



भारतीय प्रौद्योगिकी
संस्थान
(भारतीय खनि विद्यापीठ)
धनबाद

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**INDIAN INSTITUTE
OF TECHNOLOGY**
(INDIAN SCHOOL OF MINES)
DHANBAD

GPC510 - Well logging

Semester - Winter 2024; Lecture - 10

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TEACHING OUTLINE

Week 5/6

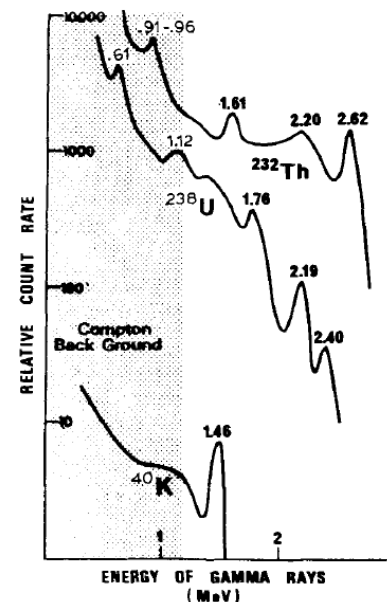
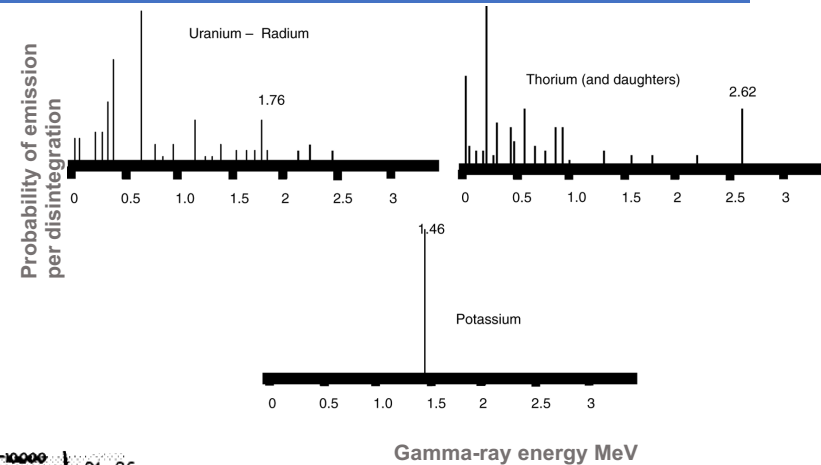
[Tutorial 14](#) – Natural gamma ray spectrometry tool and measurement principle

AGENDA

- Natural gamma ray spectrometry
- Tool specification
- Computation of individual component
- Calibration
- Applications [hydrocarbon, sedimentology, mineral exploration]

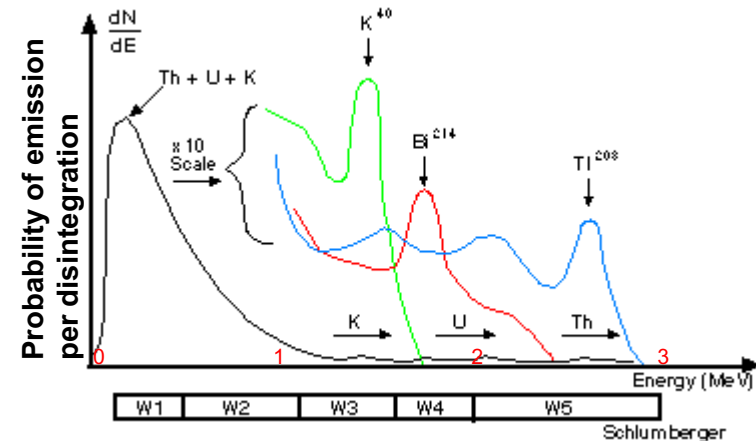
NATURAL GAMMA SPECTROMETRY (NGS)

- Conventional tool measure total gamma ray radiation irrespective of energy
- NGS tool measure gamma rays with energies ranging from 0.5 to 2.5 MeV
- Total gamma ray spectrum composed of (i) high energy region (ii) low energy region resulting from Compton scattering + lower energy emission from thorium and uranium
- In high energy range, three most distinctive peaks of natural radioactive minerals (Potassium ^{40}K , Uranium ^{238}U , Thorium ^{232}Th)



TOOL DESCRIPTION

- The tool measures the counting rates in a number of windows of specific energy bands
- Different service company have multiple measurement windows (SLB – uses five windows , Atlas – three windows)
- High energy region is approx. 10% of the spectrum in terms of counting rates
- Combination of low and high energy spectrum helps to reduce statistical uncertainty



