PETROPHYSICS, VOL. 64, NO. 5 (OCTOBER 2023); PAGES 700–713; 21 FIGURES, 4 TABLES. DOI: 10.30632/PJV64N5-2023a6

The Potash Identification (PID) Plot: A Rapid Screening Crossplot for Discrimination of Commercial Potash[1]

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ABSTRACT

Potash minerals are the primary source of potassium (K), which is used for the manufacture of gunpowder, fertilizer, and as a sodium-seasoning substitute. Commercial potash minerals are all evaporites. Because potassium-40 (^{40}K) is radioactive (decaying to argon-40 (^{40}Ar) and releasing a gamma ray (GR) in the process), commercial potash mineralization is often discovered when GR (γ ray) logs in petroleum wells drilled through evaporite sequences "go off scale."

However, not all potash minerals may be commercial sources of potassium via underground mining techniques, and potassium is not the only radioactive element. For example, the mineralogy of the McNutt "potash" Member of the Salado Formation in southeast (SE) New Mexico is extremely complex, consisting of multiple thin (i.e., less than 10 ft thick) beds of six low-grade (radioactive) potash minerals, only two of which are commercial for underground mining. There are also four nonradioactive evaporite minerals, one of which may interfere with potash milling chemistry and numerous claystones and marker beds (shales and/or volcanics), with GR count rates comparable to the low-grade potash mineralization in this sequence.

Because of this complexity, traditional borehole wireline (WL) and logging-while-drilling (LWD) potash assay techniques, such as GR log-to-core assay transforms, may not be sufficient to identify potentially commercial potash mineralization for underground mining (Teufel, 2008) in SE New Mexico. Crain and Anderson (1966) and Hill (2019) developed linear programming and multimineral analyses, respectively, to estimate potash mineralogy and grades from multiple borehole geophysical measurements. However, both of these approaches require large sets of multiple log measurements.

In SE New Mexico, petroleum wells are drilled through the Salado Formation evaporite (including the McNutt "potash" Member) with air, then cased and cemented in place without running WL measurements. Then, the wells are drilled out to total depth (TD) in the underlying sediments with water-based mud. Complete log suites are run from TD to the casing shoe, with only the GR and neutron logs recorded through the cased evaporite sequence for stratigraphic and structural correlation.

As a result, essentially all recent oil and gas wells in SE New Mexico have casedhole gamma ray and neutron logs through the Salado evaporite. Hill and Crain (2020) developed a simple crossplot involving only GR and neutron log data, which could discriminate between anhydrous and hydrated potassium evaporite minerals. Logs from these wells could provide a rapid potash screening database if used properly. This technique can be used with both openhole and casedhole petroleum well logs, as well as corehole WL logs, and provides discrimination of commercial potash mineralization from noncommercial (potash and non-potash) radioactive mineralization.

Case histories of the use of PID crossplots in evaporite basins of Michigan, Nova Scotia, Saskatchewan, and SE New Mexico are described. This technique may also be useful in screening potential potash deposits elsewhere in the world.

INTRODUCTION

Potassium

Potassium is the seventh most common element in the Earth's crust (Helmenstine, 2019). It is a common component in both commercial and noncommercial minerals. It is economically important as a food preservative and seasoning, as well as a major component in gunpowder and fertilizer.

Metallic potassium is highly reactive. Like sodium metal, potassium metal will spontaneously combust if exposed to air. Because of this, it does not exist in the native

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state. Potash (simple, high-grade potassium) minerals are all evaporites.

^{40}K is radioactive and decays to ^{40}Ar, which is a stable isotope, releasing a GR in the process. The potassium-argon age dating technique has been used to date igneous and volcanic rocks as old as 4.5 billion years and as young as 20,000 years (Britannica, 2020). Commercial potash deposits are often discovered when GR curves in wells drilled through evaporites go off scale.

"POTASH," K_2O, AND US POTASH HISTORY

There is no natural potash (K_2O) mineral. The term "potash" traces its origin to North American colonial times when potash, used in the manufacture of gunpowder, was one of the first colonial exports. The process of manufacturing potash included the following steps:

- Hardwood timber was burned.
- The ashes were leached.
- The resulting black powder (the "pot ash," or K_2CO_3) was refined to K_2O and used to manufacture gunpowder—first in the mother country and later in the colonies.

The current use of the term "potash" is one of convenience for commodity transactions. As a result, all naturally occurring evaporite "potash minerals" have been assigned equivalent potash (K_2O) values.

In spite of its North American history, by the end of the 19th century, most of the potash used in the US for gunpowder and fertilizer was imported from mines in eastern Europe. Blockades of German ports during WWI denied the US access to these eastern European potash supplies and resulted in potash shortages. As a result, the US government declared potash to be a "strategic mineral" and provided for the establishment of "potash reserves/enclaves" wherever commercial-grade US potash deposits were discovered. Modest potash deposits were discovered, between WWI and WWII, in SE NM, the Paradox Basin of Eastern Utah, and later, deep deposits in the Michigan Basin, as the result of oil and gas well drilling.

The 1940s discovery of the Prairie Evaporite Formation potash deposits in Saskatchewan eclipsed all US potash deposits combined and changed the economics of the US potash mining industry, making the US potash enclaves superfluous. However, they still exist.

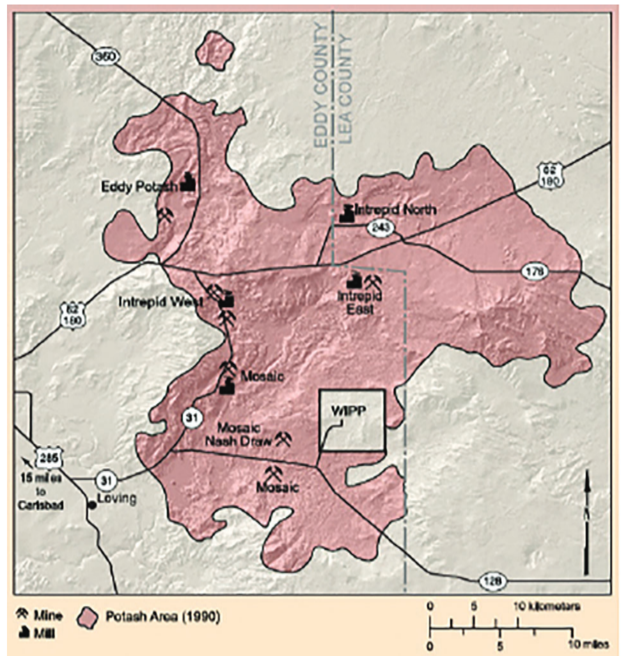


Fig. 1—SE New Mexico potash enclave and Waste Isolation Pilot Project (after Barker and Gundiler, 2008).

SE NEW MEXICO POTASH AREA/ENCLAVE

Low-grade potash was discovered in SE New Mexico oilwell cores in 1925. The US Secretary of the Interior created the "SE NM Potash Area/Enclave" in 1931, a few miles ENE of Carlsbad (see Fig. 1). The purpose of this order was to preserve this strategic mineral resource for future development should foreign sources be denied again. In spite of the Prairie Evaporite potash deposits, this enclave still exists.

