IAEA-UNECE Interregional workshop on uranium, coal and oil & gas classification:
Towards a better understanding of energetic basins and application of UNFC-2009

Project Number & Title: INT2/019

Developing Technology and Management of Sustainable Uranium Extraction

Ulaan Baatar, Mongolia
August 16-19th, 2016

Organizer
The International Atomic Energy Agency (IAEA)
in collaboration with the Government of Mongolia through the Ministry of Mining, Mongolia

Earth. Insight. Values.

IAEA-UNECE Interregional workshop on uranium, coal and oil & gas classification:
Towards a better understanding of energetic basins and application of UNFC-2009

Innovation Case Studies

Industry-best-practice ISR

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DMT / TÜV Nord Innovation Projects

Mining Technology

- Development of innovative exploration and extraction technologies (upgrade for existing technologies); e.g. ISR of non-uranium resources.
- Currently 45 R&D projects & proposals (as of August 2016).
- Some highlights: Automated mining via smart sensor monitoring, Technology in nuclear waste disposal technologies, PG NORM removal & land management, smart-seismic shallow target surveying
- EU standardization initiatives.
- 6D-BIM – *Building Information Modeling* (4D=3D+time, 5D=4D+cost, 6D=5D+train schedule).
- Environmental sustainable mining now anchored in company guidelines.

Internationalisation

- Core Partner in EIT Raw Materials initiative
- New branches: *DMT Turkey*, *DMT Middle East*, *DMT Canada*

Global Megatrends

Growing demand in critical technology metals

- Focus on secondary resources and deep mines
- Increasing demand for automated mining and smart sensors (e.g. automated core scanning)
- Certification of resource origin

Changes in energy production

- Increasing demand for automated mining and smart sensors (e.g. automated core scanning)

Increasing Urbanization

- Mining needs to become smart and more sensitive

Summary of Roll-Front History

- ***Gruner*** **(1956) describes the multiple accretion process to concentrate uranium in sediments.**
- ***Harshman*** **(1962) recognizes alteration as a guide to uranium deposits in the Shirley Basin, and published pictures and diagrams of roll fronts being mined in open pit mines at the time.**
- ***Hans Adler*** **(1964) discribes a concept of genesis of „ore-rolls“ for sandstone-type uranium deposits.**
- ***Shawe & Granger*** **(1965) summarize „ore-rolls“.**
- ***Bruce Rubin*** **(1970) describes roll-front zonation using a diagram that is still widely used today.**

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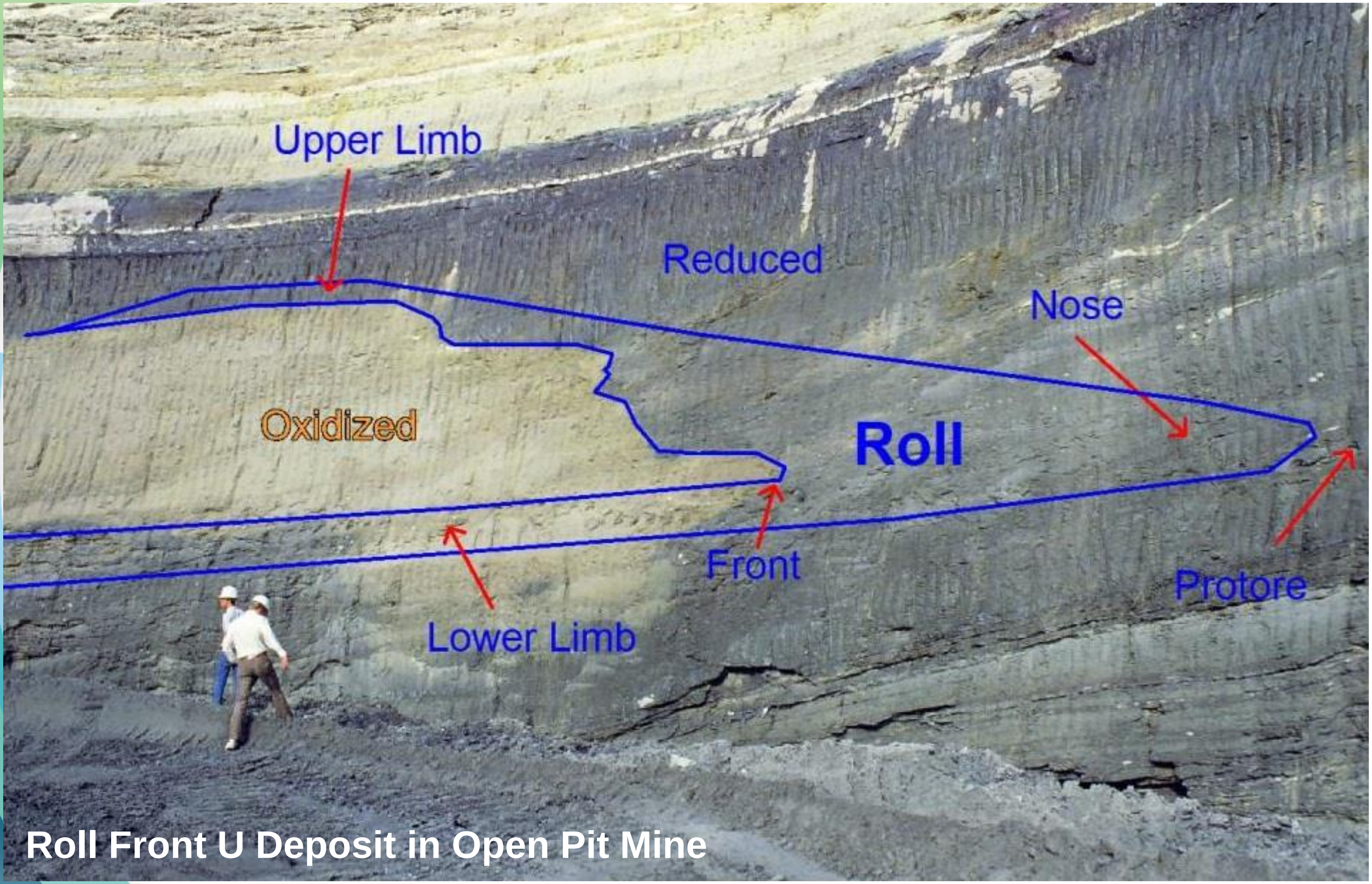
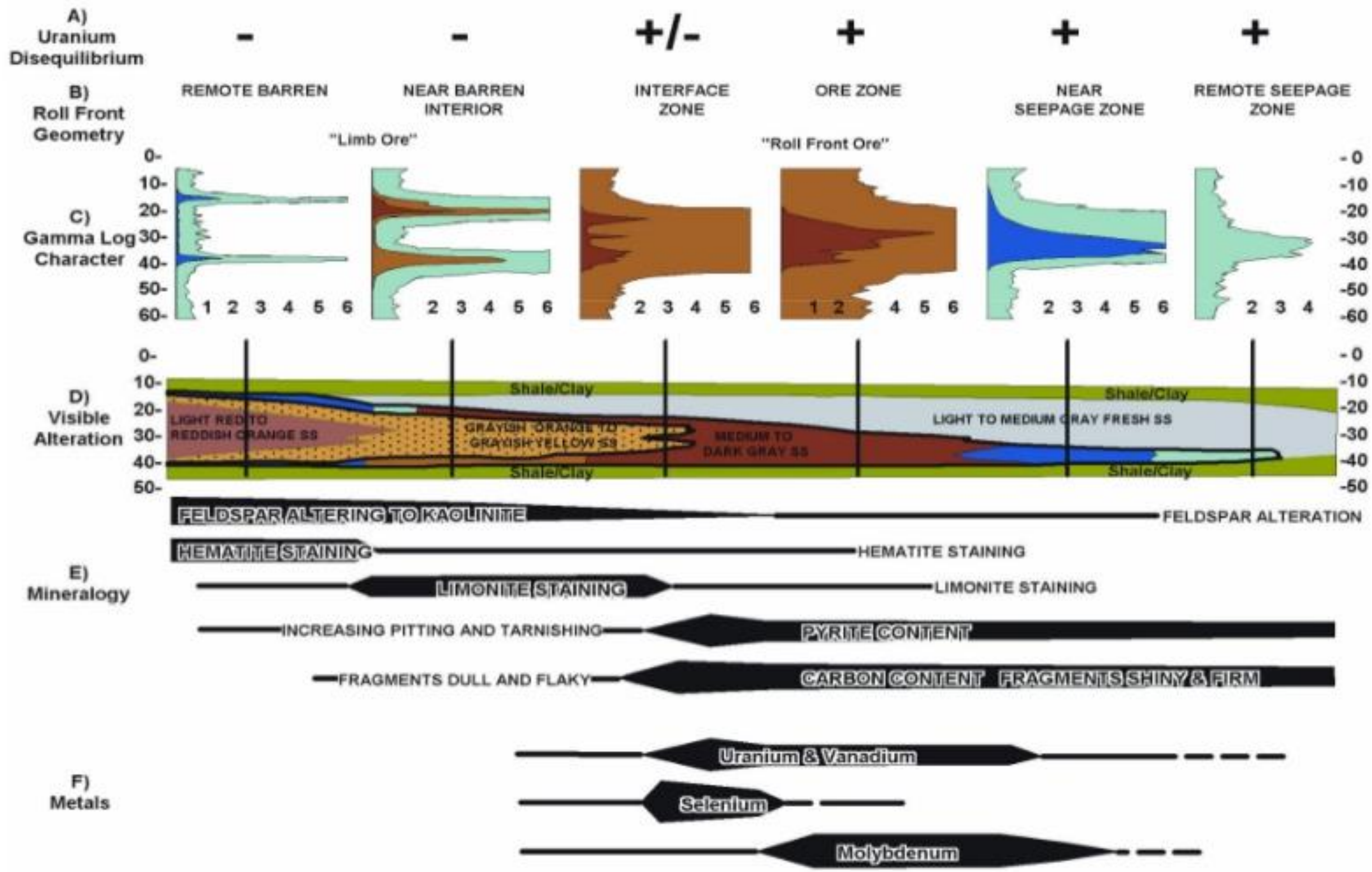
Mapping of sedimentary uranium roll-front deposits



