



Fugro's Innovation for the Mining Market

Uta Alisch, German Day at Mining Indaba, 6 February 2018

Economic pressure leads to opportunities through innovation:

- Million tons of rock have been mined and discharged after processing creating huge tailings
- **Processing old tailings (Remining) can gain back raw materials**
- Material in tailings is fine grained = **easy to process**
- Tailings are **easy accessible**

Some Pros about Tailings:

- At the surface
- Processing plants are mostly already there (need just some adaption, improvements)
- Processing technologies has been improved (more efficient)
- Logistics are there
- Tailing dam safety and environmental issues can be addressed simultaneously

Remining of Tailings

Challenges for mining the tailings

- **Fast and cost effective screening technologies** for tailings are required
- Design for remining requires new efficient characterization
- Innovative (in-situ) mining and processing technologies required

Characterization of tailings: Metal content and soil type

- Metal concentration and distribution for qualified resource estimation
- Geotechnical characterization for design of remining activities
- Soil type and grain size for processing



Tailing Planta Matta in Copiapo, Chile



Tailing Requinoa, Chile – Reprocessing Cu and Mo

CPT-XRF probe for tailings characterization

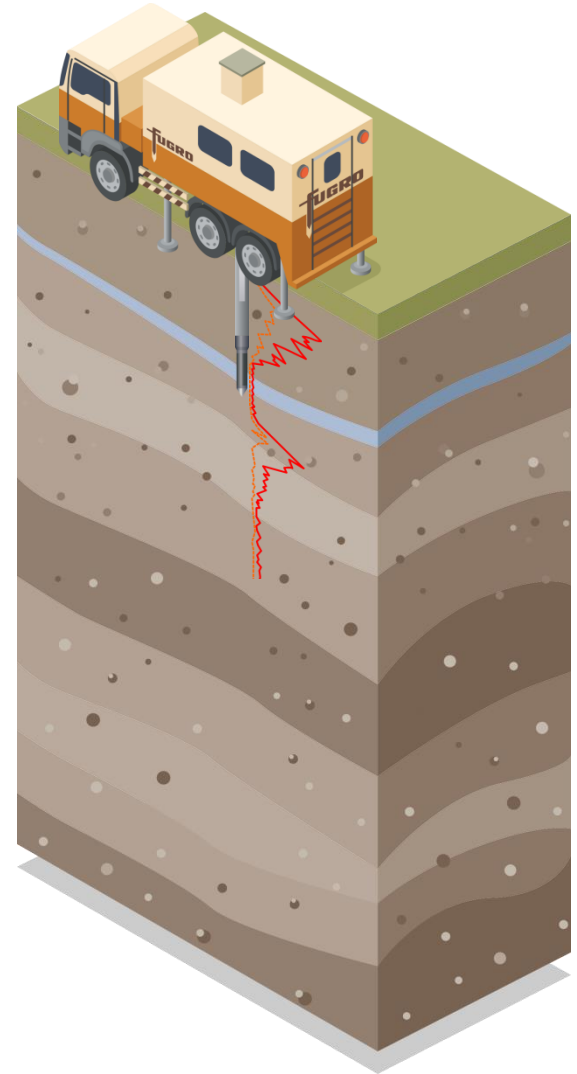
Multiparameter probe:
Metal concentration and
soil classification
in one push



← XRF Window

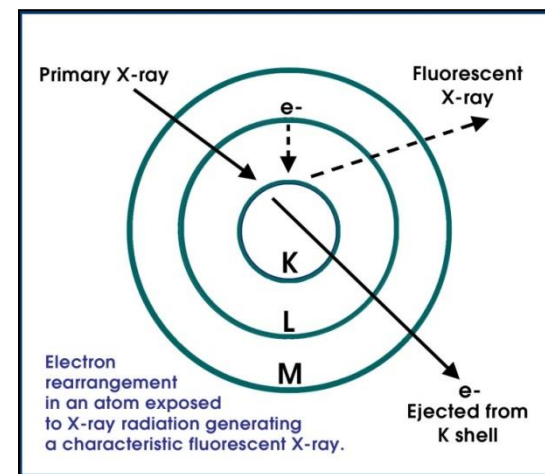
← CPTU

- Tip resistance
- Sleeve friction
- Porewater pressure



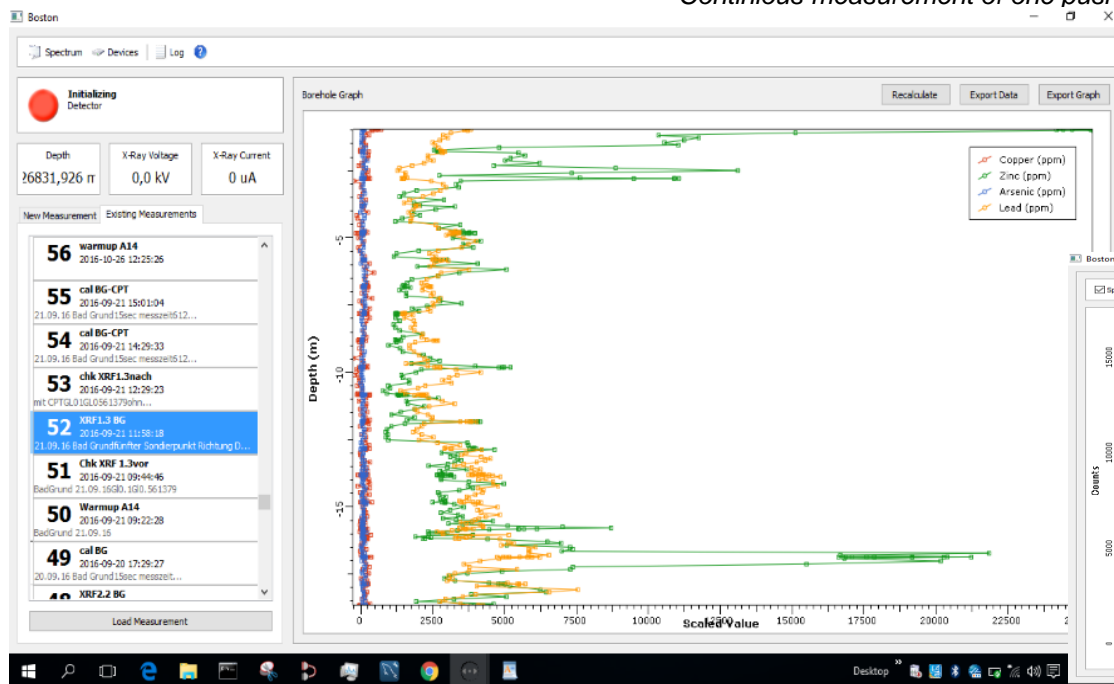
The XRF-CPT Technology

- Based on X-Ray Fluorescence
- Measures energy spectra for certain intervals (10-30 cm)
- Records data (concentration values of elements) in real time
- Provides high resolution data
- Very fast (100 – 150 m / day)
- Cost effective

