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Advancements in Exploration and In-Situ Recovery of Sedimentary-Hosted Uranium

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Presented by Peter Woods, IAEA

HEATHGATE

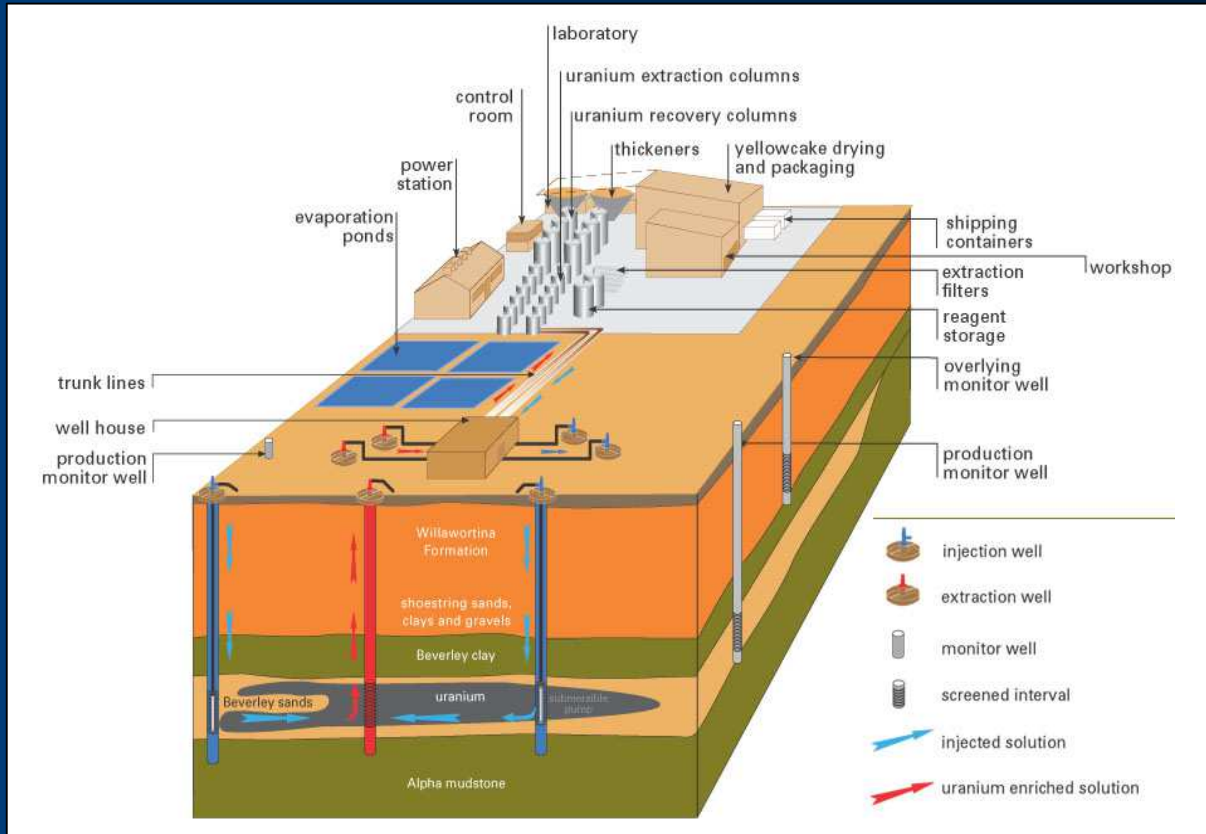
UIT UMWELTLEISTUNGEN

Context and Outline

- **ISR feasibility – determining factors**
  - What counts?

- **High-resolution shallow seismic**
  - Methodology from 'oil&gas hunting' adapted to mineral exploration in sedimentary basins
- **New down-hole logging tool**
  - Advanced PFN technology combined with lithologic logging
- **Moving theory to practice**
  - Reactive-transport modelling for optimizing ISR – It works!

Beverley ISR plant
Schematic
(source: EIS 1998)



ISR feasibility – determining factors

ISR Feasibility – Determining Factors

- **Confinement condition**
  - Overall sedimentary stratification and hydrogeology
- **Hydrology**
  - Depth below surface/below groundwater table
  - Permeability/porosity
- **Mineralogy/geochemistry**
  - Uranium mineralogy
  - Reactive minerals and interfering components
  - Groundwater salinity
- **Uranium ore deposit**
  - Morphology
  - Uranium resource/reserve
  - U grade

Key factors -

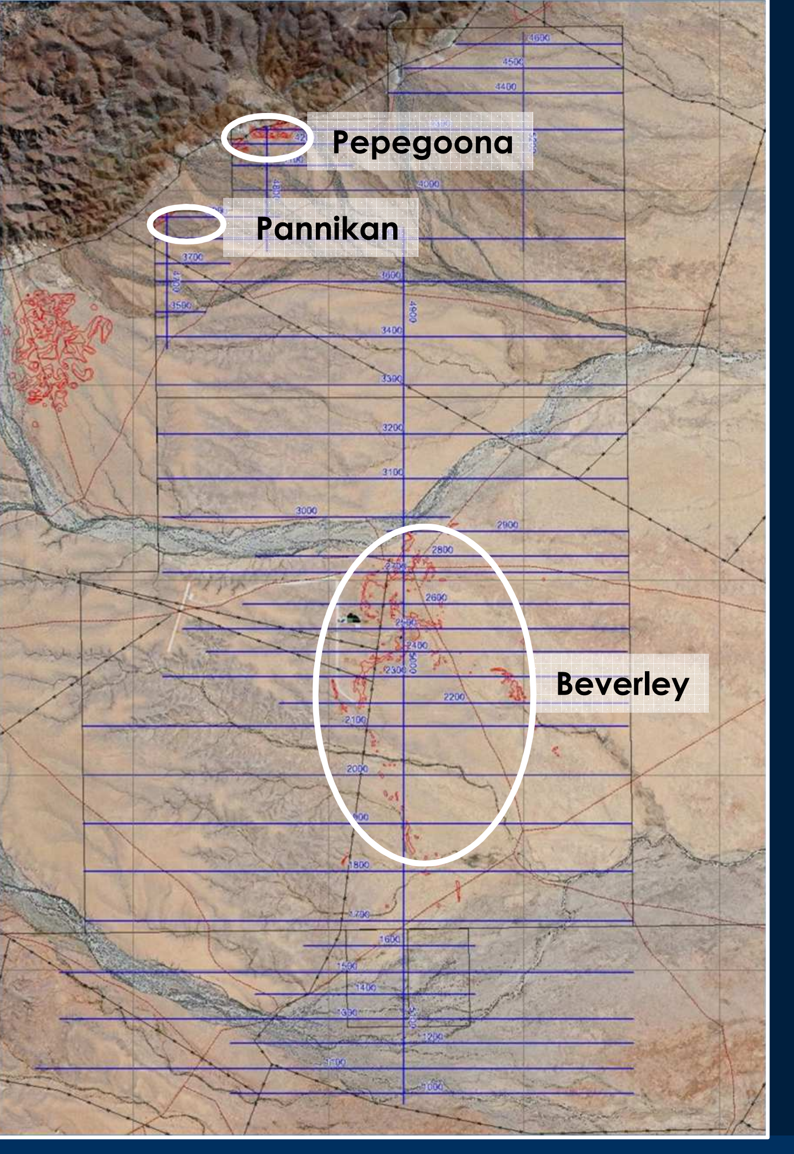
new methods to measure those reliably and economically

↔ **Technological/economic/regulatory feasibility**
↔ **Database for wellfield planning and operation**