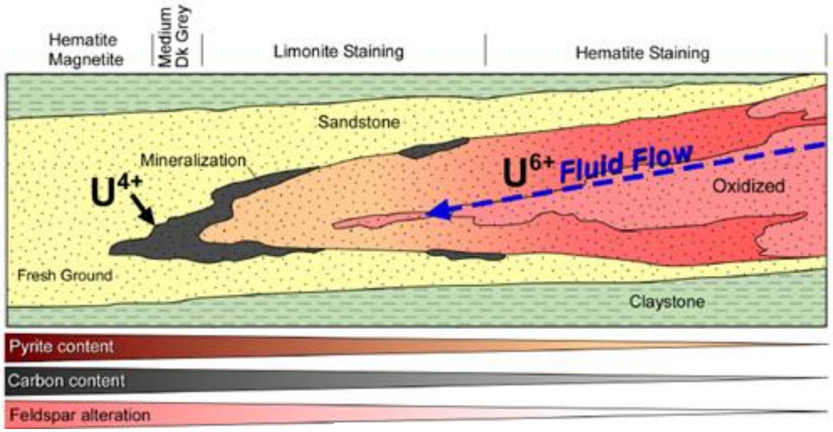
Mapping of Basic Roll-Front Characteristics[9,14,15]



[9] Rubin (1970), [14] Harris & King (1993), [15] Ur-Energy (2010)

Formation of a Roll-Front System[9,10]

- **Uranium sources**
  - Hydrothermal fluids
  - Precambrian vein deposits
  - Precambrian U-enriched granites and derived arkoses
  - Uraniferous volcanic tuffs



Modified from Rubin (1970), Granger & Warren (1974)

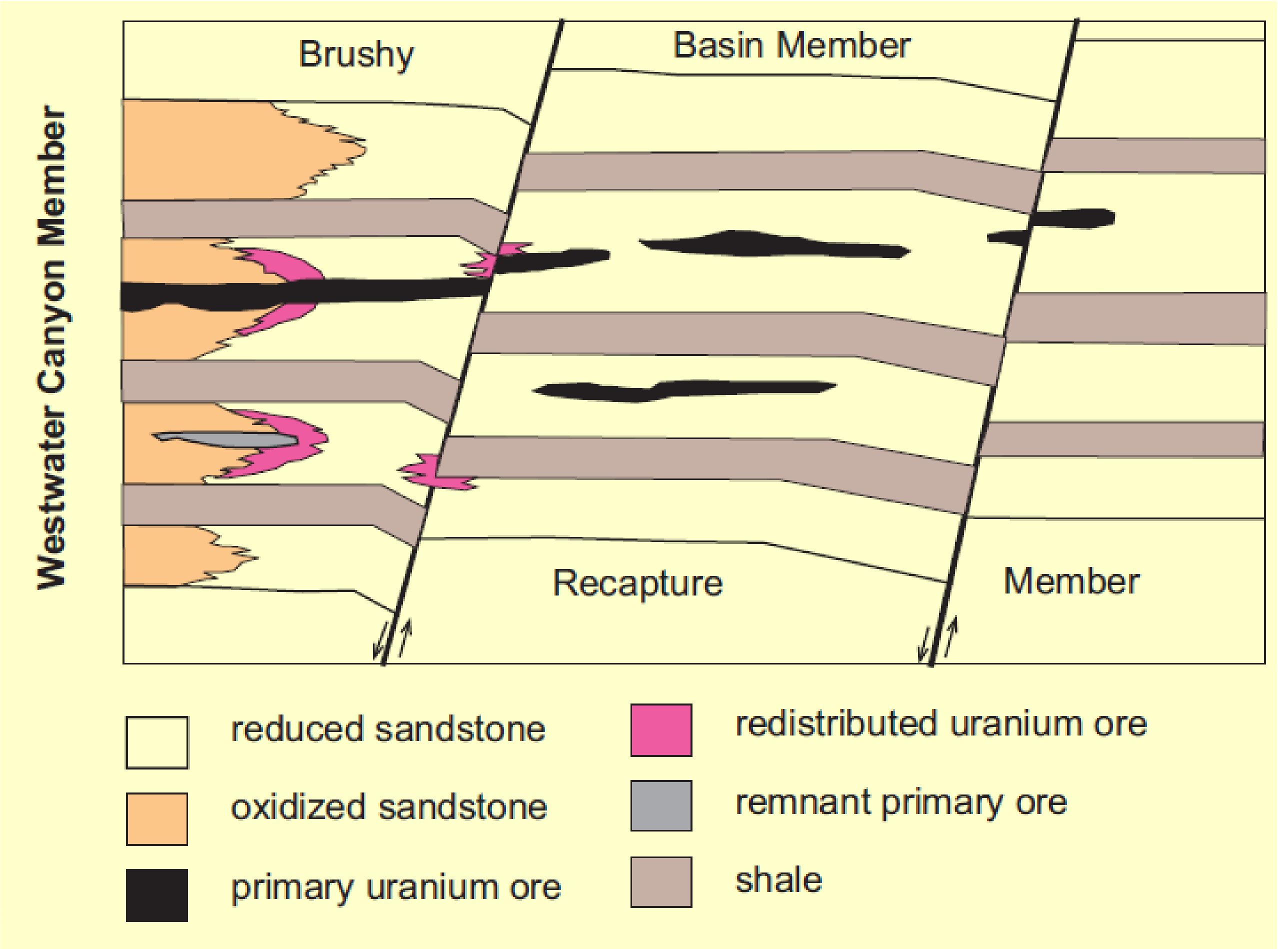
- **The two latter, individually or in combination, are most likely sources for most roll-front deposits in sandstone.**
- **Uranium is transported in oxidizing surface and groundwaters.**
- **Uranium is precipitated at reduction-oxidation (redox) interface.**
- **Redox interface migrates downdip with continued oxidation and precipitation.**

