Using Potash Identification (PID) Plot to Distinguish Commercial Potash Mineralization*

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Abstract

The mineralogy of McNutt "Potash" member of the Salado Formation in SE New Mexico, is extremely complex, consisting of:

- Six (radioactive) potash minerals, only two of which are commercial.
- Radioactive, non-potash "Claystones" and "Marker Beds".
- Four non-radioactive evaporite minerals, one of which interferes with potash milling chemistry.

Because of this complexity, traditional wireline and Logging While Drilling (LWD) Potash Assay techniques, such as Gamma Ray log to core assay transforms, linear programming, and multi-mineral analyses are not effective. Numerous oil and gas wells, in the area, have cased hole gamma ray and neutron logs, through the Salado Evaporite, run for stratigraphic and structural correlation. The logs, from these wells could provide a rapid screening database, if used properly. A simple screening cross-plot technique utilizing only Gamma Ray and Neutron Porosity, is proposed and successfully demonstrated for potash deposits in Michigan, Nova Scotia, and Saskatchewan, as well as SE New Mexico. This technique can be used with both open- and cased-hole petroleum well logs, as well as core hole wire-line logs, and provides discrimination of commercial potash mineralization from non-commercial (potash and non-potash) radioactive mineralization.

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Using The Potash Identification (PID) Plot

To Distinguish Commercial Potash Mineralization

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The Problem

SE New Mexico Potash Assay Results

- A Mining Company claimed the following Potash Assay results from their analysis of Cased-Hole GR logs from a recently drilled Oil Well:
  - **Five intercepts of commercial grade (%K_2O Sylvite and/or Langbeinite) Potash Ore.**
  - **Total Reserves in excess of 1.2 MM Metric Tones of Potash/Acre Reserves.**
- Core Assays from core hole, located only 200 ft from the above oil well yielded the following XRD/XRF assay Results:
  - **Only one marginal (%K_2O Langbeinite) Potash intercept in a stratiform evaporite basin.**
- ***How could they have been so wrong?***

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What is Potash (K_2O)

- ***There is no mineral with the formula: K_2O.***
- The term, "Potash" (K_2O) traces its origin to North American Colonial times:
  - Hardwood timber was burned,
  - The ashes leached,
  - The leachate dried, and
  - The resulting black powder (Pot Ash, or K_2CO_3), refined to K_2O and used in the manufacture of gun powder.
- The current usage of "Potash" (%K_2O) is one of convenience for commodity transactions.
  - ***All natural occurring potassium minerals have been assigned equivalent "Potash" (%K_2O) values.***

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US Potash History

- Potash, derived from the ashes of burned hardwood logs, was one of the first major exports of British Colonial North America.
- ***Prior to World War I, most Potash used in the US, for gun powder and fertilizer, was imported from mines in Eastern Europe.***
- ***Blockades of German Ports, during World War I, denied the US of access to Eastern European mined Potash, forcing rationing.***
- ***Shortages of mined potash, during World War I, resulted in Potash being declared a "Strategic Mineral".***
- Modest US potash deposits were discovered between World War I and World War II, in SE New Mexico, the Paradox Basin of E Utah, and later deep deposits in The Michigan Basin.
- ***Discovery of the Prairie Evaporite Potash Deposits in Saskatchewan, in the 1940's eclipsed all US Potash operations and changed the economics of US Potash mining operations.***

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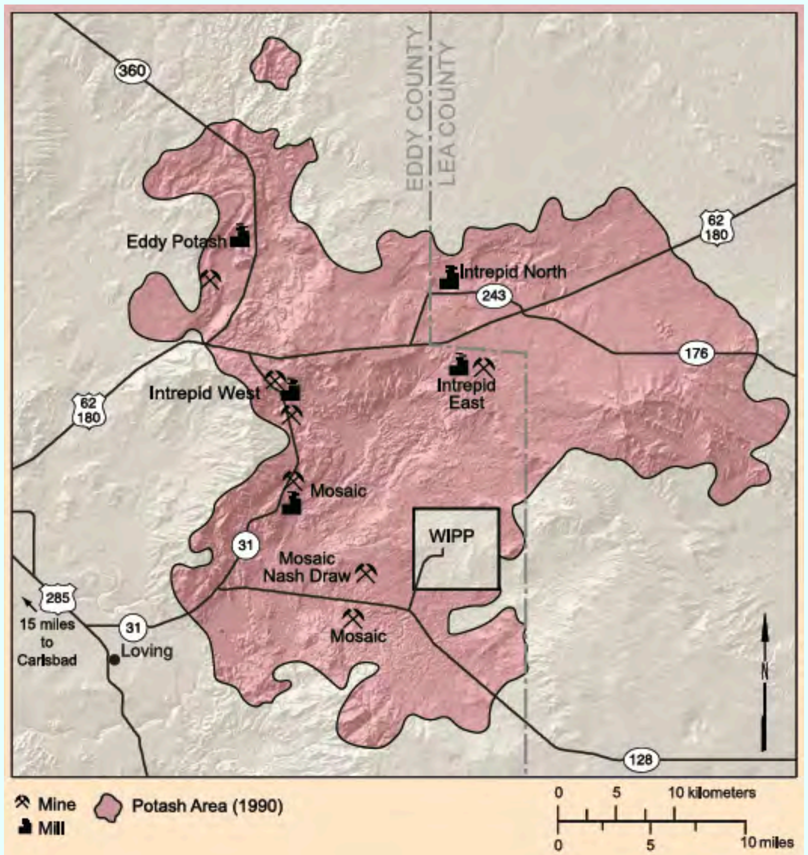
SE New Mexico Potash Area



After Baker and Gundiler, 2008

- Potash was discovered in SE New Mexico oil well cores, in 1925.
- The US Secretary of the Interior created the SE New Mexico Potash Area/Enclave, in 1931.
- The purpose of the order was to preserve this *strategic mineral* resource for future development.
- Because of the Prairie Evaporite deposits, Potash is no longer considered to be a US *strategic mineral*.
- In 1973, the US DOE condemned a 16 square mile area within the SE New Mexico Potash Area as a Waste Isolation Pilot Project (WIPP) for storage of radioactive waste.