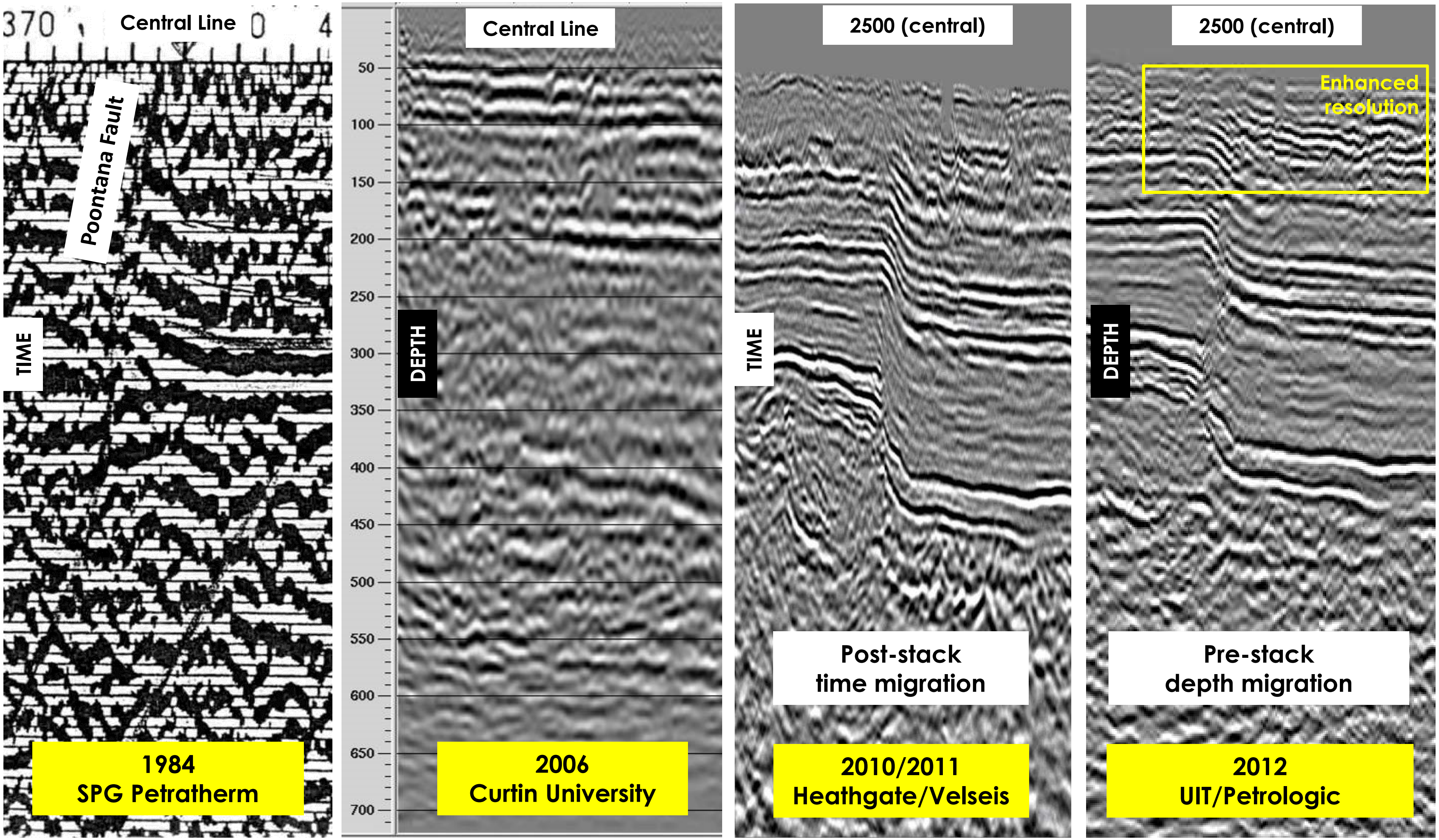
Seismic survey 2010/2011 Paralana Lease:

- 40 lines / 318 line km
- 5 m shot interval
- 5 m geophone intervals
- Envirovibe vibroseis buggies 60kN

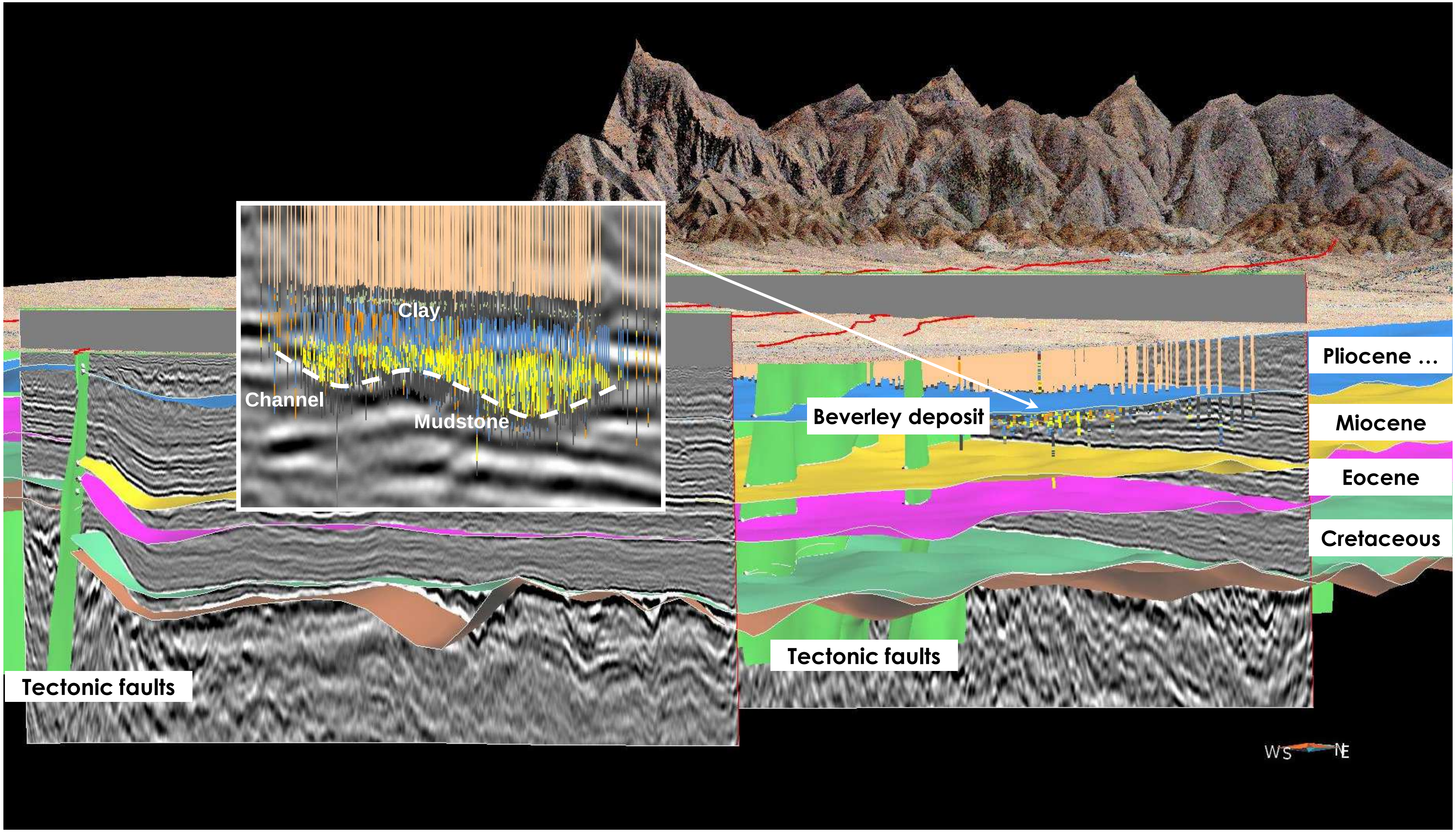
High-resolution shallow seismic



Seismic in Paralana Lease: Historical



3D Basin Model Based on 2D Seismic Grid



High-Resolution Shallow Seismic

- **Distinct measure of stratigraphy and irregularities**
  - Indication of tectonic faults
  - Potential indicators for uranium mineralization
- **Improved basis for hydrogeological models (regional/local)**
  - Well-resolved sedimentary stratigraphy
  - Consideration of tectonic faults as barriers and potential fluid pathways

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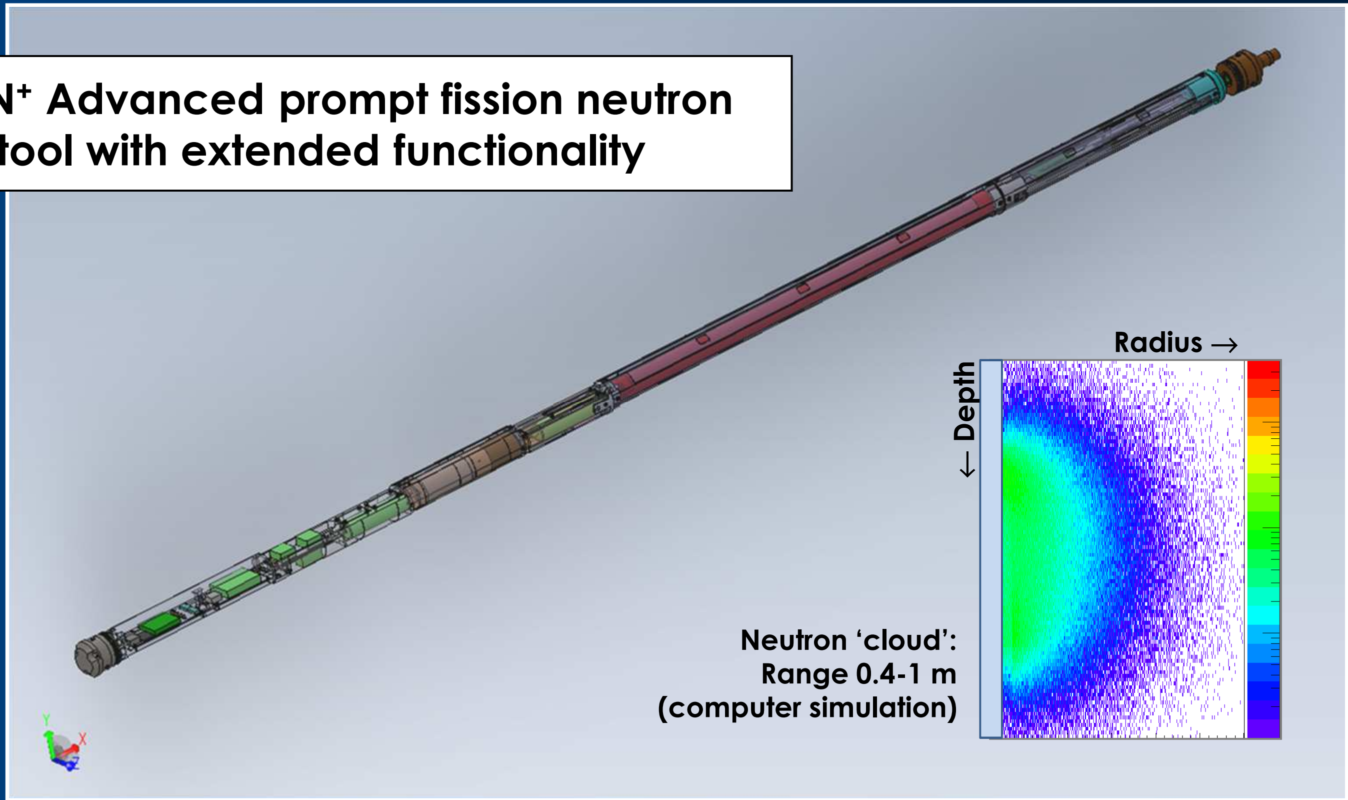
- **Improved concept for further seismic surveying (dedicated to optimize drilling programs)**
  - Optimized geometrical setup (2D → optional 3D) (5 m → 2.5 m spacing for depth < 500 m)
  - System hardware/source
  - Software for maximum output/best resolution

