HAGFORSTVÄTTEN - ERFARINGER FRA 10 ÅRS UNDERSØKELSE OG SANERING

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INTRODUCTION TO THE HAGFORS SITE

- Said to have been one of northern Europes largest dry cleaning operations
- Operated by:
  - the state (1970 - 1979)
  - a private company (1979 - 1989) and
  - the local region (1989 - 1993)
- Estimated loss of ~ 1.000 tonnes of PCE over time, mainly to air
- A 5 – 10 % (??) loss to soil, would result in 50 – 100 tonnes of PCE DNAPL in the source areas

THE HAGFORS SITE

4 X WASHING MACHINES

2005: SWEDENS FIRST EVER THERMAL TREATMENT (STEAM INJECTION) REMOVED 5.000 KG PCE

ADDITIONAL PCE DNAPL DISCOVERED AFTER 2005

SEWER PIPE TO CREEK

ESKER MATERIAL

ADDITIONAL PCE DNAPL DISCOVERED AFTER 2005

PREVIOUS MUNICIPAL WATER WELLS

CREEK ”ÖRBÄCKEN”
(RECEIVES SOME 300 KG PCE PER ANNUM)

DRILLING METHODS 1993 - 2015

Method	1993 - 2005	2005 - 11	2013 – (NIRAS)	Note
Auger	■	■		Only possible for the unsaturated zone, several augers broken in hard deposits
ODEX	■	■		”Down the hole-drilling” – very poor geological information
Hollow Stem Auger		■		Better quality than auger, but unable to reach bedrock (due to gravel, stone etc.
MIP probing		■		High resolution contaminant data, but unable to penetrate gravel, stone,etc.
Sonic/Rotosonic		■	■	The only method able to produce soil cores over the entire drilling depth (25 m)

SAMPLING OF ”UNDISTURBED” CORES OVER THE ENTIRE SOIL DEPTH HAS ONLY BEEN POSSIBLE SINCE 2007 (ROTOSONIC)

BUT VERY LARGE DIFFERENCE IN DOCUMENTATION OF DATA FROM EACH CORE 2007 V.S. 2015

THE ON-SITE HANDLING/DOCUMENTATION OF SOIL CORES HAS EVOLVED A LOT, AND IS EQUALLY IMPORTANT AS DRILING METHOD

ON-SITE HANDLING OF SOIL CORES 2015

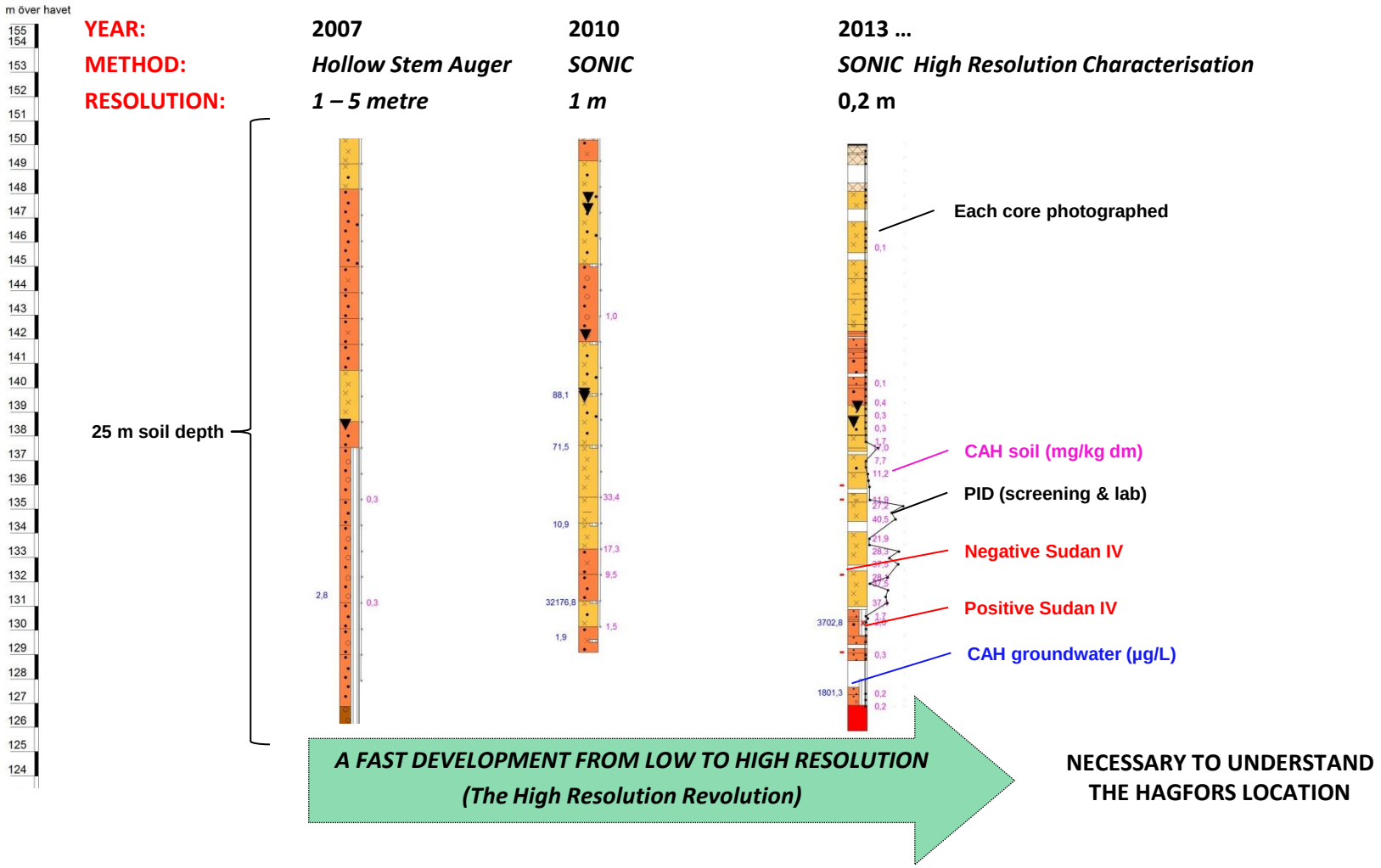
- PID screening
- Sudan IV NAPL test
- Each core photographed
- Detailed geological characterisation
- Systematic sampling to plastic bag & glass
  - In Hagfors, every 25 cm
  - PID_{LAB} measurements
  - Chemical analysis of selected samples
- Level specific water samples depending on PID & geology