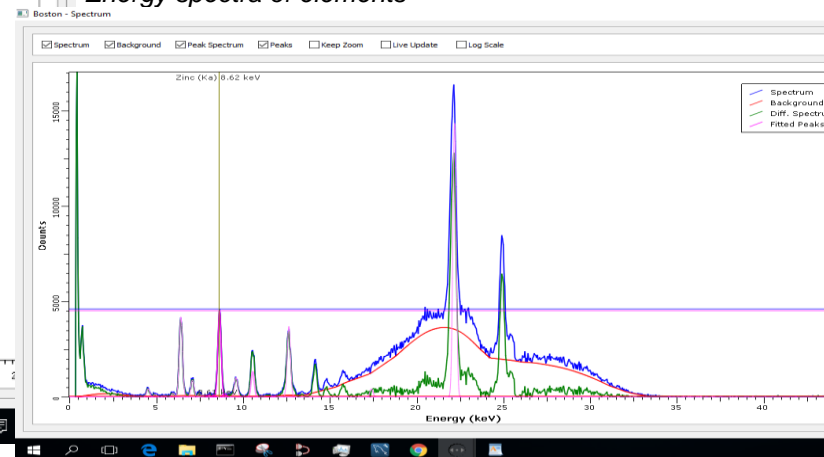


Principle

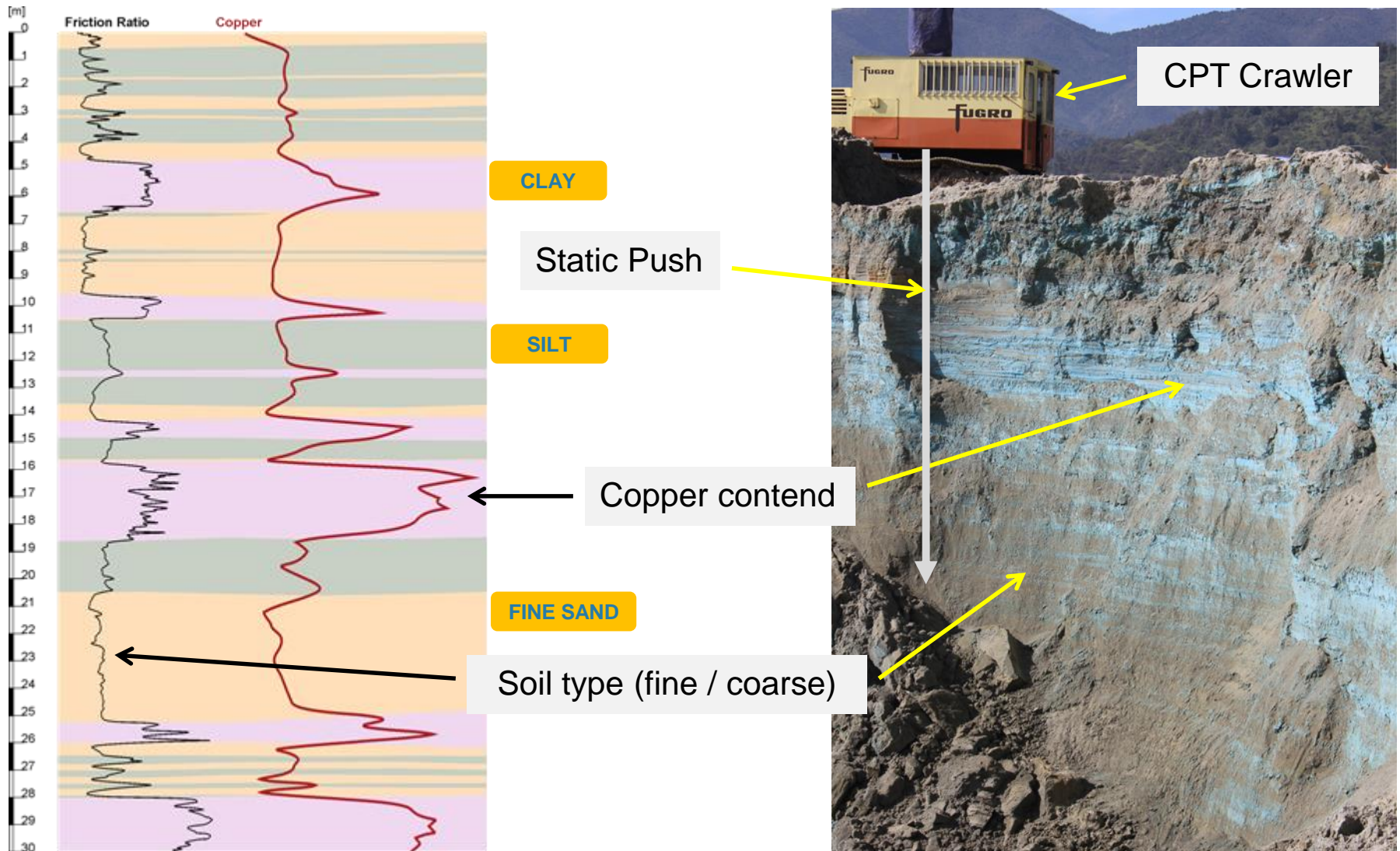
Continuous measurement of one push



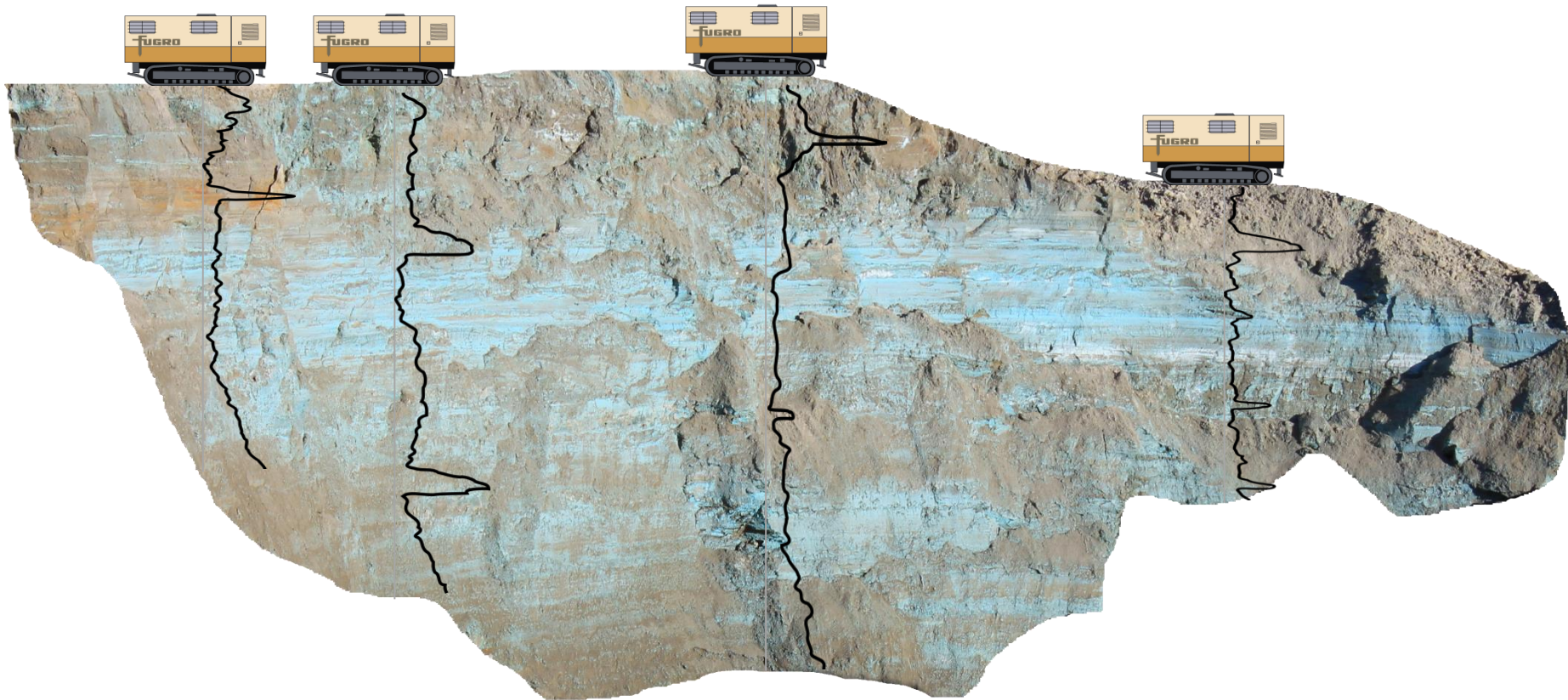
Energy spectra of elements



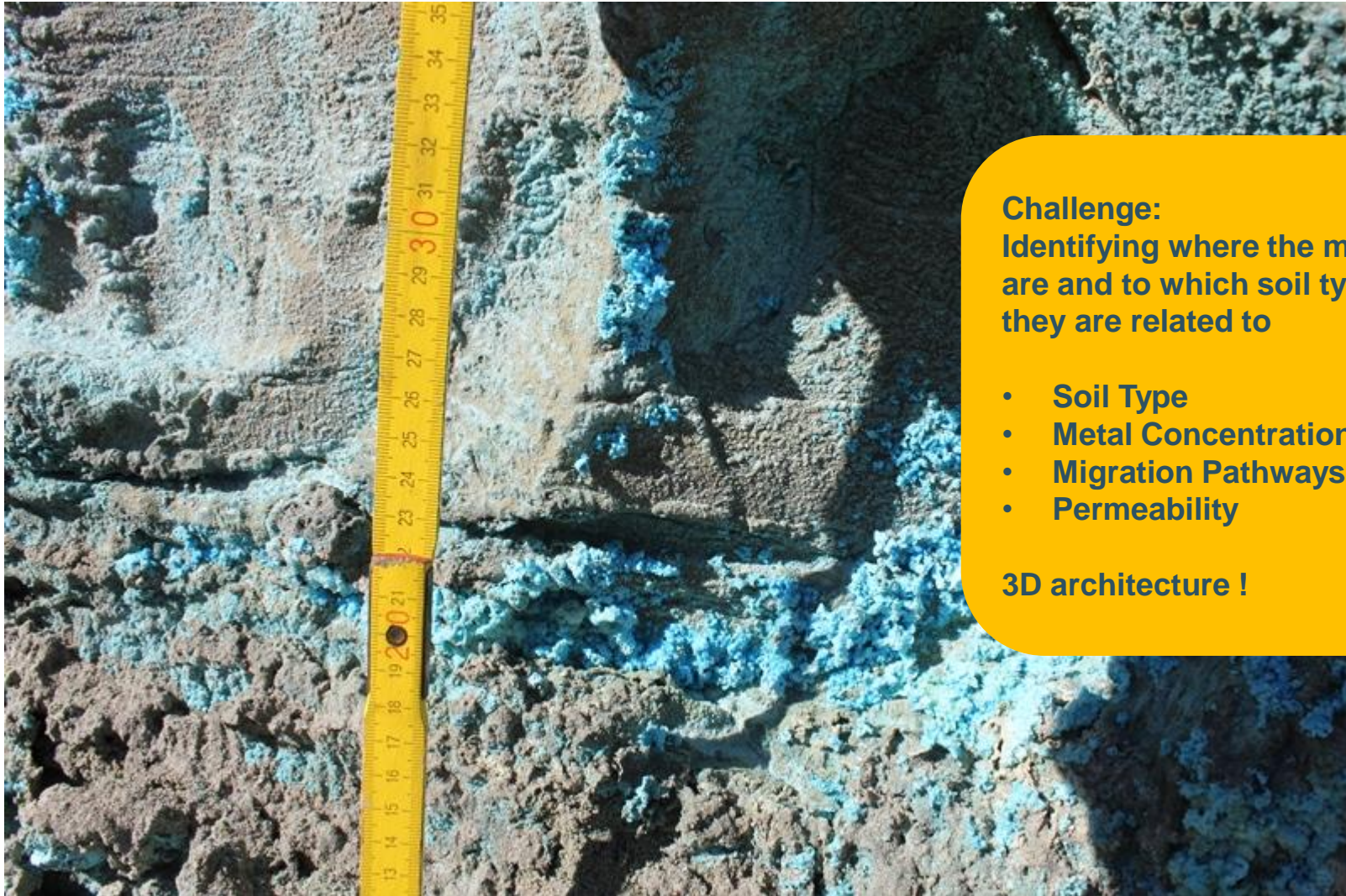
XRF-CPT Tailings Investigation



XRF-CPT Tailings Investigation