TOOL DESCRIPTION

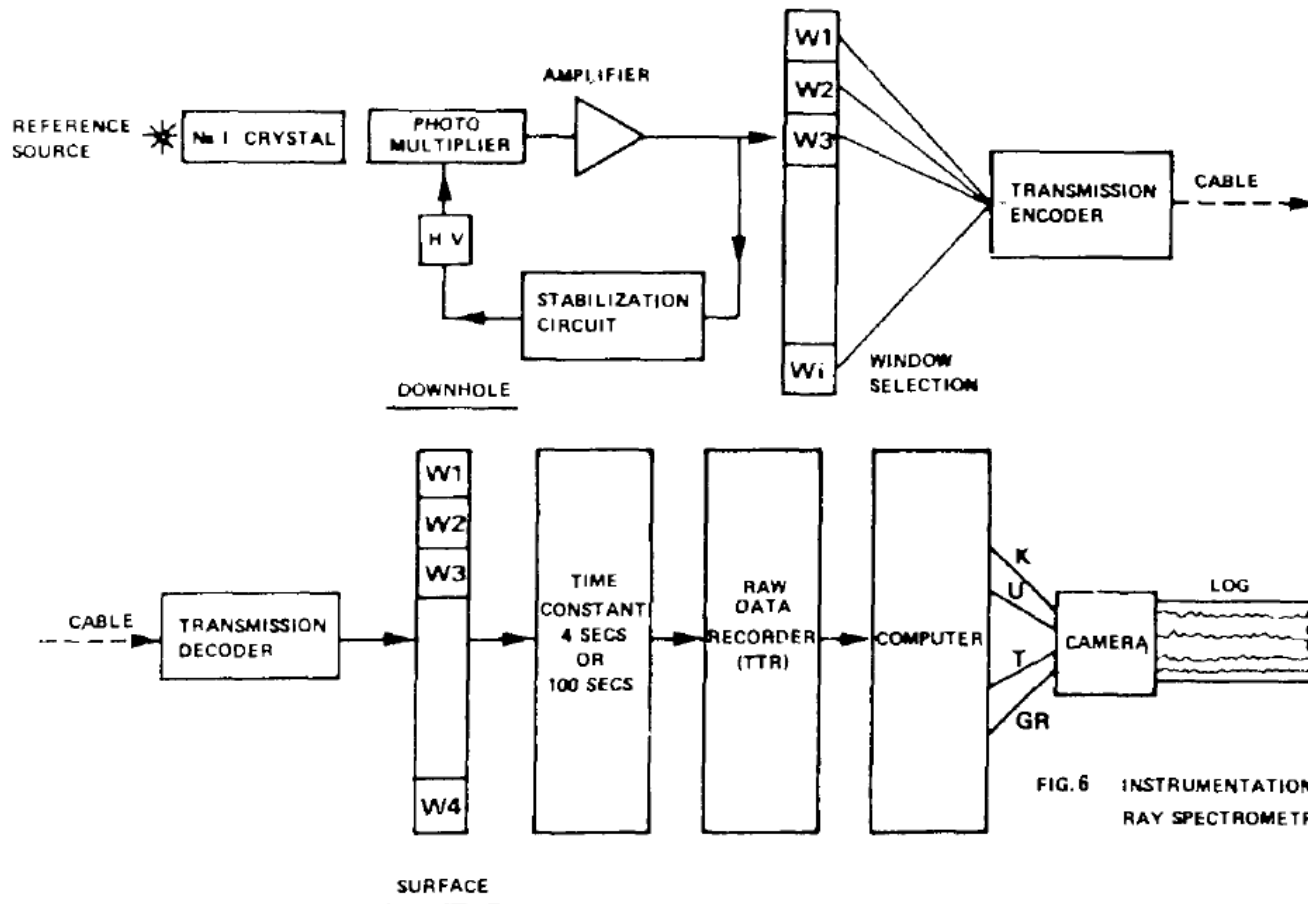
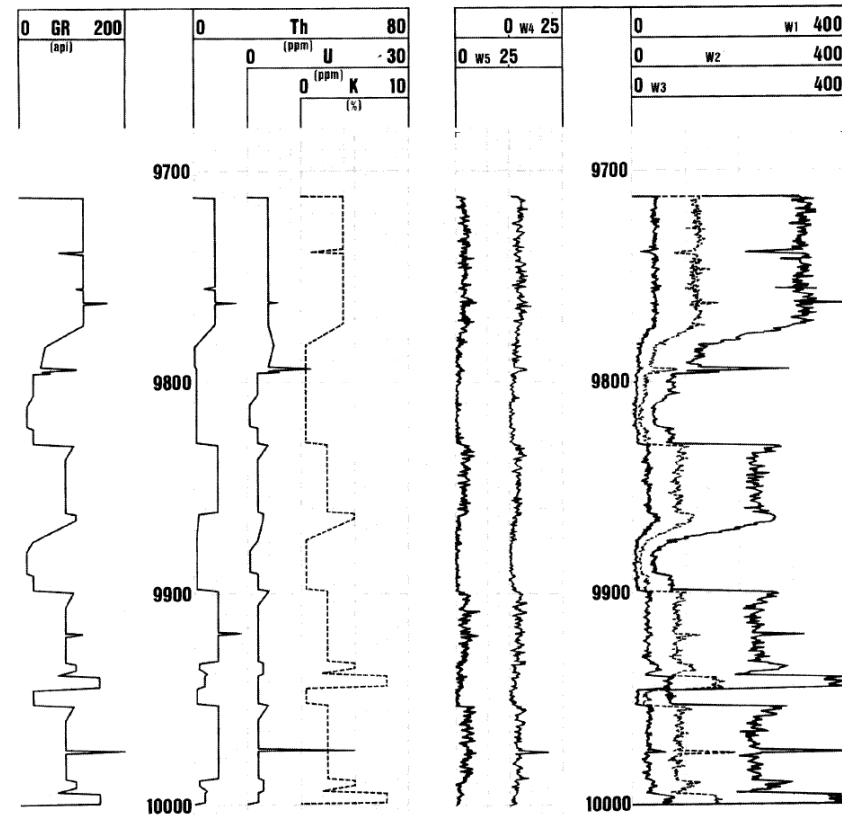


FIG. 6 INSTRUMENTATION OF GAMMA RAY SPECTROMETRY TOOL

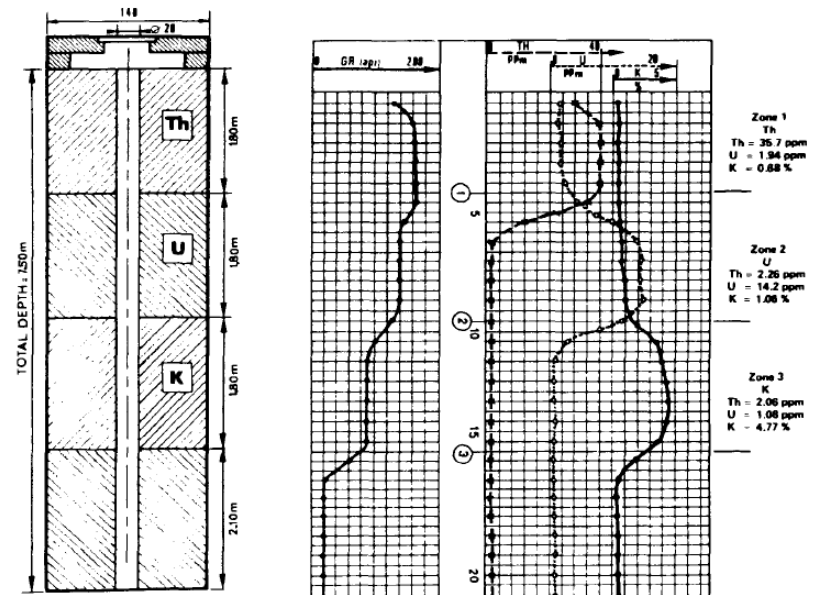
TOOL DESCRIPTION

- Combination of low and high energy spectrum helps to reduce statistical uncertainty
- A synthetic log is created (figure – left, model)
- Assuming a succession of levels with different Th, K , U content, artificial window count rates are created (figure – right) in five energy bands
- SGR use a sodium iodide crystal doped with thallium – defined as NaI (TI), which is fed into a photo-multiplier, an amplifier and a multi-channel analyser