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SE New Mexico
McNutt Member, Salado Formation

South East New Mexico McNutt Member, Salado Formation Major Components

Mineral Name	Formula	Crystal Class	%K	Equivalent % K_2O	Gamma Ray (API)
Sylvite	KCl	Isometric	53.45	63.18	953
Langbeinite	$K_2SO_4(MgSO_4)_2$	Isometric	18.84	22.70	342
Carnallite	$KCLMgCl_2 \cdot 6(H_2O)$	Orthorhombic	14.07	16.95	256
Kainite	$MgSO_4KCl \cdot 3(H_2O)$	Monoclinic	15.07	18.92	285
Leonite	$K_2SO_4MgSO_4 \cdot 4(H_2O)$	Monoclinic	21.32	25.69	386
Polyhalite	$K_2SO_4MgSO_4(CaSO4)_2 \cdot 2(H2O)$	Triclinic	12.97	15.62	236
Anhydrite*	$CaSO_4$	Orthorhombic	-	-	-
Gypsum	$CaSO_4 \cdot 2(H_2O)$	Monoclinic	-	-	-
Halite	NaCl	Isometric	-	-	-
Kieserite**	$MgSO_4 \cdot (H_2O)$	Monoclinic	-	-	-
Marker Beds	Variable	-	??	??	Variable
Claystones	Variable	-	Variable	??	Variable

01.07.09, DGH

*While the mineral, Anhydrite, is not radioactive, the Union anhydrite and other SE NM "Anhydrite Beds have GR signatures equivalent to or higher than, Potash "Ore Zones".

**While Kieserite is non radioactive and contains no potassium, significant amounts of Kieserite will render otherwise commercial Potash zones "non-commercial".

Commercial Potash Minerals in Red.

Non-Commercial Potash Minerals in Black.

Non-Potash Evaporite Minerals in Violet.

Associated Non-Mineral Radioactive Insoluble Materials in Green.

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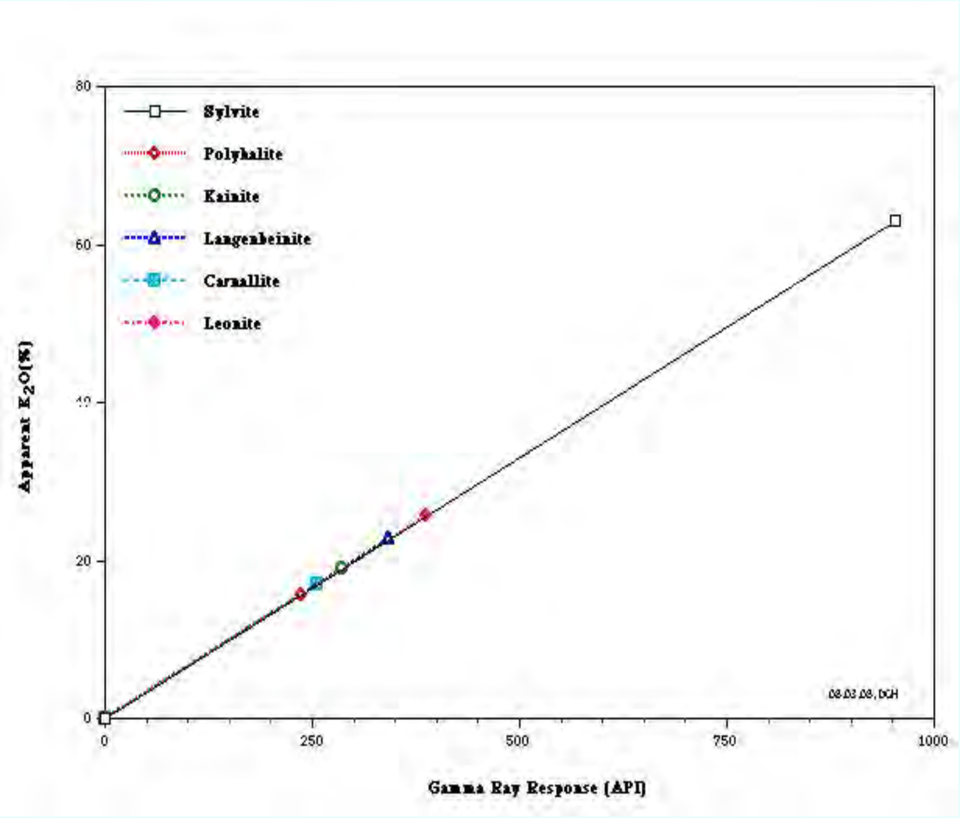
Potash Mineral GR Relationships



- 100% Potash Mineral API - %K_2O Relationships are Linear

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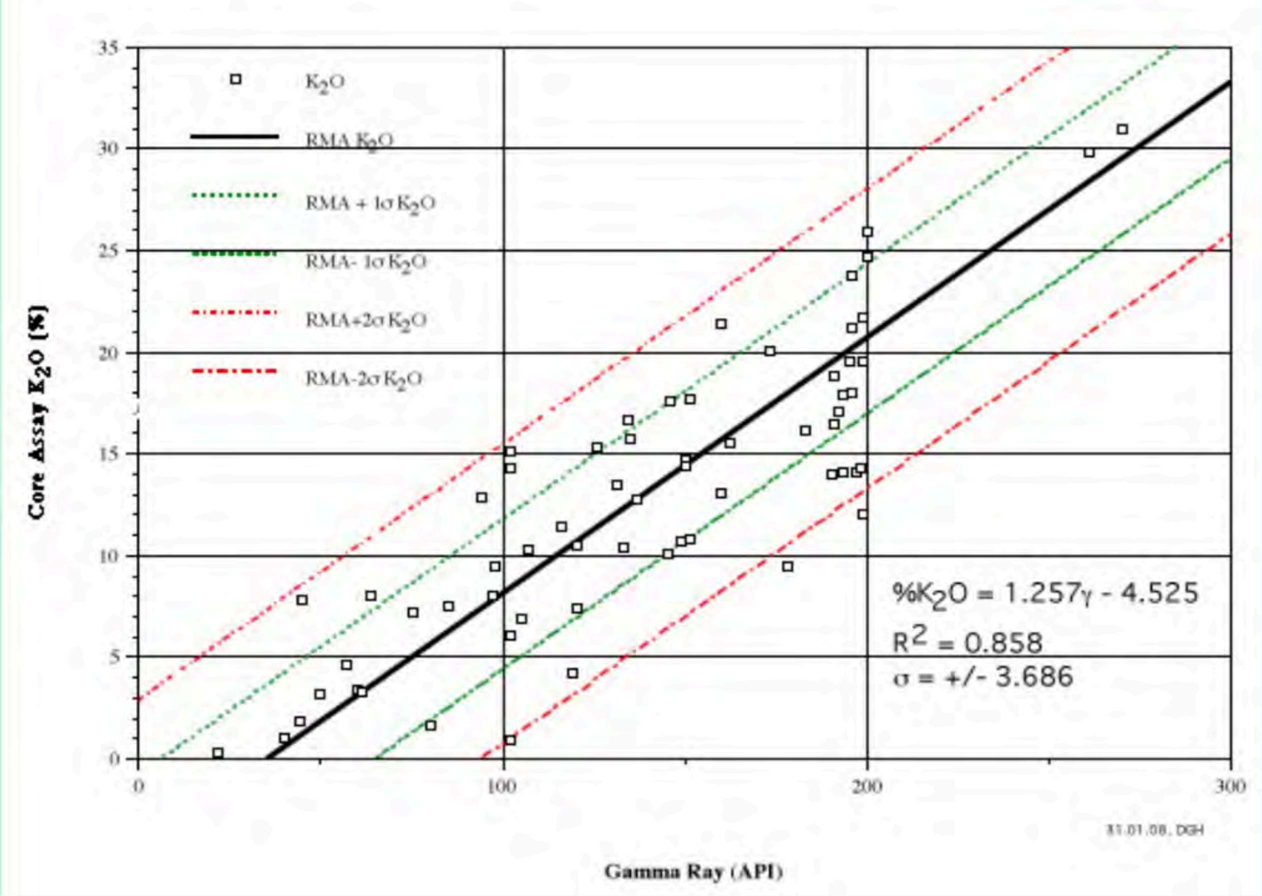
SE New Mexico Linear Gamma-Ray Log API to "Apparent Total %K_2O" Transform



