Use of Surface Lithogeochemistry to Estimate Magnitude of Blind Uranium Mineralization in Northern Arizona Collapse Breccia Pipes

Abstract

DIR Exploration, Inc., has established a geochemical technology that permits pre-drilling estimation of the magnitude of uranium resources present in northern Arizona collapse breccia pipes by surface sampling the primary metal leakage surrounding these structures. The accuracy and reliability of the method is sufficient to serve as a rapid and very cost-effective substitute for much of the exploration drilling historically applied to breccia pipe prospects.

Three main factors have been determined to govern the extent of uranium and metal sulfide mineralization in collapse breccia pipes during the breccia pipe mineralization process. These factors are: (1) timed existence of bacterial feedstock (oil); (2) upwelling, metal-rich brines; and (3) consequent generation of two proximal geochemical reduction barriers capable of precipitating metal sulfides and uraninite from upwelling mineralizing fluids.

Four independent geochemical parameters found in metal leakage values from bulk surface rock chip samples serve as proxies for the breccia pipe mineralization-controlling factors just described. Multi-variable linear regression of these four parameters against published uranium reserves-plus-production figures from each test case produced a linear equation that predicts 97.95% of the variation in log value of the uranium resource present in the sampled cases. The statistical nature of the defined linear equation is such that its application to hitherto undrilled breccia pipe targets in northern Arizona is very strongly justified. Test application of the equation to twenty-three unmined breccia pipes with appreciable exploration drilling already completed verifies the results of the statistical tests of the linear equation.

Introduction

Although the general idea was proven valid more than 50 years ago (Miesch et al., 1959; 1960), exploration geologists generally regard the task of using geochemical data to predict the size of a mineral resource as impossible. For example, believing there are no other useful ways to discover and assess the value of mineral occurrences, one geologist adamantly maintains, “It is the drill hole, stupid!” (Muessig 1998).

The exploration geochemical method described here was established by early 2010, at the end of a long search for a practical, inexpensive means of distinguishing between economically-mineralized, uranium-bearing collapse breccia pipes and similar looking barren geological structures located in northern Arizona west of the Navajo Reservation. As Figure 1 shows, the drill-hole-free prospect evaluation method described in this report is highly predictive of the amount of uranium ore in any given mineralized collapse breccia pipe.
Characteristics of Breccia Pipes Relevant to the Geochemical Uranium Resource Size Prediction Method

A major key to comprehending why the DIR geochemical breccia pipe uranium mineralization assessment technique works is the vertical metal zoning exhibited across the uraninite and metal sulfides deposited at ore level in these vertical structures. Highest concentrations of Cu and Pb in mineralized breccia pipes are found at the focus of U mineralization, below the greatest ‘sulfide-cap’ concentrations of Ag, As, Cd, Co, Fe, Mo, and Ni. See Figure 2.

The origins of this consistent vertical zoning in uranium-mineralized breccia pipes can be understood by referring to Figure 3. In this subhorizontal roll-front type-case of low temperature uranium deposit formation, organic matter-fermenting bacteria that precipitate U and Cu (and Pb?) are upstream of the zone of sulfate-reducer bacteria that subsequently take Mo, As, Ni, Fe, Cd, Ag, and Zn out of solution. By rotating the Figure 3 geologic section ninety degrees counterclockwise, it becomes clear that the subhorizontal metal zoning seen in low-temperature roll-front uranium deposits is the same as the vertical metal zoning observed in low-temperature Arizona breccia pipes. This fact, however, requires that mineralizing waters in breccia pipes moved vertically upward rather than horizontally. McMurray (2007) explains how this necessary upward fluid movement in the Arizona breccia pipe cases took place by invoking artesian rise. Stratigraphic (Figure 9 of Lessentine 1969) and mineralization age data (Ludwig and Simmons, 1992) indicate the Permian Sonoma and Cretaceous Nevadan orogenies provided the hydrostatic head to drive breccia pipe mineralizing fluid flow. Consistent with these stratigraphic and mineralization age data, Figure 4 shows the distribution of known...
While the oxygenated fluids that form the roll-front uranium deposits like those illustrated in Figure 3 are generally reduced by organic trash material syngenetically deposited in sandstones, the epigenetic origin of collapse pipe breccias, as well as the much higher uranium grades found within the pipes, preclude dispersed syngenetic organic matter serving as a reductant for breccia pipe uranium mineralization. However, given the very common occurrence of asphaltic material in pipe breccias (Wenrich 1985; Wenrich and Palacas, 1990; Ludwig and Simmons, 1992), it is clear that hydrocarbons accumulated in Arizona collapse breccia pipes in the past. Rauzi (1990) has identified the Precambrian Chuar Group as the best petroleum source rock in the Grand Canyon region. Organic geochemical data provided by Wenrich and Palacas (1990) prove, in fact, that asphaltic material in northern Arizona breccia pipe was not derived from the much younger Permian rocks hosting the collapse breccias.