CALIBRATION

- The tool is calibrated with four sources of known composition, one each containing ^{40}K , ^{238}U , ^{232}Th and one containing a mixture.
- Each source is placed next to the detector and measurements are made
- Calibration purpose is accurately report the difference in the amount of radiation from each of the sources and the total count rate is calibrated to the Houston test pit



Example test pit of Schlumberger in Calmart

COMPUTATION OF TH, U, & K CONTENT

- Theoretically three equations are sufficient to derive Th, U and K content of the formations relating its count rates in each window
- Weighted least square method is used to derive Th, U and K content, where W_i is the count-rate from window i ; A_i , B_i and C_i are the calibration coefficients (obtained from calibration test pit) and r_i is factor representing statistical error

$$W_i = A_i \text{Th} + B_i \text{U} + C_i \text{K} + r_i$$

The purpose is to minimize r^2 value, $\sum_{i=1}^n r_i^2$

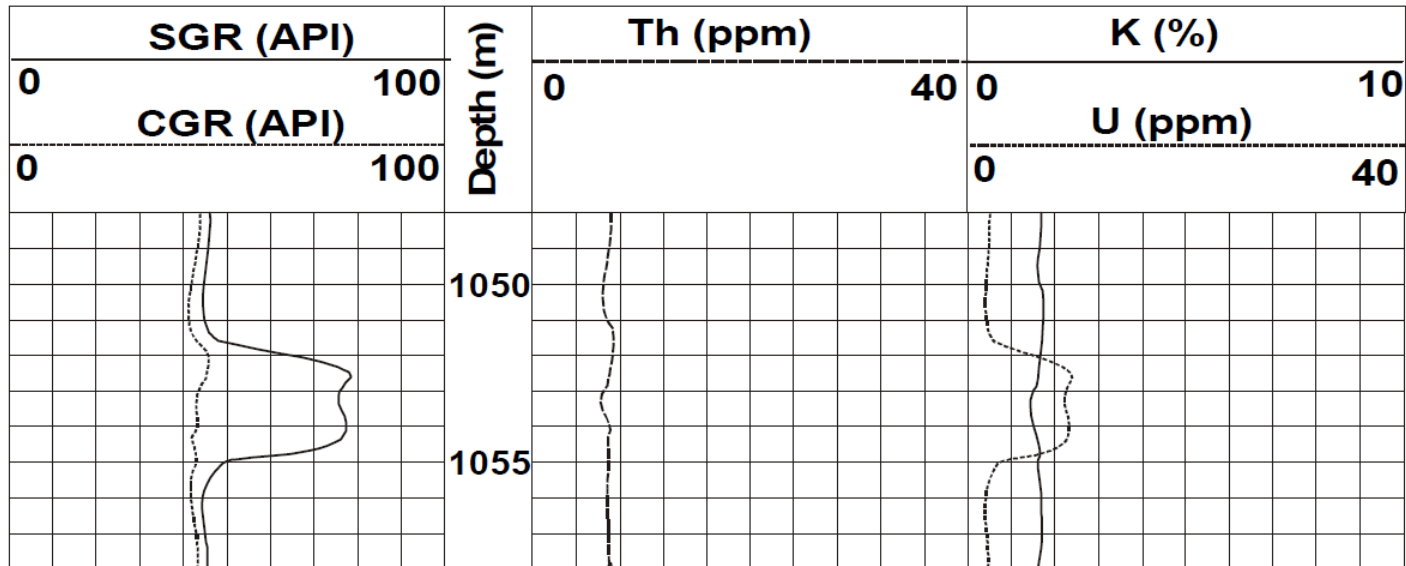
- After determination of three components, the total gamma ray response will be a linear combination

$$\text{GR} = A\text{Th} + B\text{U} + C\text{K}$$

LOG DISPLAY

- SGR tool produces:

- (i) K curve (%)
- (ii) Th curve (ppm)
- (iii) U curve (ppm)
- (iv) Sum GR (SGR) = K + Th + U [use an approx. $4 * Th + 8 * U + 16 * K$ to convert to API]
- (v) Computed GR (CGR) = K + Th (Uranium free)



INFLUENCING FACTOR

- The radius of investigation is similar to the total gamma ray tool
- Beside hole size, mud-density and bulk formation density, the measurement also depends upon energies of the gamma rays
- Logging speed need to be lower for a good quality data (i.e., to maintain standard deviation at less than 2.5 %)
- Lower tool speed helps to improve vertical resolution
- The tool can be run centred to the borehole or eccentric
- For a hole drilled with potassium rich mud i.e, KCL, SGR, CGR and Potassium content will be impacted
- Borehole correction need to be applied for centred or eccentric tool configuration using established charts