XRF-CPT Tailings Investigation



Challenge:
Identifying where the metals
are and to which soil type
they are related to

- Soil Type
- Metal Concentration
- Migration Pathways
- Permeability

3D architecture !

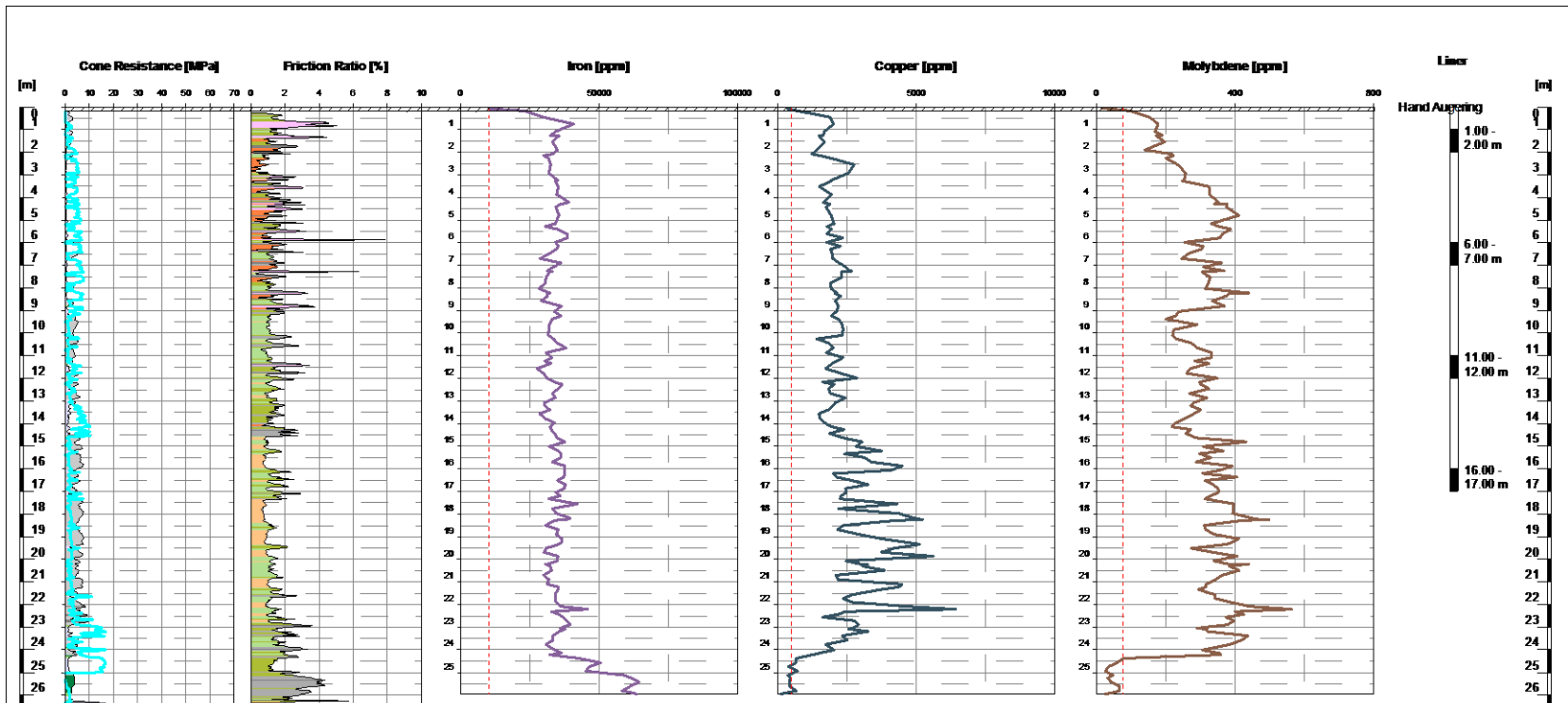
XRF-CPT Investigation – El Teniente’s Colihues tailing, Chile



