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Assessment of potash potential in the Holbrook Basin, eastern Arizona, USA

Steven Rauzi & Jon E. Spencer

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Assessment of potash potential in the Holbrook Basin, eastern Arizona, USA

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Abstract

Historic drilling data in the Holbrook basin of east-central Arizona indicate a potash resource of 0.68 to 2.5 billion metric tons. The potash, located many hundreds of feet underground, is present near the top of extensive bedded salt deposits of Permian age. Some of this potash underlies Petrified Forest National Park (PFNP).

Solution mining would be expected to recover about 30% of the resource while conventional underground mining could recover about 70%, in part because some minerals of the deposit are not readily soluble. Initial estimates of total recoverable resources range from 0.21 to 1.75 billion metric tons, assuming the entire deposit is available for development. The potash deposit is deep enough that conventional underground or solution mining would have little or no effect on the surface except for the presence of the mining facilities themselves.

About a quarter of the potential potash resource underlies PFNP. Another quarter of the deposit lies under private and state trust lands within the expanded park boundaries. U.S. law prevents leasing or mining under national park lands. An emerging strategy is to split the surface and mineral estates of private lands within the expanded park boundary. The park service would own the surface and mining companies would own the minerals, which are then not subject to the ban on mining federal park resources. Potash beneath the expanded park lands could be accessed from outside the park boundaries through tunneling and lateral drilling.

Introduction

Potash prices skyrocketed in late 2007 reaching a high of about $850 per ton in early 2009 (Figure 1). Rapidly rising demand for fertilizer and limited expansion of production were leading causes of the increase (Sergeant, 2008). Good potash deposits are rare, there are few global producers, and growth in demand is great; the Arizona potash resource appears to be an economically attractive and viable target for development.

Arizona Potash

Potash is present near the top of extensive salt (halite - NaCl) deposits in the Pennsylvanian-Permian Supai Group (270-220 Ma) of east-central Arizona (Figures 2, 3, 4, and 5), where bedded salt underlies an area of about 3,500 mi2 (9,065 km^2) and attains a maximum aggregate thickness of 655 ft (200 m) (Rauzi, 2000). The extent of the salt defines the Holbrook salt basin. Potash extends over an area of about 600 mi^2 (1,554 km^2), is within the upper part of the halite, and ranges up to about 40 ft (12 m) thick. Thickness of the potash unit was estimated from the interval between initial to final inflections of high gamma ray emissions (derived from potassium) in 117 wells drilled for potash in the 1960s and 1970s (Figure 5). There is essentially one potash unit. Depth to the potash ranges from 700 to 2,000 ft (213 to 610 m) but the depth in most holes is between 1,000 to 1,450 ft (305 to 442 m). Structural mapping of the top of a regionally persistent anhydrite bed about 100 ft (30 m) above the potash zone indicates that the potash is generally flat-lying and unbroken by faults (Rauzi, 2000, Plate 2).

Estimates of total potash in the potash zone of the Holbrook salt basin require an estimate of total volume and of potash grade. Total volume was estimated using the contour map of Figure 2 as follows: The contours were digitized using ESRI ArcGIS software, and the area of each enclosed contour area was then calculated. Most of these areas have a boundary representing the minimum thickness (for example 10 ft (3 m)) and maximum thickness (for example 20 ft (6 m)). The simplest approach to volume estimate for a particular contour interval is to use the intermediate thickness (in this example, 15 ft (4.5 m)) and multiply it by the calculated area (Table 1A). However, for an approximately circular area, with a