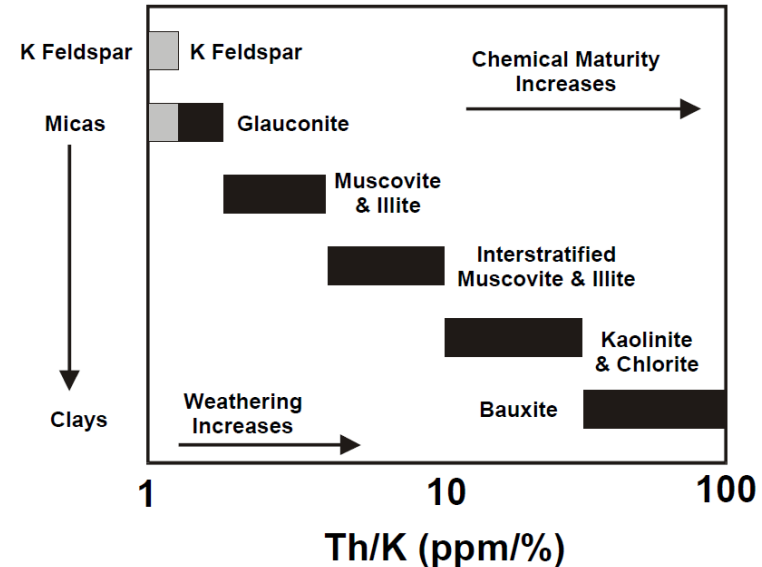
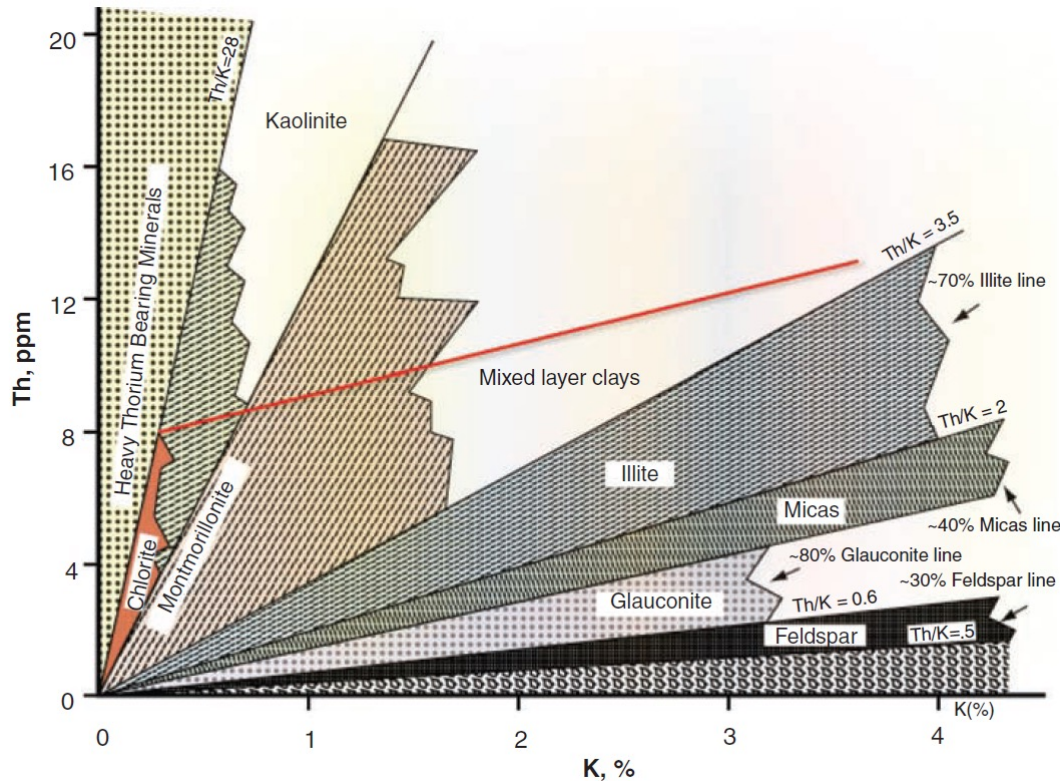
NATURAL GAMMA SPECTROMETRY (NGS/SGR)

- **Potassium:** Sediments with uncommon amounts of chemically unstable grain. Potassium feldspar, micas and alteration products such as kaolinite, sericite and chlorite are examples of potassium rich rocks.
- **Thorium:** Related to detrital and not purely chemical sediments. Th found mostly with clay that are associated with heavy minerals. These heavy minerals are more abundant in the silty fraction. More common in residual sediments such as bauxite, kaolinite and bentonite, which are formed by the alteration of volcanic ash. It is also presented in tuffs, conglomerates and greywacke sandstones.
- **Uranium:** Associated with both chemical and detrital sediments such as shales, organic matter and uranium-bearing heavy minerals. It is also abundant within phosphates, tuff, conglomerates, greywacke sandstones and carbonates of confined media.

NATURAL GAMMA SPECTROMETRY (NGS/SGR)

Element	Characteristics
Thorium	<ul style="list-style-type: none">• Insoluble in water.• Usually combined with shales, may supply certain information on the clay content.• Combined with heavy minerals in igneous rocks.
Uranium	<ul style="list-style-type: none">• Usually not linked to the clay contamination of rocks.• Depends on the organic matter content.
Potassium	<ul style="list-style-type: none">• One of the basic components of shale rocks.• Indicator of the presence of feldspars and micas.• Mainly occurs in oxidized form (K_2O).• Stabilizes clay minerals as kcl.

MINERAL IDENTIFICATION



Clay-bearing sandstone – Th/K ratio plot

Arkose sandstone – contain feldspar with significant potassium and low thorium ($\text{Th}/\text{K} < 1 \text{ ppm}/\%$)

Micaceous sandstone – contain mica with ratio varies $1.5 < \text{Th}/\text{K} < 2.5$

Graywakes – contain both feldspar and mica, ratio is intermediate between 1 and 2.5

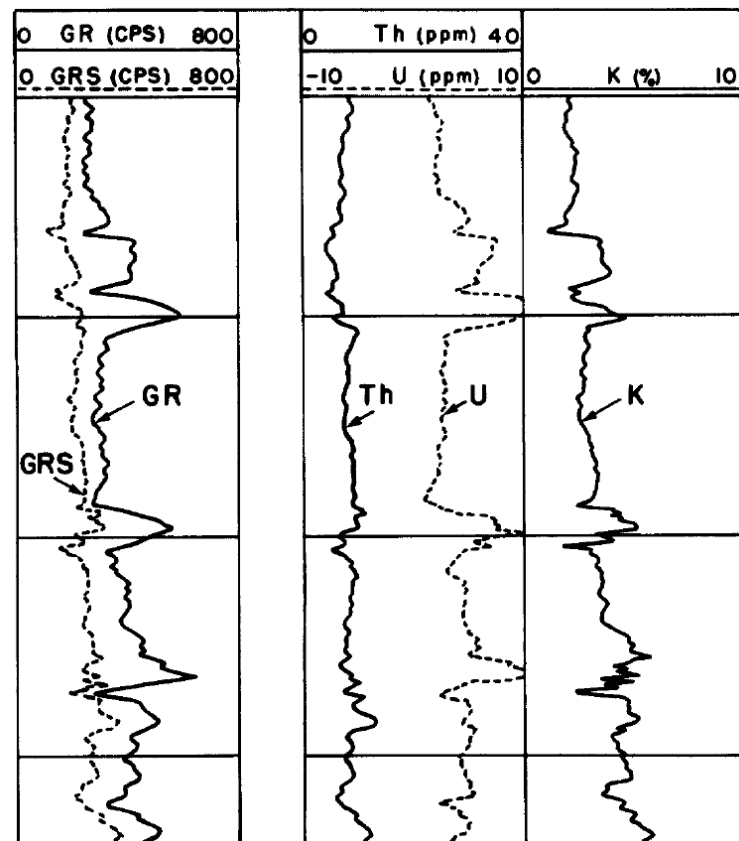
Greensands – contain glauconite (mica group mineral containing iron, magnesium and potassium) with ratio Th/K between 1 to 1.5 $\text{ppm}/\%$

Heavy-mineral bearing sandstones – abundant in U or Th or both. Typically, Th/K ratio is above 25 and U/K is above 20 $\text{ppm}/\%$ despite the formation contains potassium in the form of mica, feldspar or glauconite

CARBONATES

K	Th	U	Explanation
Low	Low	Low	Pure carbonate, no organic matter or oxidizing environment.
Low	Low	High	Pure carbonate, organic matter, reducing environment.
Low	High	Low	Not a carbonate, or shaly carbonate with rarer low K high Th clay minerals, no organic matter or oxidizing environment.
Low	High	High	Not a carbonate or shaly carbonate with rarer low K high Th clay minerals, organic matter, reducing environment.
High	Low	Low	Glauconite carbonate, no organic matter or oxidizing environment. Also consider K-bearing evaporites.
High	Low	High	Algal carbonate, or glauconite present, organic matter, reducing environment.
High	High	Low	Shaly carbonate, no organic matter or oxidizing environment.
High	High	High	Shaly carbonate, organic matter, reducing environment.