[9] Rubin (1970), [10] Granger & Warren (1974)

Multi-stage U Ore Deposit Roll-Front Formation

Multi-stage ore deposit formation: Probably multiple roll-front deposits of different scale[4].

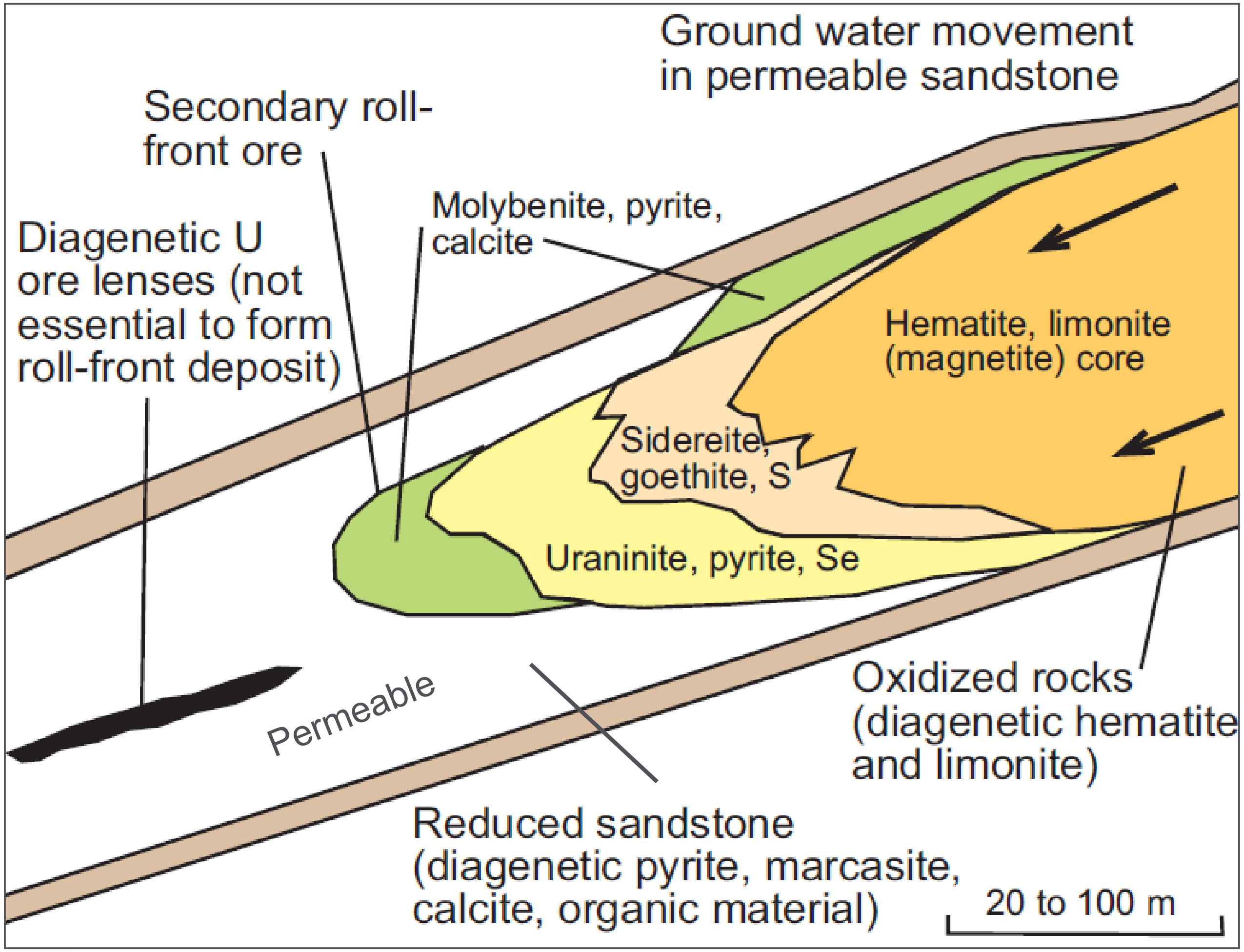
Remnant primary ore may resemble disrupted roll-front (partially remobilized and redistributed).



[4] McLemore, V. (2007) Geological controls of uranium recovery of Grants uranium deposits, New Mexico, GSA Denver Annual Meeting, Colorado, Paper No. 92-2.

'Architecture' of (redistributed) roll-front deposits

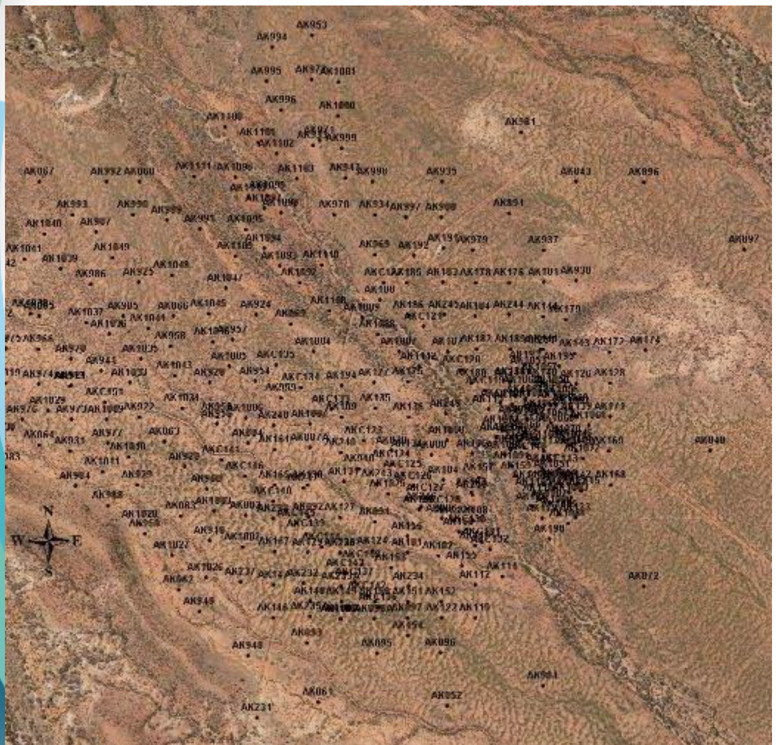
Sketch of the formation of redistributed sandstone uranium deposits (e.g. New Mexico[4]).