Fugro CPT Crawler
Static push @ 20 to

Hydro Gun
10,000 to / day

XRF-CPT data Tailings Investigation Colihues Tailing



Copper from 14 - 25 m
in a silty - sandy material

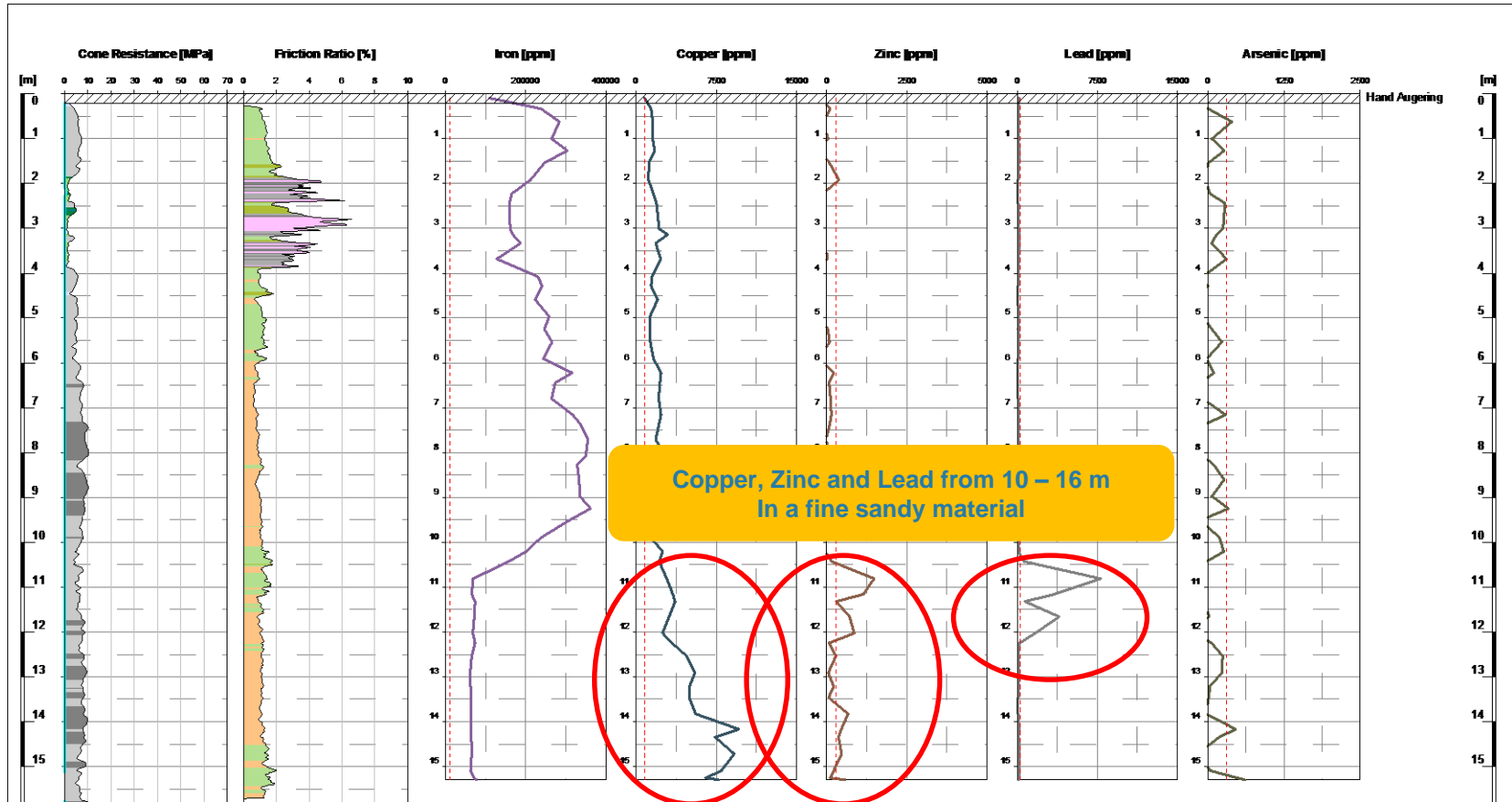
<p>Robertson CPT Soil Classification (S&B) (modified)</p> <p>Legend (Cobes in Friction Ratio Profile)</p> <ol style="list-style-type: none"> 1 Silty/clay, fine grained 2 Organic/silt, peat 3 Clay 4 Clay to silty clay 5 Clayey silt to silty clay 6 Silty silt to clayey silt 7 Silty sand to sandy silt 8 Sand to silty sand 9 Coarse to medium sand 10 Gravel to gravelly sand 11 Very silt, fine grained 12 Very silt sand to clayey sand <p><small>Soil types 11 and 12 are heavily overconsolidated or cemented.</small></p>	<p>Soil Density and Consistency (interpreted)</p>	<p>Legend Cone Resistance Profile</p> <ul style="list-style-type: none"> very loose loose medium dense dense very dense very soft soft firm stiff very stiff hard 	<p>Legend</p> <ul style="list-style-type: none"> Contaminant Distribution measured with XRF Probe [ppm] Detection Limit 	<p>Notes:</p> <div style="text-align: right;"> </div>
<p>Depth (CPT): 26.48 m bgs</p>				

XRF-CPT Investigation – Cu - tailing Copiapo, Chile

- CPT provides geotechnical data
- XRF provides metal concentrations
- High Resolution / Fast / Real Time
- Enables 3D modeling of resources for remining
- Sampling of soil and groundwater in one campaign