After Nelson, 2007

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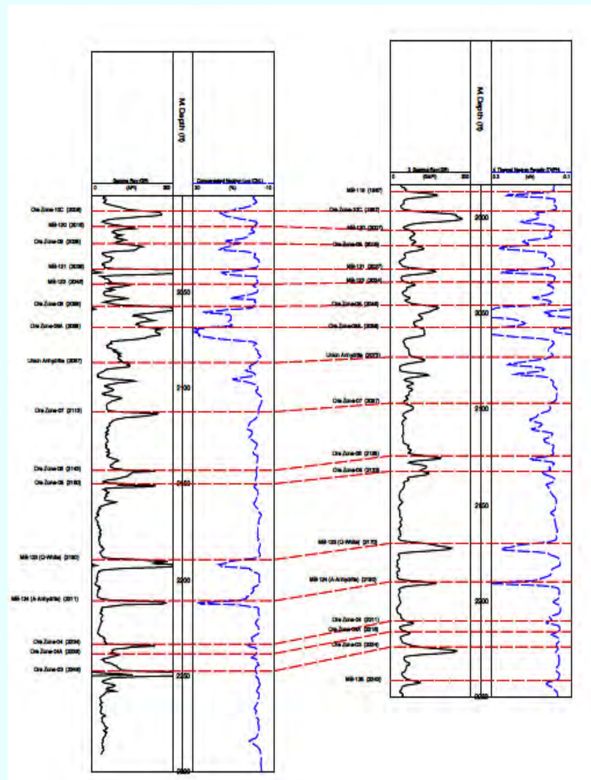
Linear GR - % K2O Validation Test
Well Offset by Core Hole



Core Hole (on left) is approximately 200 ft. West of the Well (on right).

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Validation Test:
Cased Well GR Log Predictions vs. Corehole XRD Assays

Potash	Mining Co Cased Well Log Predictions			Corehole Assay Analysis			% Error
Ore Zone	Thickness (ft)	Grade ($\%K_2O$, S/L)	Grade x Thickness ($\%K_2O$/ft, S/L)	Thickness (ft)	Grade ($\%K_2O$, S/L)	Grade x Thickness ($\%K_2O$/ft, S/L)	of Log Predicted Grade x Thickness
10c	5.4	29.0 S	156.6	4.5	7.7 S	34.7	351
8A	5.1	4.0 S	20.4	none Reported	none Reported	-	-
6	2.5	16.0 S	40	0.5	11.7 S	5.9	578
5	5.3	14.0 S	74.2	1.5	7.8 L	11.7	534
3	4	26.0 L	104	3.5	12.3 L	43.1	141

L = Langbenite S = Sylvite

- Predicted Potash grades and thicknesses from well Cased-Hole Gamma Ray and Neutron Logs are Significantly Greater than the Core XRD Assays, for the same “Ore Zones”.
- ***Potash Grade-Thickness Estimates From GR Well Logs, alone, Are Not Reliable, Greatly Exceeding the Maximum “Measured Ore” Error of 20% Required for Mapping Potash Reserves.***

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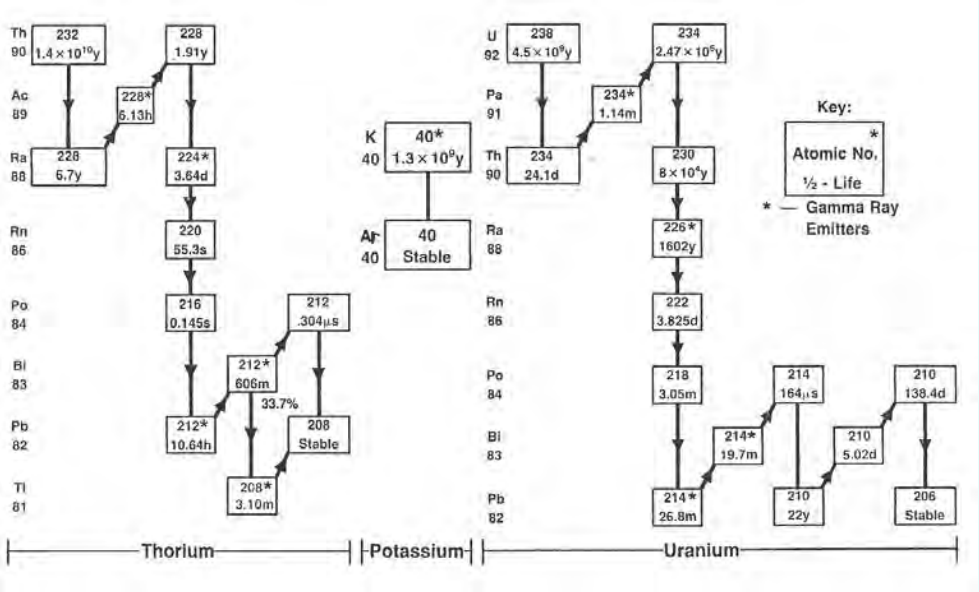
Natural Radioactive Isotopes



After Serra et al., 1980

- ^{40}K to ^{40}Ar decay
- ^{238}U Decay Series (primarily ^{214}Pb and ^{214}Bi decays)
- ^{232}Th Decay Series (primarily ^{212}Pb and ^{212}Bi decays)