APFN+ Advanced prompt fission neutron tool with extended functionality



New down-hole logging tool – APFN+

Support by APMI, TX (USA), particularly by Dr Donald Steinman, Dr Russel Hertzog, in early development phase gratefully acknowledged

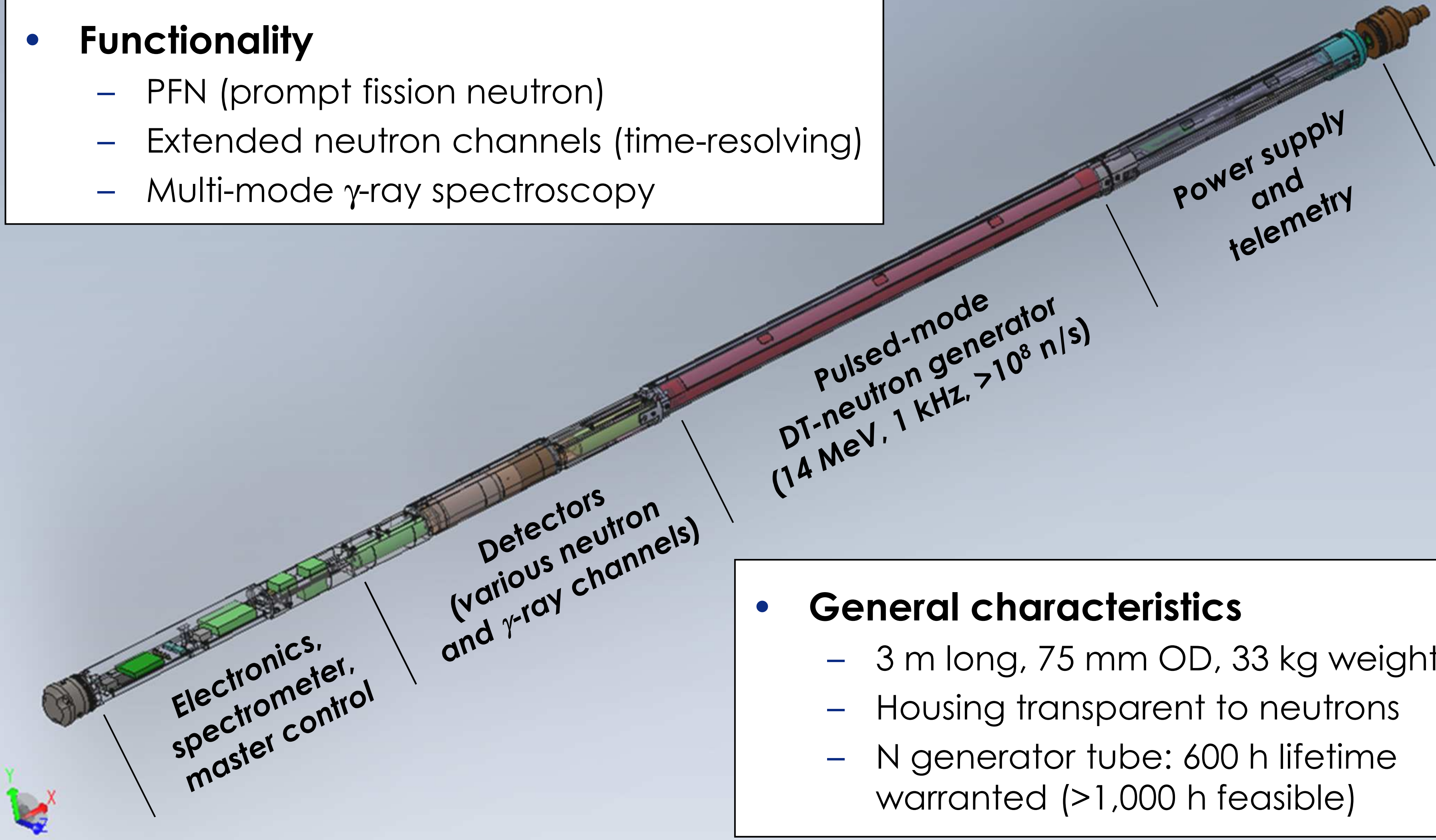
APFN+ Background

Development/Production by UIT Dresden
Launched at Heathgate, S.A.

- **Motivation for development**
  - Systematic errors/influences in conventional PFN logs (borehole size, varying neutron absorption in formation, porosity, bulk density, etc.), 10-30% effect (up to 80% possible)
  - Improve accuracy by in-tool corrections
  - Extend functionality → lithologic logging
- **Advancements**
  - Pulsed neutron generator technology/control
  - Extended neutron detection channels operated in time-resolving mode
  - γ-ray spectrometer based on high-performance scintillator ($CeBr_3$) operated in several modes:
    - Natural γ-rays
    - γ-rays from fast-neutron inelastic scattering
    - γ-rays from thermal-neutron capture
    - γ-ray spectra from neutron activation

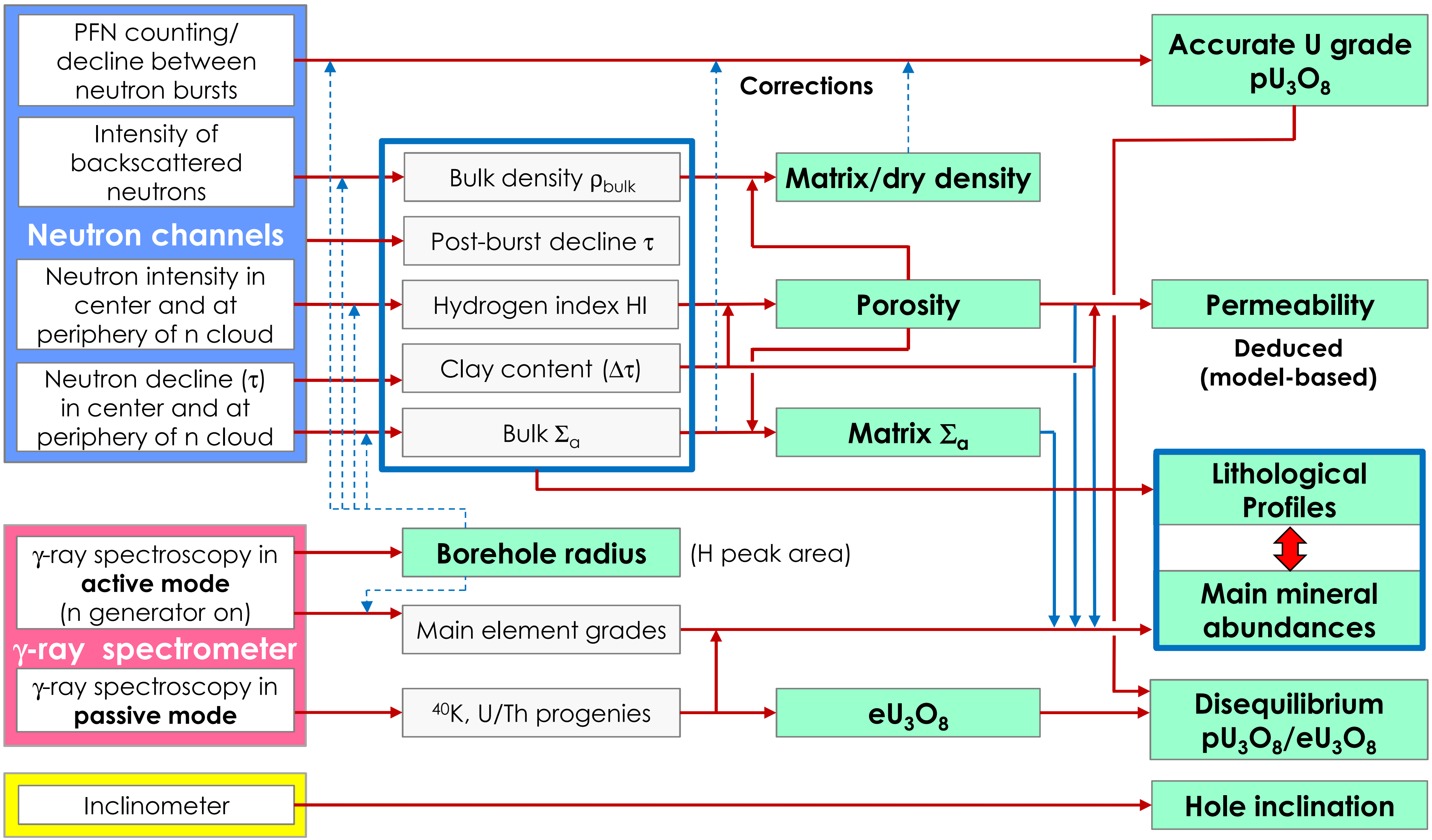
APFN⁺ – Advanced PFN Logging Tool

- **Functionality**
  - PFN (prompt fission neutron)
  - Extended neutron channels (time-resolving)
  - Multi-mode γ-ray spectroscopy