In 1973, the US Atomic Energy Commission ((AEC), now Department of Energy (DOE)) condemned a 36-square mile area within the New Mexico Potash Enclave (see Fig. 1), as a Waste Isolation Pilot Plant (WIPP) for long-term storage of highly radioactive waste. As part of this action, the AEC drilled, cored, and logged, with complete sets of commercial and USGS wireline measurements, 21 coreholes to evaluate compensation for minerals rights owners.

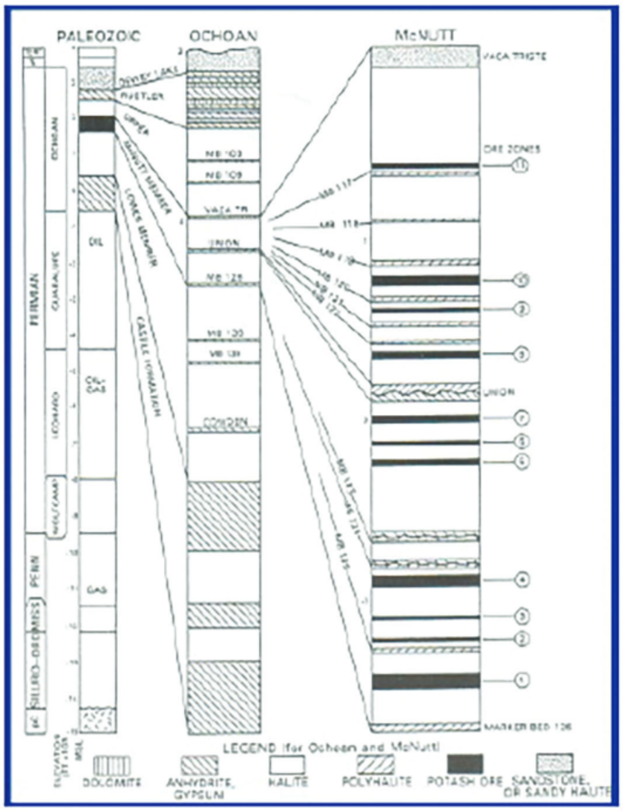


Fig. 2—Regional stratigraphic column for the SE NM potash area (after Griswold, 1982).

SE NEW MEXICO OIL/GAS WELL DRILLING, LOGGING, AND CASING PROTOCOLS

Most SE New Mexico oil and gas reservoirs are below the Salado evaporites, which include the 11 potash zones of the McNutt Member (Fig. 2). Over time, the typical SE NM petroleum well drilling, logging, and casing programs have developed:

- Air drilling through the Salado evaporites
- Borehole cased and cemented to the surface without logging
- Oil/gas wells drilled to TD, using water-based muds
- Complete set of FE logs run from TD to the surface casing shoe
- GR and neutron *only*, run through the cased interval

As a result, the only evaporite wireline measurements available from essentially all SE NM petroleum wells will be casedhole GR and neutron logs. The State of New Mexico requires that log copies from all petroleum, water, and environmental wells be placed on file in a state repository available to the public after a discrete proprietary period.

SE NEW MEXICO McNUTT MEMBER, SALADO FORMATION LITHOLOGY AND MINERALOGY

The SE NM potash resources are confined to the McNutt Member of the Salado Formation of the Ochoan evaporites. Figure 2 shows the regional stratigraphic column of the SE NM potash area, with expanded sections of the Ochoan evaporite and the McNutt Member of the Salado Formation, along with the 11 potash ore zones and associated USGS regional marker (most probably ash) beds. For example, the Tenth potash ore zone is located between USGS Marker Beds 119 and 120. Potash salts are among the last to precipitate from a bittern. As a result, not every "ore zone" evaporite contains commercial potash at every location.

Table 1—SE New Mexico McNutt Member, Salado Formation Major Rocks and Minerals

Mineral Name	*Formula*	*Crystal Class*	*%K*	*Equivalent %K_2O*	*Gamma Ray (API)*
Sylvite	KCl	Isometric	53.45	63.18	953
Langbeinite	$K_2Mg_2(SO_4)_4$	Isometric	18.84	22.7	342
Carnallite	$KMgCl_3{\bullet}6(H_2O)$	Orthorhombic	14.07	16.95	256
Kainite	$MgSO_4KCl{\bullet}3(H_2O)$	Monoclinic	15.07	18.92	287
Leonite	$K_2Mg(SO_4)_2{\bullet}4(H_2O)$	Monoclinic	21.32	25.69	387
Polyhalite	$K_2Ca_2Mg(SO_4)_4{\bullet}2(H_2O)$	Triclinic	12.97	15.62	236
Anhydrite*	$CaSO_4$	Orthorhombic	-	-	-
Gypsum	$CaSO_4{\bullet}2(H_2O)$	Monoclinic	-	-	-
Halite	$NaCl$	Isometric	-	-	-
Kieserite**	$MgSO_4{\bullet}(H_2O)$	Monoclinic	-	-	-
Marker Beds	Variable	-	-	?	Variable
Claystones	Variable	-	-	?	Variable

Table 1 summarizes the mineralogy and major rocks and minerals of the SE NM McNutt Member of the Salado Formation, as well as the accepted chemical formulas, assigned equivalent %K2O, and (100%) GR responses (SLB, 2000; Ellis, 2007). Those entries in red are the commercial potash minerals, while those in green are considered to be noncommercial for underground mining. There are six (radioactive) potash evaporite minerals:

- Sylvite
- Langbeinite
- Carnallite
- Kainite
- Leonite
- Polyhalite

Only two of which—sylvite and langbeinite—are considered to be commercial for underground mining and four non-potassium evaporite minerals:

- Anhydrite
- Gypsum
- Halite
- Kieserite

This table also includes marker (ash?) beds and claystones, which have variable mineralogy and can have GR signatures approaching and even exceeding those of the low-grade potash zones. The non-potash evaporites do not contain potassium and are not radioactive.

SE NEW MEXICO POTASH COMMERCIAL STANDARDS

At the time of the current study, commercial potash reserves standards were in flux. However, based upon a 1986 Secretary of the Interior Order, the following standards were generally accepted by the US Bureau of Land Management (BLM):

- At least one bed of ≥ 4 ft thickness
- Sylvite and/or langbeinite grade ≥ 4% K_2O equivalent concentration
- A rather elastic areal extent requirement involving commercial grade intercepts in a triangular area defined by at least three separate coreholes/wells

WIRELINE ANALYSES

Initial Wireline Analysis Validation Attempt

Ignoring the variable gamma ray responses of the marker beds and the claystones, plotting the Table 1 pure potash mineral GR vs. equivalent %K_2O yields the linear relationship of Fig. 3.