XRF-CPT data Tailings Investigation Copiapo



Copper, Zinc and Lead from 10 – 16 m
In a fine sandy material

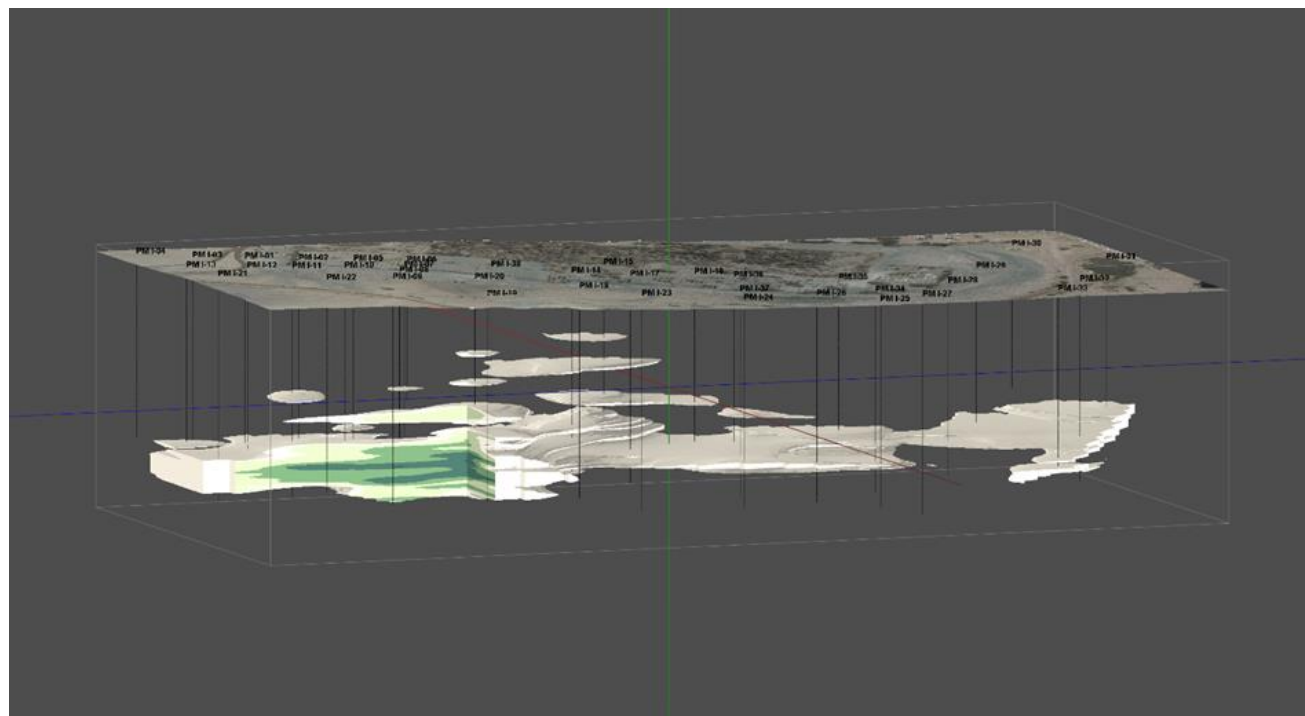
<p>Robertson CPT Soil Classification 1986 (modified)</p> <p>Legend (Codes in Friction Ratio Profile)</p> <ol style="list-style-type: none"> 1 Sorbelle, fine grained 2 Organics/soil, peat 3 Clay 4 Clay to silty clay 5 Clayey silt to silty clay 6 Silty silt to clayey silt 7 Silty sand to sandy silt 8 Sand to silty sand 9 Coarse to medium sand 10 Gravel to gravelly sand 11 Very stiff, fine grained 12 Very stiff sand to clayey sand <p>Soil types 11 and 12 are heavily overconsolidated or cemented.</p>	<p>Soil Density and Consistency (Interpreted)</p> <p>Legend Cone Resistance Profile</p> <ul style="list-style-type: none"> very loose loose medium dense dense very dense very soft soft firm stiff very stiff hard 	<p>Legend</p> <ul style="list-style-type: none"> — Contaminant Distribution measured with XRF Probe [ppm] - - - Detection Limit 	<p>Notes:</p> <p>Project:</p> <p>Test Location:</p>	
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XRF-CPT Investigation – Cu - tailing Copiapo, Chile

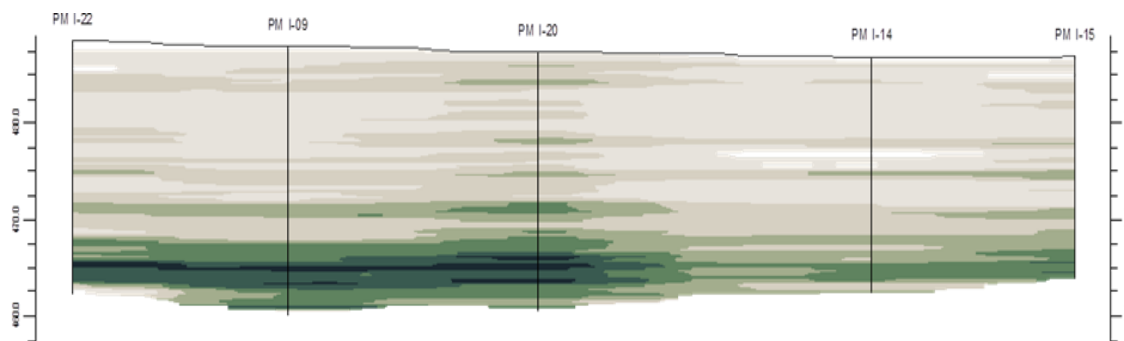


- Grid of 40 points / 100m spacing
- 2 weeks site investigation
- Liner sampling for calibration (lab tests)
- Depth 25 - 30 m
- Map of copper distribution (total depth)

Tailings Investigation Copiapo - Results

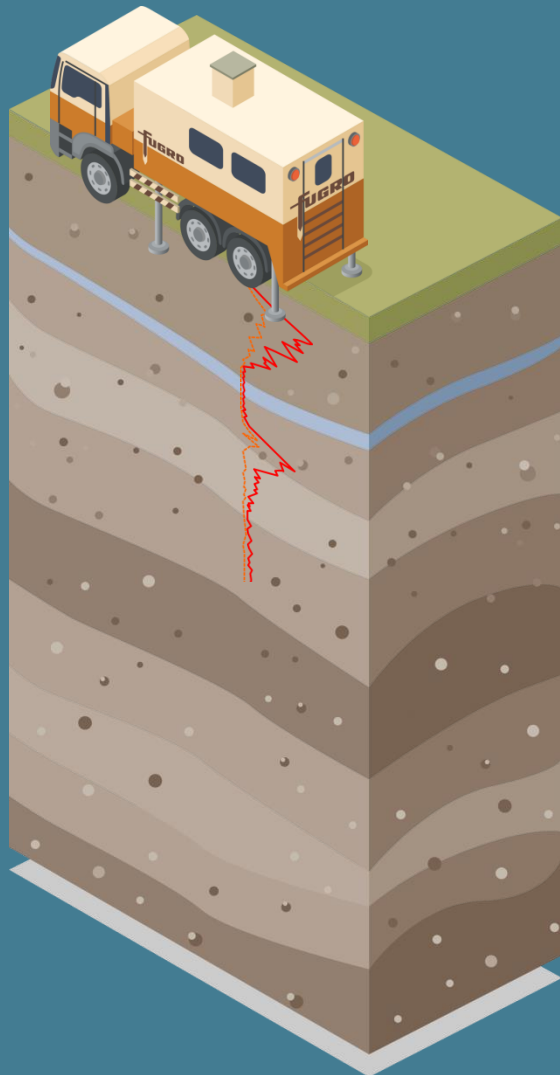


- 2D / 3D distribution of copper
- Volume estimation / concentration
- Resource estimation
- How much do we have and where
- Baseline data for remaining design



Conclusions:

- System for real-time high resolution tailings characterization
- Geotechnical and metal data
- Fast and reliable
- Daily productivity 75-100 m
- Continuous measurement (point measurements possible)
- Cost effective compared to traditional approaches (drilling & sampling)
- Delivers digital data for 3D models



Thank you for your attention

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To work safely, responsibly and sustainably

you need **relevant,**
reliable, insightful
information.