**Summary of the Geological and Geochemical Framework Necessary for Breccia Pipe Uranium Mineralization**

Figure 5 illustrates the three main factors identified here as controlling the presence and extent of uranium and metal sulfides in collapse breccia pipes. These factors are:

1. Presence of bacterial feedstock; i.e., crude oil;
2. Supply of upwelling metal-rich (and oil-rich) brines;
3. Consequent generation of two vertically stacked geochemical barriers:
   a. A lower or upstream reducing environment gley barrier (Beus and Grigorian, 1975, p. 46) capable of precipitating uranium from solution; and
   b. An upper or downstream reducing environment hydrogen sulfide barrier that exothermically oxidizes the oil feedstock to CO$_2$, H$_2$O, and converts SO$_4^{2-}$ to S$^2$ and HS$^-$. Variation in any or all of the described mineralization-controlling variables would have direct consequences on the amount of uranium and accompanying metal sulfides deposited within any given pipe.

**Sampling Method**

The surface rock chip sampling technique used to assess the amount of uranium found in Arizona breccia pipes is rapid and simple to execute. The geologist completes a single circuit around the circumference of the structural or geophysical target, taking a single quarter- to half dollar-sized rock chip as a subsample at an interval varying from about 50 to 100 feet. Each such small rock chip is combined with all other traverse chips to yield a single bagged sample weighing at least 2 pounds (1 kg). Figure 6 shows a typical sample traverse using the Canyon Mine breccia pipe as an example. Three to eight of these sample traverses over suspected breccia pipes can be completed in a single day by an individual geologist.

The surface rock chip sampling method is further standardized to the following important practice: except for the avoidance of chert, caliche, and pedogenic calcareous flowstone, no sampling preference whatsoever is given to rock type or rock alteration. It is absolutely important for the purpose of maintaining the validity of the breccia pipe uranium resource prediction method described here that no bias be introduced to the surface sampling procedure.

**Sample Analyses**

All laboratory analyses involved in the development of the exploration method described in this report were conducted by BV Upstream Minerals (formerly Acme Labs), Vancouver, BC. Sample preparation and analysis carried out at BV Upstream Minerals consists of BV’s PRP70-250 prep procedure and Group AQ200 ICP-MS analysis (37 elements including U). BV Upstream reports blank, standard, and replicated analyses along with sample analytical results, which provides one means for monitoring laboratory analytical quality. In addition, DIR submits a minimum 5-10% unidentified sample duplicates/standards for further sampling and analytical quality control. Historical
sample analysis turnaround times are 3-4 weeks from date of sample shipment to Vancouver.

**Predicting Buried Breccia Pipe Uranium Resources from Analyses of Weak Surface Mineralization**

Using surface geochemical sampling as a breccia pipe uranium resource assessment tool is based on the fact that primary system metal leakage surrounding breccia pipe ore bodies is the direct product of the same geological and geochemical processes that have produced uranium mineralization in many of the northern Arizona breccia pipes. Knowing this, it was hypothesized that the cumulative “input” of each major geological and geochemical process creating economic uranium mineralization could be used to statistically predict the mineralizing system’s “output”; i.e., the contained amount of uranium ore existing in the subsurface.

