwater
- Small size rig
- Max depth 30-35 m bgl
- Dynamic!
ROTARY SONIC DRILLING

- Continuous core sampling
- CMT multilevel screens (3 or 7 channel)
- ~4 inch diameter
- Max depth 30-60 m+
- Large rig
- Fast
- Casing?
HAND DRILLING

- Grab soil samples
- Max depth 2-3 m bgl
- No casing
- Slow
- For difficult access access
### ANALYTICAL METHODS

#### Volatile compounds:

<table>
<thead>
<tr>
<th>Method</th>
<th>Soil</th>
<th>Soil gas</th>
<th>Water</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>DSITMS</td>
<td>Soil</td>
<td>Soil gas</td>
<td>Water</td>
<td>3-6 min</td>
</tr>
<tr>
<td>GC-ECD/FID/MS</td>
<td>Soil</td>
<td>Soil gas</td>
<td>Water</td>
<td>15-30 min</td>
</tr>
<tr>
<td>MIMS</td>
<td>Soil</td>
<td>Soil gas</td>
<td>Water</td>
<td>3-6 min</td>
</tr>
<tr>
<td>Hapsite</td>
<td>(Soil)</td>
<td>Soil gas</td>
<td>Water</td>
<td>15-30 min</td>
</tr>
</tbody>
</table>

#### Heavy metals:

<table>
<thead>
<tr>
<th>Method</th>
<th>Soil</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>NITON</td>
<td>Soil</td>
<td>1 min</td>
</tr>
</tbody>
</table>

~20 % lab. analyses for confirmation
SATURN MS FIELD LAB
Direct Sampling Ion Trap Mass Spectrometry

- US EPA method 8265
- Volatile contaminants
- Mass spec
- No Columns
- 3-6 min per sample

Interfaces
Sorbent trap for soil gas
**FIELD ANALYSES WITH DSITMS METHOD**

**Contaminants**

<table>
<thead>
<tr>
<th>Typical compounds:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>PCE, TCE, DCE CF DCM TCA</td>
<td></td>
</tr>
<tr>
<td>Sum of Isomers Sum VC+DCA</td>
<td></td>
</tr>
<tr>
<td>BTEX MTBE</td>
<td></td>
</tr>
<tr>
<td>Not TPH</td>
<td></td>
</tr>
</tbody>
</table>

**EPA Method 8265. Analysis of Soil, Solids and Groundwater by DSITMS (Direct Sampling Ion Trap Mass Spectrometry)**

<table>
<thead>
<tr>
<th>Compound</th>
<th>Volume of gas sampled (L)</th>
<th>Volume collected (L)</th>
<th>MeOH Concentration (g/L)</th>
<th>Del Limit (g/L)</th>
<th>Compound collected (mL)</th>
<th>Volume of H2O (mL)</th>
<th>Del Limit (g/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tetrachloroethylene</td>
<td>10</td>
<td>20</td>
<td>2</td>
<td>10</td>
<td>10</td>
<td>100</td>
<td>20</td>
</tr>
<tr>
<td>Trichloroethylene</td>
<td>10</td>
<td>20</td>
<td>2</td>
<td>10</td>
<td>10</td>
<td>100</td>
<td>20</td>
</tr>
<tr>
<td>Chloroform</td>
<td>10</td>
<td>20</td>
<td>2</td>
<td>10</td>
<td>10</td>
<td>100</td>
<td>20</td>
</tr>
<tr>
<td>cis-1,2-Dichloroethylene</td>
<td>10</td>
<td>20</td>
<td>2</td>
<td>10</td>
<td>10</td>
<td>100</td>
<td>20</td>
</tr>
<tr>
<td>Benzene</td>
<td>10</td>
<td>20</td>
<td>2</td>
<td>10</td>
<td>10</td>
<td>100</td>
<td>20</td>
</tr>
<tr>
<td>Toluene</td>
<td>10</td>
<td>20</td>
<td>2</td>
<td>10</td>
<td>10</td>
<td>100</td>
<td>20</td>
</tr>
<tr>
<td>Ethylbenzene</td>
<td>10</td>
<td>20</td>
<td>2</td>
<td>10</td>
<td>10</td>
<td>100</td>
<td>20</td>
</tr>
</tbody>
</table>