LARGE AMOUNT OF DATA MANAGED WITH DATABASE

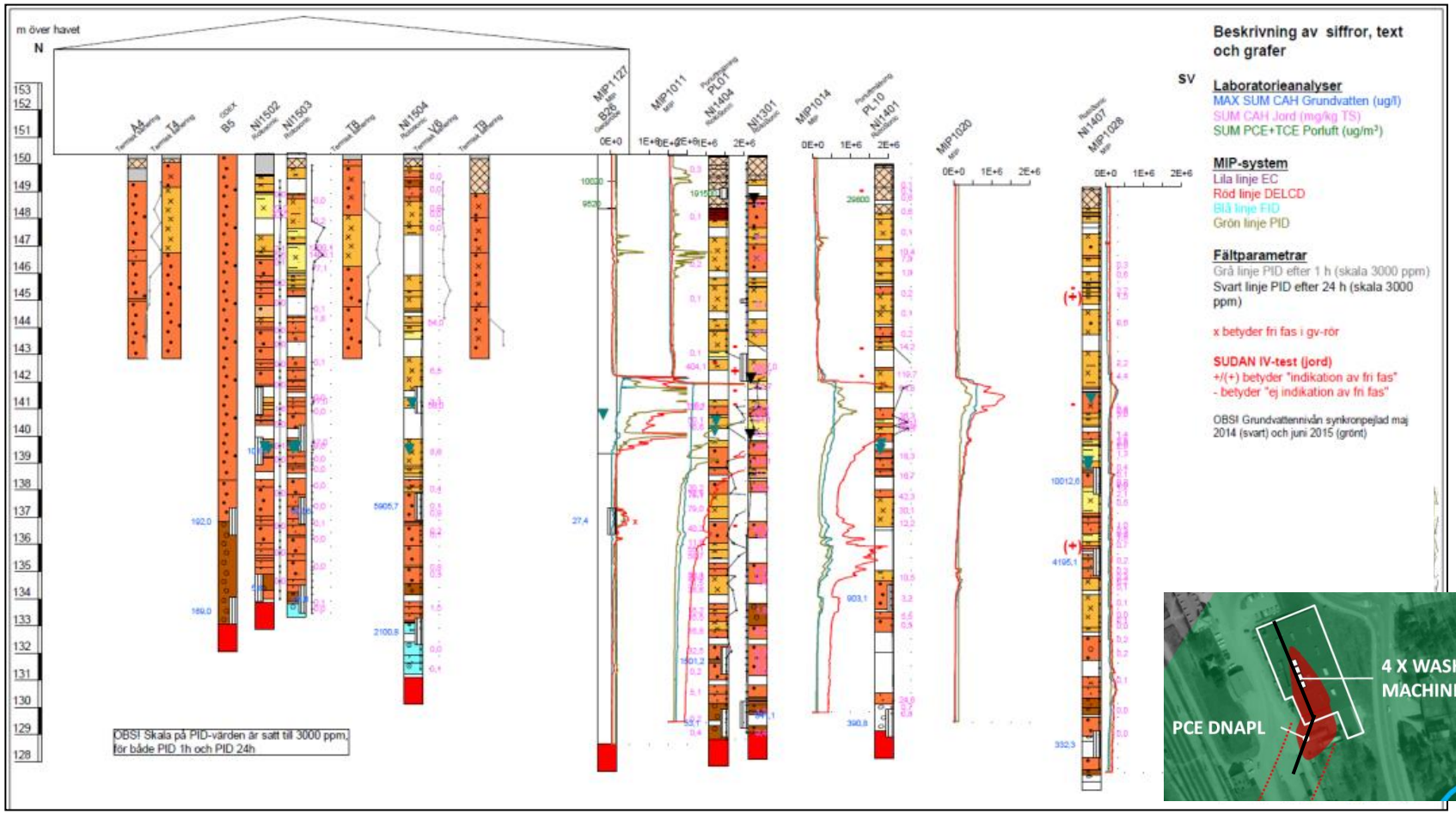
ON-SITE HANDLING ”10 YEARS AGO”