*Fugro's Data Acquisition,
Analysis & Advice provides
a strong foundation for your
projects.*

*Helping you to deliver on
your promise of a smarter,
more connected and
sustainable future.*



(Data) Acquisition



Analysis



Advice









Capability

Asset integrity

 GEOSPATIAL SERVICES	 CONDITION SURVEY	 NONDESTRUCTIVE TESTING	 STRUCTURAL INVESTIGATION	 ENGINEERING ANALYSIS	 CONSULTANCY	 RESEARCH & DEVELOPMENT	 POSITIONING
 LABORATORY TESTING	 CONSTRUCTION MATERIALS TESTING	 QA/QC	 PROJECT MANAGEMENT	 ASSET MANAGEMENT	 DATA INTEGRATION & REPORTING	 STRUCTURAL MONITORING	 FATIGUE MONITORING

Site Characterization & Consulting

 MAPPING	 SITE INVESTIGATION	 SAMPLING	 BOREHOLE GEOPHYSICS	 ENGINEERING GEOPHYSICS	 LABORATORY TESTING	 DYNAMIC LABORATORY ANALYSIS	
 INSTRUMENTATION	 GEOTECHNICAL MONITORING	 FOUNDATION TESTING	 ENGINEERING ANALYSIS	 DATA INTEGRATION & REPORTING	 RESEARCH & DEVELOPMENT	 CONSULTANCY	 PROJECT MANAGEMENT

Remining of Tailings

Remining must be profitable – Most cost effective Solution required

	Dry Mining	Wet Mining	In-Situ Mining
Mining	Excavater, Multi Bucket Excavator	Hydro Guns Dredger	Fracking Leaching
Transport	Trucks, Wheel Loader Conveyor Belts	Trenches Pipelines	(Horizontal) Wells Drains, Pipelines
Material for Plant	Dry, sticky	Slurry	Liquid
Energy Demand	High	Medium	Low
Operational Costs	High	Medium – High	Low

The most cost effective solution depends on the architecture of the metal distribution

Wet Mining (Hydroguns – Trenches – Pipelines)



Wet Mining (Hydroguns – Trenches – Pipelines)



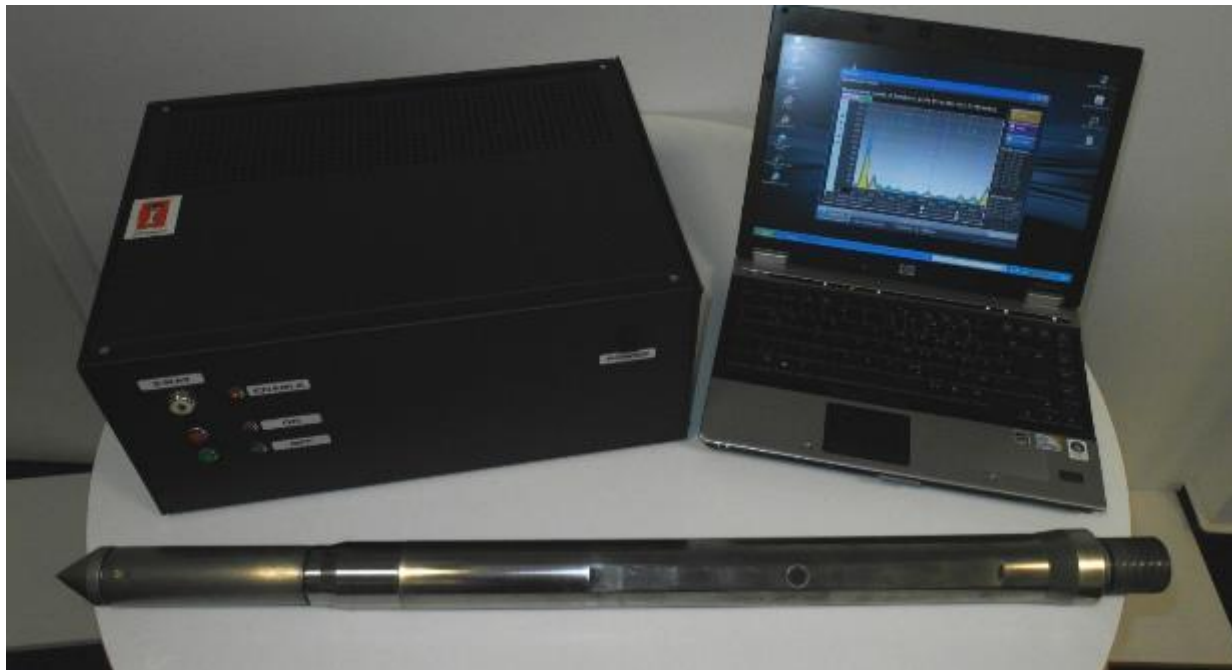
Wet Mining (Hydroguns – Trenches – Pipelines)