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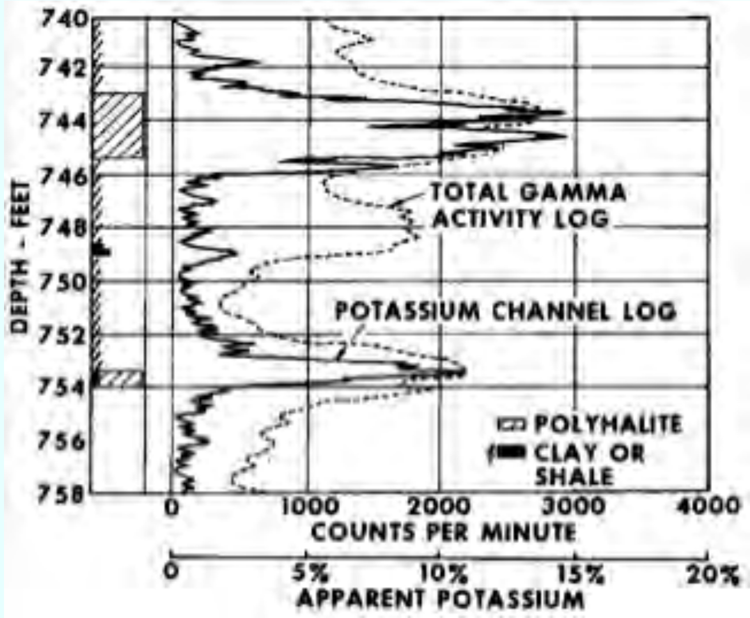
SE New Mexico
K-U-T vs. Total Count GR Logs



After Fertl, 1979

- ***Comparison of Total Count and K-U-T Gamma Ray Log Gamma Ray responses in McNutt Member of Salado Formation, SE New Mexico.***
- ***The 747 – 749 ft Non ^{40}K total count GR anomaly is comparable to that of the 752.5 – 754.5 ft Polyhalite (Non-Economic Potash) anomaly.***

K-U-T GR separates ^{40}K from U & Th Series

BUT not Commercial Potash from Non-Commercial Potash

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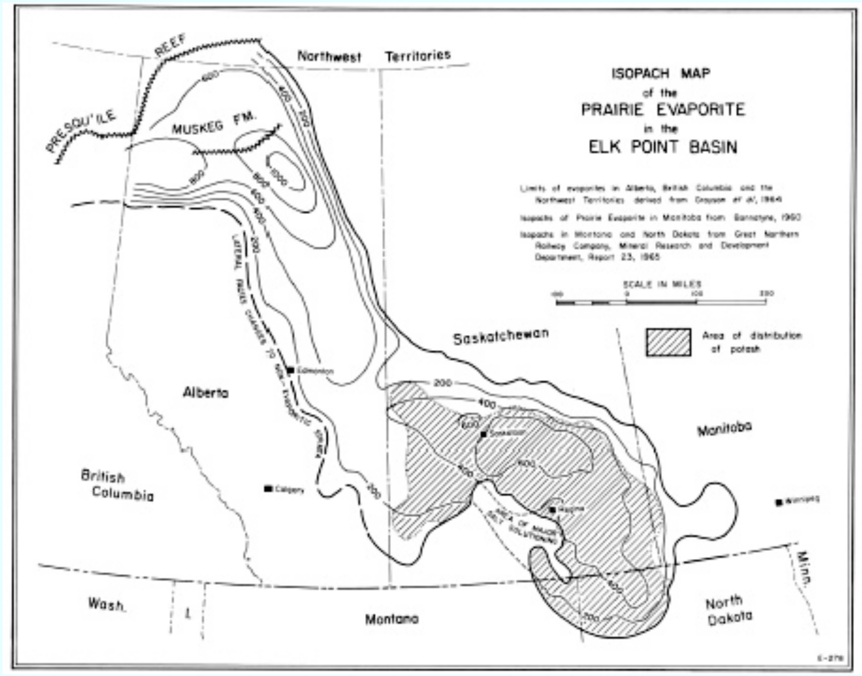
Saskatchewan
Prairie Evaporite Potash Deposits Extent



After Holter, 1969

Prairie Evaporite Potash Deposits underlie roughly the SE 25% of the Province of Saskatchewan and extend into Northern North Dakota.

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Saskatchewan Prairie Evaporite

"The Saudi Arabia of Potash"

- Discovered during the 1940's and has been continuously produced, since 1962.
- Very simple (distinct Sylvite and Carnallite, with minor Dolomite and claystones) mineralogy and structures.
- Massive (up to 15 m, or 50 ft, thick), high grade (up to over 50% Sylvite, or KCl), uniform (can correlate over several miles, using seismic reflection techniques) and extensive (see map).
- Supplies 25 – 30% of world demand (with reserves for several hundred years, at this level) and 70% of U.S. demand.
- **Because of this, near-by, stable supply, *Potash is no longer considered to be a U.S. "Strategic Mineral".***

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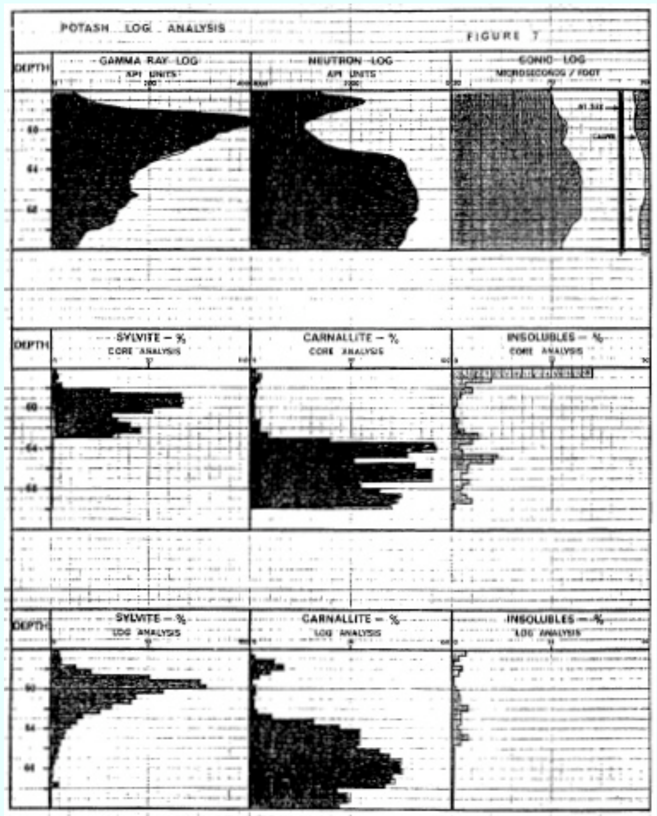
Saskatchewan Prairie Evaporite