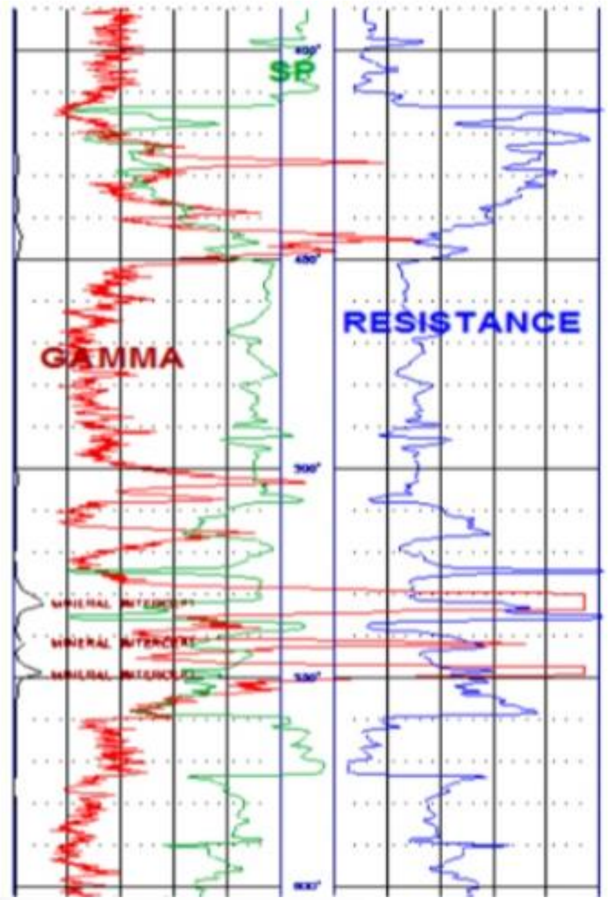
[4] McLemore, V. (2007) Geological controls of uranium recovery of Grants uranium deposits, New Mexico, GSA Denver Annual Meeting, Colorado, Paper No. 92-2.

Drilling Exploration for Roll-Fronts/Paleochannels

- Exploration and delineation drilling to locate paleochannels.
- Many U ore deposits are *Measured Resources* due to the dense exploration drill grid pattern required to identify paleochannel pattern.



Mapping of Uranium Roll-Fronts using Gamma-Resistivity Log Used in Geophysical Logging of Bore Holes[11]



- Typical ISR logging measures gamma (radioactivity) and electrical conductivity (resistivity in sedimentary formation changes).
- Mineral intercepts are commonly defined as:

Thickness – Average Grade – Depth / GT

(GT = Grade x Thickness)

- Example

3.1m – 0.12% eU_3O_8 – 162m / 0.37

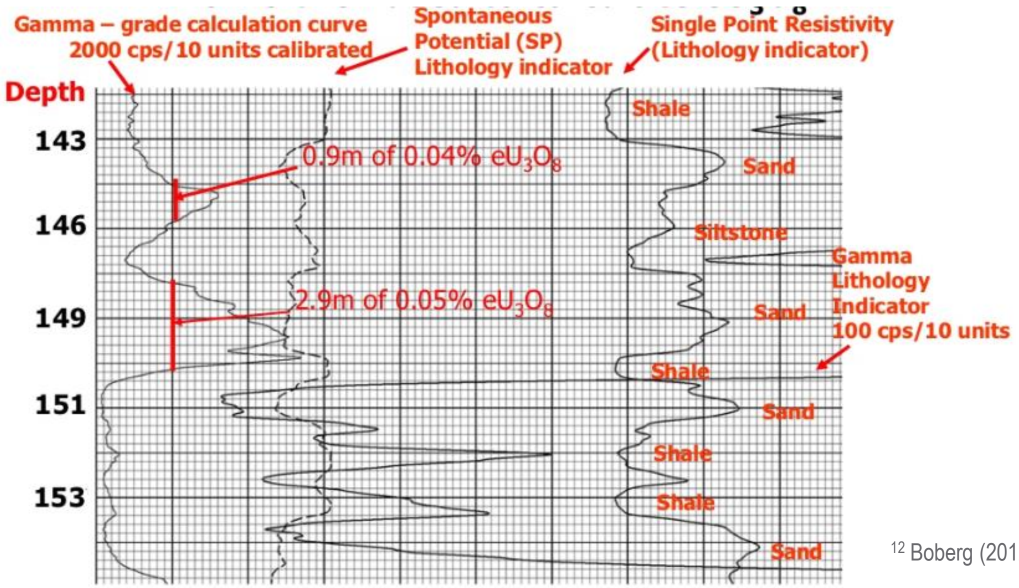
GT = 0.37 (3.1m x 0.12%)

[11] Van Holland (2010)

Calculation of *Equivalent Uranium* (eU_3O_8)[12]

Downhole probe measures natural gamma radiation released by uranium daughter products (mainly Bismuth 214, not Uranium) which is then used to calculate eU_3O_8

Varying chemical nature of decay products (e.g. Rn is a short-lived gas easily moved by groundwater) results in each decay product being dissolved and moved differentially, resulting in disequilibrium in the uranium deposit.



[12] Boberg (2012) IAEA Meeting Vienna

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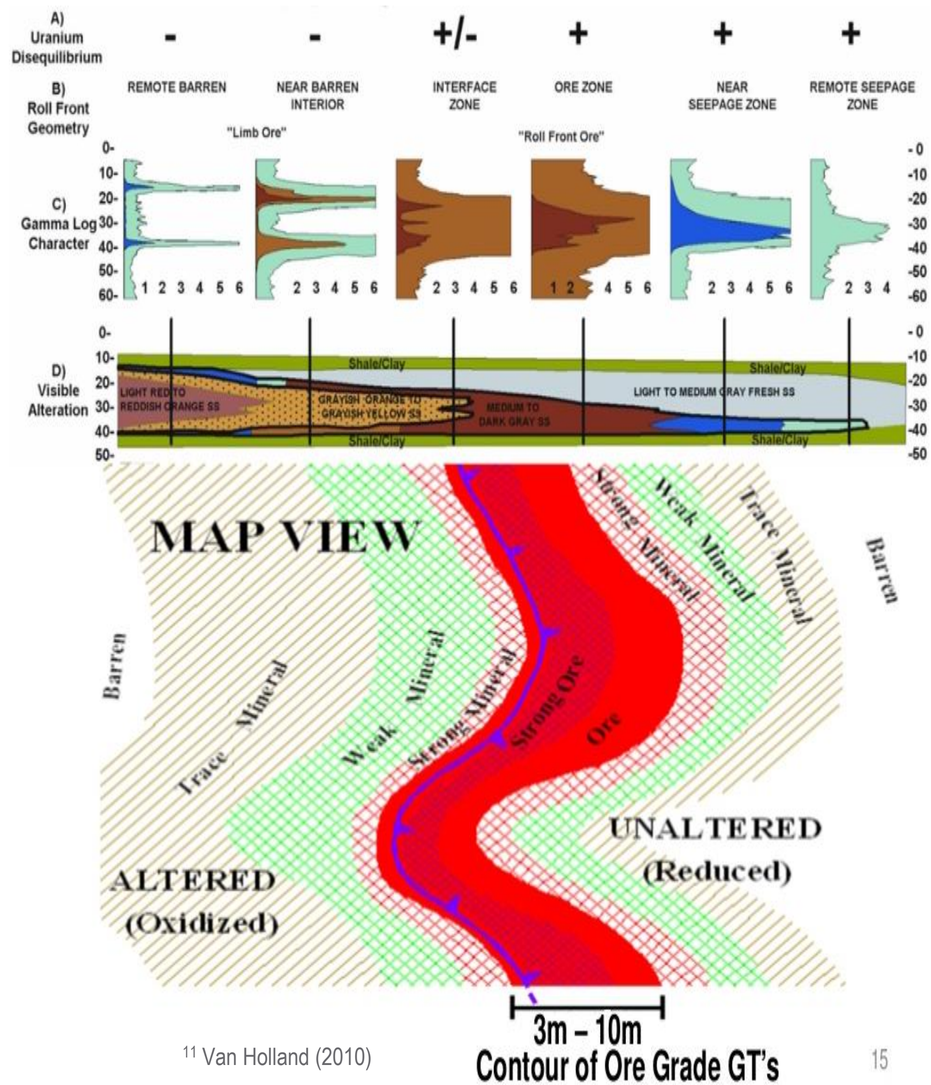
Mapping of sedimentary uranium roll-front deposits