A geologist with a SE NM mining company developed a similar empirical relationship based upon seven SE NM wells and coreholes with McNutt Member core assays and modern GR API unit logs to develop a least-squares (LSQ) core-based %K_2O transform. A review by a petrophysicist with extensive potash experience suggested that a reduced major axis (RMA) model, such as that in Fig. 4, which distributes the fitting errors equally between both variables, be used instead of the LSQ regression model, which places all fitting errors on the dependent variable. The rationale for this change is that for petrophysical data such as this, neither variable data can be considered to be *noise-free*. A second

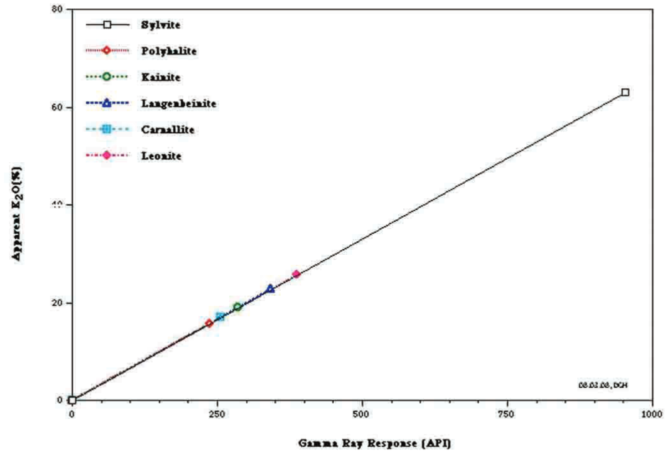


Fig. 3—Linear relationship between potash mineral matrix API response and assigned %K_2O (after Hill, 2019).

review by an experienced mining geophysicist echoed these comments and added that the model should be based on grade thickness, as is done for uranium evaluation (Nelson, 2007).

Evaluation of the RMA Model

To evaluate the SE NM GR to %K_2O transform, a series of grade-thickness maps was prepared, including Fig. 5, for the known wells and coreholes surrounding the WIPP site.

Table 2 compares the %K_2O transform predicted assay to the actual wet chemistry from two coreholes identified on the Fig. 5 map. Obviously, the RMA transform is overly optimistic.

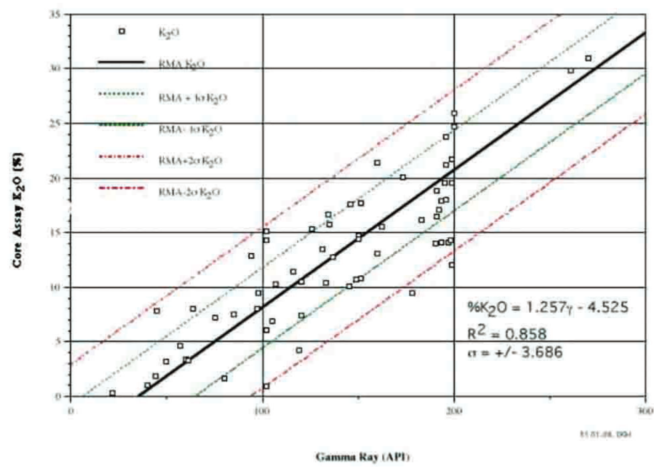


Fig. 4—RMA GR to %K_2O relationship from seven SE NM well cores and GR logs (after Hill, 2019).

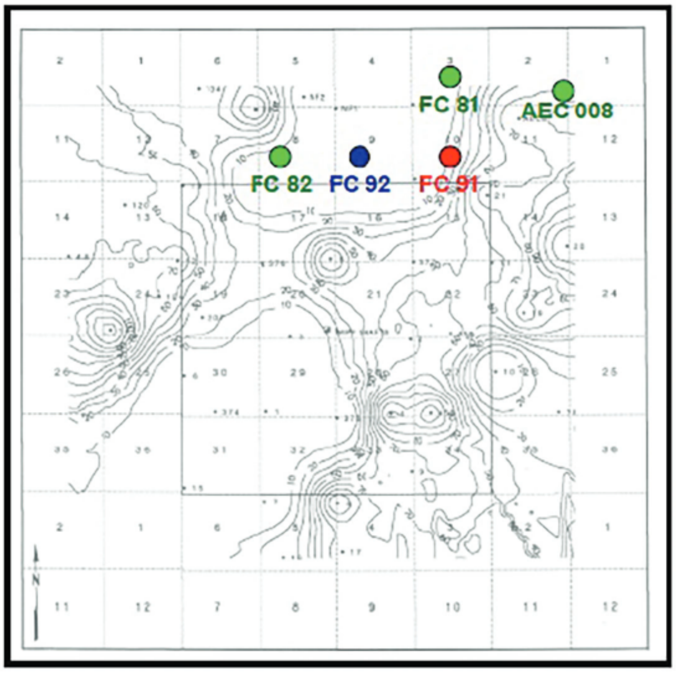


Fig. 5—WIPP site area, tenth ore zone RMA transform potash grade-thickness map.

Table 2—SE New Mexico McNutt Member, Salado Formation WIPP Site Predicted vs. Wet Chemistry $\%K_2O$

Corehole	FC-91 ($\%K_2O$-Ft)	FC-92 ($\%K_2O$-Ft)
RMA Predicted Assay	**105**	**111**
Wet Chemistry Assay	<10	<10

A corehole was drilled and logged 200 ft from one of the cased wells that had initiated the claims of commercial potash. Modern API GR neutron porosity logs were run, and a potash evaluation was conducted using the RMA GR model. The resulting core was evaluated, and wet chemistry assays were conducted on the recovered core material. Figure 6 shows the correlated GR and neutron logs between the corehole on the left and the well on the right. The correlation between various beds is excellent, as it should be for the closely spaced (200 ft) well and corehole in a stratiform evaporite deposit.

Table 3 summarizes the results of this validation test. Obviously, more than GR alone is needed for a McNutt Member evaporite potash screening tool. The question is, why?

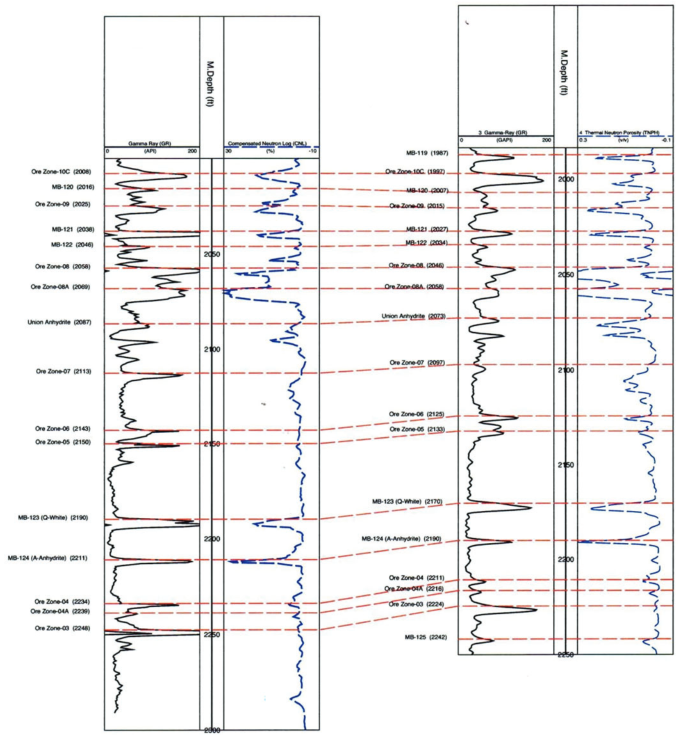


Fig. 6—RMA GR to %KO transform evaluation corehole on the left and cased well on the right (after Hill, 2019).