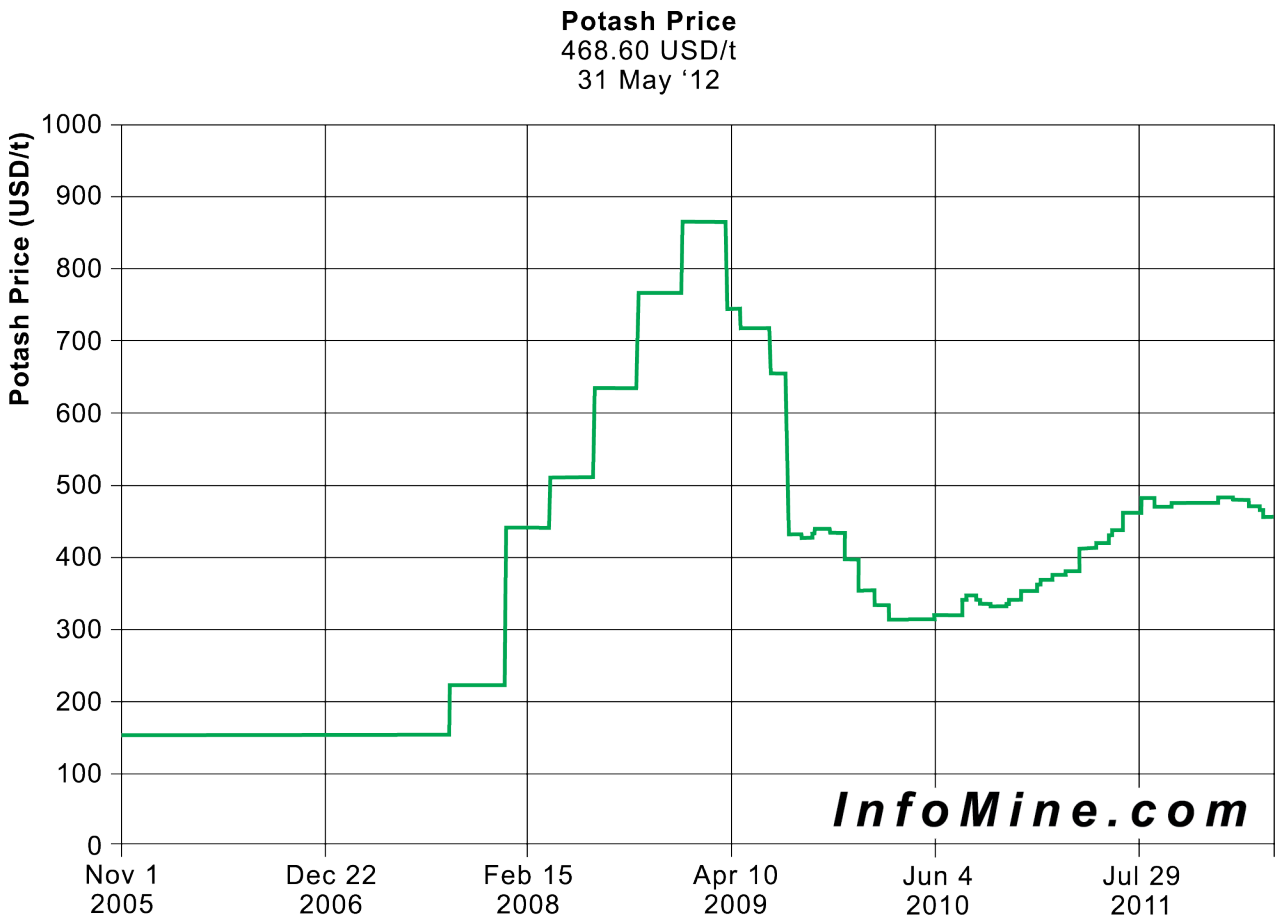

Figure 1. Price of muriate of potash (KCl) in dollars per ton. Price increased sharply in 2007 reaching a high of just over $850 per ton in early 2009 and has since settled back to about $500 per ton. Source: InfoMine.com, accessed June 13, 2012: http://www.infomine.com/investment/metal-prices/potash/all/.

lower thickness on the outside of the circular area and a higher thickness on the inside, the average thickness is not the average of the minimum and maximum thicknesses, but rather is closer to the minimum. Specifically, the average thickness over a circular area with a cone-shaped sub-surface volume is one third the height of the apex (not one half). Accordingly, we made a second estimate of potash volume by using, as average thickness for each calculated area between contours, a value equal to the lower contour value plus one-third of the contour interval. This resulted in a lower estimate of total volume (Table 1B). Even though the lower volume estimate is our preferred value, we include the higher volume estimate because the number of historic data (well) points is still sparse for the area and there is considerable uncertainty in the calculations.

Two estimates of potash grade were used in calculations of total potash tonnage (Table 1). A high value of 20% average grade was reported by Carr (1966) based on analysis of drill data near the central and northern parts of Arkla Exploration Company's acreage block. A low value of 6% average grade is based on assays from five holes drilled by Duval (Figure 2; Table 2).

The total potential potash resource in the Holbrook basin thus ranges from 682 million metric tons (6% average grade, lower volume estimate) to 2.58 billion metric tons (20% average grade, higher volume estimate). With our preferred volume estimate (Table 1B), the upper resource value is 2.27 billion metric tons.