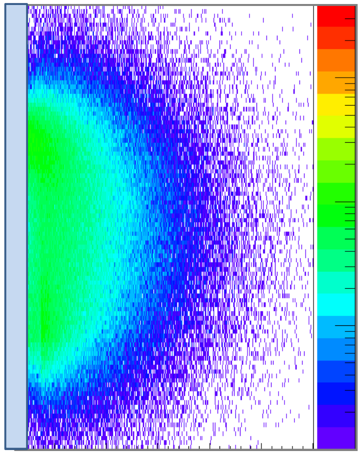
- **General characteristics**
  - 3 m long, 75 mm OD, 33 kg weight
  - Housing transparent to neutrons
  - N generator tube: 600 h lifetime warranted (>1,000 h feasible)

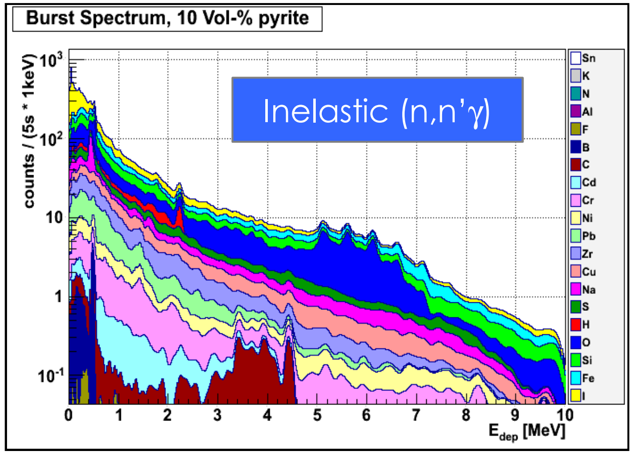
APFN+ Functionality, Algorithms and Data Output

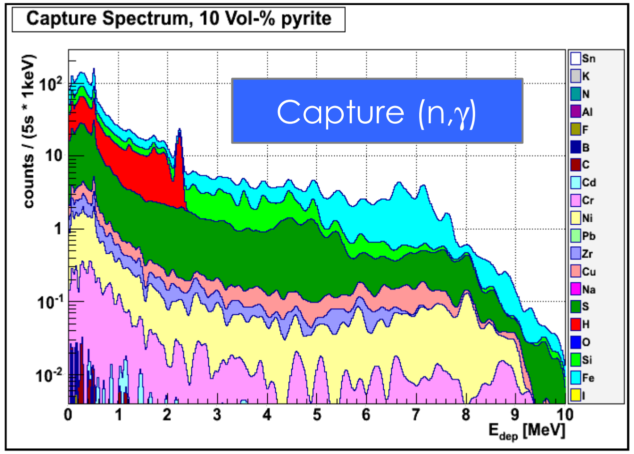


APFN+ Algorithms and Validation

- **Extensive computer simulations**
  - MCNP5/6 software from Los Alamos National Laboratory (LANL)
  - Lithologic model for variation of sedimentary formations