Table 3—SE New Mexico McNutt Member, RMA GR to $\%K_2O$ Model Validation Test Results (after Hill, 2019)

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 – Langbonite S – Sylvite

ALTERNATIVES TO THE RMA GR TRANSFORM

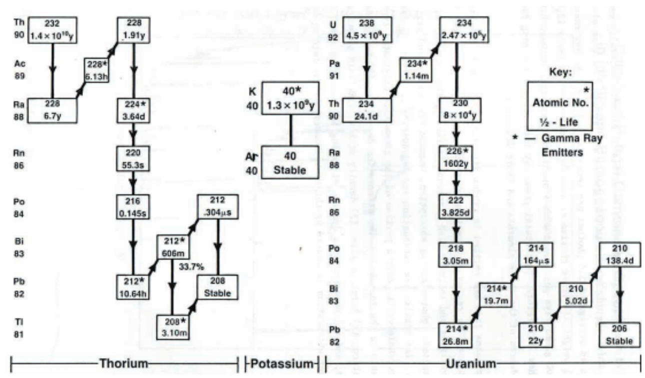


Fig. 7—Potassium, uranium, and thorium, K-U-T decay series (after Guo, 1982).

Non-Potash Radioactive Sources

First of all, potassium is not the only naturally occurring radioactive element in the Earth's crust. Figure 7 shows the radioactive decay series for the three naturally occurring radioactive elements: ^{40}K, ^{238}U, and ^{232}Th. While the ^{40}K to ^{40}Ar decay is direct, both ^{238}U and ^{232}Th decay through a series of radioactive daughter products before reaching a stable Pb isotope. While neither of these two parent elements emits gamma rays on their decay, several of their daughter products for both the ^{238}U and ^{232}Th series do.

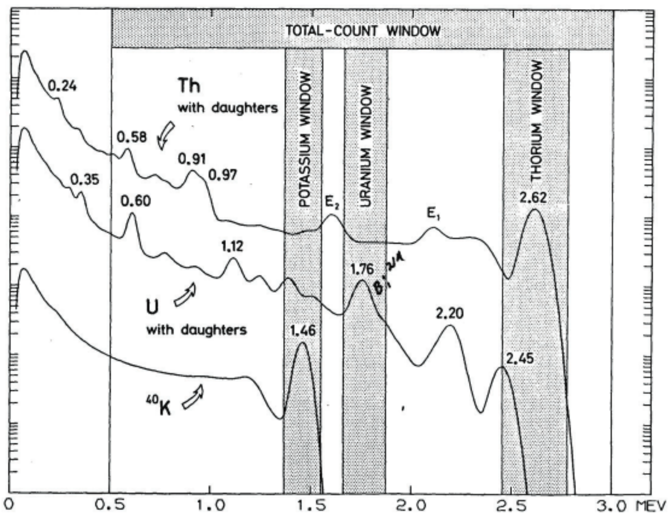


Fig. 8—Gamma ray count energy windows for the total count and K-U-T spectral GR windows (after Guo, 1982).

Common WL GR sondes measure the total decay counts over a large energy window, as shown in Fig. 8. The SE NM claystones and marker beds contain clay minerals, which often contain trace uranium and/or thorium, as well as potassium, raising the possibility of all three types of radioactive elements being present to contaminate the GR to potash transform. Special K-U-T GR sondes attempt to separate the effects of the higher energy decays of the ^{238}U and ^{232}Th decay series from that of the single ^{40}K to ^{40}Ar decay. Because daughter product decays of both the ^{238}U and ^{232}Th series also occur within the potash window, these effects must be removed to get the true potassium signal. This is done either by techniques called stripping or Kalman filters (Fertl, 1979; Mathis et al., 1984).

Figure 9 shows a K-U-T example from SE NM, total count, and potassium channel of a K-U-T spectral GR sondes, with the scales shifted to overlap in the high peaks. While a K-U-T spectral gamma ray sonde might eliminate

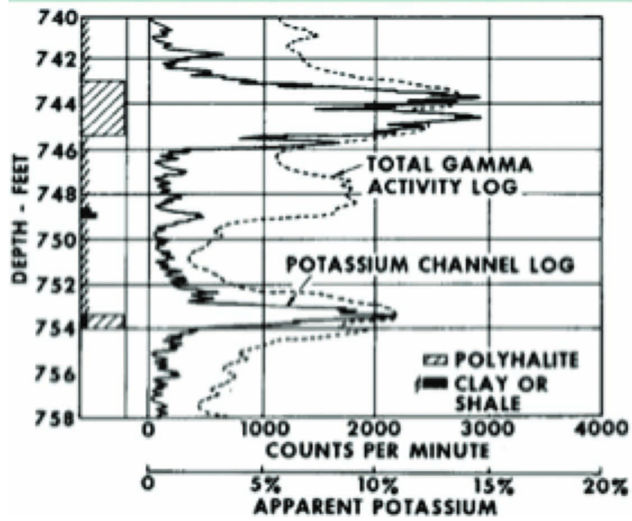


Fig. 9—SE NM total count and K channel GR response example (after Fertl, 1979).

marker beds, it would not eliminate the noncommercial potash minerals or potassium clays from the commercial potash minerals. In fact, the potash mineral in the overplot example of Fig. 9 is polyhalite, which is not considered commercial for underground mining.

Crain and Anderson (1966) used gamma ray, GNT neutron, and sonic logs with linear programming to successfully discriminate between sylvite and carnallite in the Prairie Evaporite of Saskatchewan. Hill (1993) used gamma ray, density, CNL neutron, and sonic logs with multimineral analysis for the Windsor Group evaporites of Cape Breton Island. However, the only well logs available for most SE NM oil and gas wells will be casedhole GR and neutron.

THE POTASH IDENTIFICATION (PID) PLOT

Table 3 compares the gamma ray and neutron responses for the most common minerals and rocks in the McNutt Member of the Salado Formation of SE New Mexico. The obvious difference between sylvite and langbeinite, which are commercial for underground mining, and carnallite, kainite, leonite, and polyhalite, which are not, is that the first two are anhydrous, while the other four are hydrated. The SE NM claystones and marker beds contain hydroxyl ions and often water of hydration, both of which contain hydrogen ions. The neutron porosity log really responds to hydrogen ions (Ellis, 1986) in the adjacent wall rock, which makes it a good second discriminator, as the noncommercial potash minerals are all hydrated, as are the clays and ash beds, while the two commercial minerals are not.

Table 4—SE New Mexico McNutt Member, Salado Formation Chemistry, Gamma Ray, and Neutron Responses (after Hill, 2919)

Mineral Name	Formula	Gamma Ray (API)	NPHI (%LS)
Sylvite	KCl	953	-3
Langbeinite	$K_2SO_4(MgSO_4)_2$	342	-2
Carnallite	$KClMgCl_2 \cdot 6(H_2O)$	256	61
Kainite	$MgSO_4LCl \cdot 3(H_2O)$	286	61
Leonite	$K_2SO_4MgSO_4 \cdot 4(H_2O)$	270	45
Polyhalite	$K_2SO_4MgSO_4(CaSO_4)_2 \cdot 2(H_2O)$	236	25
Anhydrite*	$CaSO_4$	-	-2
Gypsum	$CaSO_4 \cdot 2(H_2O)$	-	61
Halite	NaCl	-	-3
Kieserite**	$MgSO_4 \cdot (H_2O)$	-	43
Marker Beds	Variable	Variable	Variable
Claystones	Variable	Variable	Variable

Dewan and Greenwood (1955) may have been the first to recognize the utility of using both GR and neutron logs to identify potential economic potash deposits. Interestingly enough, they were considering this for SE NM. Alger and Crain (1965) showed a Prairie Evaporite Formation log suite, which contained both GR and neutron logs, along with sonic and density, but did not go into any detail. Crain and Anderson used GR, GNT-neutron, and sonic logs with linear programming to estimate sylvite, carnallite, and insolubles for Prairie Evaporites. Tixier and Alger (1967) pointed out that using neutron logs could eliminate carnallite because it is hydrated. However, they did not go much beyond this statement and suggested that GR neutron, density, and sonic all be used in a joint interpretation. All of these authors were using early (including GNT and SNP) neutron logs first- and second-generation logging measurements. Hill (1993) used modern GR, density (FDC or LDL), neutron (CNL), and sonic logs (BHC) with multimineral analysis to estimate sylvite, halite, anhydrite, carnallite, and insoluble for the Windsor Group evaporites of Cape Breton Island. Unfortunately, the only logs available from most SE NM oil and gas wells are casedhole GR and neutron, which eliminates the more sophisticated analyses.