Exploration drilling so far suggests that potash is confined to the northern part of the Holbrook salt basin where bedded salt reaches its maximum thickness (Rauzi, 2000). The salt appears to have formed by desiccation of saline mud flats and salt pans of an inner sabkha (supra-tidal environment in arid climates). The occurrence of potash near the top of the salt deposit may be due to the relative solubility of potash and salt

Table 1A. Volume of potash deposit,1 method A2								
Upper bound contour (ft)	Lower bound contour (ft)	Contour sequence	Area (m2)*	Area (km^2)	Area (mi^2)	Average thickness (ft)	Average thickness (m)	volume (m^3)
20	10	17	615,570,211	615.6	237.6	15	4.6	2,815,107,674
10	0	18	588,199,374	588.2	227	5	1.5	896,645,388
30	20	14	144,765,553	144.8	55.9	25	7.6	1,103,395,984
30	20	9	55,485,025	55.5	21.4	25	7.6	422,904,157
35	30	5	41,179,683	41.2	15.9	32.5	9.9	408,030,398
35	30	7	25,125,579	25.1	9.7	32.5	9.9	248,957,721
30	20	12	21,288,058	21.3	8.2	25	7.6	162,256,543
30	20	16	15,503,060	15.5	6	25	7.6	118,163,569
10	0	6	14,301,907	14.3	5.5	5	1.5	21,801,687
35	30	11	9,628,591	9.6	3.7	32.5	9.9	95,405,251
35	30	4	8,890,614	8.9	3.4	32.5	9.9	88,092,978
10	0	10	8,128,523	8.1	3.1	5	1.5	12,391,040
10	0	1	6,845,637	6.8	2.6	5	1.5	10,435,422
10	0	13	5,589,548	5.6	2.2	5	1.5	8,520,653
10	0	2	3,771,564	3.8	1.5	5	1.5	5,749,335
10	0	3	3,275,605	3.3	1.3	5	1.5	4,993,300
32	30	15	3,247,554	3.2	1.3	31	9.5	30,693,347
10	0	8	2,111,337	2.1	0.8	5	1.5	3,218,502
							total	6,456,762,950
1Thickness contours for potash deposit were drawn based on 117 drill intercepts and interpretation of geophysical logs.								
2Average thickness used is average of upper and lower bound								
*Contours were digitized and areas between contours were calculated using ESRI ArcMap software.								
Assuming average grade of 20% potash, total resource is volume x grade x density =						2,582,705,180.0	metric tons (i.e., 2.58 billion metric tons)	
Assuming average grade of 6% potash, total resource is volume x grade x density =						774,811,554.0	metric tons (i.e., 775 million metric tons)	

Table 1B.Volume of potash deposit,1 method B2								
Upper bound contour (ft)	Lower bound contour (ft)	Contour sequence	Area (m^2)*	Area (km^2)	Area (mi^2)	Average thickness (ft)	Average thickness (m)	volume (m^3)
20	10	17	615,570,211	615.6	237.6	13.3	4.07	2,502,317,933
10	0	18	588,199,374	588.2	227	3.3	1.02	597,763,592
30	20	14	144,765,553	144.8	55.9	23.3	7.11	1,029,836,252
30	20	9	55,485,025	55.5	21.4	23.3	7.11	394,710,547
35	30	5	41,179,683	41.2	15.9	31.7	9.65	397,568,080
35	30	7	25,125,579	25.1	9.7	31.7	9.65	242,574,190
30	20	12	21,288,058	21.3	8.2	23.3	7.11	151,439,440
30	20	16	15,503,060	15.5	6	23.3	7.11	110,285,997
10	0	6	14,301,907	14.3	5.5	3.3	1.02	14,534,458
35	30	11	9,628,591	9.6	3.7	31.7	9.65	92,958,963
35	30	4	8,890,614	8.9	3.4	31.7	9.65	85,834,184
10	0	10	8,128,523	8.1	3.1	3.3	1.02	8,260,694
10	0	1	6,845,637	6.8	2.6	3.3	1.02	6,956,948
10	0	13	5,589,548	5.6	2.2	3.3	1.02	5,680,435
10	0	2	3,771,564	3.8	1.5	3.3	1.02	3,832,890
10	0	3	3,275,605	3.3	1.3	3.3	1.02	3,328,867
32	30	15	3,247,554	3.2	1.3	30.7	9.35	30,363,311
10	0	8	2,111,337	2.1	0.8	3.3	1.02	2,145,668
								5,680,392,448
1Thickness contours for potash deposit were drawn based on 117 drill intercepts and interpretation of geophysical logs.								
2Average thickness used is weighted (2:1) toward lower bound								
*Contours were digitized and areas between contours were calculated using ESRI ArcMap software.								
Assuming average grade of 20% potash, total resource is volume x grade x density =						2,272,156,979.1	2.27 billion metric tons	
Assuming average grade of 6% potash, total resource is volume x grade x density =						681,647,094	682 million metric tons	

during the evaporation of sea water across the sabkha. Repeated incursions of sea water appear to have preferentially dissolved and re-precipitated the potash thereby separating and concentrating the potassium from the halite.