Note: Stylolites can locally concentrate U, clays and organic matter.



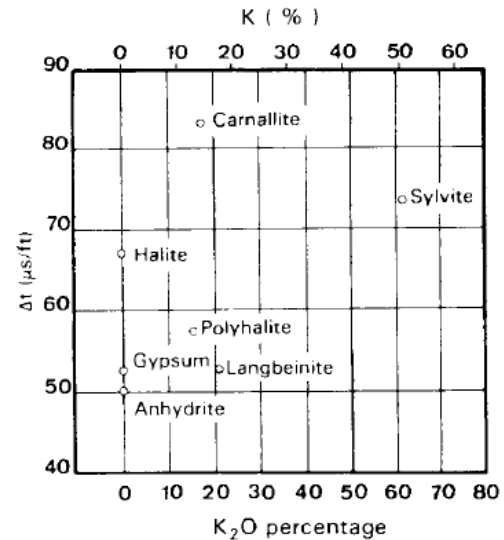
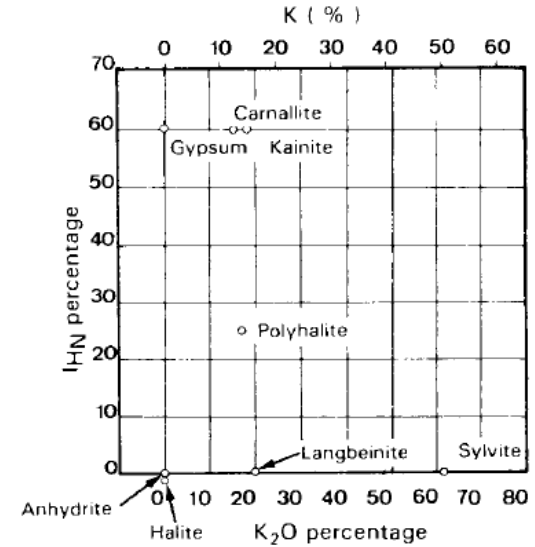
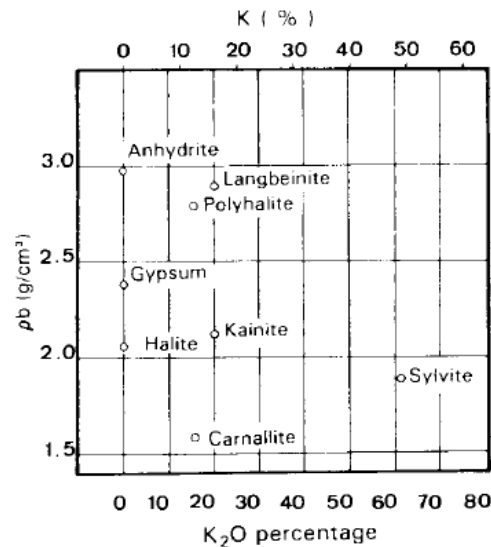
EVAPORITES

- Besides shale, specific potassium-bearing evaporites showed large gamma ray response
- Abundance of potassium and nearly zero thorium content helps to identify evaporites from shale
- Evaporites are deposited in oxidizing environment, low amount of uranium or nearly zero

Name	Composition	K (wt%)	Density [FDC] (g/cm ³)	Pe [LFDC] (b/e)	Porosity [CNL] (%)	ΔT [Sonic] (μs/ft)
Sylvite	KCl	52.44	1.86	8.51	-3	74
Langbeinite	K ₂ SO ₄ (MgSO ₄) ₂	18.84	2.82	3.56	-2	52
Kainite	MgSO ₄ KCl(H ₂ O) ₂	15.7	2.12	3.5	>60	-
Glaserite	(K Na) ₂ SO ₄	24.7	2.7	-	-	-
Carnalite	KCl MgCl ₂ (H ₂ O) ₆	14.07	1.57	4.09	>60	83
Polyhalite	K ₂ SO ₄ MgSO ₄ (CaSO ₄) ₂ (H ₂ O) ₂	13.37	2.79	4.32	25	57.5