- PID screening (entire core)
- Sudan IV NAPL test
- Each core photographed
- Detailed geological characterisation (lack of details depending on drilling method)
- Systematic sampling to plastic bag & glass
  - All subsamples merged into one sample
  - In Hagfors, every 25 cm
  - PID_{LAB} measurements
- Chemical analysis of a selection of samples

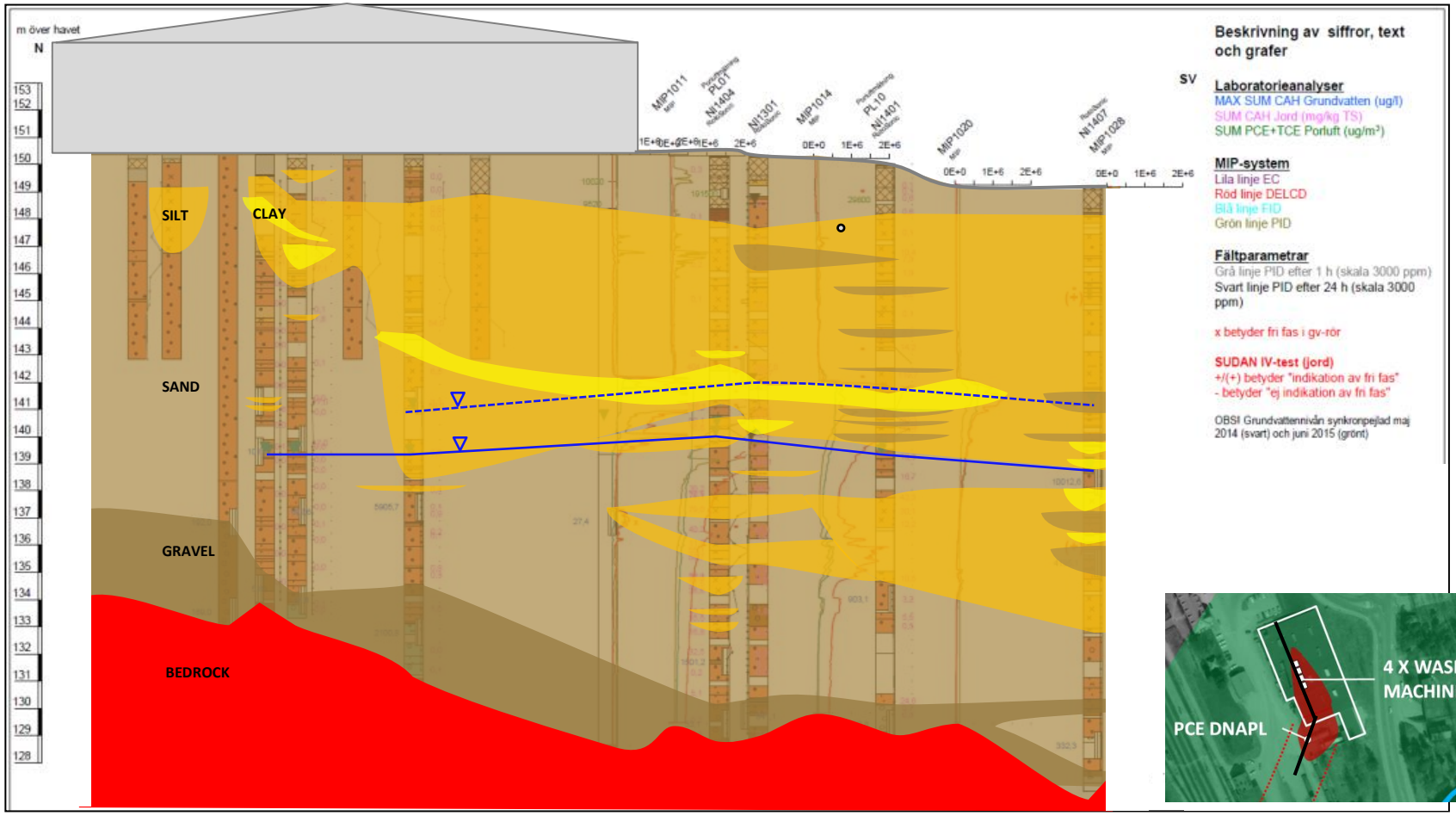
DATA COLLECTION 2007 - 2015



HIGH RESOLUTION REQUIRES DATA MANAGEMENT



CHARACTERISTICS OF THE SOURCE ZONE



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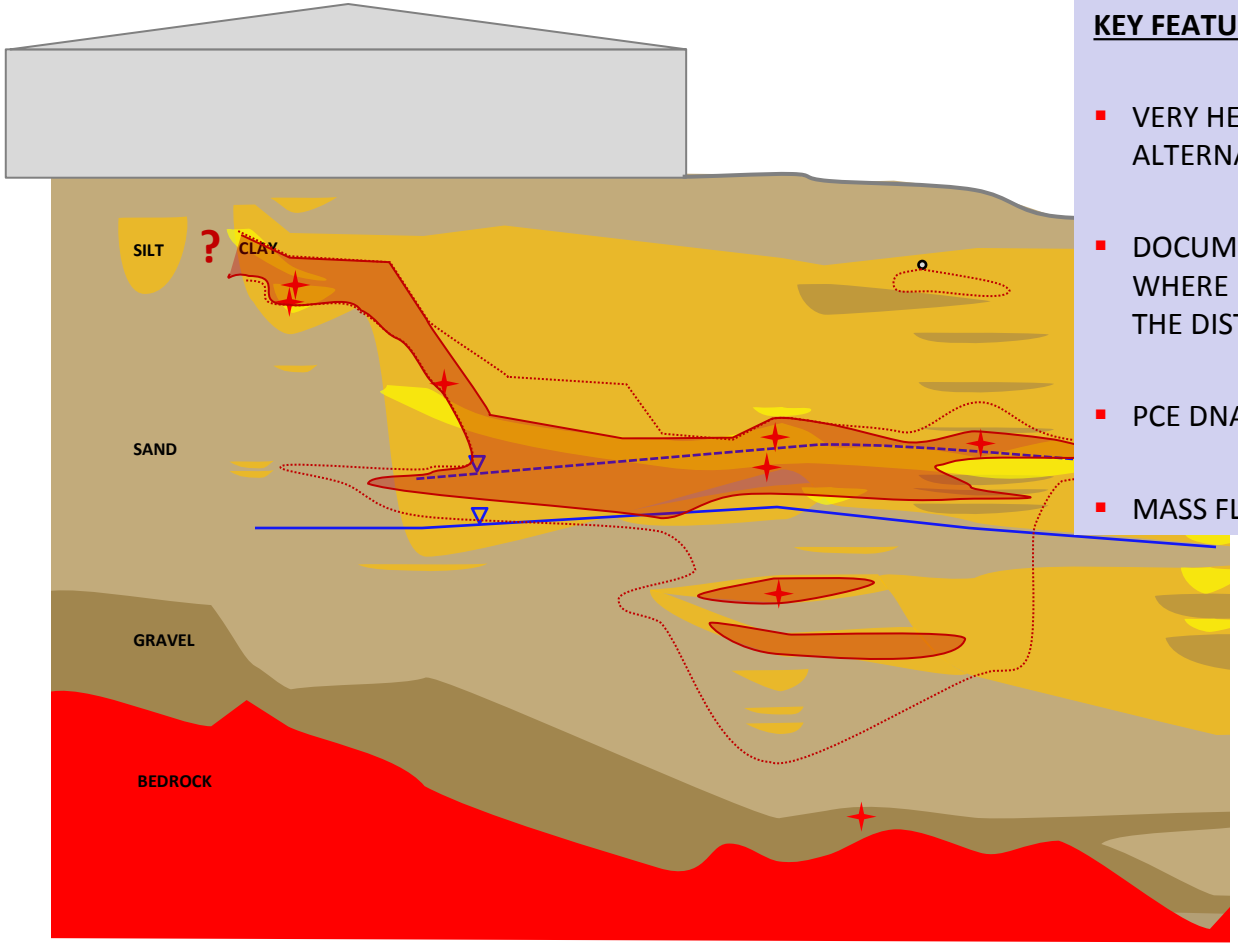
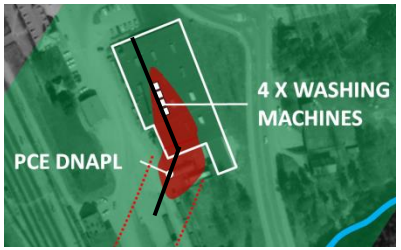
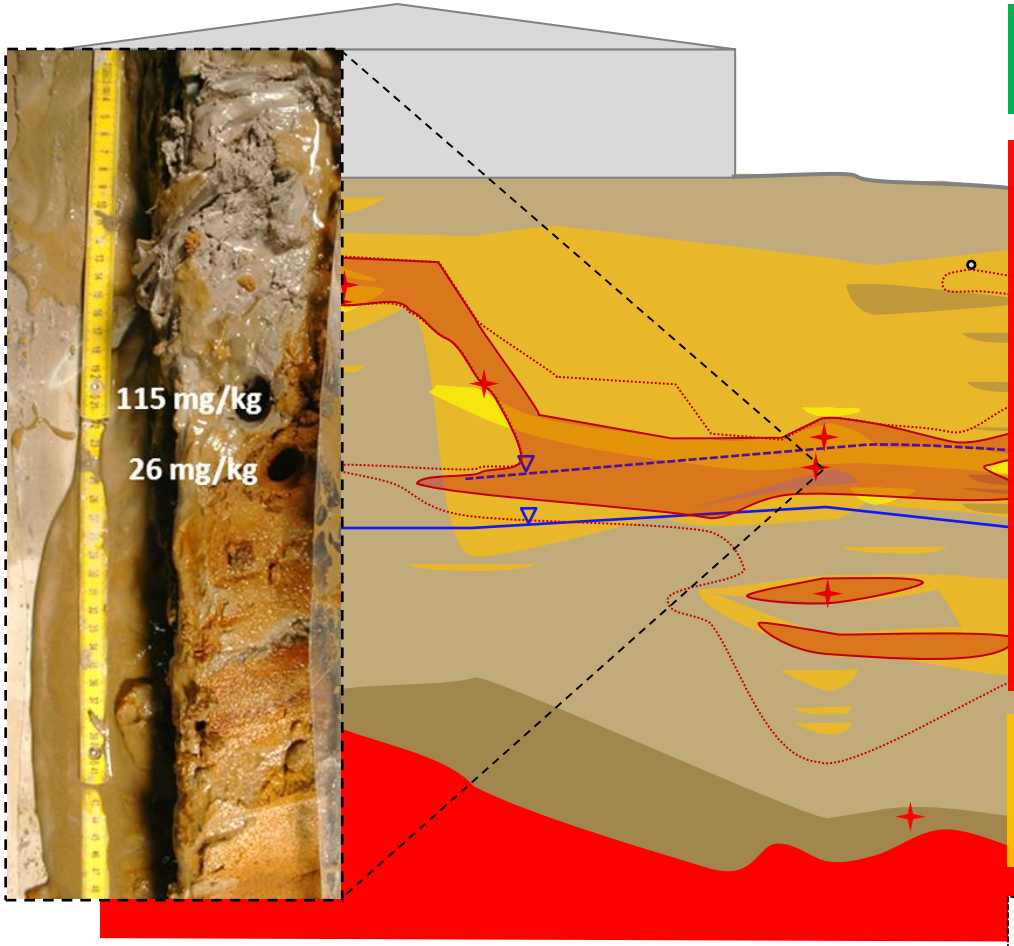