**Other compounds that the method has been tested and validated.**

- Acetone 67-64-1
- Benzene 71-43-2
- Bromodichloromethane 75-27-4
- Bromoform 75-29-2
- Bromomethane 74-83-9
- Carbon disulfide 75-15-0
- Carbon tetrachloride 56-23-5
- Chlorobenzene 108-90-7
- Chloroform 67-66-3
- Chloroform 74-87-3
- Dibromochloromethane 124-48-1
- 1,1-Dichloroethane 75-34-3
- 1,2-Dichloroethane 107-06-2
- 1,1-Dichloroethene 75-35-4
- cis,trans-1,2-Dichloroethene 156-59-2
- trans,1,2-Dichloroethene 156-60-5
- Dichloromethane 75-09-2
- 1,2-Dichloropropane 78-87-5
- cis,trans-1,3-Dichloropropane 10061-01-5
- trans,1,3-Dichloropropane 10061-02-6
- Ethylbenzene 100-41-4
- 2-Hexanone 569-78-6
- Methyl ethyl ketone (MEK) 78-93-3
- Methyl isobutyl ketone (MIK) 108-10-1
- Methyl-tet-butyl ether (MTBE) 1634-04-4
- Styrene 100-42-5
- 1,1,2-Trichloroethane 79-34-5
- Tribromomethane 127-18-4
- Toluene 108-88-3
- 1,1,1-Trichloroethane 71-55-6
- 1,1,2-Trichloroethane 79-00-5
- Trichloroethene 79-01-6
- Vinyl acetate 108-05-4
- Vinyl chloride 75-01-4
- Xylenes 1330-20-7
FIELD ANALYSES WITH DSITMS METHOD

Typical detection limits

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Groundwater</td>
<td>1-3 µg/L</td>
<td></td>
</tr>
<tr>
<td>Soil</td>
<td>10-15 µg/kg</td>
<td>low level EPA method 5035 (H₂O)</td>
</tr>
<tr>
<td></td>
<td>100-200 µg/kg</td>
<td>high level EPA method 5035 (MeOH)</td>
</tr>
<tr>
<td>Soil gas</td>
<td>Sorbent trap</td>
<td>dependent of volume:</td>
</tr>
<tr>
<td></td>
<td>1 liter: 20 µg/m³</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10 liter: 2 µg/m³</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Direct gas sample (in tedlar bag): 5.000 µg/m³</td>
<td></td>
</tr>
</tbody>
</table>
NITON XL3t
Heavy metal field screening

— XRF X-ray fluorescence
— 1 min
— Site screening
— Heavy metal contamination
— Direct on soil or
— On soil samples
— Surface content

<table>
<thead>
<tr>
<th></th>
<th>XL3t 600</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>6 mm detector</td>
</tr>
<tr>
<td>Sb</td>
<td>30</td>
</tr>
<tr>
<td>Sn</td>
<td>20</td>
</tr>
<tr>
<td>Ag</td>
<td>10</td>
</tr>
<tr>
<td>Cd</td>
<td>10</td>
</tr>
<tr>
<td>Pd</td>
<td>10</td>
</tr>
<tr>
<td>Te</td>
<td>50</td>
</tr>
<tr>
<td>Sr</td>
<td>7</td>
</tr>
<tr>
<td>Rb</td>
<td>4</td>
</tr>
<tr>
<td>Hg</td>
<td>7</td>
</tr>
<tr>
<td>Pb</td>
<td>8</td>
</tr>
<tr>
<td>Se</td>
<td>4</td>
</tr>
<tr>
<td>As</td>
<td>9</td>
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<td>Zn</td>
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<td>Cu</td>
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<td>Ni</td>
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<td>Co</td>
<td>40</td>
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<tr>
<td>Fe</td>
<td>75</td>
</tr>
<tr>
<td>Mn</td>
<td>55</td>
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<tr>
<td>Cr</td>
<td>65</td>
</tr>
<tr>
<td>V</td>
<td>20</td>
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<td>Ti</td>
<td>100</td>
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<tr>
<td>Sc</td>
<td>90</td>
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<tr>
<td>Ca</td>
<td>330</td>
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<tr>
<td>K</td>
<td>575</td>
</tr>
<tr>
<td>Mo</td>
<td>9</td>
</tr>
<tr>
<td>Zr</td>
<td>5</td>
</tr>
</tbody>
</table>
INVESTIGATION TOOLS

Source zone: LNAPL/DNAPL
High concentrations (mg/l or mg/kg)

Plume: Dissolved contaminants from LNAPL/DNAPL
Often low concentrations (µg/l or µg/kg)

- Geology
- Hydrogeology
- Chemistry
GEOLOGY & HYDROGEOLOGY

– Geology
  ▪ Continuous core samples
  ▪ Electrical conductivity (clay/sand, saturated/unsaturated)
  ▪ CPT tests (Sleeve friction, tip resistance, pore pressure)
  ▪ Optical log (color photos)

– Hydrogeological parameters
  ▪ Permanent screens for water level measurements
  ▪ HPT-probe: continuous hydraulic conductivity and vertical pressure gradients
  ▪ Slugtests: depth specific hydraulic conductivity
CORE SAMPLING
Dual-Tube system (Geoprobe)

- Continuous core sampling (1.25” cores) in 2.25” casing
- Option for water sampling at select depths
- Option for screening with “Prepack” screens for gas/water
SOIL CORES
Example

Most cores show <100% recovery from the soft coarse grained sediments
SOIL SAMPLES
Photo Ionisation Detector