With the insight gained from the information in Table 4, a simple graphic—the potash identification (PID) plot—was designed (Fig. 10) for GR and neutron only data, which can be used with either digital data or handpicked points from the printed field or processed log prints. Figure 10 shows the PID master for SE NM, which shows all six SE NM potash minerals, as well as the four SE NM non-potash evaporites. The only preprocessing required is environmental corrections.

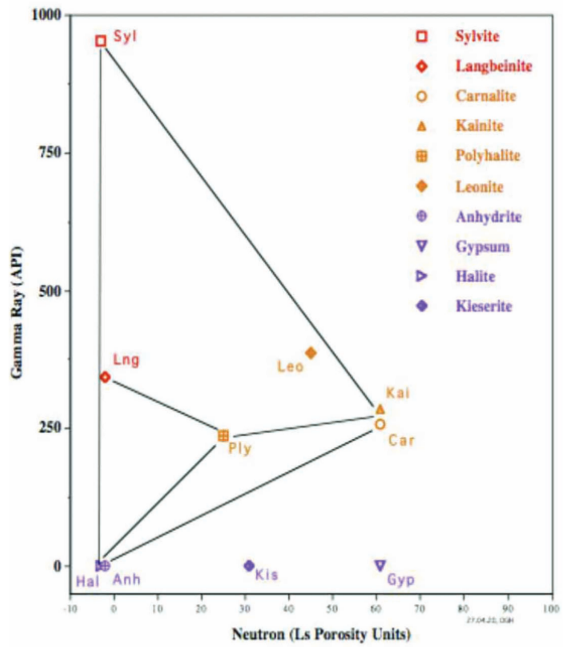


Fig. 10—SE NM potash identification (PID) plot master.

PID PLOT VALIDATION

With the PID plot defined, it was validated using wells from three North American potash locations.


Fig. 11—Prairie Evaporite (after Holter, 1969).

Prairie Evaporite, Saskatchewan

The Prairie Evaporite of Saskatchewan, discovered during the 1940s and continuously produced since 1962, could easily be dubbed "The Saudi Arabia of Potash" (see Fig. 11). The geology and mineralogy are:

- Simple structure and mineralogy
- Distinct sylvite and carnallite intercepts with only minor dolomite and claystone stringers
- Massive (up to 15 m thick) beds
- High-grade (up to over 50%) sylvite
- Uniform (can correlate over several miles using seismic reflection)
- Extensive (covers roughly the SE quarter of the province of Saskatchewan, spilling over into NE Montana and NW North Dakota (see Fig. 11)

At the time of the current study, the Prairie Evaporite was supplying roughly 25 to 30% of the world's potash demand and 70% of the US demand, with sufficient reserves to do so for several hundred years. Figure 12, from Crain and Anderson (1966), is one of the earliest linear programming attempts to estimate potash assays from wireline measurements using the GR, GNT, and sonic logs, which were available at the time. Crain (2010) further described the steps needed to accomplish this with the older wireline measurements.

Figure 13 shows PID displays from two modern Prairie Evaporite wells. The one on the left is from a section that is high-grade sylvite, with all points plotting on the PID sylvite – anhydrite/halite line. The one on the right is from a well with lower grade sylvite, some carnallite, and other minor minerals. The PID separates the sylvite from the carnallite nicely.

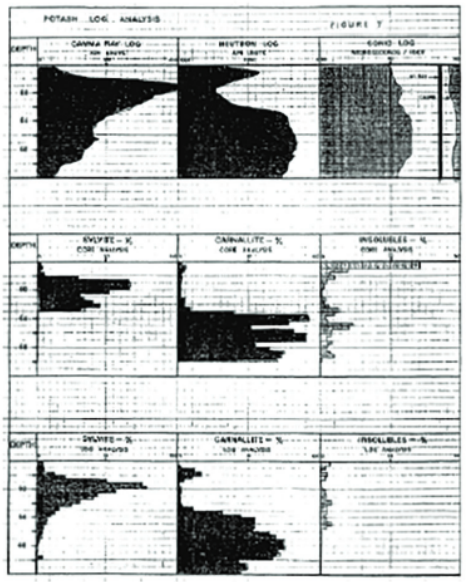


Fig. 12—Prairie Evaporite well logs, core assays, and linear programming log assays (after Crain and Anderson, 1966).

Windsor Evaporite, Cape Breton Island

A high-grade but minor reserves potash deposit in a complex structural setting was discovered in the Windsor Group evaporite of Cape Breton, Island, Nova Scotia (far right, Fig. 14 cross section). The mineralogy is essentially sylvite, with little contamination by carnallite, associated with halite and minor amounts of gypsum and anhydrite. Hill (1993) conducted a multimineral analysis using modern GR, CNT neutron, FDC density, and BHC sonic. Figure 15 compares the core-wet chemistry analysis (Fig. 15a) to the multimineral analysis (Fig. 15b). The results are very good.

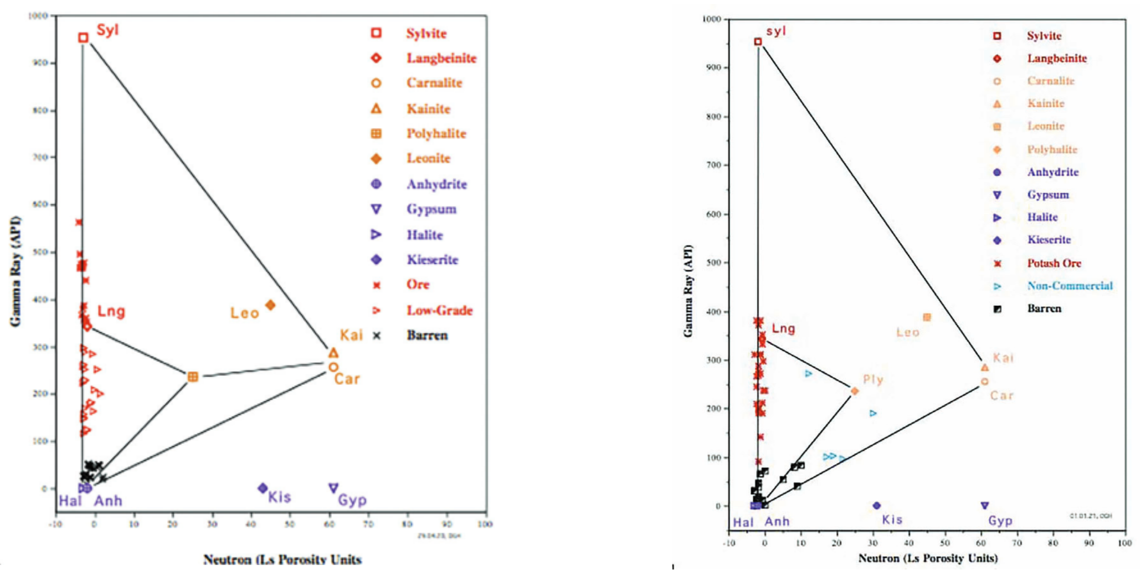


Fig. 13—PID plots for two Prairie Evaporite wells (after Hill and Crain, 2020).