Specific geochemical parameters were used as proxies for each major geochemical/geological input factor ultimately determining breccia pipe uranium resource size. After much statistical trial-and-error, regression of selected field measurements of these input proxies against corresponding mine reserves produced a particular kind of linear equation, a production function (“PF”), with remarkably strong predictive power (Figure 1).

Such a PF estimated through ordinary least squares (“OLS”) regression represents a calibration curve constructed using the calibration standards of the firmly known uranium reserves of individual breccia pipes, and the metal leakage analyses taken from rocks at the surface of each breccia pipe in the calibration standard set. Input-output data used to derive the PF concerned in this report were obtained from the Arizona-1, Hacks 2/3, Hermit, Kanab North, Orphan, Pigeon, and Pinenut breccia pipes. An average of about 3 different sampling traverses was completed around and above each index breccia pipe. Usually, each separate surface sampling traverse above and around a given uranium-mineralized breccia pipe was completed by a different geologist using a unique sampling path determined by that sampler.

The geochemical method being described here used several of the exploration data-handling geochemical procedures and findings promoted by Beus and Grigorian (1975) in *Geochemical Exploration Methods of Mineral Deposits*. Among other things, these authors demonstrate (pp. 90-98) that the employment of combinations (‘nesting’) of single element lab analyses with analyses of similar-behaving metals increases the sensitivity of geochemical sampling in detecting the weak metal leakage created by ore body formation, and decreases sampling and analytical error. For these reasons, functionally-similar metals used in the statistical determination of the DIR breccia pipe uranium resource-predictive PF were nested into a single compound geochemical parameter before being subjected to the statistical regression that generated the breccia pipe uranium PF provided in this report.

Table I below provides the identities, functions, and historical origins of each of the controlling variables used in the OLS linear regression of the northern Arizona uranium-mineralized collapse breccia pipe PF.

![Figure 6. Example of a surface bulk chip sample traverse, Canyon Mine, Coconino County, Arizona.](image)

**Table I. Dependent and controlling variables of the linear production function. All individual element concentrations are in ppm.**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Identity</th>
<th>Type of Variable</th>
<th>Function(s) of Variables</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>AB</td>
<td>(As<em>Co</em>Mo)/(Cu<em>Pb</em>U)</td>
<td>Independent</td>
<td>Input proxy: corresponds to strength of the two geochemical barriers in the mineralizing system</td>
<td>Beus and Grigorian, 1975, pp. 134-144</td>
</tr>
<tr>
<td>ORE</td>
<td>(Cu<em>Pb</em>U)</td>
<td>Independent</td>
<td>Input proxy: corresponds to relative richness and volume of mineralizing fluids</td>
<td>Authors</td>
</tr>
<tr>
<td>LKG</td>
<td>(As<em>Co</em>Cu*Mo)</td>
<td>Independent</td>
<td>Input proxy: mineralization depth (and erosion) indicator, see Figure 3, this report</td>
<td>Authors and Rose et al., 1979, p. 103</td>
</tr>
<tr>
<td>VNI</td>
<td>VNI</td>
<td>Independent</td>
<td>Input proxy: corresponds to amounts and age of oil formerly present in each pipe</td>
<td>Hodgson 1954; Hunt 1979</td>
</tr>
<tr>
<td>RSV</td>
<td>Pounds U3O8</td>
<td>Dependent</td>
<td>Output of the estimated production function as measured by mining and drill results</td>
<td>Quaterra, Denison Mines, USGS</td>
</tr>
</tbody>
</table>
present, during the linear equation regression. In summary, the TPF generates equation estimates that are much less mathematically presumptive than alternative production function forms.