Mapping of a Roll-Front

- Differential gamma log character indicates presence of uranium roll-front.
- Use gamma patterns to reconstruct roll-front geometry (e.g. upper limb, lower limb, nose, protore).
- Correlate drill logs of gamma log patterns to map spatial extension of roll-front.
- Generate contours of ore grade GT's for roll-front (RedOx) contouring and mapping.



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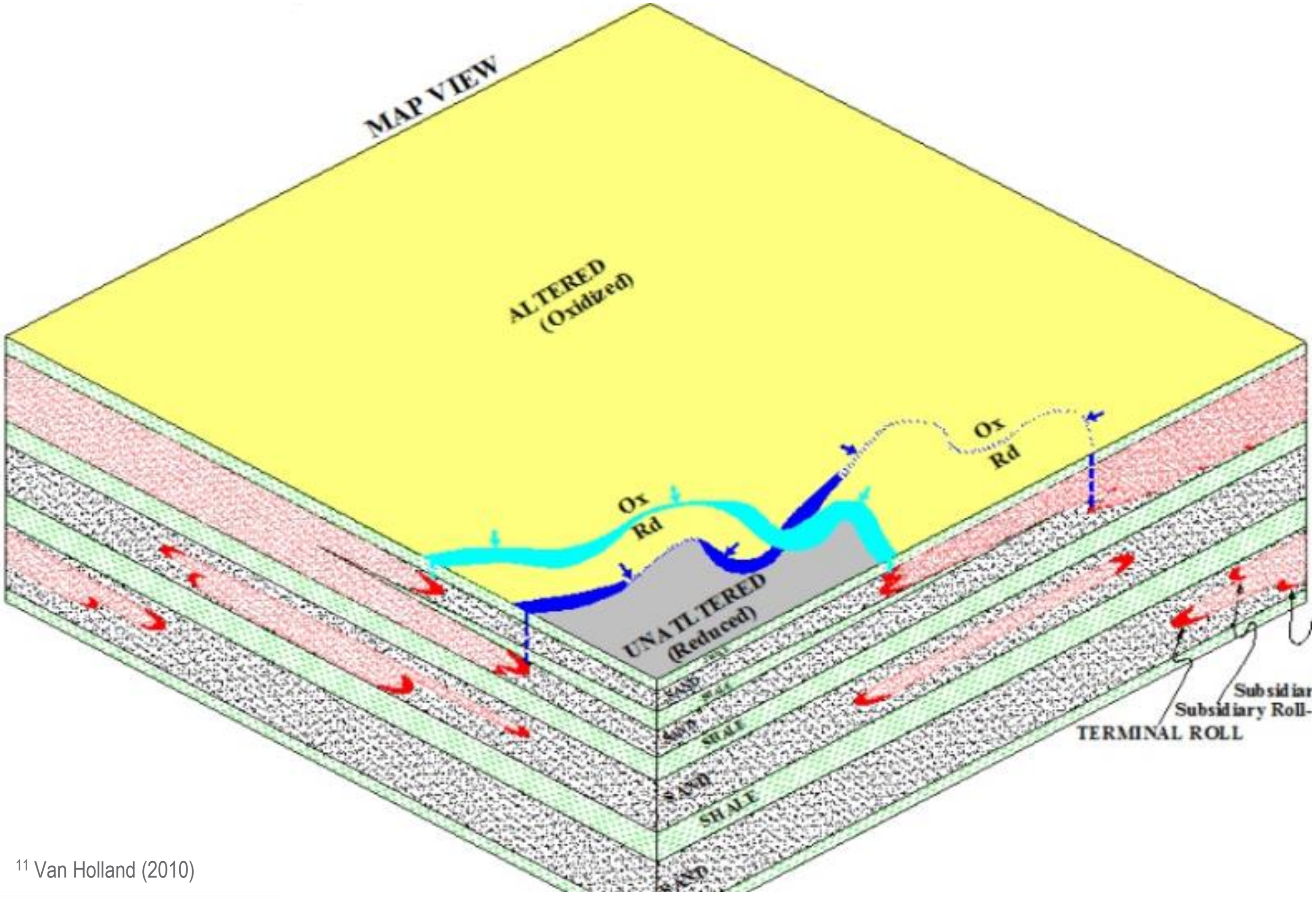
Mapping of sedimentary uranium roll-front deposits

Model-Mapping of Roll-Fronts in an Upper Sand[11]



[11] Van Holland (2010)

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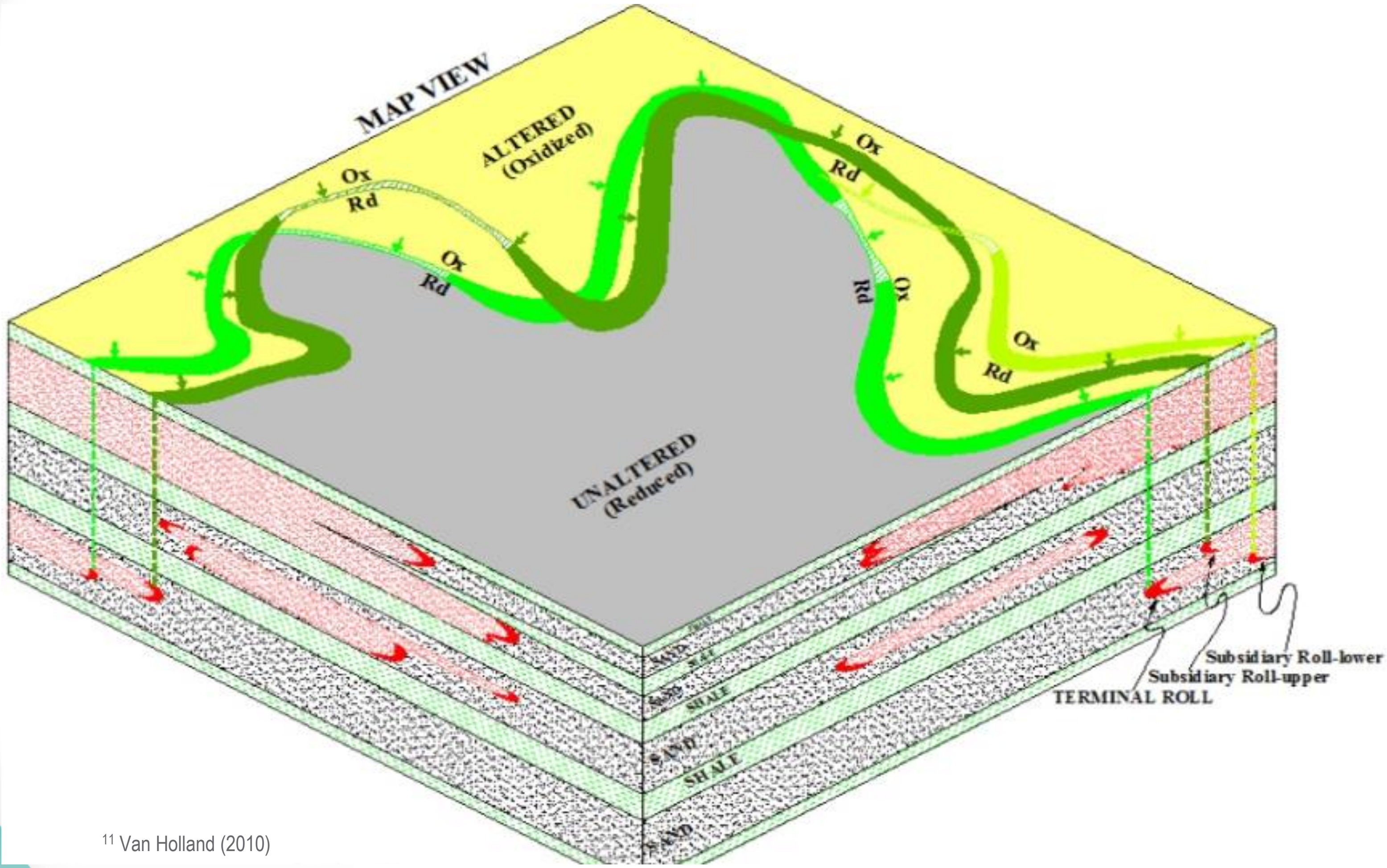
Mapping of sedimentary uranium roll-front deposits