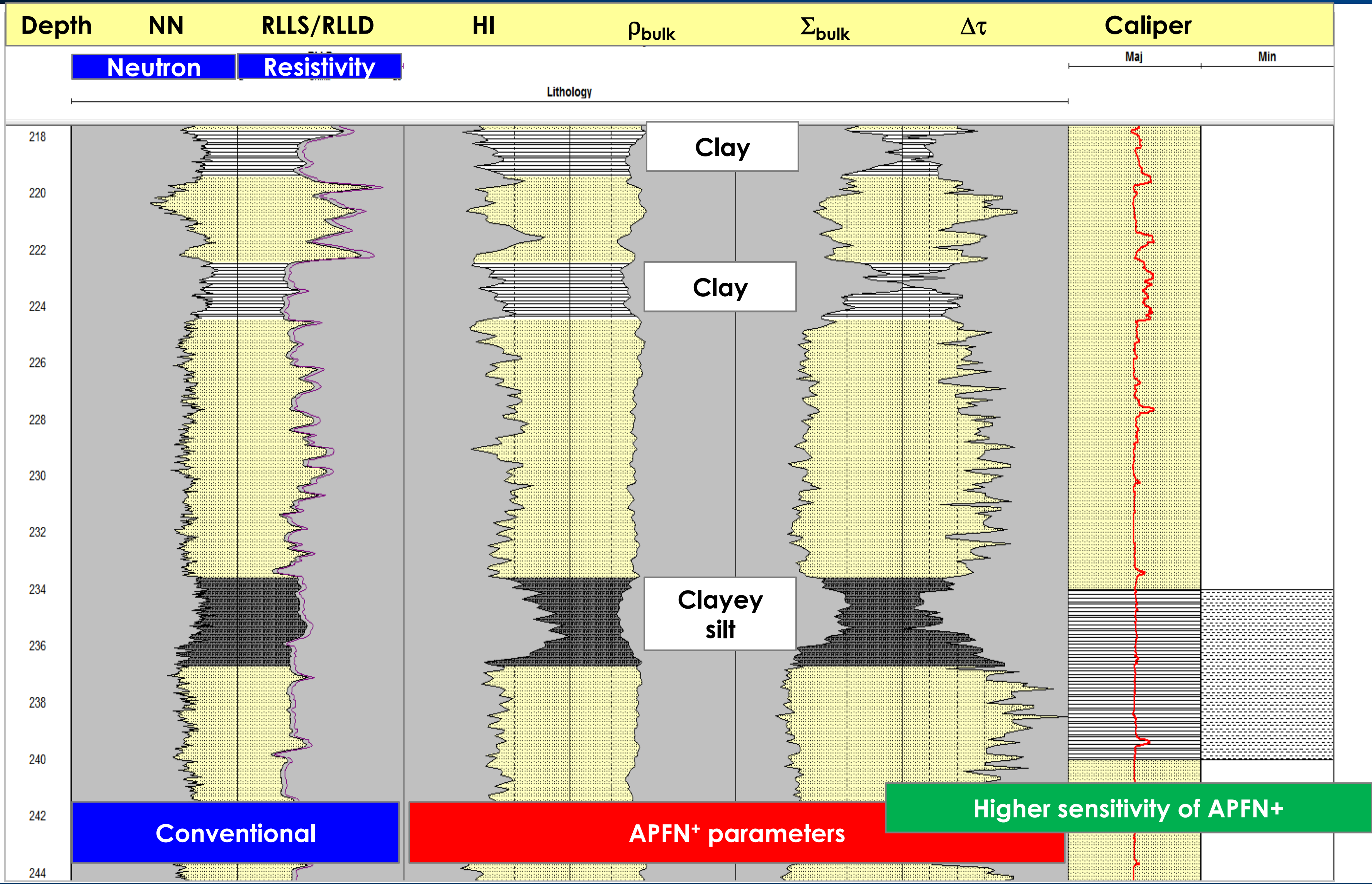




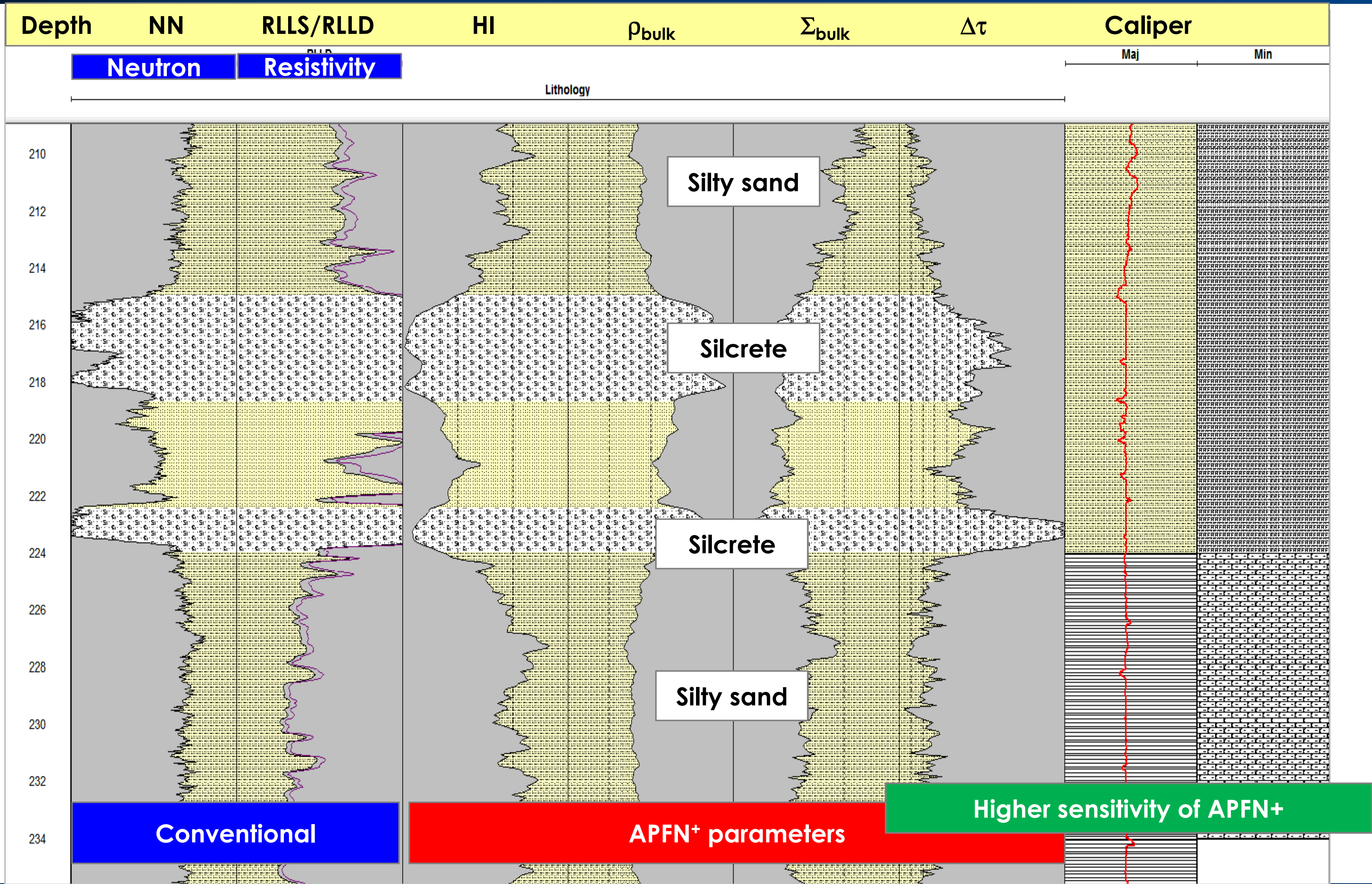


- **Extensive testwork 2011-12 / routine logging since early 2013**
  - Test pits and holes (UIT Dresden)
  - Calibration facilities: George West (TX), TRAC lab (Halliburton, TX), AMDEL (Adelaide, S.A.)
  - Beverley calibration pits/reference holes → exploration holes

Conventional vs. APFN⁺ Logging – ‘Standard’ Logs



Conventional vs. APFN⁺ Logging – 'Standard' Logs



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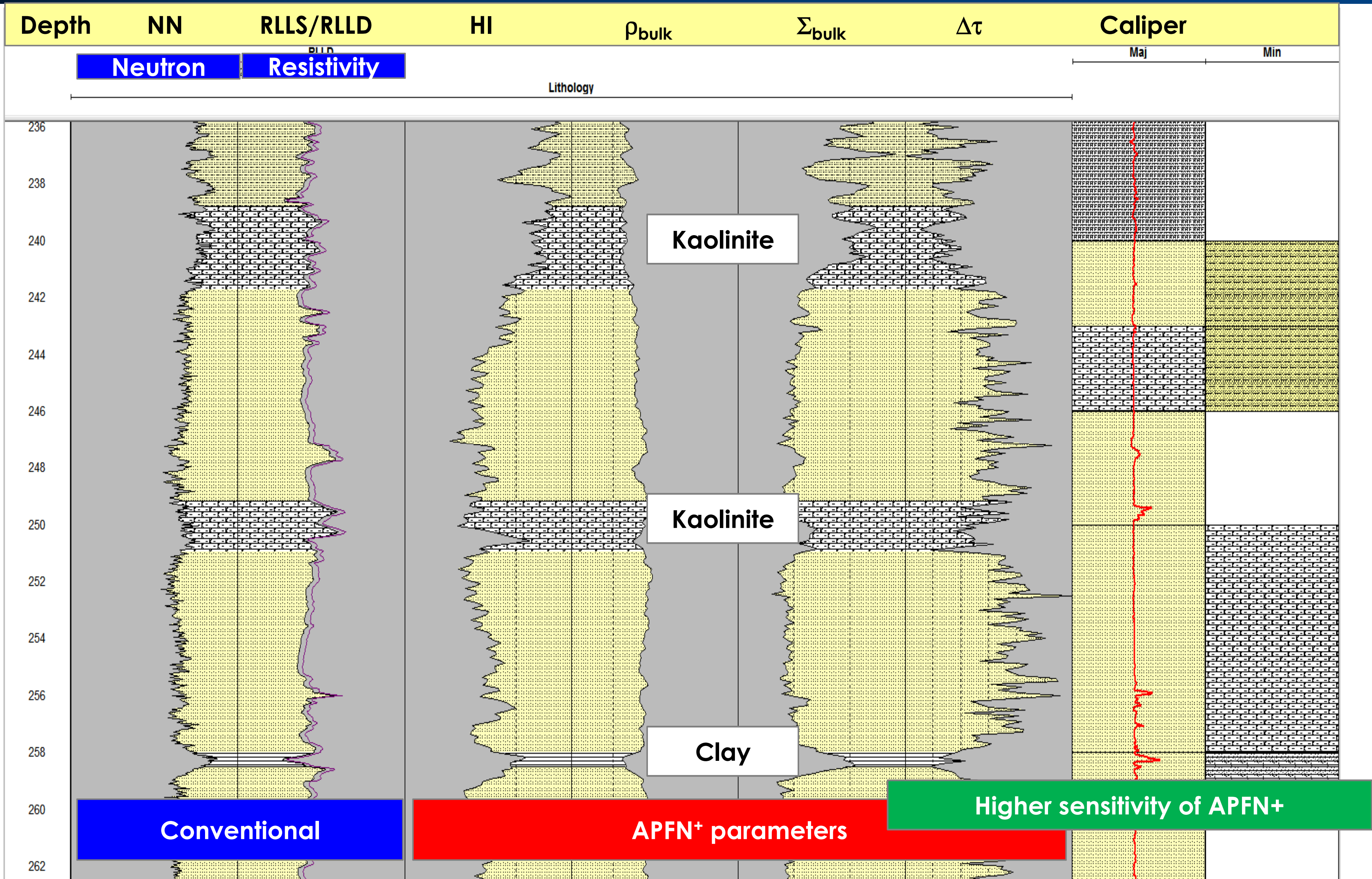