In the 1960s and 1970s, a total of 135 holes were drilled to delineate the potash in the Holbrook salt basin. Arkla Exploration Company and Duval Corporation drilled 105 holes. Other potash holes were drilled by Kern County Land, National Potash, New Mexico and Arizona Land, St. Joe American, and U.S. Borax. Indications of potash in previously drilled oil tests started the potash play (Cox, 1965). Only five holes were drilled through the entire thickness of salt but 127 holes were drilled into the upper 100 to 300 ft (30 to 90 m) of salt where potash is present (Figure 5).

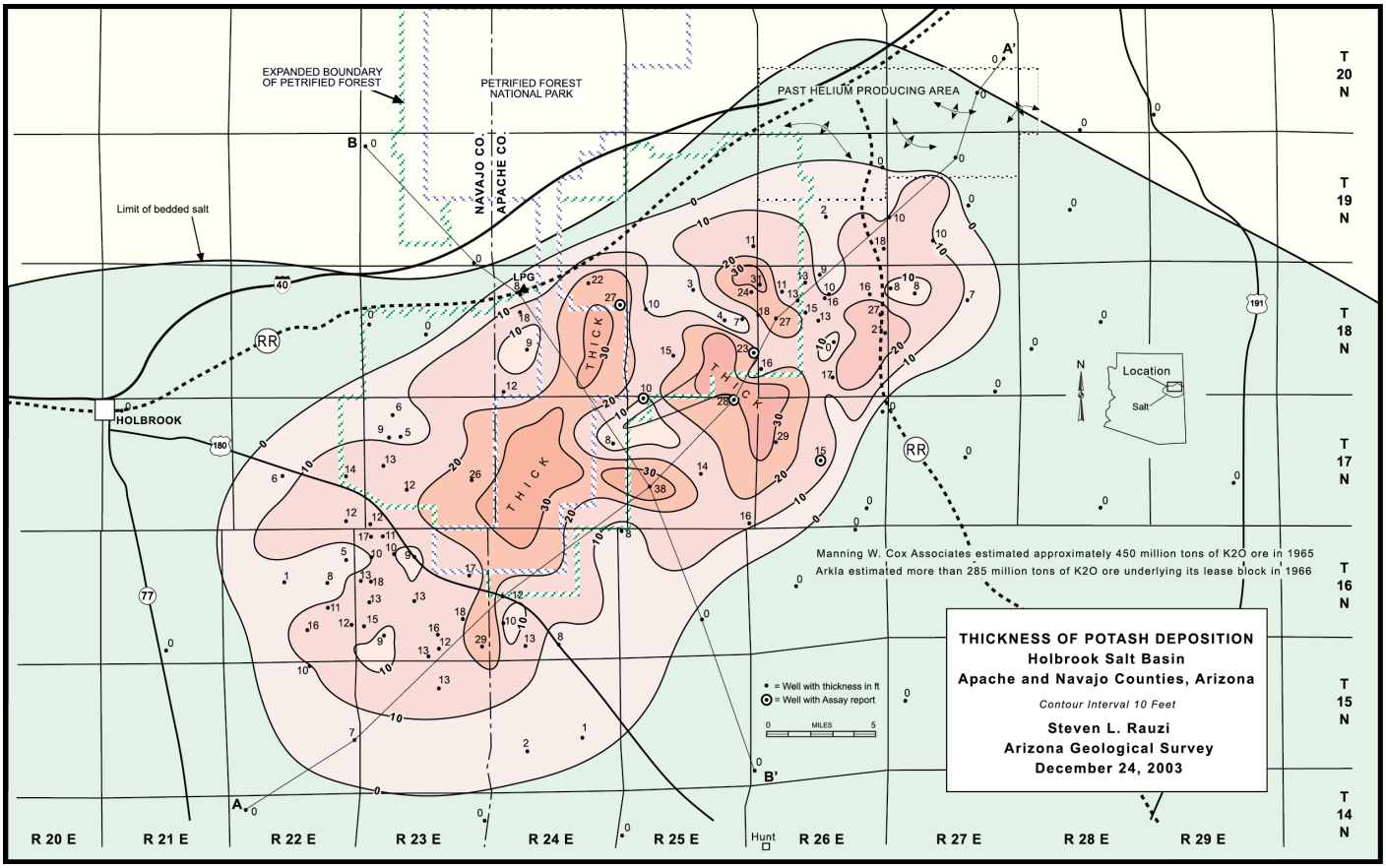

Figure 2. Map showing thickness in feet of potash in the Holbrook salt basin, Arizona and historic drill-hole sites used to generate the map. Note proximity of railroad and interstate highway. The former helium producing area is near the north-eastern extent of potash and an LPG-storage facility is near the northwestern extent. The expanded boundary of Petrified Forest National Park is shown by the green line.