Detailed Wireline Log Linear Programming & Core Assays



Wireline Measurements

Core Assays

Linear Programming
Log Assays

After Crain and Anderson, 1966

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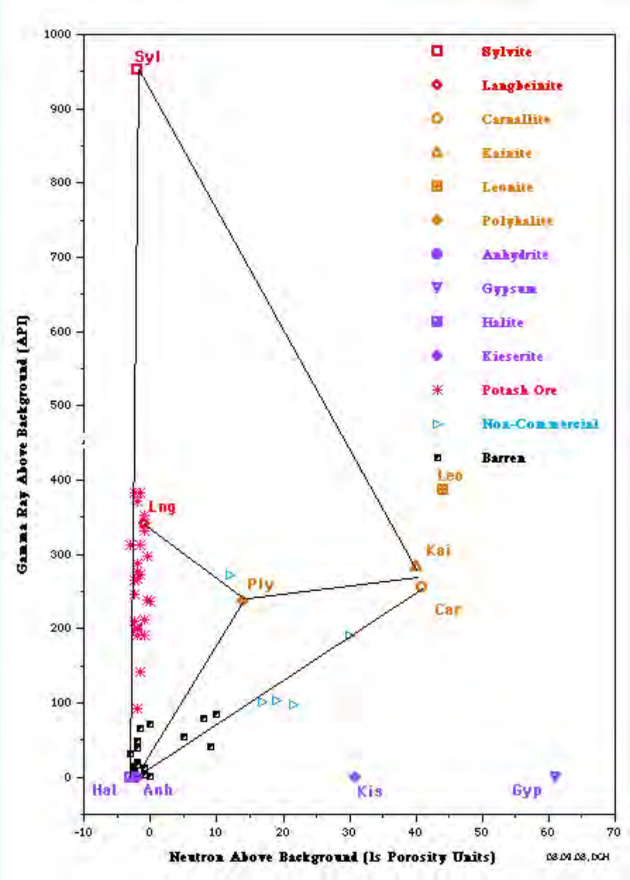
Saskatchewan: Prairie Evaporate
Gamma Ray - SNP Cross-Plot



GR-SNP Cross-Plot groups data, quite nicely into three distinct groups

Note:

- Commercial Potash Minerals are Anhydrous
- Non-Commercial Potash Minerals are Hydrated

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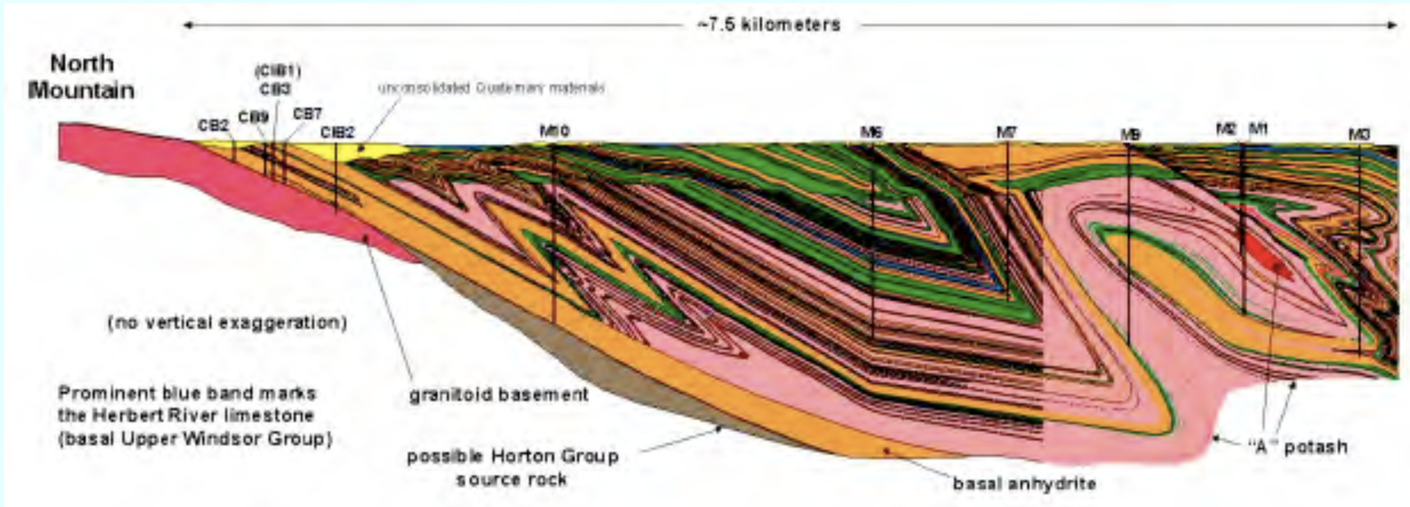
Cape Breton Island Windsor Evaporite Overview



After Giles, 2014

- Complex structural setting.
- Very simple mineralogy.
- Massive, high-grade, but ephemeral, Sylvite ore zones, with little contamination.

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Cape Breton Island Windsor Evaporite Mineralogy

- Commercial Potash Minerals:
  - High Grade (up to over 50%) Sylvite.
- Non-Commercial Potash Minerals:
  - Carnallite (minor amounts).
- Other Evaporite Minerals:
  - Anhydrite (trace - minor amounts).
  - Gypsum (trace - minor amounts).
  - Halite.
- Other Materials
  - Shales (minor amounts).

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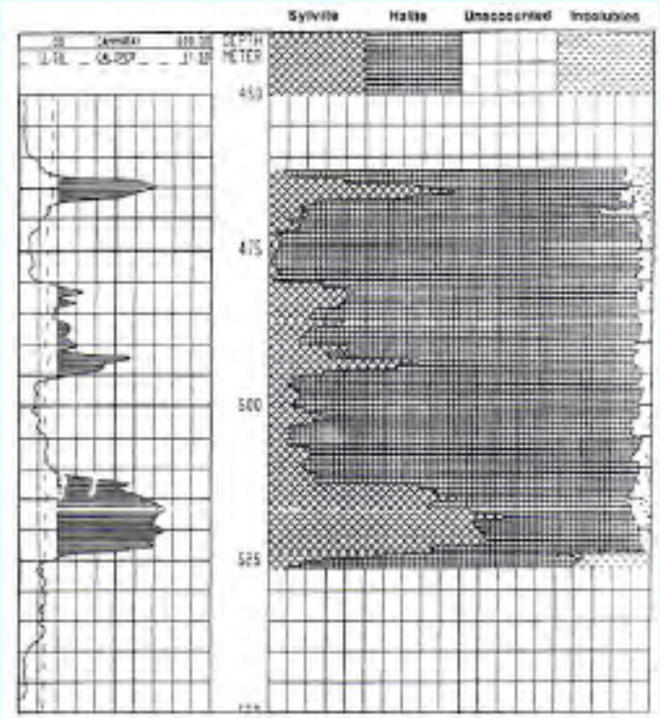
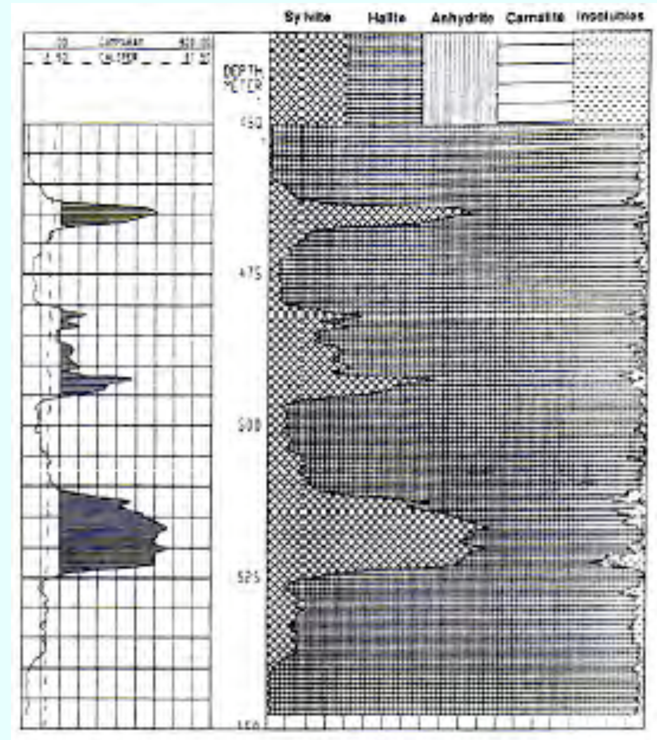
Cape Breton Island Windsor Evaporite