Model-Mapping of Roll-Fronts in a Middle Sand[11]



[11] Van Holland (2010)

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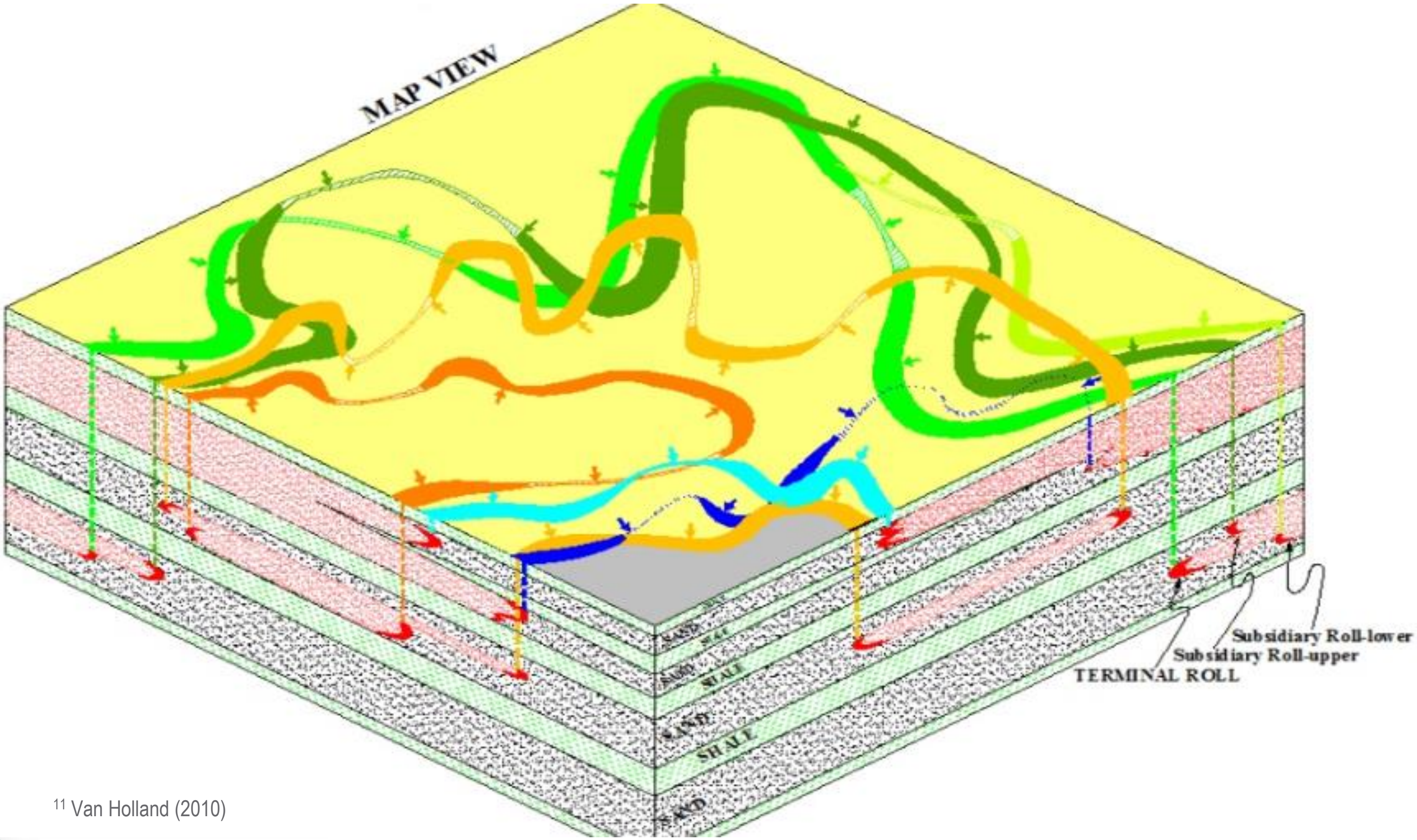
Mapping of sedimentary uranium roll-front deposits

Model Composite Mapping Showing the Complexity of Roll-Fronts in all 3 Sands[11]



[11] Van Holland (2010)