PID readings of headspace over soil samples
ELECTRICAL CONDUCTIVITY LOG
Geoprobe

Geology, auger well

Interpreted log

Equipment

Boring B1
+34,0

Ledningsevne mS/m
0 10 20 30 40 50 60 70 80

GVS

NORDROCS Short Course Dynamic Investigations September 18, 2012
CPT-LOG, EC-LOG AND OPTICAL LOGS

- CPT-test (sleeve friction, tip resistance & pore pressure)
- EC-log for tracing of ZVI injection with DKP tracer
- Optical log of subsurface (color photos)
HYDRAULIC PROFILING TOOL (HPT)
Estimation of K-value and vertical gradient

- HPT pressure clearly indicates the soil hydraulic properties
- Measures K-values of $10^{-4} - 10^{-6}$ m/s
- Much more reliable than EC-log in mixed geology
PNEUMATIC SLUG TEST
Estimation of K and water sampling

- Good correspondence between K-values from Slug test vs. HPT
- Reliable input for flux calculations (M=A*v*C)
CONTAMINANTS - SOURCE ZONES

– In-Situ measurements - probes
  ▪ Fluorescence based probes (UVOST, TARGOST, FFD)
  ▪ Thermal/Diffusive probes (MIP, MiHPT)

– Soil sampling and on-site/off-site analysis
  ▪ Continuous core samples
  ▪ Depth specific soil cores
  ▪ Hydrophobic dye (shake-test)
  ▪ Headspace screening of soil samples (PID)
  ▪ Chemical analysis of soil samples (field/lab)

– In-Situ measurements - membranes
  ▪ FLUTE NAPL-liner for NAPL detection
  ▪ FLUTE FACT-liner for collection of pore water on GAC-material
LASER INDUCED FLUORESCENCE (LIF)  
In-situ LNAPL detection (UVOST, Dakota)

- All PAH’es fluoresc under UV light
- Different response at different wavelengths.
- UV light (XeCl laser, 308 nm) is emitted and fluorescense response (emission spectrums) is collected through a fiberoptical cable and is shown in “real-time” at surface
- Detection limit of 10-50 ppm in soil
DYE-LIF
New LIF-based system for DNAPL (Dakota)

- Continuous injection of dye at approx. 30 cm below the sapphire window
- Dye dissolves preferentially in NAPL (organic phase) in the soil outside the window
- LIF-detection of the dye, - it only fluoresces when dissolved in organic phase
MIP - Membrane Interphase Probe
Geoprobe

Oil contamination

PCE contamination
MIP with GC/MS for speciation of chlorinated ethenes

- Standard MIP system
- On-site GC/MS system for detection of VOC in samples of carrier gas
- Typical sampling per meter

Courtesy of DTU Environment (Damgård et al)
MIP, CORES, SUDAN IV-SHAKE TEST
DNAPL detection

M412 and K401 (80 cm apart)
DIRECT DETECTION OF PCE DNAPL

DNAPL pumped from monitoring well during water sampling

DNAPL detected during drilling
MiHPT
Combined MIP and HPT

MiHPT logging at the X-VOC site near the former Schilling Air Force Base, Salina, KS

Courtesy of GeoProbe Systems: Wes McCall, Tom Christy, Dan Pipp

GeoProbe Systems, Capital Region, NIRAS - 2012
MiHPT – example log

XSD and PID = $1 \times 10^7 \mu V$
FLUTE LINER
Flexible Liner Underground Technologies everting (FLUTe) Membrane
FLUTe FACT LINER, MIP & CORES (PCE)
Example from DK-site
CONTAMINATION - GROUNDWATER PLUMES
Dissolved concentrations

– Sampling and on-site/off-site analysis
  ▪ Depth specific water samples (SP16/SP22, GeoProbe)
  ▪ Continuous water samples (Waterloo system)
  ▪ Discrete water samples combined w soil (Dual Tube)

– In-Situ measurements - probes
  ▪ Termal/Diffusive (low detection MIP, ENISSA-MIP, MIP-GC)
DEPTH SPECIFIC WATER SAMPLES
Geoprobe
CONTINUOUS WATER SAMPLING
Waterloo profiler

- Waterloo profiler modified (Stone Environmental)
- Groundwater is extracted continuously from the probe. On-line field measurements
- Water is sampled, water level measured and K estimated
LOW-DETECTION MIP
MIP with new controller box for detection of low VOC concentrations (Geoprobe)

Response test with 0.5 ppm TCE

Comparison of MIP-XSD logs with standard controller boxes vs. new “low level” box from Geoprobe systems (>10 increased sensitivity)
OUTRO

– Several field analytical methods are available

– Multiple probes are available for in situ measurements
  – information on both geology and hydrogeology at high
    resolution (cm-scale) – and at large depth (<35 m)
  – High resolution data on contaminant distribution - essential
    for DNAPL investigations
  – Continuous progress in development of probes and
    technologies for detection and quantification of contaminants

– Site conditions and investigation objective will determine which
  combination of methods will be optimal for the specific
  investigation strategy