KEY FEATURES, HAGFORS:

- VERY HETEROGENOUS CONDITIONS – ALTERNATING HIGH/LOW K LAYERS
- DOCUMENTED TRANSPORT PROCESS, WHERE LOW-K LAYERS HAVE CONTROLLED THE DISTRIBUTION
- PCE DNAPL IN CLAY & SILT
- MASS FLUX IN SAND & GRAVEL



EVALUATION OF IN-SITU METHODS



CRUCIAL TO ESTABLISH CONTACT BETWEEN CONTAMINANT & REAGENT (FLUID, HEAT, …)

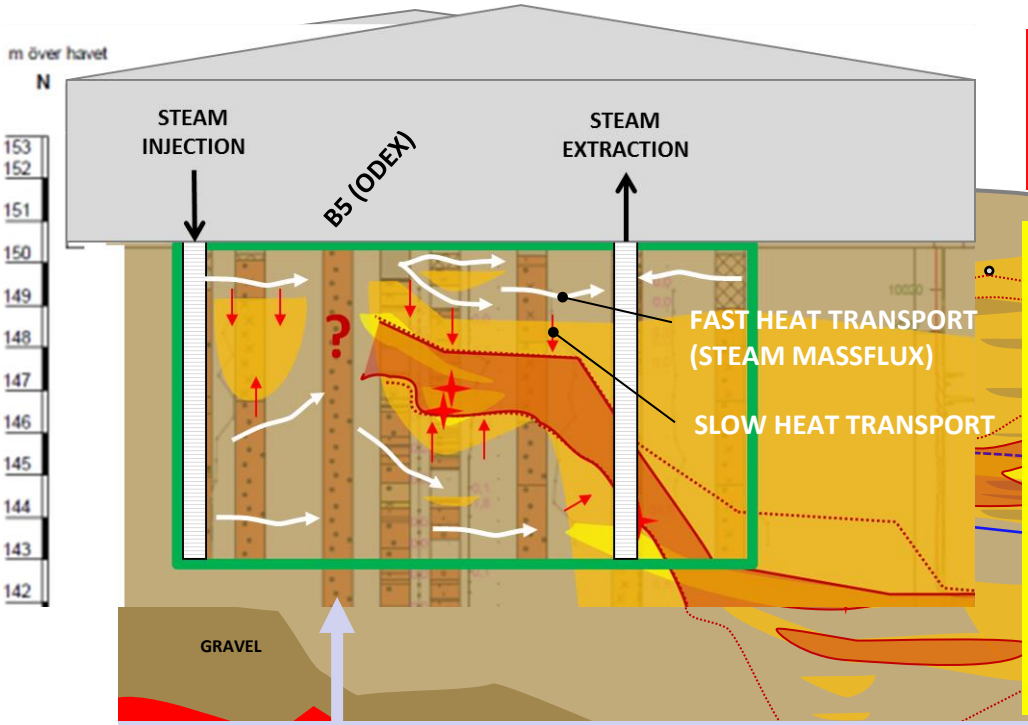
IN SITU METHODS THAT DEPEND ON MASS FLUX WILL LIKELY PERFORM POORLY AT THE SITE, DUE TO THE HETEREOGENOUS SUBSURFACE

- *VENTILATING TECHNIQUES*