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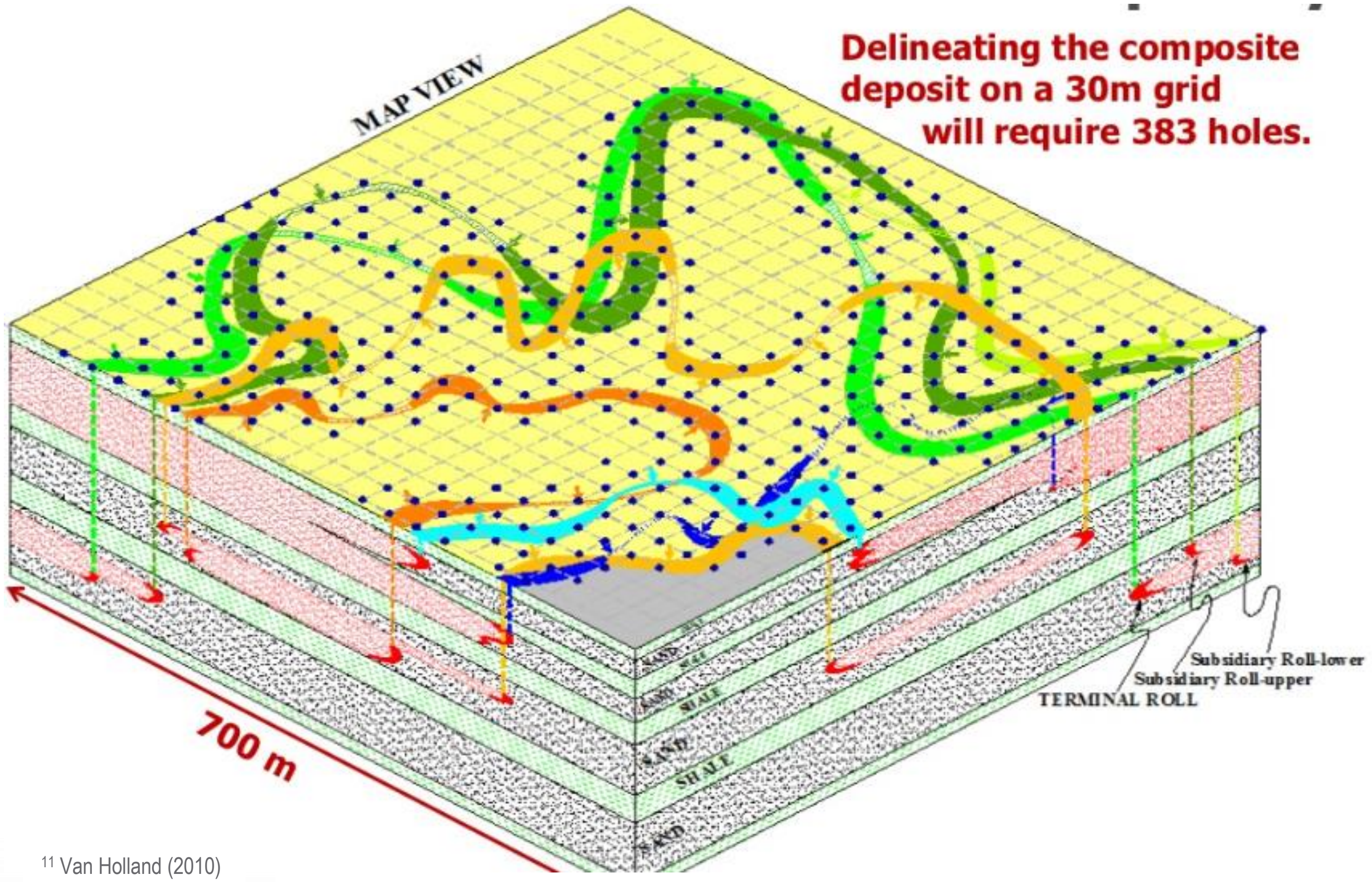
Mapping of sedimentary uranium roll-front deposits

Model Drill Pattern to Test Roll-Front Complexity[11]

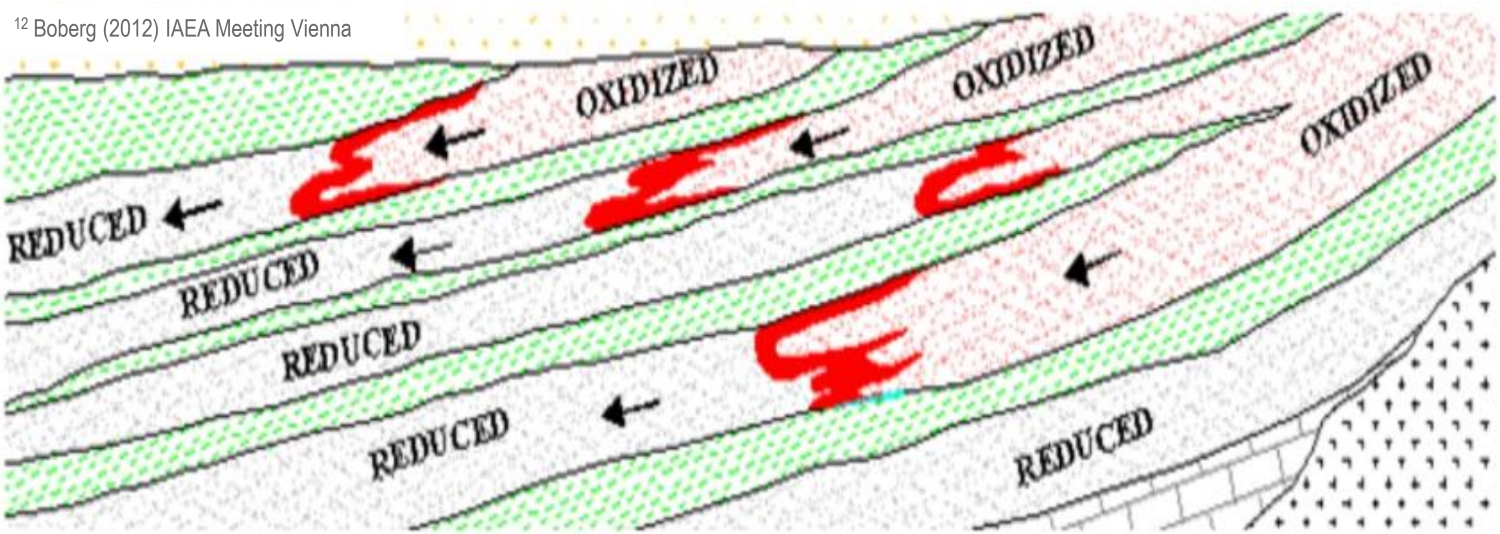


[11] Van Holland (2010)

‚Stacking‘ of Roll-Fronts in Multiple Sands

- **It is not uncommon for multiple sand layers in a sedimentary sequence to contain multiple roll-fronts.**
- **The complexity of the 3D view of changes in a roll-front combined with the variations in the shape and dimensions of the altered tongue make mapping of each individual roll-front a challenge, let alone multiple stacked fronts.**

[12] Boberg (2012) IAEA Meeting Vienna



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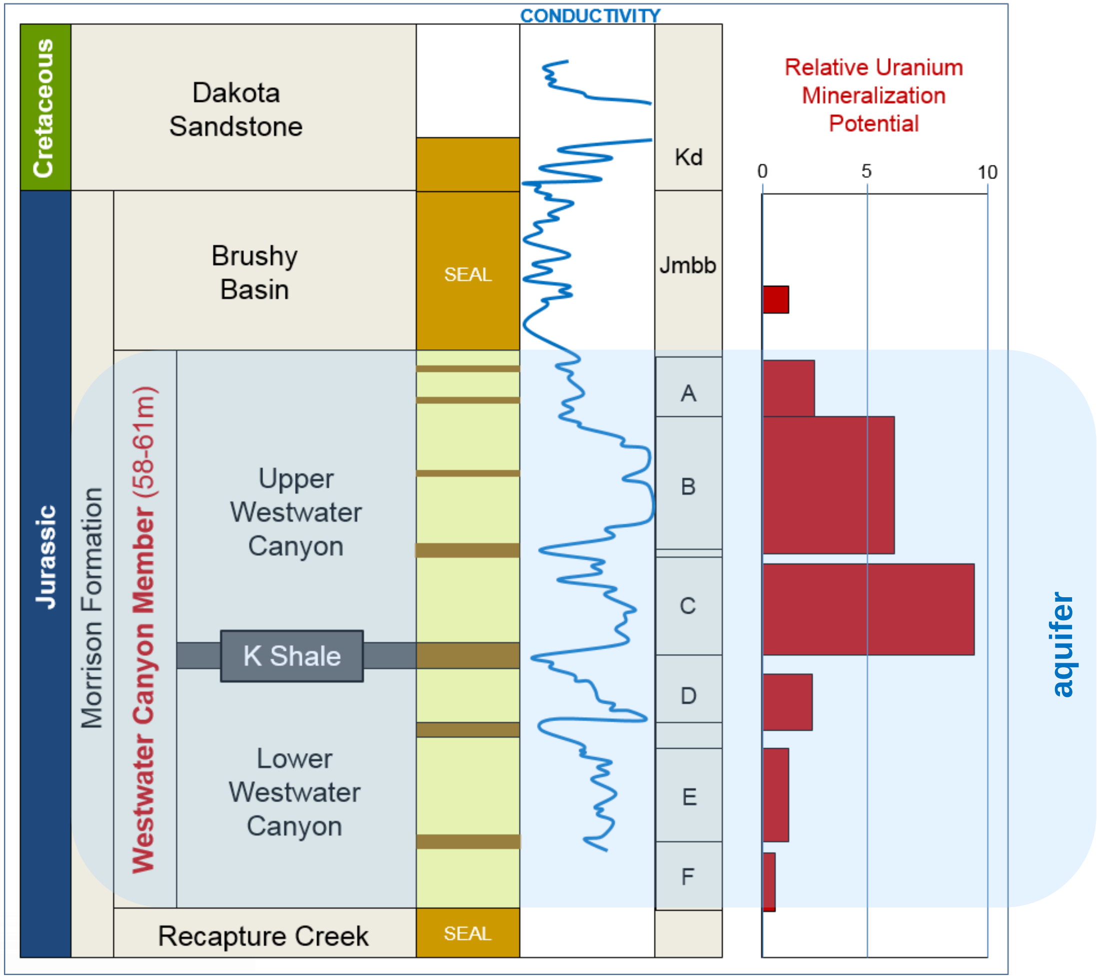
Mapping of sedimentary uranium roll-front deposits