Table 2A. Weighted average %K_20

drill hole	K_2O (av %)	thickness (ft)	% x ft
01-23	6.74	23.9	161.1845
01-24	8.16	8.3	67.691
01-29	7.62	10.4	79.249
01-36	3.67	27.3	100.128
01-44	4.76	19.16	91.2676
		89.06	499.5201

5.61 weighted average %K_2O

Table 2B. Weighted average %K_20*

drill hole	K_2O (av %)	thickness (ft)	% x ft
01-23	6.74	23.9	161.1845
01-24	8.16	8.3	67.691
01-29*	8.19	9.5	77.773
01-36*	4.29	23.15	99.3185
01-44	4.76	19.16	91.2676
		84.01	497.2346

5.92 weighted average %K_2O

*more restricted interval with higher grades

Most holes were cored through the upper 100 ft (30 m) of salt to get direct information about the nature of the potash deposits.

Arkla and Duval reported the presence of potassium minerals sylvite (KCl), carnallite ($KMgCl_3$), and polyhalite ($K_2Ca_2Mg(SO_4)4{\cdot}2H_2O$) in the potash unit (Cox, 1965; Carr, 1966). Cox further indicated that carnallite was only locally present in the potash unit and that none of Duval's holes encountered carnallite at the time of his report. Six holes drilled by Kern County Land and Arkla contained as much as 3% K_2O as carnallite and a thin zone below the potash unit contained as much as 6% K_2O as carnallite (Cox, 1965). Duval made a visual estimate of the K2O content by dragging a sharp 4-H pencil across the surface of a core. The hardness of sylvite was such that the 4-H pencil gouged the sylvite but left a black mark on the halite. As a result, the geologist was able to estimate the K_2O content within 2% to 3% (Cox, 1965). Scattered blebs and traces of potash persist to about 30 ft (9 m) below the potash unit. Well logs, samples, core

descriptions, and six assay reports from the potash drilling are available in the well files of the Arizona Oil and Gas Conservation Commission at the Arizona Geological Survey in Tucson (Appendices 1 and 2).

To date, there has been no commercial production of potash in Arizona, either by conventional or solution mining, even though drilling by late 1965 indicated about 450 million tons of ore-grade K2O covering an area of 80 mi2 (207 km_2) (Cox, 1965). Cox estimated that 100 million tons of at least 60% K2O product were economically recoverable. By early 1966, Arkla estimated a potential of more than 285 million tons of nearly 20% average grade K_2O underlying its lease block, where about 92% of nearly 55,000 acres (22,258 hectares) remained untested (Carr, 1966). Carr reported that the amount of potash under Arkla's prospective area exceeded the minimum economic requirement to justify installation of mining and ore-processing facilities by 540%. Overproduction of potash in Saskatchewan during a period of government subsidies and a global glut of potash in the late 1960s may have been the biggest factors in preventing development of Arizona potash at the time.

Another factor in the lack of exploitation of Arizona potash may be that the area underlain by potash in east-central Arizona is approximately centered under the PFNP. Isopach (thickness) mapping suggests that some of the thickest potash lies beneath the southern part of the PFNP (Figure 2).

The Petrified Forest Expansion Act of 2004 substantially increased the area of the park (Figure 2) but funds to buy the lands within the expansion were not appropriated at the time of the Expansion Act. The location of some of the potentially thickest potash under the PFNP expansion areas will require a creative approach to achieve access and development of Arizona's potash deposits. The federal government owns the minerals under the existing PFNP lands, which cover approximately 20% of the potash volume. The mineral rights within the expanded area, which cover an additional 28% of the potash volume, are owned by various entities and the intention of the National Park Service (NPS) is to acquire those rights if and when funds are appropriated by the