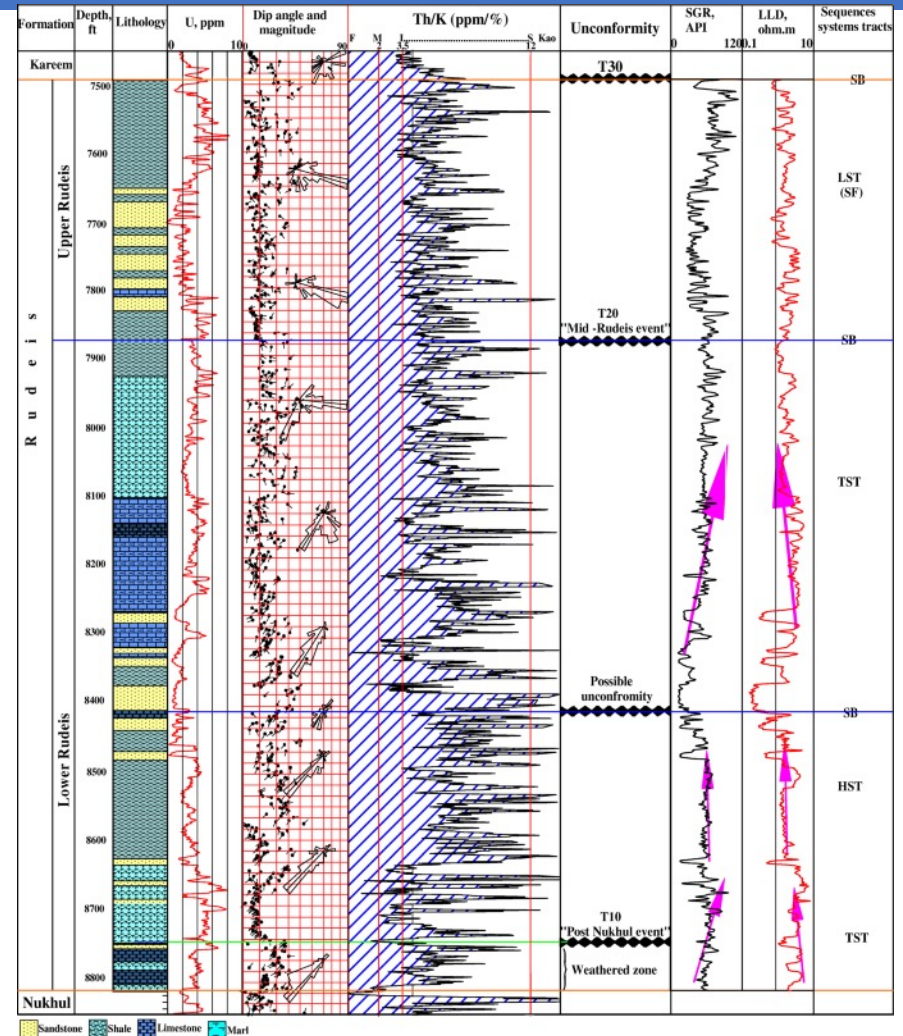
EVAPORITES

- Cross-plot of potassium (K %) versus density, sonic travel time, NPHI could be used to identify types of evaporites mineral



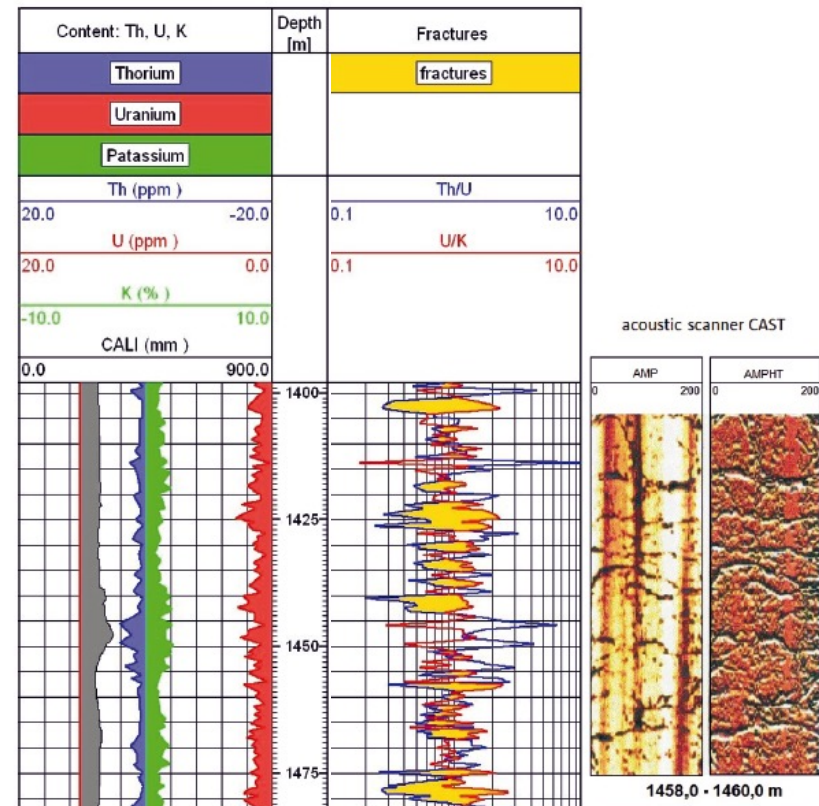
UNCONFORMITY

- Abrupt changes in mean Th/K ratio are indicator of deposition environment change i.e., identification of unconformities
- Very difficult to detect with other logs



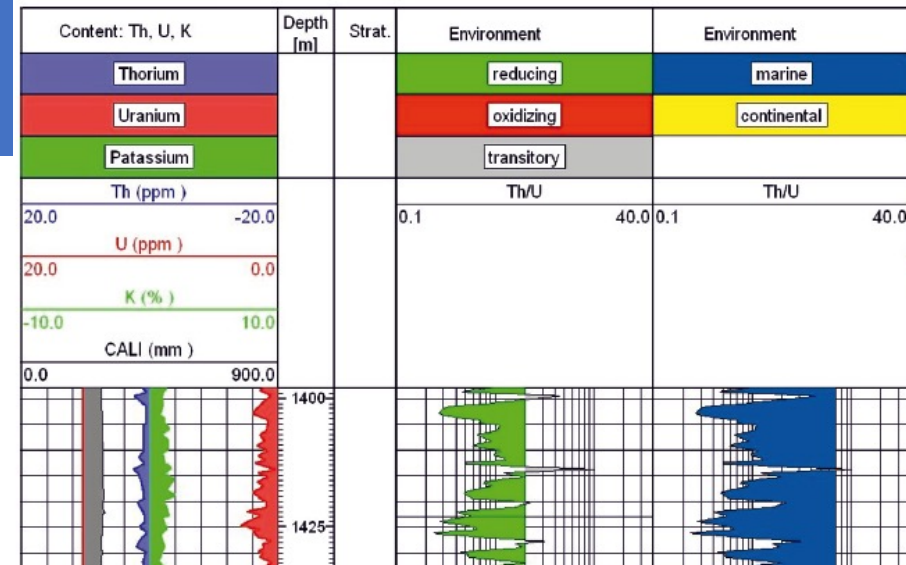
FRACTURE/FISSURE

- In reducing conditions, circulation of hydrothermal or underground waters dissolve uranium salt may be precipitate in fractures
- Appear as peak in U curve but validation need to be with image log



SEDIMENTOLOGY

- Powerful tool for sedimentological applications, for example depositional environment, grain size and mineralogical analysis