The TPF for the simple two-input case is (ibid., p.105):

\[
\ln(Q) = \ln(a) + b \ln(V_1) + c \ln(V_2) + \frac{1}{2} d [\ln(V_1)]^2 + \frac{1}{2} e [\ln(V_2)]^2 + f [\ln(V_1)] [\ln(V_2)]
\]

(1)

Where \( Q \) = output; \( a, b, c, d, e, \) and \( f \) are coefficients; and \( V_1 \) and \( V_2 \) are the input factors.

This two-input case is expandable when there are more inputs involved in the production process. For example, the TPF equation form for a four-input case like that involved in Arizona uranium-mineralized breccia pipes is:

\[
\ln(Q) = \ln(a) + b \ln(V_1) + c \ln(V_2) + d \ln(V_3) + e \ln(V_4) + \frac{1}{2} f [\ln(V_1)]^2 + \frac{1}{2} g [\ln(V_2)]^2 + \frac{1}{2} h [\ln(V_3)]^2 + \frac{1}{2} i [\ln(V_4)]^2 + j [\ln(V_1)][\ln(V_2)] + k [\ln(V_1)][\ln(V_3)] + l [\ln(V_1)][\ln(V_4)] + m [\ln(V_2)][\ln(V_3)] + n [\ln(V_2)][\ln(V_4)] + o [\ln(V_3)][\ln(V_4)] + p [\ln(V_1)]^2 [\ln(V_2)]^2
\]

(2)

Where \( Q \) = output; \( a, b, c, d, e, f, g, h, i, j, k, l, m, n, \) and \( o \) are coefficients; and \( V_1, V_2, V_3, \) and \( V_4 \) are input factors.

From equations (1) and (2) it is evident that the TPF is linear in its coefficients and parameters. This means that, with the addition of random error term, the unique coefficients of the TPF for Arizona breccia pipe uranium mineralization can be statistically estimated using OLS linear regression (Gujarati 1995, p. 37, and pp. 52-87).

The calibration standards data employed in the TPF linear regression for Arizona uranium-mineralized breccia pipes are provided in Table II on page 7. The linear regression work of this study was carried using the OLS function of the software statistical program, EVIEWS. The actual OLS-estimated, four-input case translog production function instrumental in predicting subsurface uranium resource in Arizona uranium-mineralized collapse breccia pipes before exploration drilling is provided below:

\[
\ln(RSV) = 20.58295 + 1.680893 \ln(AB) - 2.671193 \ln(LKG) - 2.087851 \ln(VNI) + 1.668921 \ln(ORE) - 4.112063 (\frac{1}{2}) [\ln(AB)]^2 - 2.159605 (\frac{1}{2}) [\ln(LKG)]^2 - 2.437741 (\frac{1}{2}) [\ln(VNI)]^2 - 5.434522 (\frac{1}{2}) [\ln(ORE)]^2 + 2.987246 \ln(AB) \ln(LKG) - 4.016427 \ln(AB) \ln(VNI) + 3.405604 \ln(LKG) \ln(VNI) - 4.588988 \ln(ORE) \ln(AB) + 3.609574 \ln(ORE) \ln(LKG) - 4.494184 \ln(ORE) \ln(VNI)
\]

(3)

Table III presents the main statistical test results of the OLS regression of the Table II data. Table III shows that the above breccia pipe uranium-mineralized collapse breccia pipes before exploration drilling is provided below:

\[
\ln(RSV) = 20.58295 + 1.680893 \ln(AB) - 2.671193 \ln(LKG) - 2.087851 \ln(VNI) + 1.668921 \ln(ORE) - 4.112063 (\frac{1}{2}) [\ln(AB)]^2 - 2.159605 (\frac{1}{2}) [\ln(LKG)]^2 - 2.437741 (\frac{1}{2}) [\ln(VNI)]^2 - 5.434522 (\frac{1}{2}) [\ln(ORE)]^2 + 2.987246 \ln(AB) \ln(LKG) - 4.016427 \ln(AB) \ln(VNI) + 3.405604 \ln(LKG) \ln(VNI) - 4.588988 \ln(ORE) \ln(AB) + 3.609574 \ln(ORE) \ln(LKG) - 4.494184 \ln(ORE) \ln(VNI)
\]

(3)

Figure 7. Vertical cross-section showing basic elements of a mineralizing collapse breccia pipe and the bulk surface rock chip sample geochemical parameters which permit statistical estimation of its contained uranium resource.