Multi-Log and Core Analysis Assays





After Hill, 1993

Core Assay (LHS) and Multi-Log Assay mirrors the wireline data.

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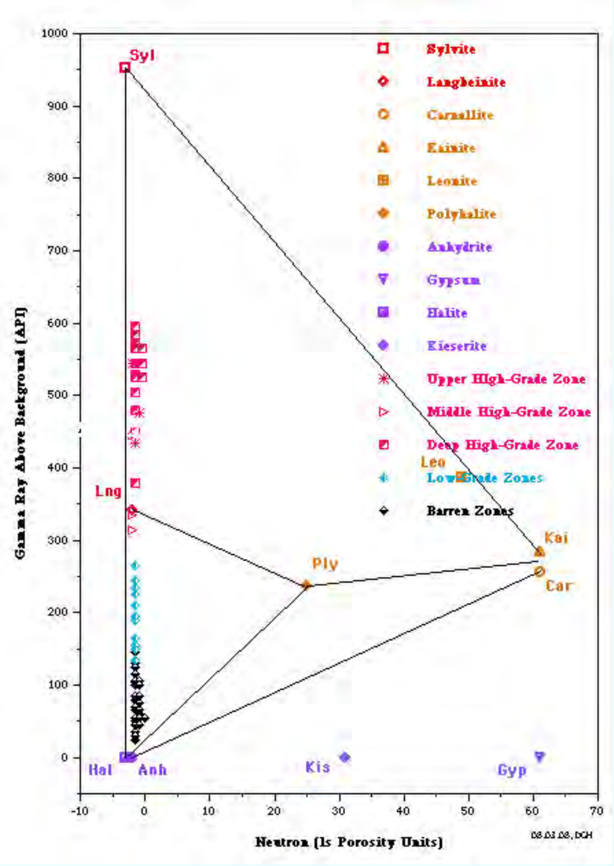
Cape Breton Island Windsor Evaporite

Gamma Ray - CNL Cross-Plot



- GR-Neutron Cross-Plot groups the data into three groups: with a transition between the low-grade Potash ore and barren zones
- There is essentially no clay or non-commercial potash

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Michigan Basin
Salina A-1Evaporite Potash

- The Stratigraphy of the Michigan Basin is much like that of Stacked Bowls, with a complete geologic section from Cambrian through Jurassic Periods, resting on a Pre-Cambrian Basement
- The Salina A-1 Evaporite consists of Shale, Dolomite, Halite and Potash, near the base of the Late Cayugan Stage of the Upper Silurian Epoch age rocks.

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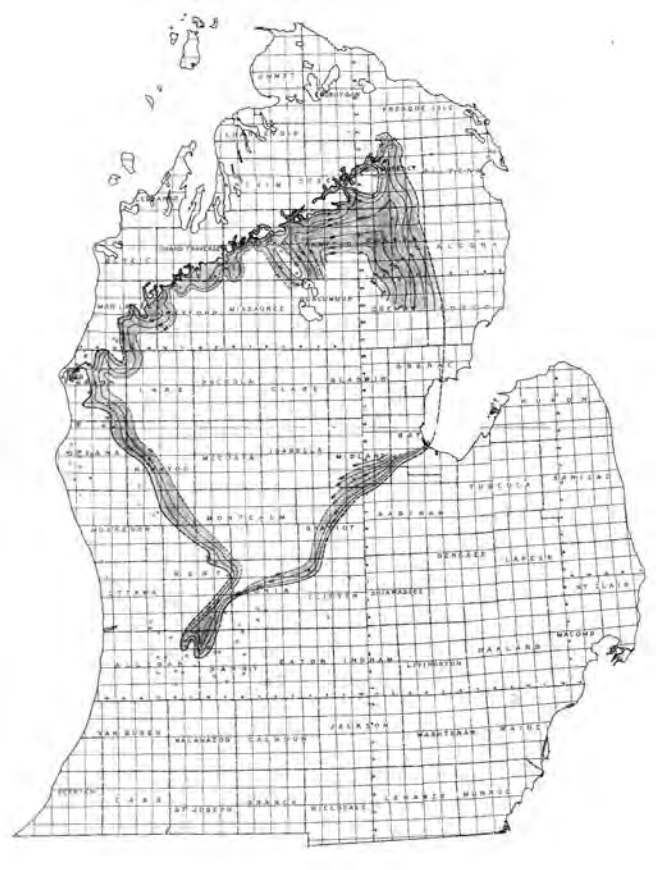
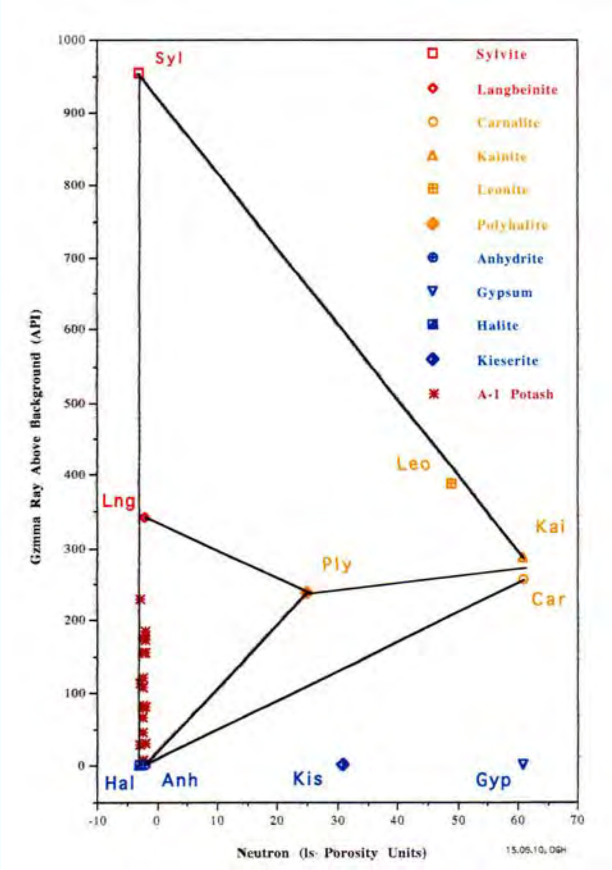
Michigan Basin Salina A-1Evaporite