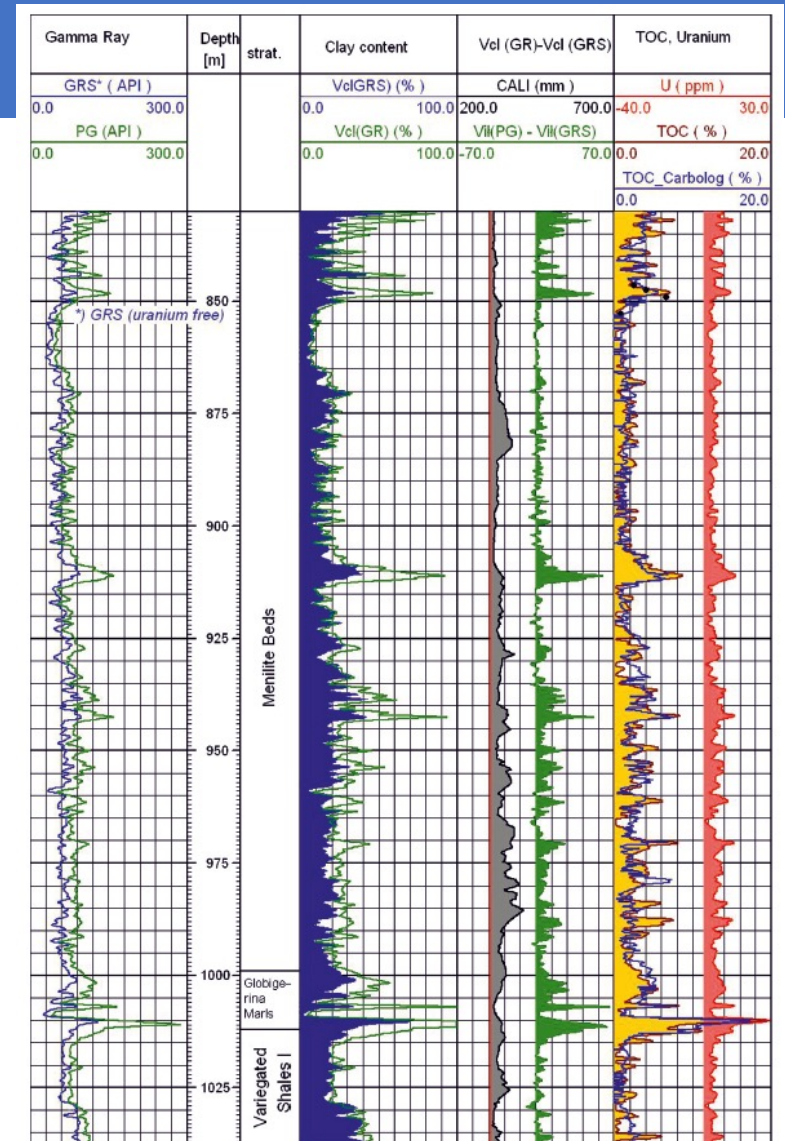


SGR Observation	Sedimentological Inference
Presence of glauconite	Marine, mainly continental shelf origin.
Phosphatic deposits	Marine, mainly continental shelf origin, with warm water in a reducing environment.
Uranium	Low energy, reducing conditions
Clay type	Analysis of depositional environment.
Bauxite	Warm, humid, continental environment with good drainage.
Feldspars	Indicator of the degree of evolution of sand facies, only found in abundance close to the igneous source.



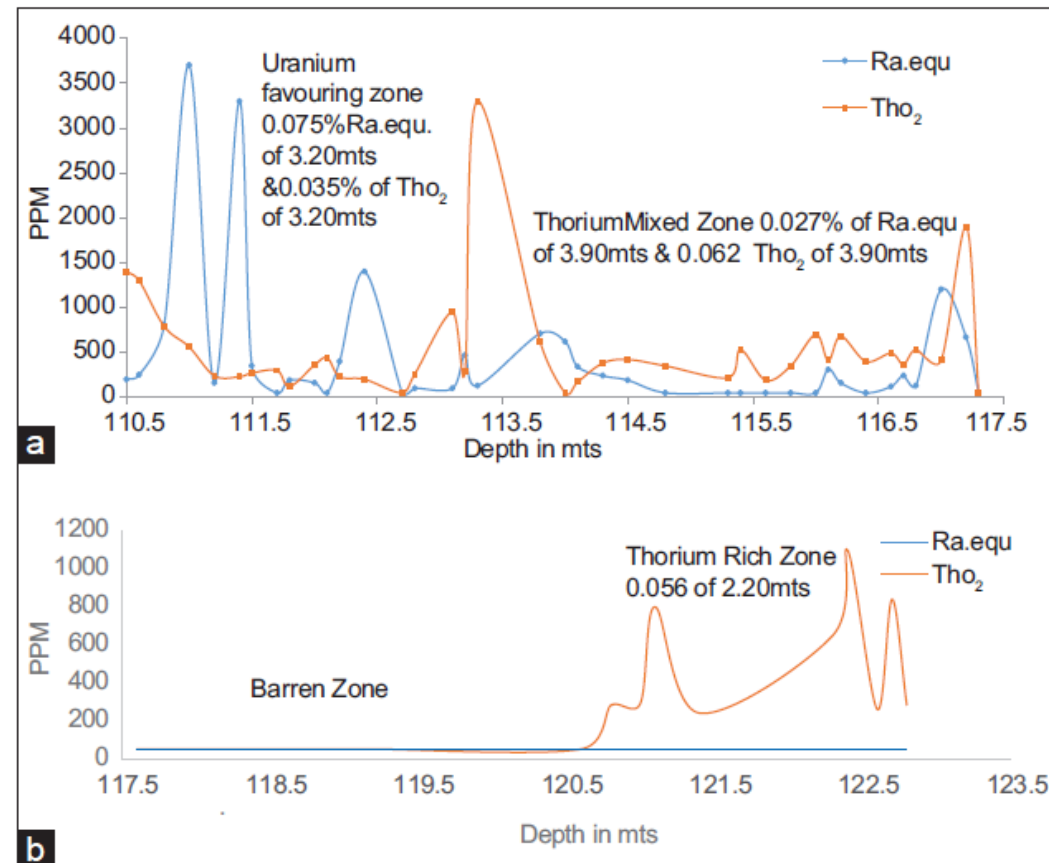
HYDROCARBON POTENTIAL

- Unconventional shale reservoirs are organically rich
- Strong correlation observed between uranium and organic material
- Empirical correlation between core derived organic matter and SGR log or U curve response can be used to derive total organic carbon