- *AIR SPARGING*
- *DIRECT INJECTIONS*
- *ETC.*
- … WOULD LIKELY RESULT IN A FAST EFFECT IN SAND/GRAVEL, BUT NEARLY NO EFFECT IN THE LOW-K LAYERS (WHICH HOLDS MOST PCE)

- COOLING GROUNDWATER WILL LIKELY RESULT IN POOR PERFORMANCE FOR MANY THERMAL APPLICATIONS

BUT WHAT ABOUT THE 2005 THERMAL TREATMENT (STEAM INJECTION)??

WHAT ABOUT EARLIER REMEDIATIONS?



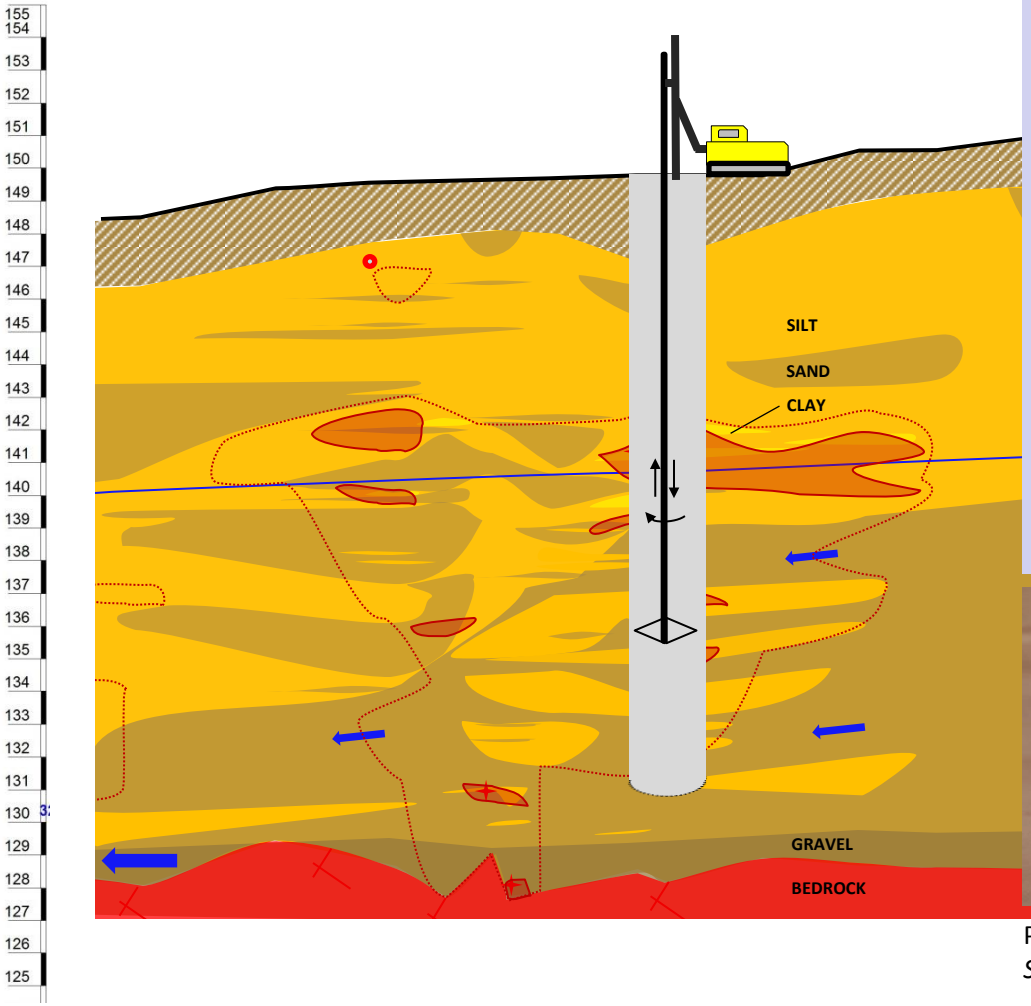
HIGH RES. SAMPLING IN 2015 REVEALED PRESENCE OF PCE DNAPL (DROPLETS) WITHIN THE THERMALLY TREATED AREA