Salina A-1Extent

After Elowski, 1980



Michigan Basin Well PID



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SE New Mexico

McNutt Member Salado Formation

- Very complex mineralogy.
- Thin (less than 10 ft. thick), ephemeral, low-grade Sylvite, Langbeinite, & mixed Sylvite/Langbenite ore zones, containing significant thinly bedded impurities of claystones, non-economic Potash minerals and/or non-potash evaporites.
- Both vertically and aerially heterogeneous, due to non-commercial potash minerals, other evaporites, marker beds, anhydrite beds, and claystones.
- ***Low Grade (≥ 4 ft 10% KO_2) Sylvite and (≥4 ft of 4% K_2O) Langbenite Potash Mineralization.***
- The potash mineral most commonly identified in the USDOE Waste Isolation Pilot Plant (WIPP) well core descriptions was non-commercial *Polyhalite*.

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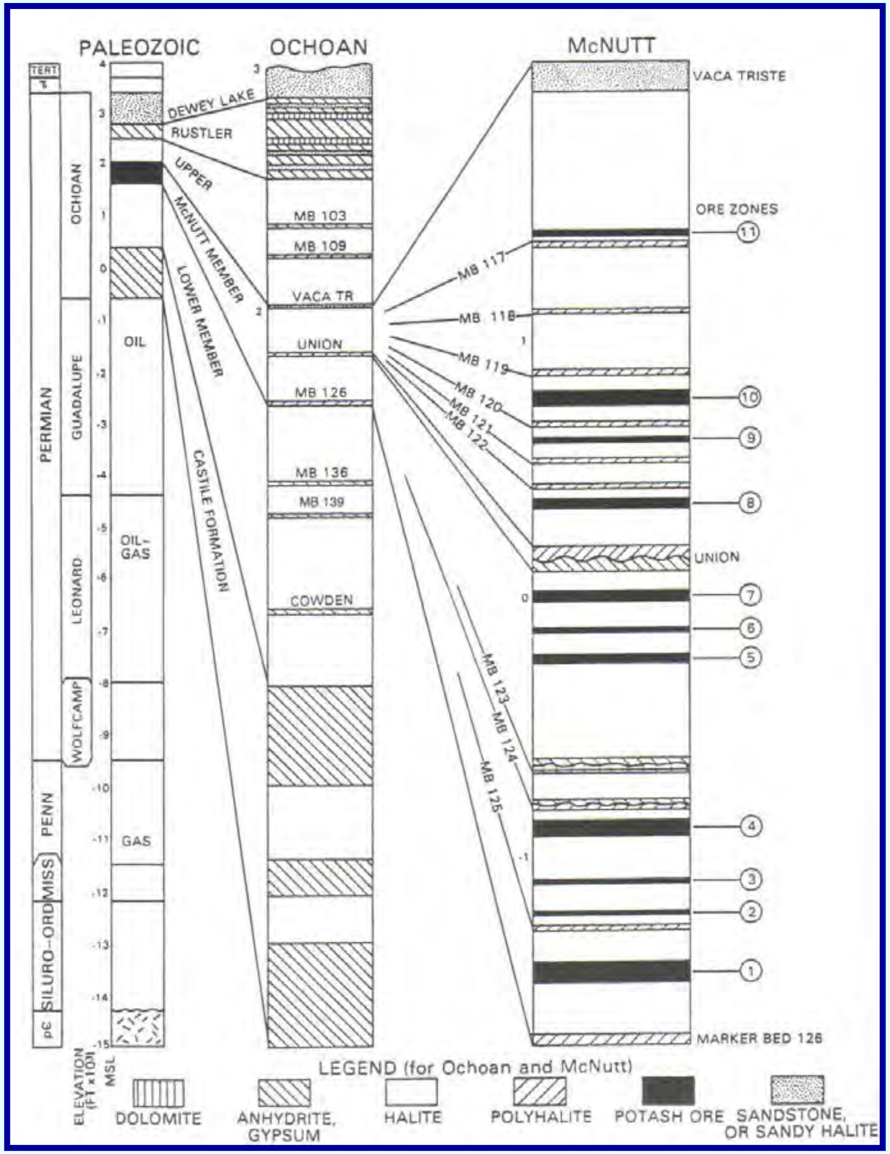
Regional Stratigraphic Column of the SE New Mexico Potash Area with Expanded Sections of the Ochoan Evaporite and the McNutt Member of the Salado Formation Showing Correlation of USGS Marker Beds with Potash Ore Zones (modified from Griswold, 1982)

For example:
The 10th potash ore zone is located between marker beds 119 &120.



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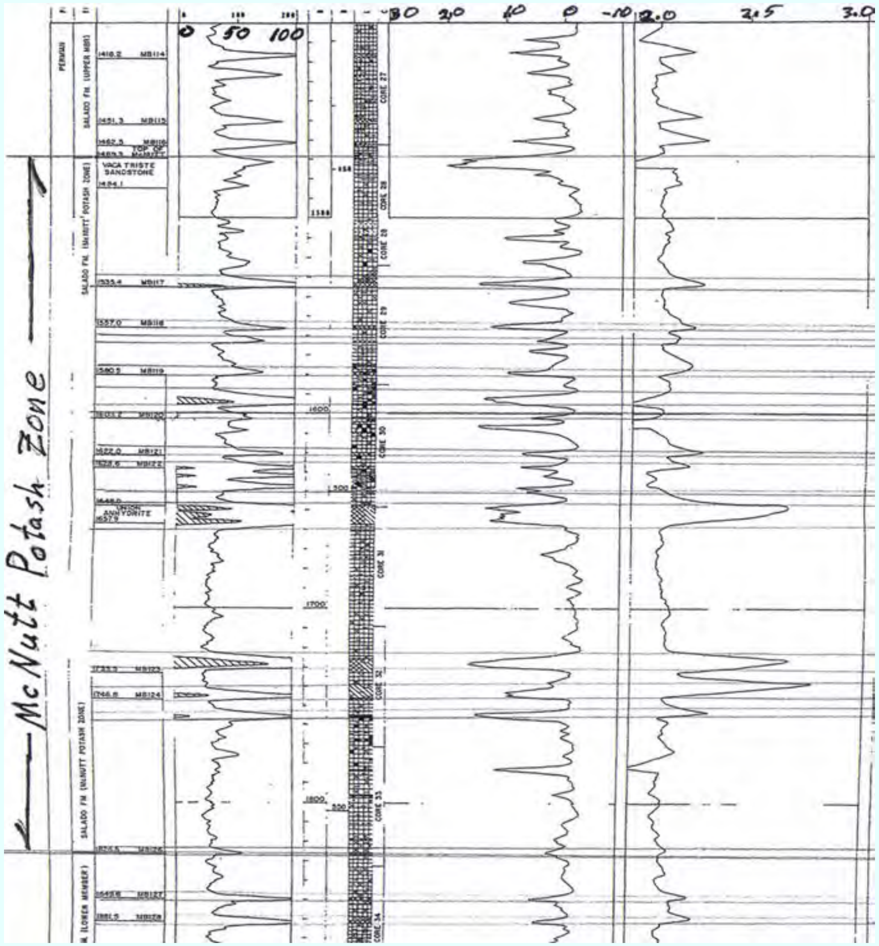
SE New Mexico Potash Area Example: AEC-8