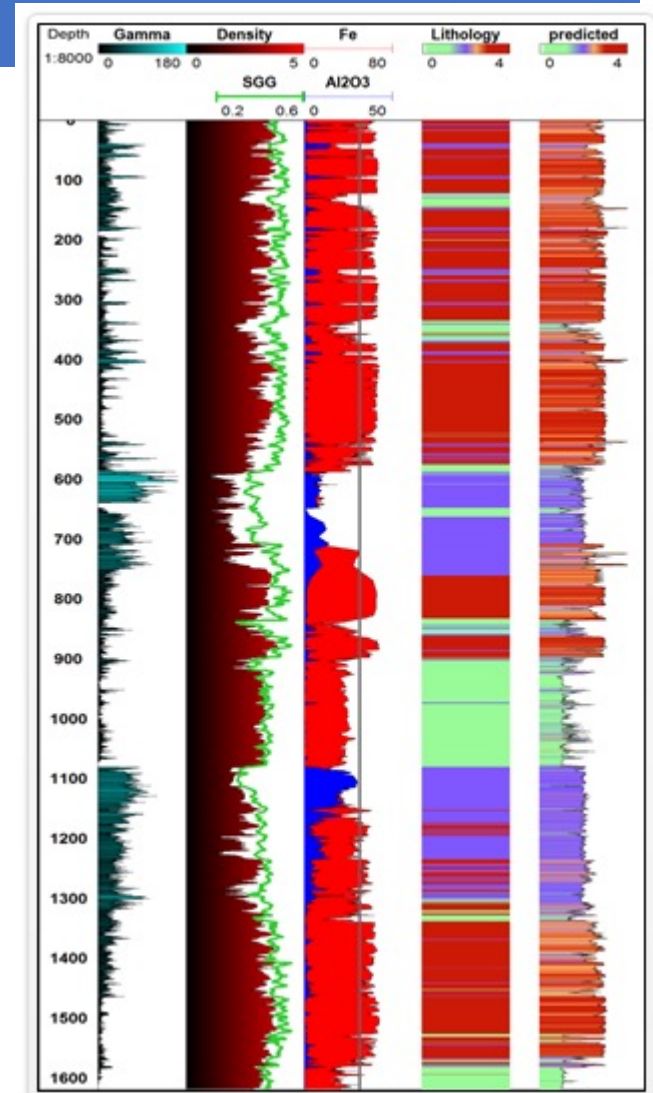
MINERAL EXPLORATION - URANIUM POTENTIAL

- Natural gamma ray spectrometry is an excellent tool for Uranium exploration
- Both detection of uranium ores and estimation of uranium content present within the geological formation



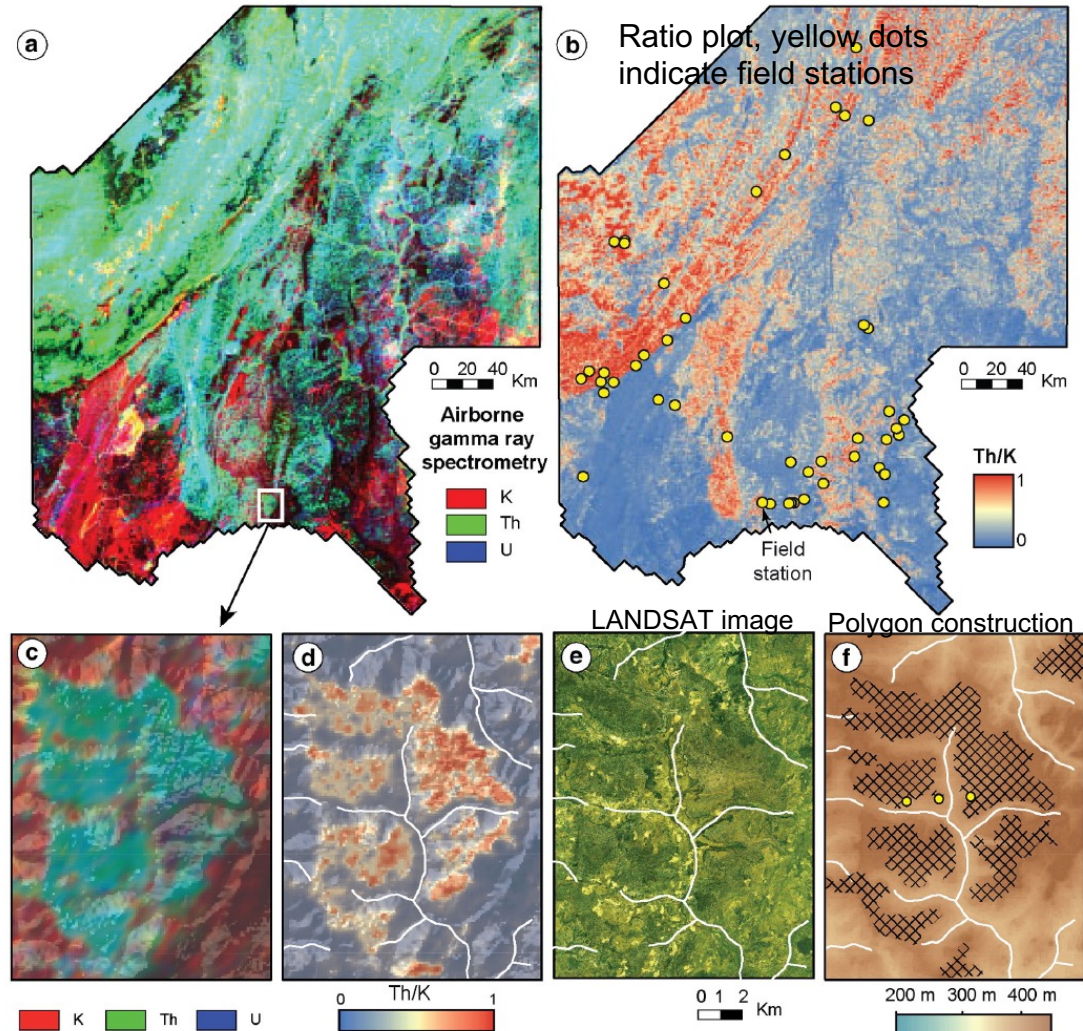
MINERAL EXPLORATION - IRON ORE

- Spectral gamma ray log is used as heavy mineral indicator (HMI) with signal dominated by iron in iron-rich rocks
- DET CRC adopted a fuzzy logic technique using SGR and Gamma ray count (CPS) which proved to be robust and cost-effective approach to classify iron ore geology



AIRBORNE GAMMA RAY SPECTROMETRY

- Large scale regolith mapping with airborne radiometric survey (100m to 200m line spacing)
- Maps are produced of three distinctive minerals and their ratios
- Representative of upper 30 cm of earth surface



END OF LECTURE

data collection



H_2 - CH_4 blend
Underground
Storage Reservoir



DNA analysis



Subsurface
simulation
experiments



Geochemistry
analysis

Thank you

Acid formation (H^+ , H_2S)