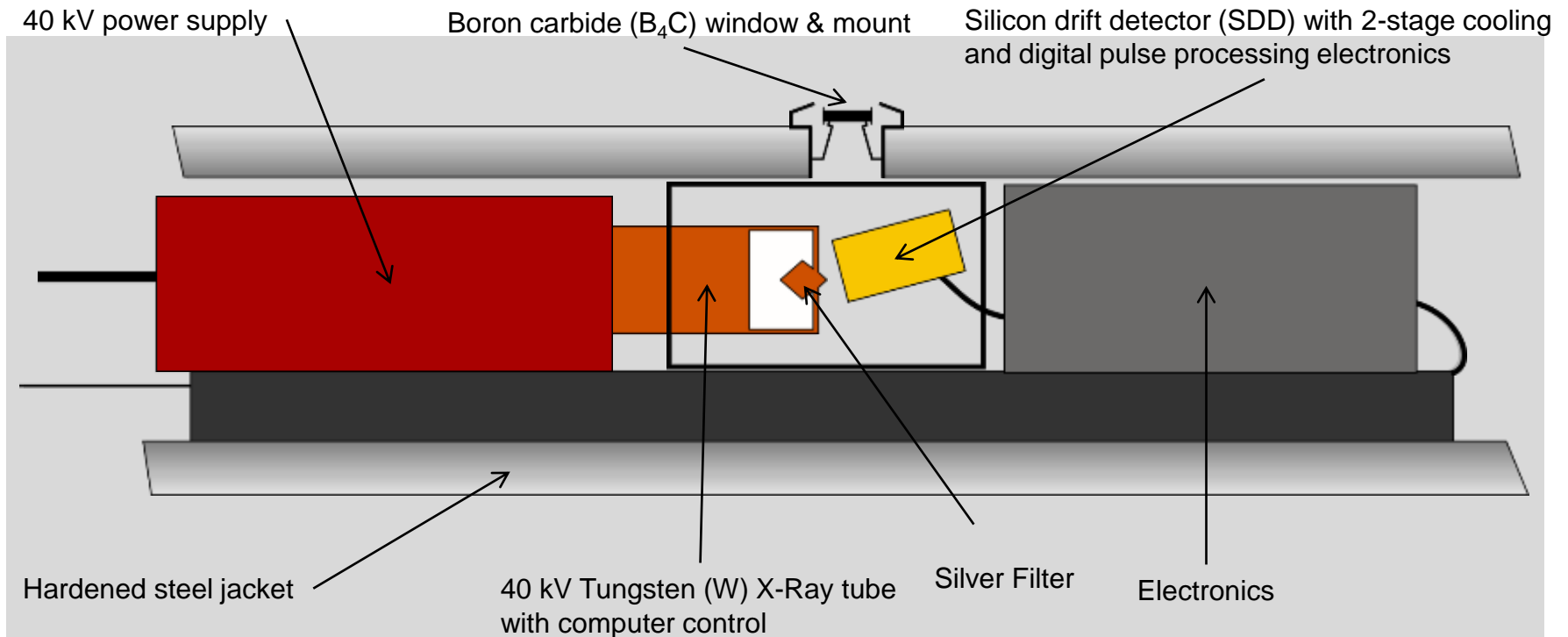
The CPT – XRF System

Fugro has developed an X-Ray Fluorescence (XRF) probe that is able to measure metal concentrations in the subsurface in real-time.

The sensor is connected to a CPT cone and can be deployed with top push CPT equipment.



The CPT – XRF System

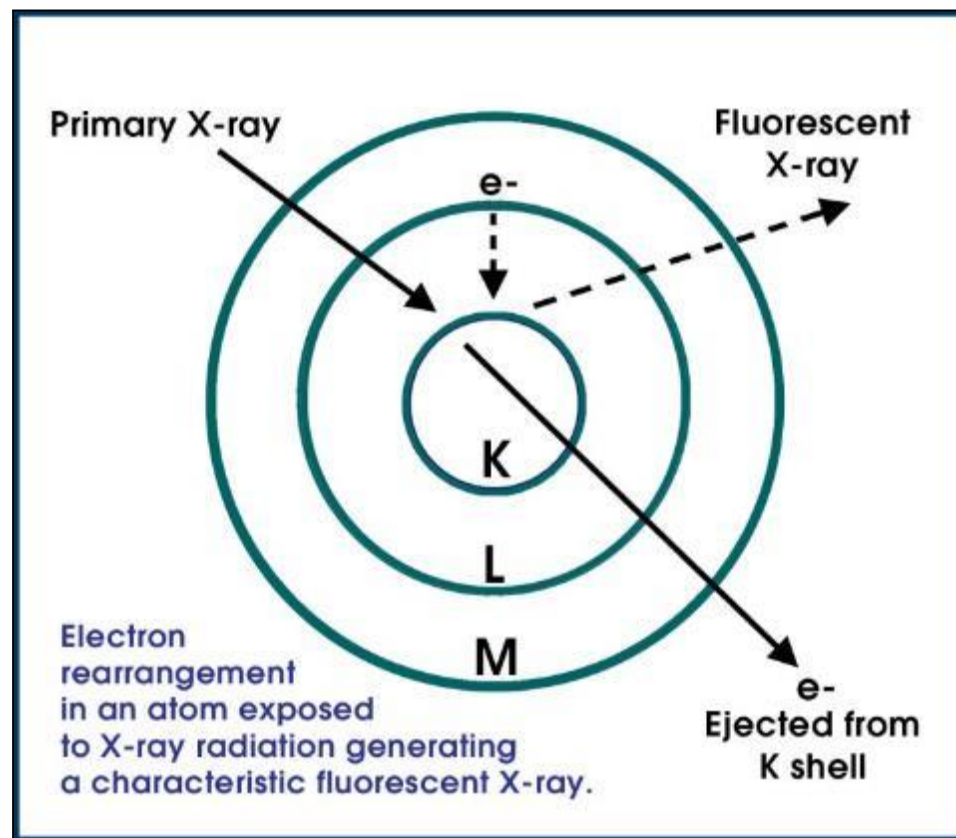


All electronics are built in the downhole tool

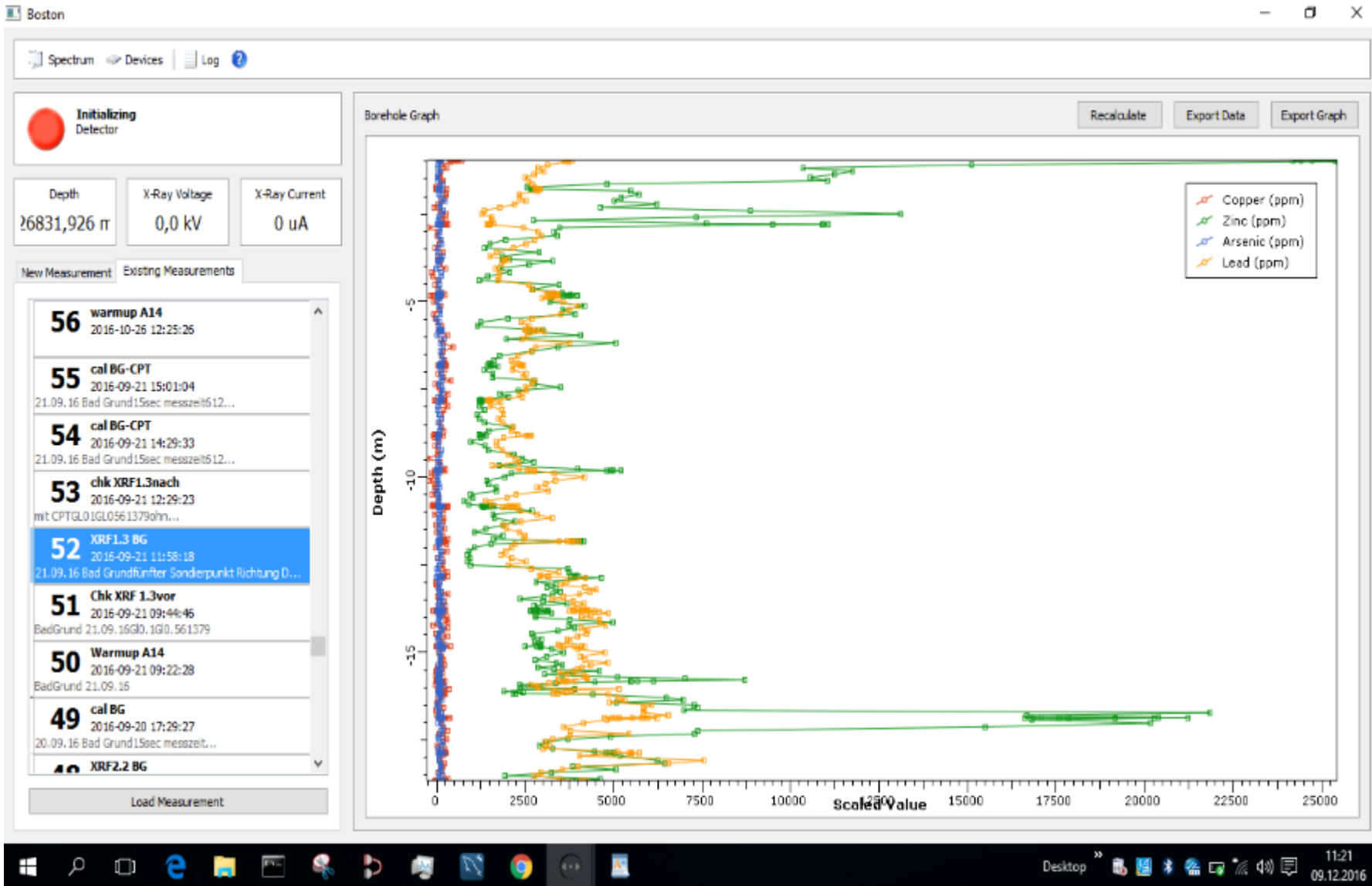
ED-XRF (*energy dispersive X-Ray fluorescence*) Basics