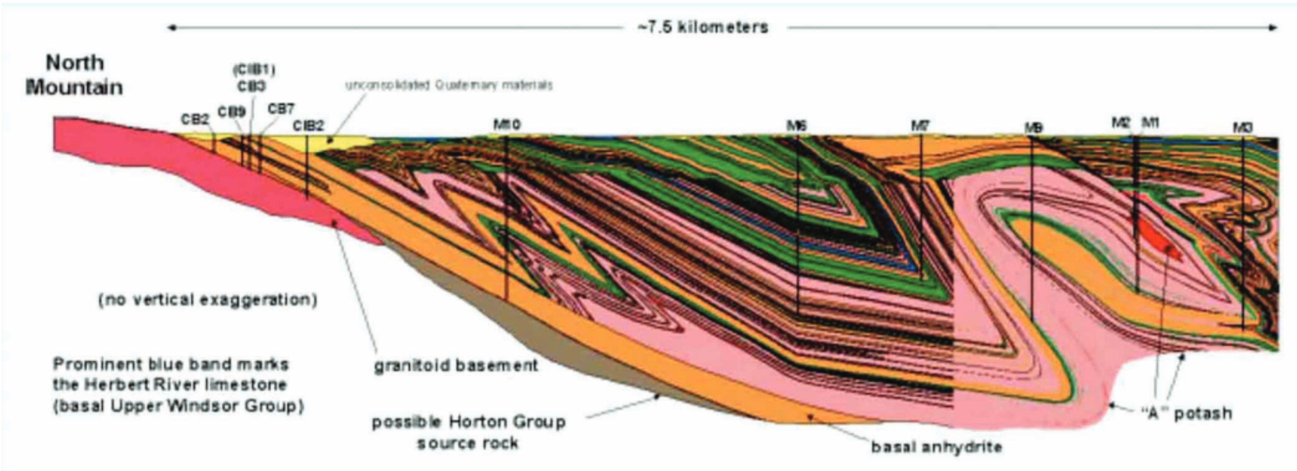


Fig. 14—Cape Breton Island structural cross section showing the Windsor evaporite deposit on the right (after Giles, 2003).

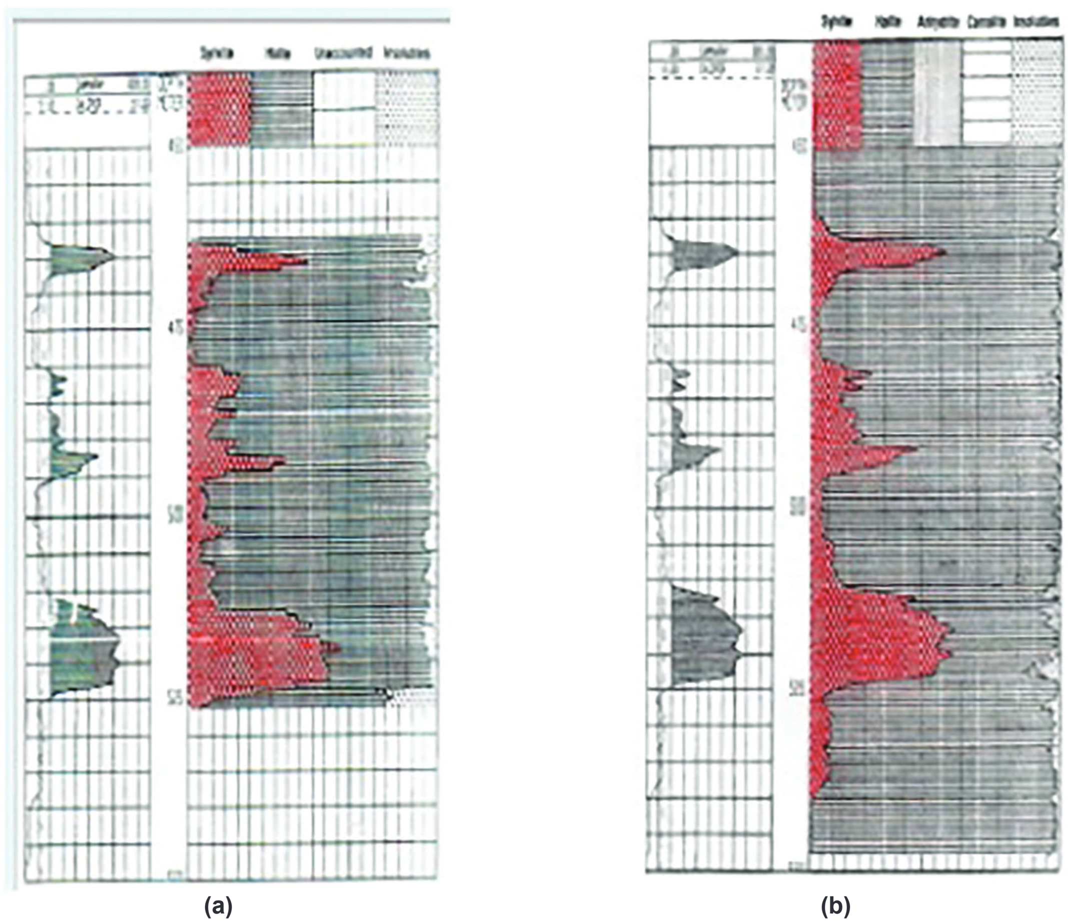


Fig. 15–(a) Cape Breton Island well core assay and (b) multimineral assay (after Hill, 1993).

There was little, if any, carnallite in this well, and the PID plot (Fig. 16) shows all points (both high-grade and lower grade sylvite) plotting on the sylvite – anhydrite/halite line, as they should.

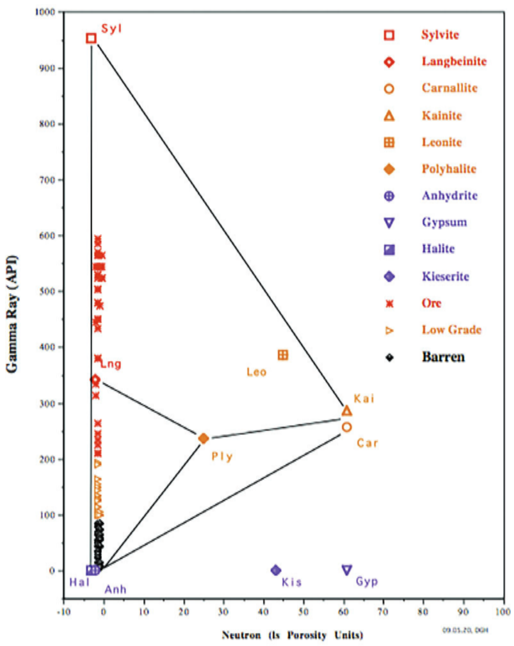


Fig. 16—Cape Breton Island well PID plot (after Hill, 2019).