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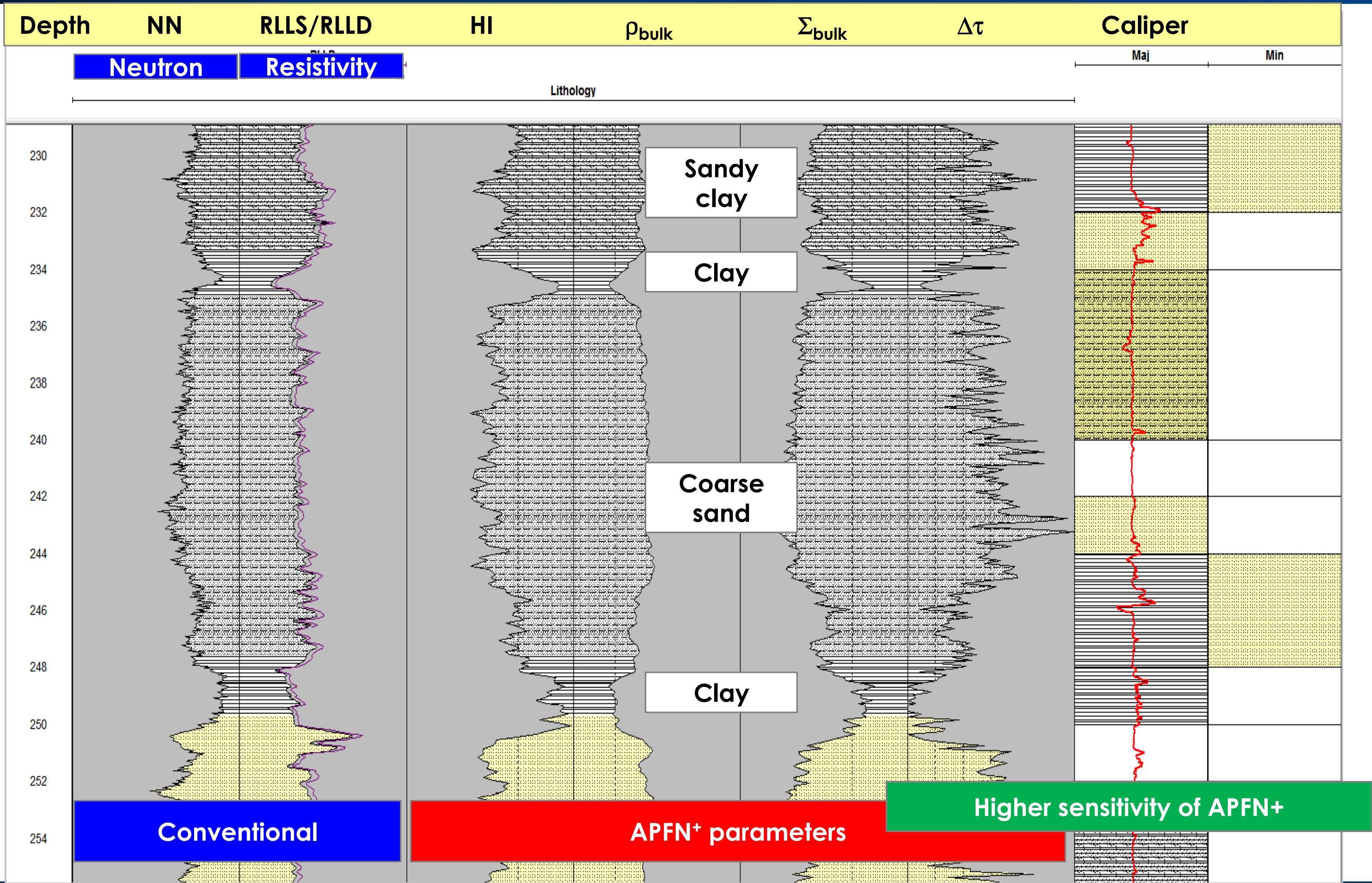
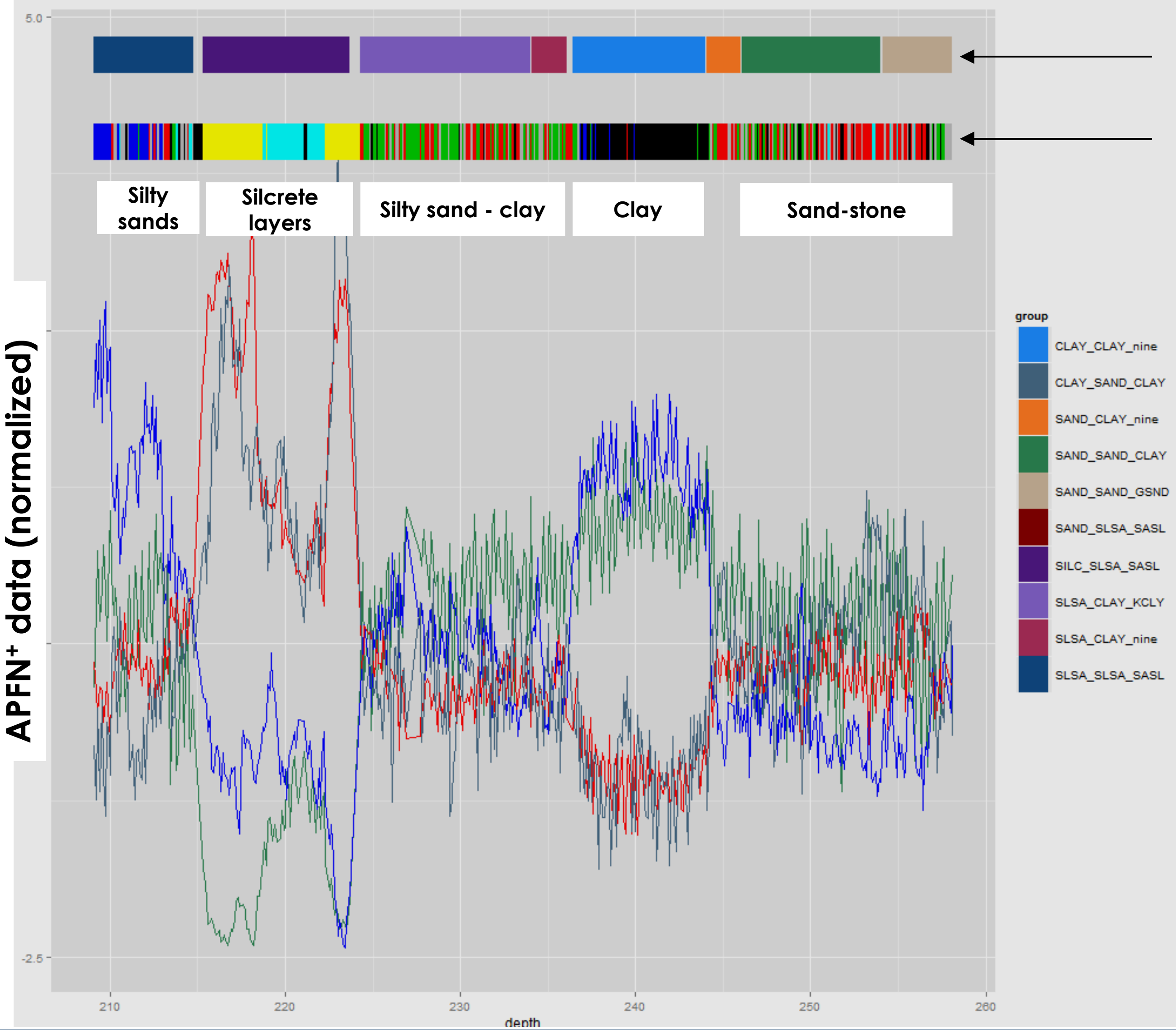


Lithological Profiles from APFN$^+$ (Example)



Conventional (subjective)

APFN$^+$ based algorithm:
- High resolution
- Objective
- Shepard's nomenclature for sand-silt-clay systems (meanwhile extended)

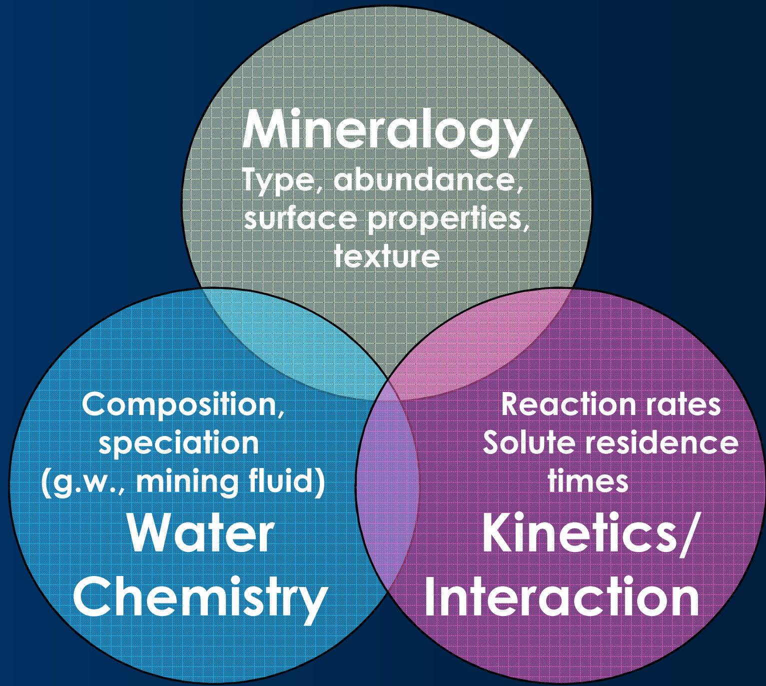
Quantitative lithology

Linked to uranium mineralization (pU_3O_8) and porosity/ permeability

Integrative Power of APFN⁺ - All by ONE Logging Tool

- **Borehole parameters**
  - Borehole diameter (from H^+ capture γ-peak) – validated against calliper tool
  - Inclination (current upgrade)
- **U grade pU_3O_8: PFN technology improved (important corrections)**
  - Increased sensitivity (lower level of detection <0.005 wt%)
- **γ-spectroscopy in passive mode → eU_3O_8 → disequilibrium / Th**
- **Hydrological parameters**
  - Hydrogen index measured → deduced (free-fluid) porosity → permeability
  - Data plausible / validation against core assays and pump tests in progress
- **Lithological logging**
  - Data **quintuple** from neutron channels to 'calculate' lithology (validated on the basis of extensive logging experience since early 2013)
  - Elemental/mineral abundances from γ-ray spectroscopy (γ-rays from thermal-neutron capture and inelastic scattering of fast neutrons)
    → focused on reactive minerals (clays, pyrite, calcareous minerals, lignite, …)
    → organic carbon still under investigation

Substitutes all conventional logging tools / all functions now in ONE TOOL
→ Much more information at much less logging costs



Moving theory to practice:

Reactive-transport modelling for optimizing ISR (acidic) (and simulating mine-closure scenarios)

From Exploration Data to Acid ISR Performance

2D/3D mapping of:

- **Stratigraphy and hydrogeology**
- **U grade (3D/2D GT in ore horizons)**
- **Porosity/permeability**
- **Abundance of reactive minerals (focus: main reductants, other gangue minerals influencing ISR chemistry)**

Regional hydrology model

- Regional groundwater flow
- Hydraulic connectivity (strata/tectonic faults)

→ **Quantify hydrological framework of ISR**

Local hydrological model

- Wellfield design
- Flow rates/PVE
- Wellfield control (flow)