X-ray fluorescence (XRF) is the emission of characteristic "secondary" (or fluorescent) X-rays from a material that has been excited by high-energy X-rays

- X-rays are energetic enough to expel tightly held electrons from the inner orbital's of an atom.
- The removal of an electron makes the structure of the atom unstable, and electrons in higher orbitals "fall" into the lower orbital to fill the hole left behind.
- In falling, energy is released in the form of a photon
- Thus, the material emits radiation, which has energy characteristic of the atoms present.
- The term *fluorescence* is applied to phenomena in which the absorption of radiation of a specific energy results in the re-emission of radiation of a different energy (generally lower)



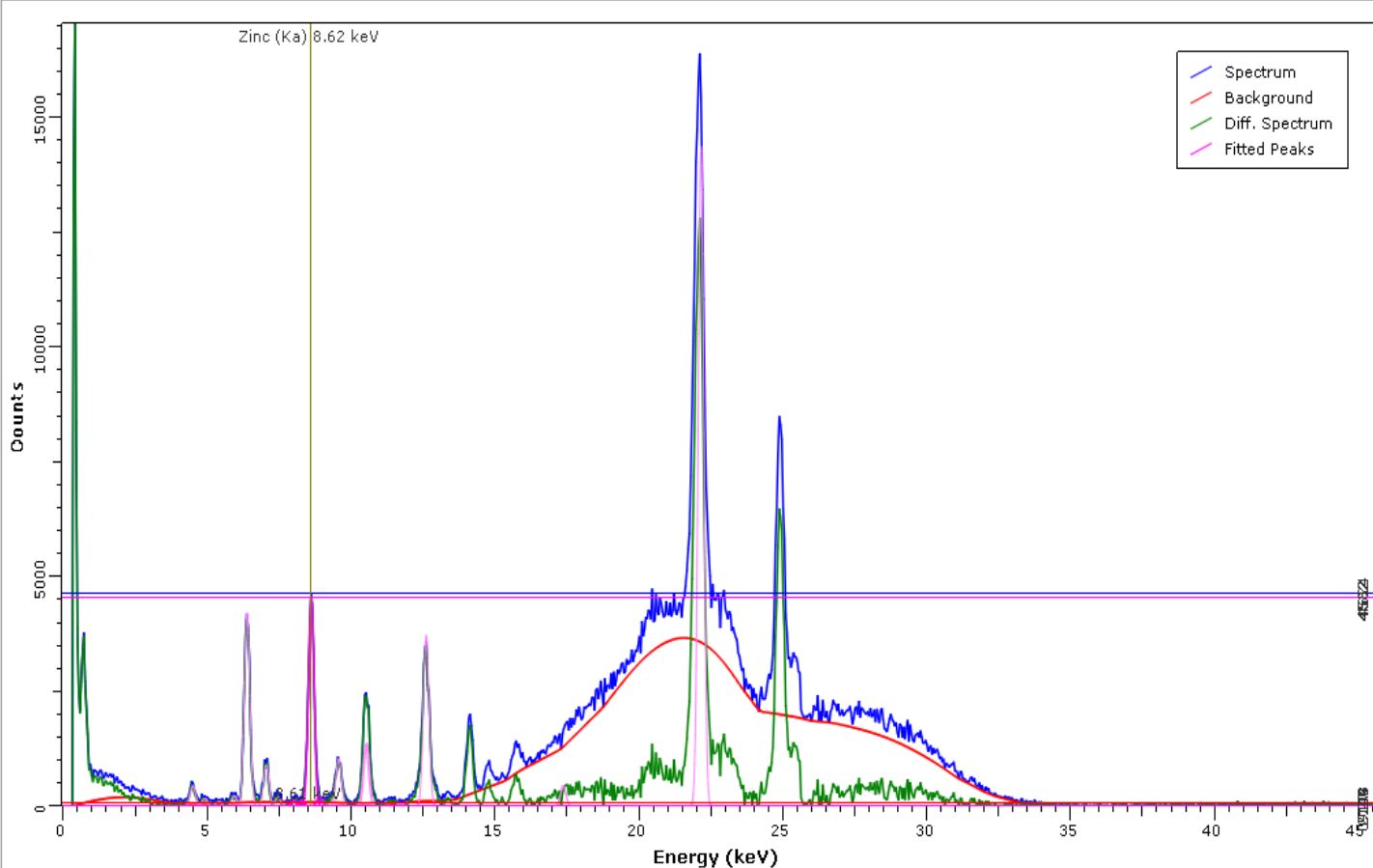
Real Time Data



What you get on screen

Boston - Spectrum

Spectrum
 Background
 Peak Spectrum
 Peaks
 Keep Zoom
 Live Update
 Log Scale



Spectrum ID	3165
Start Time	2016-09-21 11:41:27
Real Time	16.39 s
Live Time	15.16 s
Dead Time	7.53 %
Energy Calibration No.	12
Xray Voltage	39443
Xray Current	59.63
Det. Board Temp.	30.50 °C
Det. Amp. Temp.	-242.9 °C
Moisture 1	0
Moisture 2	0
Depth	16792 m
Counts Per Second	10837
Background Sum	772580
Peak Sum	0.137
Visible	True
Count correction	0

14 Titanium (Ka)	4.51 keV
H: 441 W: 3.0 Area: 0.180 %	
15 Titanium (Kb)	4.92 keV
H: 169 W: 3.0 Area: 0.0690 %	
18 Chromium (Ka)	5.41 keV
H: 99 W: 3.0 Area: 0.0403 %	
19 Chromium (Kb)	5.95 keV
H: 227 W: 3.0 Area: 0.0927 %	
22 Iron (Ka)	6.39 keV
H: 4204 W: 3.0 Area: 1.72 %	
23 Iron (Kb)	7.06 keV
H: 900 W: 3.0 Area: 0.368 %	
26 Nickel (Ka)	7.46 keV