Salina A-1 Evaporite, Michigan Basin

The Paleozoic and Mesozoic geology of the Lower Peninsula of Michigan is much like a "stack of bowls" sitting on the Pre-Cambrian basement. Deep potash salts were discovered in the Salina A-1 evaporite of the Michigan Basin (see Fig. 17) when wells drilled with saturated NaCl brine muds washed out for lack of potassium salt in the drilling mud. Subsequently, at least one solution mining project was developed near the town of Evart, Osceola County, in the West-Central Lower Peninsula of Michigan.

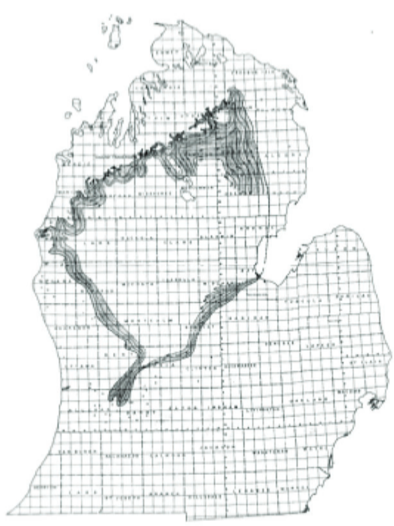
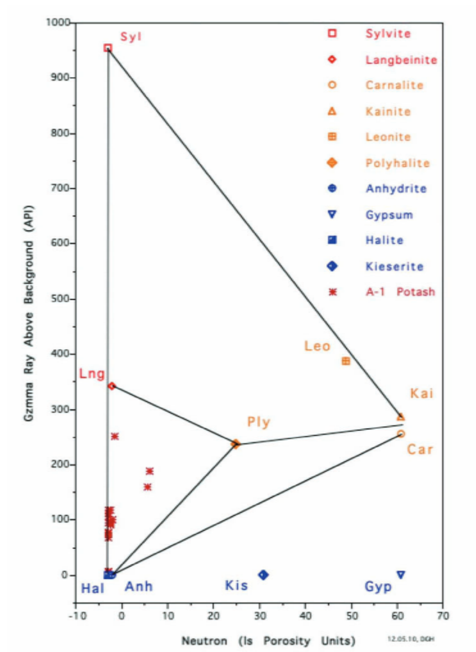
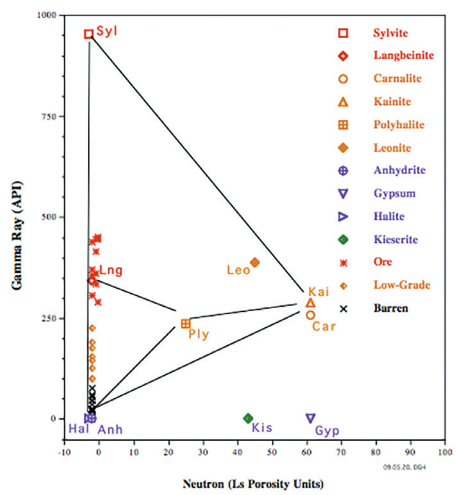


Fig. 17—The Michigan Basin known as the Salina A-1 Evaporite Extent (after Elowski, 1980; Hill, 2019).



(a)



(b)

Fig. 18—Two deep Michigan Basin Salina A-1 evaporites PID plots.

Figure 18 shows PID plots for two deep NW Michigan Basin Salina A-1 evaporite wells. In Fig. 18a, the well may have low-grade sylvite or langbeinite. The other well (see Fig. 18b) appears to have higher-grade sylvite and/or langbeinite.

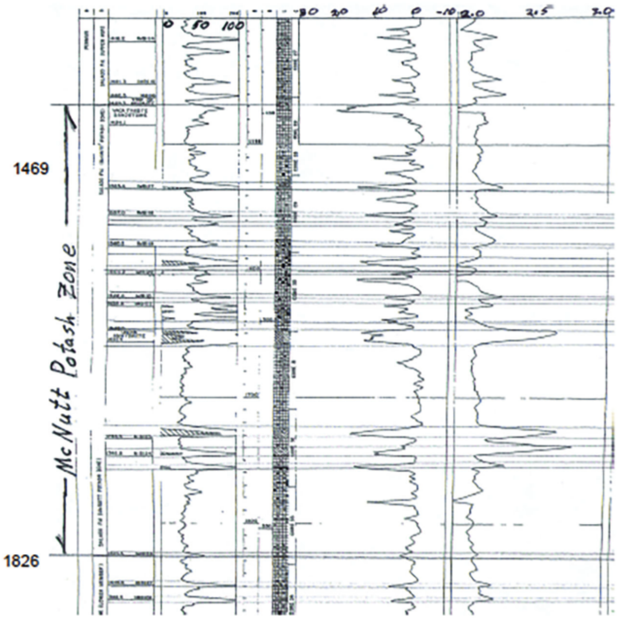


Fig. 19—AEC-8 McNutt Member, Salado Formation, SE NM, log and lithology (after Griswold, 1982).

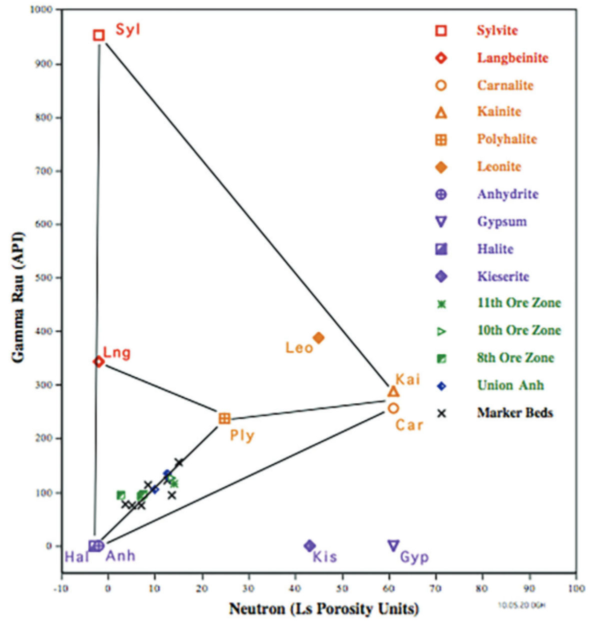


Fig. 20—AEC-8 McNutt Member, Salado Formation, SE NM, PID plot (after Hill, 2019).

McNutt Potash Member of the Salado Formation, SE New Mexico

The AEC condemnation of a 6- × 6-mile area in the SE NM potash enclave for the WIPP for the deposition of radioactive waste deposition site resulted in an extensive coring and wet chemistry assay campaign to determine the value of the condemned land for settlement with the then-current mineral rights holders. The resulting public domain data offer an excellent option to evaluate the PID for SE New Mexico.