‚Stacked‘ Roll-Fronts in Multiple Sands



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Applications of ISR and UNFC-2009

euREEphos

proposal stage

- *MAScIR* (Morocco), *Fertiberia* (Spain), *Hellagrolip* (Greece), *Agropolychim* (Bulgaria), MMI Bor (Serbia), *Phalaborwa* (South Africa).
- U/Th variable, mainly in phosphoric acid
- P acid: ca. 10 - 20% REE
- PG: ca. 80 - 90% REE
- Physical,chemical & biological engineering of PG for REE & radionuclide extraction.
- Resource classification by UNFC-2009 code

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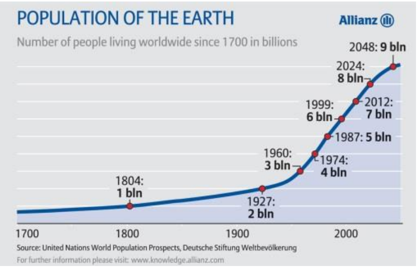
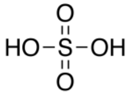
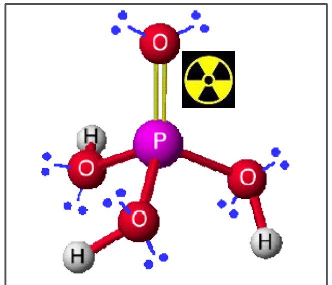
ca. 600 kg REE/MW







Phosphoric Acid - H_3PO_4

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Applications of ISR and UNFC-2009

BIOMOre

- **New In-Situ Leaching Concept for Cu Recovery from Deep Sedimentary Deposits using Biochemistry Technology**
  - EU-funded: 8.4 M€ (2014 – 2017)
  - Industry-led: KGHM Cu mine Poland (23 companies & universities).
  - Bio-chemical leaching of Cu ore (incl. hydrofracturing).
    - Research on bioleaching processes. Construction and operation of undergound test reactor in active Cu mine (KGHM Poland) to demonstrate ISR bioleaching incl. hydrofracturing and leaching of Cu ore (+ Zn, Ni, Co).
  - Turns deep European mineral resources (<1.5 km) into accessible reserves.
  - Sustainable and economic *Green Mining Project* (no tailings/hazardous chemicals, low CapEx/OpEx).
  - Potential *Mine of the Future*

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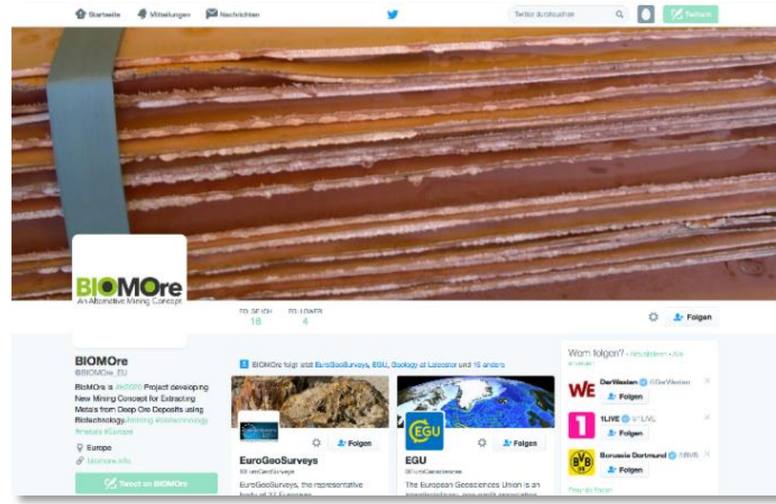
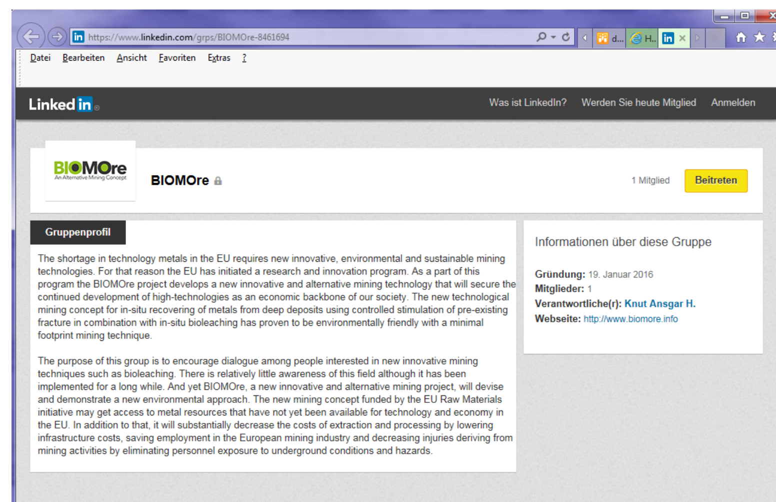
Applications of ISR and UNFC-2009





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Strategic Raw Materials for Europe

STRADE

- EU H2020 funded 1.977.509 €
- 3-yrs (12/2015 – 11/2018)
- Addresses long-term security and sustainability of European raw material supply from EU and non-EU countries.
- Brings together governments, industry, and civil society.
- Focus on strategic, socio-economic and environmental impacts of raw material supply.
- Delivers policy recommendations for an innovative EU strategy on future EU mineral raw-material supplies.

Partners: Öko-Institut e.V. (Institut für angewandte Ökologie / Institute for Applied Ecology); DMT; SNL Financial; projekt consult (Member of GFA Consulting Group); University of Dundee, Centre for Energy, Petroleum and Mineral Law and Policy; Georange (www.georange.se); University of the Witwatersrand, Johannesburg

Action Areas

European cooperation strategy with resource-rich countries

- Reviewing, engaging, revitalizing

Strengthening the raw materials sector

- Internal competitiveness
- Increasing Competitiveness
- Supporting international competitiveness

Europe's role in sustainable raw material production & supply

- Foundation
- Implementation
- International Resource Governance Alliance (IRGA)

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