1469



1826

- Salado Formation, containing the McNutt Member has 49 Marker Beds
- Many non-potash marker beds have gamma ray values (≤ 180 API) comparable to, or greater than, the 11 potash ore zones, in the McNutt Member.
- ***All potash ore zones, in AEC-8, are less than 8 ft thick.***

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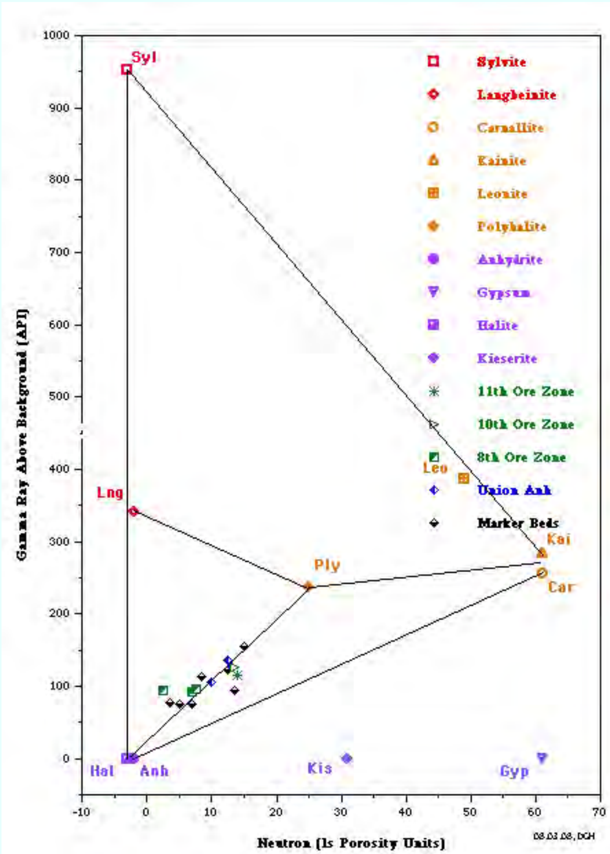
SE NM McNutt Member
AEC-8 Gamma Ray - CNL Cross-Plot



- All of the data:
  - Marker Beds
  - 8th, 10th, & 11th "ore zones"
  - Union Anhydrite
- Plot along the Polyhalite-Anhydrite/Halite line.
- ***Cannot distinguish between the above three groups.***
- ***There is NO Commercial Grade Potash in this well***

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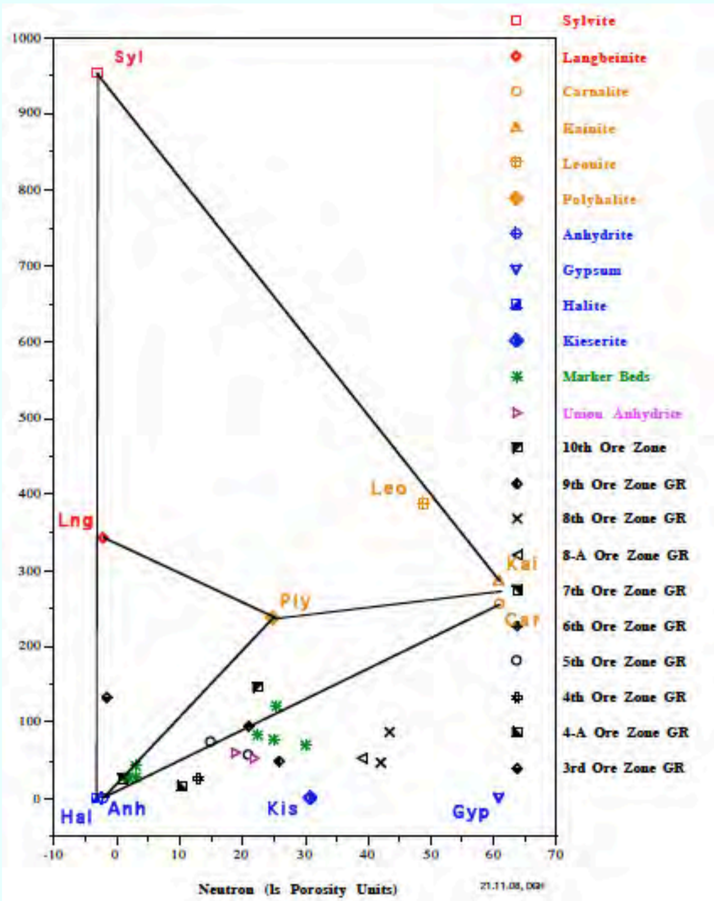
SE NM Cased Oil Well



- Only one potentially commercial interval.
- Ore Zone 3:
  - Most Probably low-grade Langbeinite
- All other “Ore Zones” are either:
  - Potash free, or:
  - Non-commercial potash minerals.

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Post Mortem

- The mineralogy of the McNutt Member of the Salado Formation, in SE New Mexico is too complex for a simple GR log to core transform.
- There are too many mineral/rock species, in of the McNutt Member of the Salado Formation, to be able to use linear programming or multi-mineral analyses techniques.
- Commercial potash minerals are anhydrous.
- The “Marker Beds”, claystones, & non-commercial potash minerals, of the McNutt Member of the Salado Formation, all have significant water content.
- The Simple GR-Neutron Potash Identification (PID) Cross-Plot, can be used to screen both cased and uncased wells, for potentially commercial potash mineralization.

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Questions?

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