Figure 19 Shows the McNutt Member stratigraphy, GR, core graphic, neutron, and density logs for the AEC-8 evaluation corehole drilled to evaluate the WIPP acreage. All of the potash zones in AEC-8 are 8 ft thick or less. The Salado Formation has 49 marker beds, which can be correlated regionally across the SE NM basin containing the potash enclave. Many of these non-potash markers have ≥ 189 API units, which are comparable to or greater than the 11 low-grade potash zones in the McNutt Member.

Figure 20 shows the AEC-8 McNutt Member PID plot. All of the data plot along the anhydrite/halite – polyhalite matrix point line, far away from the anhydrite/halite – sylvite line. A review of the Griswold (1982) and other AEC-commissioned study reports indicate that the most commonly identified potash mineral in the WIPP well cores was polyhalite.

VALIDATION TEST OIL WELL AND COREHOLE McNUTT PID

With this background, we can now look at the PID displays from the validation test of Fig. 6 and Table 3. The oil well (on the right of Fig. 6) was drilled with air through the evaporite, then cased and cemented, without logs prior to drilling to TD. Casedhole GR and neutron logs were run as part of the TD log suite. The project geologist claimed that the vendor was instructed to do casedhole environmental corrections, *in the cab*, which can be done with modern WL systems—a claim that was collaborated via a telephone call to the Roswell wireline vendor station manager. The corehole (on the left, of Fig. 6) was a slimhole project, as most mineral coreholes are, and logged open hole with modern slimhole wireline equipment.

Figure 21 shows the PID plots for this test, with the corehole PID (Fig. 21a) and the oilwell PID (Fig. 21b). Only one point in the oilwell PID plots near the sylvite – anhydrate/halite line, which corresponds to the validation test corehole assay for the langbeinite third ore zone wet chemistry assay. However, the zone thickness (2.5 ft) is under the minimum 4 ft thickness SE NM economic standard and was not echoed in the oilwell data.

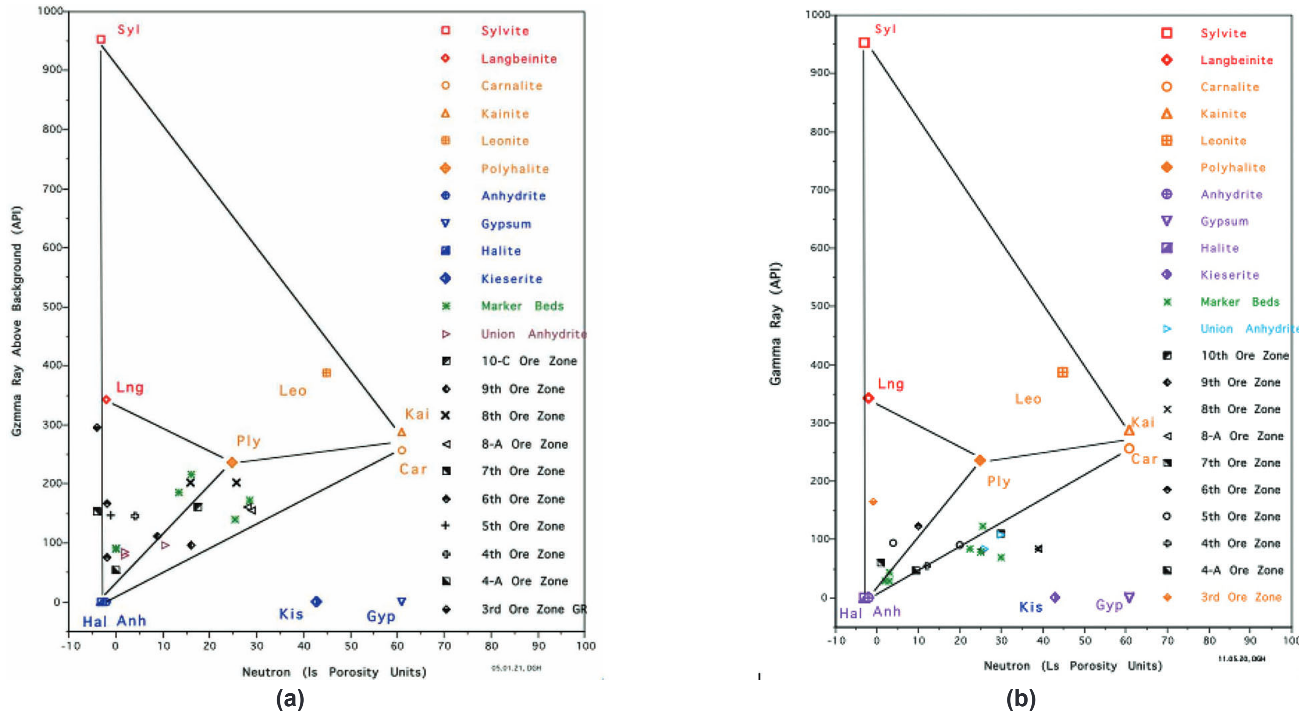


Fig. 21—Validation test PID ((a) corehole and (b) oil well) for the McNutt Member Salado Formation (after Hill and Crain, 2020).

The increased number of points posted along the sylvite – anhydrate/halite line for the corehole PID may reflect the different wireline equipment, including a shorter GR detector (the 1.5- × 7.5-in. oilfield GR detector averages over a longer interval than the 1- × 4-in. slimhole detector), the smaller borehole, and the lack of casing and cement, even though casedhole corrections were applied to the oilwell data. The corehole data point plotting near 300 API may well correspond to the 10c ore zone. While this would pass both the grade and thickness hurdles for SE NM, it is doubtful that it would support a mine, and it did not show up on the cased well PID with the longer GR detector.

A second and possibly stronger explanation for the differences between the PID plots of Fig. 21 may involve the composition of the cement used to secure the oilwell casing through the evaporite. Potassium salts are among the final salts to precipitate from a brine bittern. As a result, they would be the first to dissolve if in contact with non-potassium-saturated brines.

While the 6-in. detailed log print for the oil well is available for the authors' review, the completion report is not, so the cement composition is a *wild card*. However, the casedhole cement was most likely NaCl-saturated Portland cement (i.e., no KCl). If so, any of the richer potash beds might wash out during cementation due to the solution of the potash minerals creating thicker cement thickness sheaths opposite those zones, which could reduce the GR log values for these intervals. Since no openhole caliper logs were run prior to running the casing, the casedhole corrections would have used the bit size for the thickness of the cement sheath.

The information from Figs. 6 and 21 was summarized in Table 3. While the mining company indicated that they had obtained a complete core recovery in the corehole, no results were reported for the 8A ore zone, even though they had reported 20.4 %K_2O in their analysis of the oilwell GR log transform. Ignoring this omission, however, the % error between the LSQ GR %K_2O prediction and the actual wet chemistry assay ranged from 140 to 534%—obviously not a good "track record."

CONCLUSIONS

The PID plot has proven to be a simple and rapid method to screen for potential low-grade commercial potash mineralization in the presence of high GR shales and non-economic potash minerals. The only requirements are GR and neutron logs. This technique could prove extremely useful in any evaporite basins with extensive oil wells drilled through the evaporite to access underlying petroleum resources.

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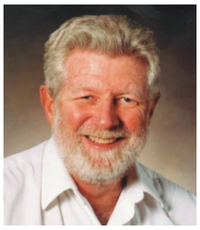

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