- **INJECTED STEAM HAS TRAVELED BY MASS FLOW IN HIGH-K LAYERS (SAND) BUT NOT IN SILTS/CLAY**
- **HEAT HAS MOVED FROM THE SAND INTO LOW-K LAYERS BY CONDUCTIVITY (A VERY SLOW PROCESS)**
- **APPROX. 40 CM OF THE LOW-K SOILS HAVE BEEN TREATED, BUT 200 CM ARE UNTREATED**

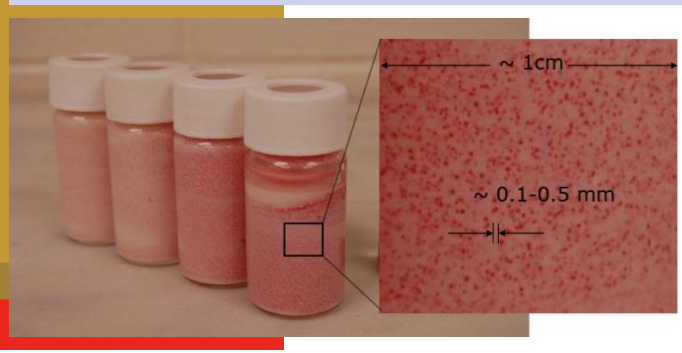
- **BEFORE 2005 – WHEN CHOOSING METHOD – THE GEOLOGICAL UNDERSTANDING WAS BASED ON LOW RESOLUTION DRILLINGS , SUCH AS "B5" (SAND)**
- **IN A WAY A CORRECT CHOICE OF METHOD, BUT BASED ON POOR QUALITY DATA…**
- **ESTIMATED COST FOR REMEDIATION: 9 MSEK**

- **<u>INVESTIGATION TECHNIQUES ARE IMPORTANT!!</u>**

SUGGESTED METHOD: ZVI-CLAY SOIL MIXING



- SOIL MIXING WITH DELIVERY OF ZERO VALENT IRON AND BENTONITE CLAY
- HOMOGENIZES THE HIGH/LOW K SOIL LAYERS
- EVEN DISTRIBUTION OF IRON POWDER



Pickering emulsion of NAPL (pink) and bentonite.
Source: Olsen, M. Colorado State University