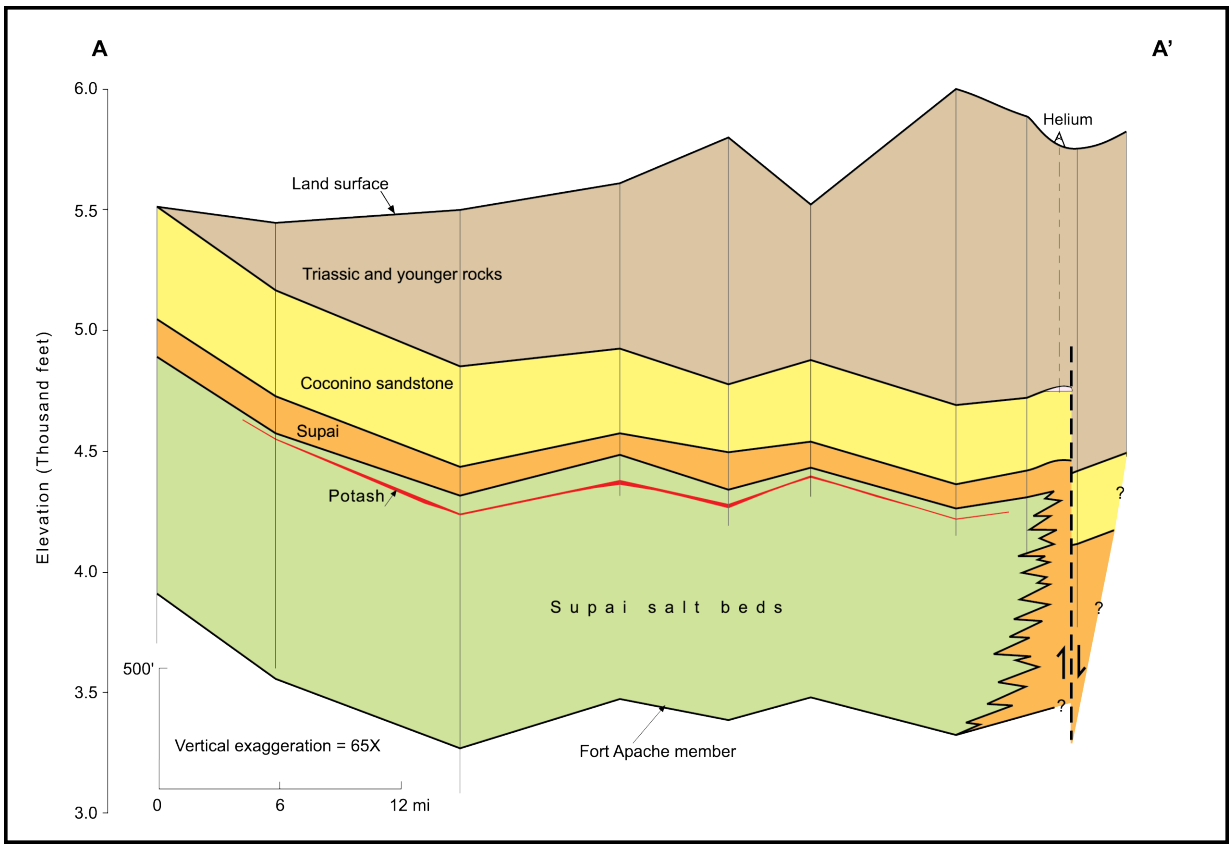

Figure 3. Diagrammatic structure section A-A' trending southwest-northeast (Figure 2) showing northern edge of Supai salt, extent of potash deposits, and former helium producing area near the northeastern limit of the salt and potash deposits. Vertical scale is exaggerated 65 times.

federal government or received through other means. Regardless of mineral ownership, any resources under the park are withdrawn from mineral entry and this may be so for the expansion areas if the NPS is successful in acquiring mineral rights. A combination of State Trust, Indian, and public and private land is potentially available for development within the expanded boundary to the west, southwest, and east, if the PFNP does not acquire the mineral rights along with the surface lands.

Future

Growing global demand for potash for use in fertilizers makes Arizona's Holbrook basin deposit more economically viable and attractive than previously recognized. The size of the resource, as reported here, is based for the first time on a basin-wide assessment of historic well data and is many times larger than fragmentary reports have indicated.

Renewed exploration has confirmed that a significant portion of the U.S. potash resource base exists in the Holbrook basin of east-central Arizona. Since 2009 the Oil and Gas Conservation Commission