→ **Optimize contact leachant-ore**

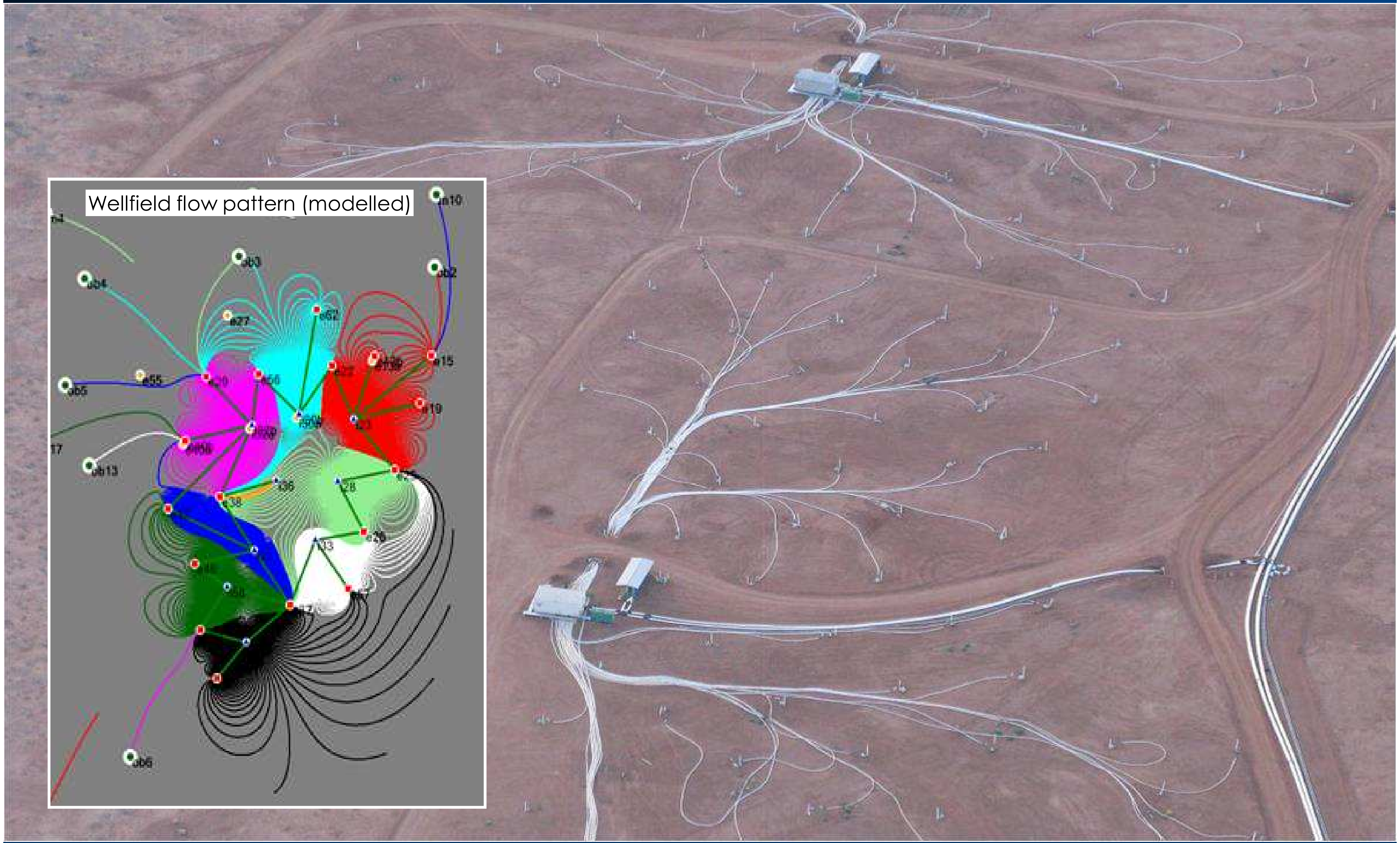
Reactive Transport Model/ Kinetic leach model

- U recovery curves as function of ore-leachant chemistry
- Consumption of chemicals