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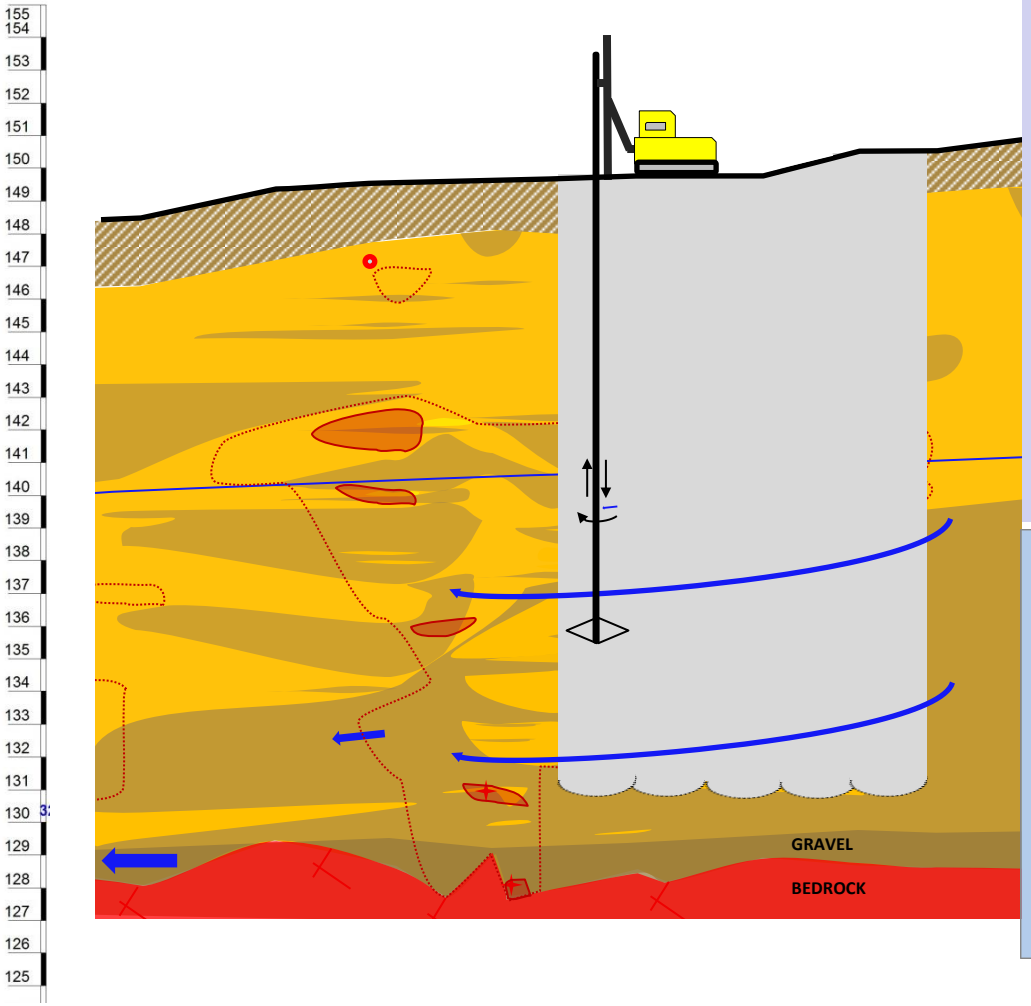
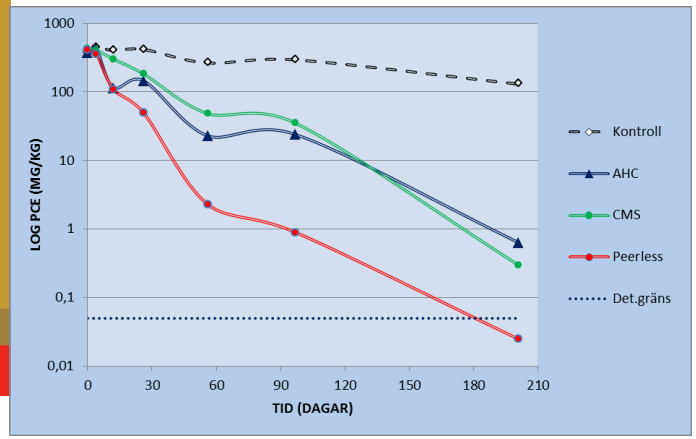


- OVERLAPPING COLUMNS TREAT THE ENTIRE SOURCE ZONE
- ZVI DEGRADES CHLORINATED HYDROCARBONS
- THE CLAY LOWERS THE HYDRAULIC CONDUCTIVITY
  - *>> TREATMENT TIME*
  - *<< MASS FLUX*



DATA FROM TREATABILITY STUDY, 2013. PCE-CONCENTRATION WITH 4 % IRON DOSAGE

PILOT TEST, DECEMBER 2014

- 8 SEPARATE TEST DRILLINGS WITH DIFFERENT IRON TYPES, IRON/CLAY DOSAGE, MIXER HEADS, ETC.
- POSSIBLE TO PASS COARSE SANDS , GRAVEL AND ISOLATED STONES
- TARGET DEPTHS (16 M BGL) WERE REACHED

- THE PILOT STUDY WILL BE FINALIZED IN 2016/17, INCLUDING:
  - EVALUATION OF VERTICAL IRON DISTRIBUTION
  - GEOTECHNICAL EVALUATION
- TO BE CONTINUED…

THANK YOU FOR YOUR ATTENTION!

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