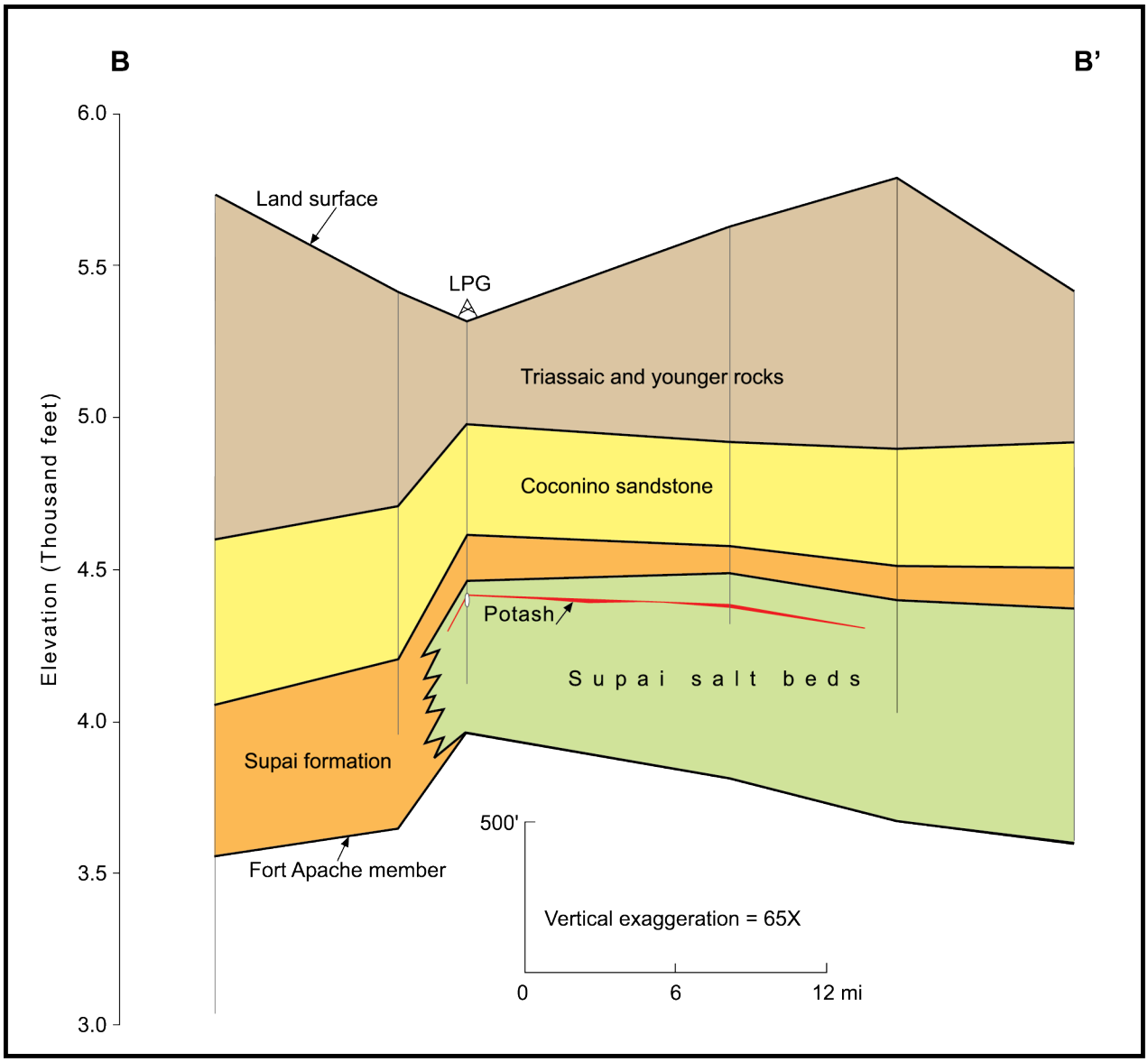

Figure 4. Diagrammatic structure section B-B' trending northwest-southeast (Figure 2) showing northern edge of Supai salt, extent of potash deposits, and storage well for liquefied petroleum gas (LPG) with cavern leached near the top of the salt deposits. Vertical scale is exaggerated 65 times.