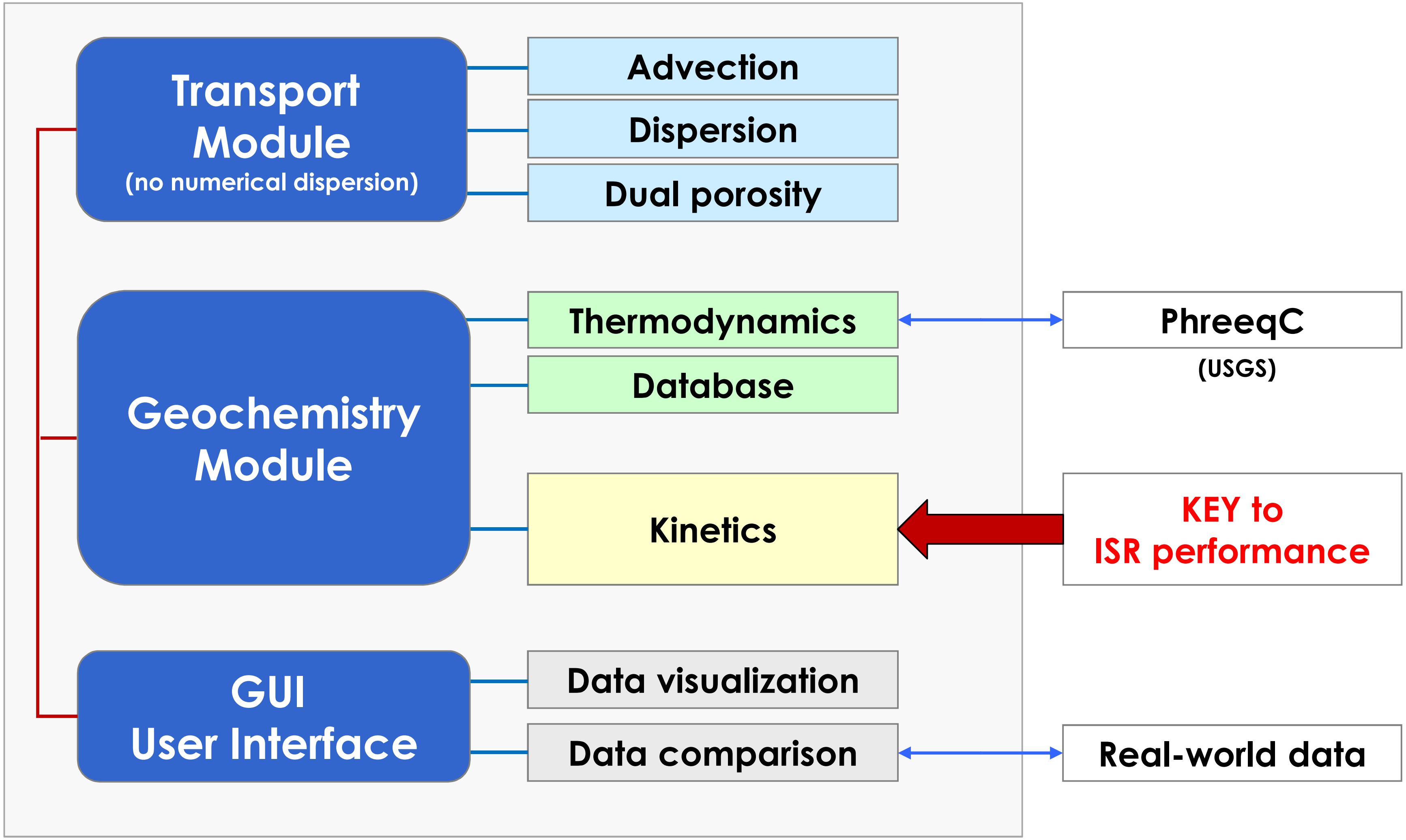
→ **Optimize leachant chemistry**

Control ISR

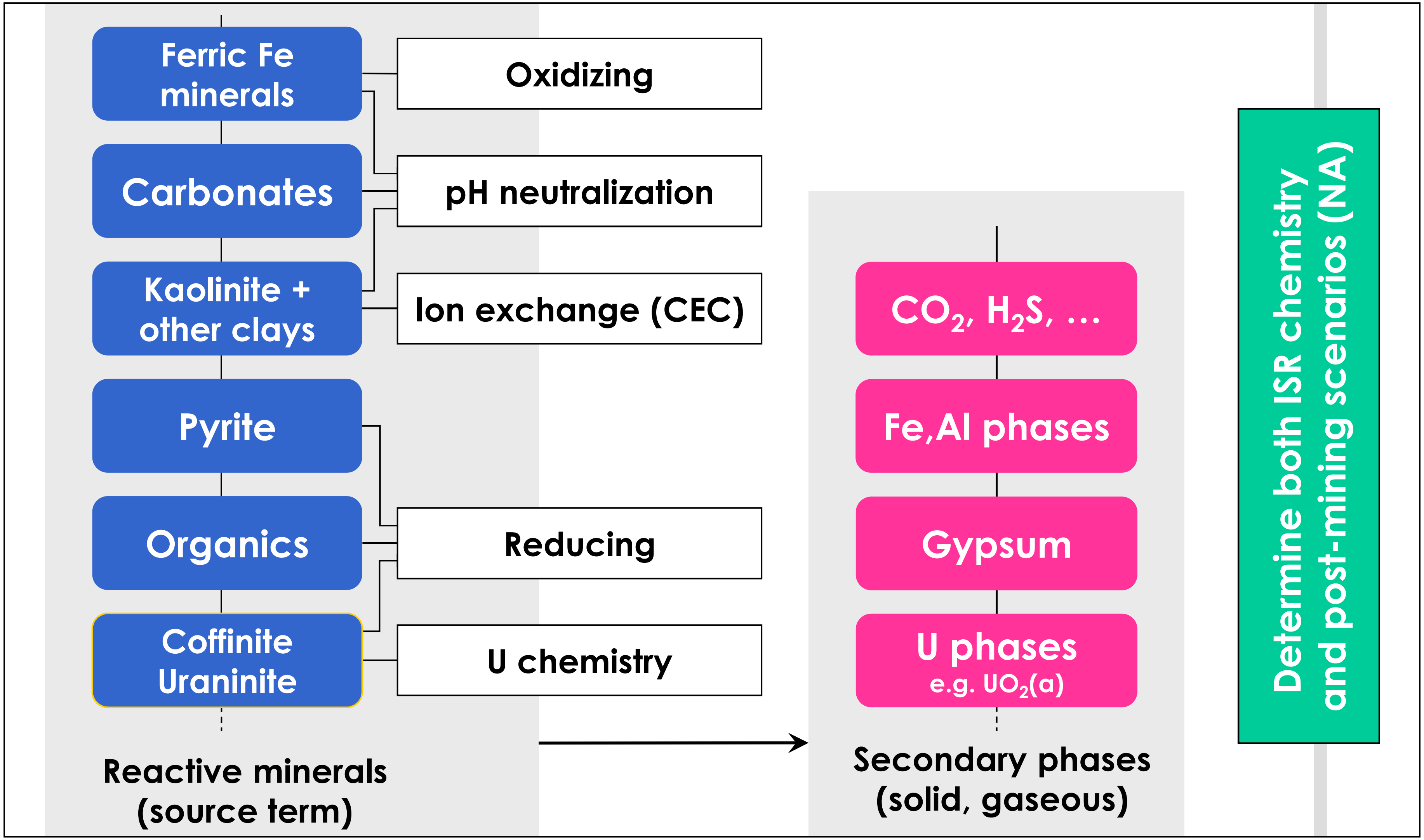
Wellfield Hydrology (Beverley North Example)



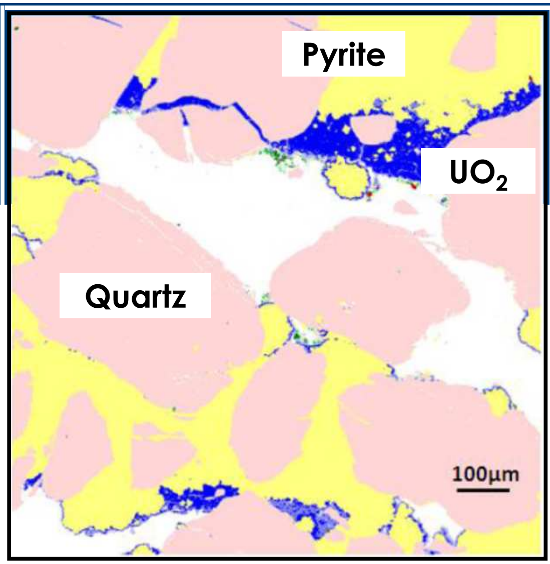
Reactive Transport Model (UIT Code TRN)



Primary Mineral Phases – Secondary Phases



In-situ Leaching Kinetics



pH value

$$Rate = r_0 \cdot [H^+]^a \cdot [A^{e-}]^b$$

Concentration of e⁻ acceptors
= absolute oxidation potential

Well quantified for:

- **Uraninite/coffinite**
- **Pyrite** } **Main competing reductants**
- **Organics**

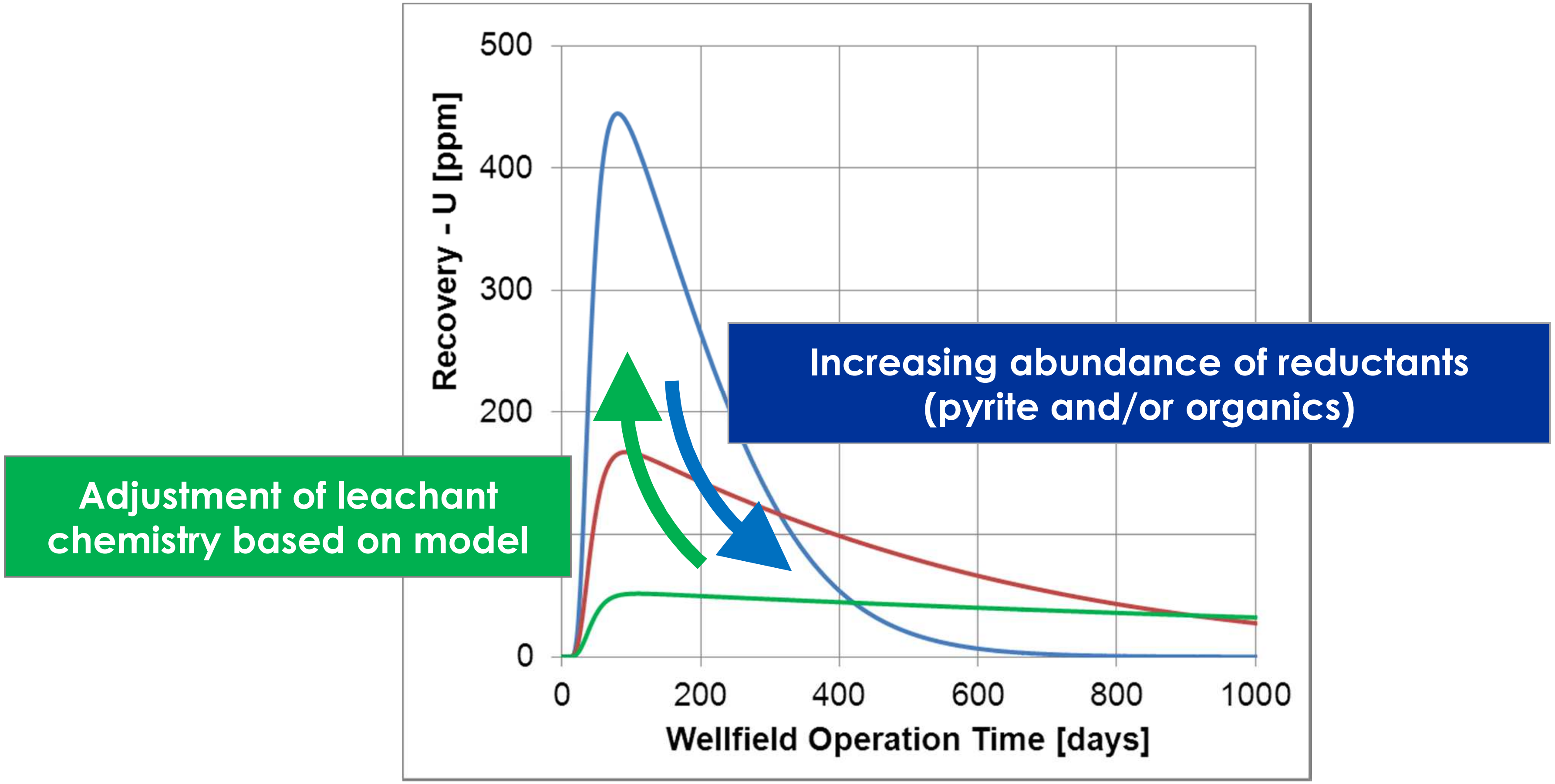
+

- **Main neutralizing minerals** → **Acid consumption**

Rates from literature as far as available and quantified by lab testing. Validated by real wellfield performance (Beverley North)

Influence of Reducing Minerals and Mitigation

Demonstration of constraint leaching and countermeasures



Catalyzed ISR – Solving the REDOX Puzzle

Based on

- **Wellfield parameters including**
  - Effective pore volume and flow rates (from hydrological modelling), both determining the pore volume exchange rate
- **Mineral abundances including**
  - Uranium ore grade
  - Abundance of sulfidic minerals (e.g. pyrite)
  - Abundance of organic matter (quantified as TOC)

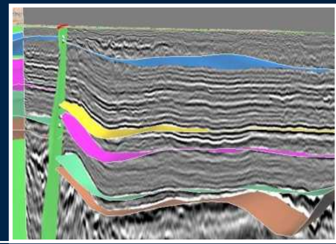
the model identifies the chemical conditions (pH, oxidation potential) that maximises U leachability and recovery.

→ Recipe for conditioning/refortifying the injection fluid to catalyze U leaching efficiently (to overcome interference by competing reductants).

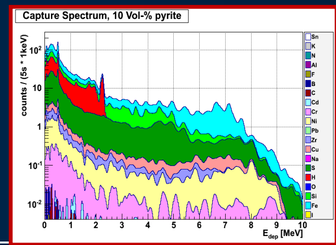
- **Field-tested in 2012/13 and meanwhile successfully implemented.**
- **Used for planning purposes and ISR control during operation.**
- **Key to reduce $/lb costs significantly.**

SUMMARY – It works:

- Adaption of advanced seismic methodology of oil&gas industry (1-5 km) to high-resolution shallow seismic in sedimentary basins (< 500 m)



- Advanced (self-correcting) PFN technology + lithologic logging in just one tool (launched at Heathgate since March 2013)



- Move theory to practice: Kinetic leach model (reactive transport) implemented to optimize and control acid ISR