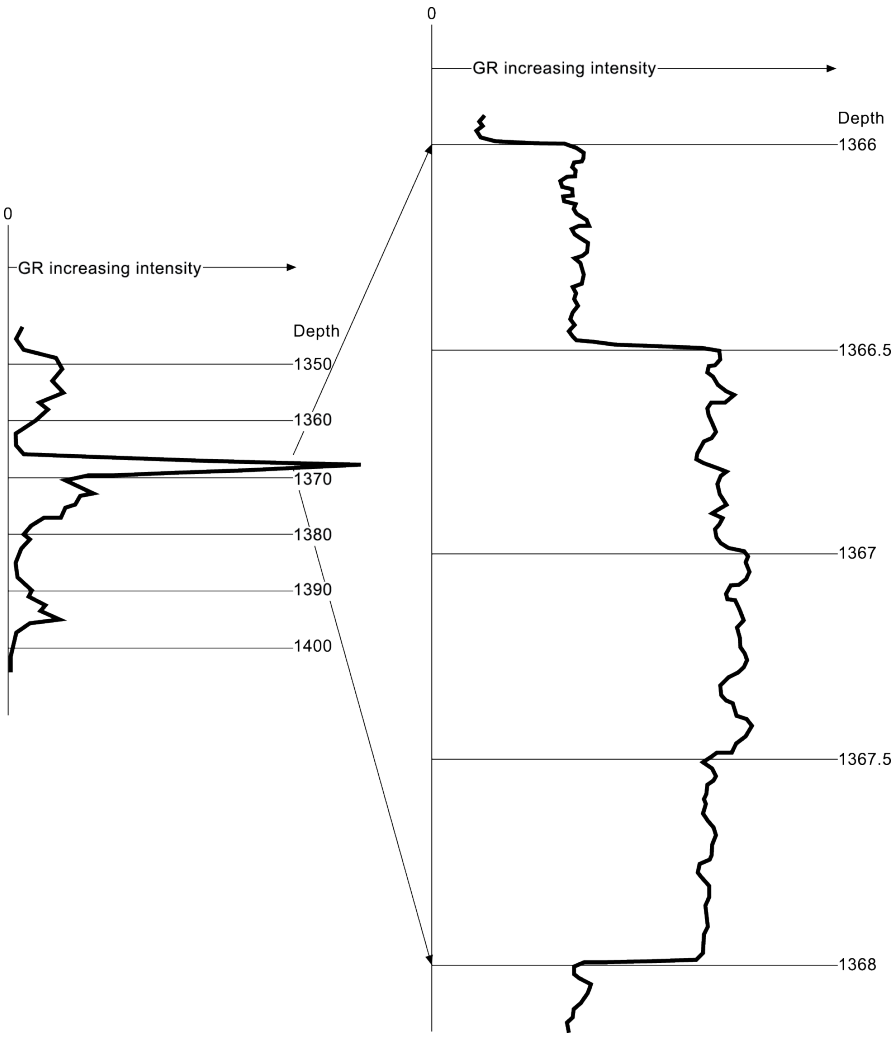

Figure 5. Typical gamma-ray (GR) curve through a potash zone. Note the much higher intensity in the potash zone. The high GR in the potash zone is indicative of potassium. A very detailed and properly calibrated GR log as shown on the right can indicate the grade of ore or purity of particular potassium minerals. Horizontal intensity scale is linear, not logarithmic.

of the State of Arizona has issued 129 well permits with 100 stratigraphic wells drilled for potash by four exploration firms: American West Potash, HNZ Potash, Passport Potash, and Potash Green. One operator reported that the recent drilling indicates a potash resource that generally correlates well with historical information. American West Potash released an NI 43-101 mineral-resource estimate in October 2011 with a calculated in-situ gross resource of 718 million metric tons of KCl and 82 million metric tons of K_2O within its lease block. American West Potash anticipates mining about 2 million metric tons of finished product per year for 40 years. Passport Potash released an NI 43-101 mineral resource estimate in March 2012 with a calculated in-situ gross resource of 713 million tons of mineralized material and 90 million tons of K_2O within its lease block.

Potash in the Holbrook basin is among the shallowest such resources in the world. Conventional underground mining could conceivably approach 90% recovery because smaller pillars are needed with the smaller overburden pressure at the depth of the Holbrook basin deposits. Several other attractive features for development of potash in the Holbrook basin include mild construction and production climate, excellent area infrastructure including a nearby railroad and Interstate Highway, nearness to agricultural markets in the Midwest and West including sea ports on the west coast, and no potential conflicts with the oil and gas industry as is the case in southeastern New Mexico.

The U.S.G.S. reports current total U.S. production at about one million tons annually with domestic consumption of about 6.5 million tons annually (Jasinski 2012). Jasinski lists domestic potash resources of about 7 billion tons with about 1 billion tons in the Holbrook basin. American West Potash has estimated that a new underground mine could produce about 2 million metric tons of finished product annually which would significantly increase U.S. production.

Potash deposits underlie many square miles of land outside the PFNP and its expanded boundary. A cooperative arrangement for exploitation of the potash resources underlying the expanded boundary could include PFNP ownership of surface lands within the expanded boundary and mining company ownership of the mineral estate. Potash beneath the expanded park lands could then be accessed from outside the park boundaries through tunneling and lateral drilling.

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Appendices - see Excel File

Appendix 1. Well Logs used to estimate potash resources (Well ID is State Permit Number). Approximately 250 wells.

Appendix 2. Well samples for potash holes available at the Arizona Geological Survey. Approximately 100 well samples.