**OLS Regression Estimation of the Breccia Pipe Uranium Resource Production Function**

To maximize the accuracy and reliability of a PF estimate, and the consequent resource prediction power of the PF, it is necessary to make certain that all significant input factors or their proxies are used in the statistical regression, and to also make certain that these factors are placed in a basic functional form that represents the natural behavior of the inputs as closely as possible (Gujarati 1995). Once an appropriate functional form has been selected, and once the most significant input factors have been identified, OLS linear regression is then used to estimate the coefficients of each input factor. These regression-estimated coefficients modify the basic functional form chosen in such a way as to make the estimate specific to the production (mineralization) process being modeled.

The *translog production function* ("TPF") was chosen for use in the breccia pipe geochemical data linear regression for two reasons (Heathfield and Wibe, 1987, pp. 105-117). First, during regression this functional form of PF permits the degree of substitution among controlling factors or inputs to vary naturally. Similarly, a TPF allows the effect of each input on ultimate output (returns-to-scale) to also naturally vary with scale of the output. This last characteristic of the TPF allows economies-of-scale intrinsic to a production process to freely emerge, if
### Input Parameters -- See Table I.

<table>
<thead>
<tr>
<th>Mined Ore Bodies</th>
<th>ORE</th>
<th>LKG</th>
<th>AB</th>
<th>VNI</th>
<th>Mean Age MY</th>
<th>Actual Lbs. Production &amp; Resource Reserves U3O8</th>
<th>Predicted Resource Pounds U3O8</th>
<th>ACTUAL-PREDICTED (Absolute relative deviation, pounds)</th>
<th>Mo PPM</th>
<th>Cu PPM</th>
<th>Pb PPM</th>
<th>Ni PPM</th>
<th>Co PPM</th>
<th>As PPM</th>
<th>U PPM</th>
<th>V PPM</th>
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<td>Hermit (traverse 1)</td>
<td>311.85</td>
<td>900.90</td>
<td>0.03</td>
<td>5.97</td>
<td>136</td>
<td>552,449</td>
<td>547,864</td>
<td>4,585</td>
<td>0.4</td>
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<td>4.5</td>
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<td>136</td>
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<td>1,433,689</td>
<td>133,689</td>
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<td>169</td>
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<td>11.2</td>
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<td>5,629,108</td>
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<td>2.80</td>
<td>9.44</td>
<td>1.35</td>
<td>2.00</td>
<td>200</td>
<td>8,122,021</td>
<td>8,687,227</td>
<td>565,206</td>
<td>0.3</td>
<td>2.5</td>
<td>1.6</td>
<td>4.5</td>
<td>1.7</td>
<td>7.4</td>
<td>0.7</td>
<td>9.0</td>
</tr>
<tr>
<td>HACKS 2&amp;3 (traverse 2)</td>
<td>3.36</td>
<td>13.01</td>
<td>1.21</td>
<td>1.96</td>
<td>200</td>
<td>8,122,021</td>
<td>7,336,911</td>
<td>785,110</td>
<td>0.2</td>
<td>3.2</td>
<td>1.5</td>
<td>4.6</td>
<td>1.9</td>
<td>10.7</td>
<td>0.7</td>
<td>9.0</td>
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<tr>
<td>HACKS 2&amp;3 (traverse 3)</td>
<td>13.73</td>
<td>13.04</td>
<td>0.22</td>
<td>1.20</td>
<td>200</td>
<td>8,122,021</td>
<td>8,324,434</td>
<td>202,413</td>
<td>0.4</td>
<td>4.4</td>
<td>2.6</td>
<td>5.0</td>
<td>1.9</td>
<td>3.9</td>
<td>1.2</td>
<td>6.0</td>
</tr>
</tbody>
</table>

| Average Relative Deviation | 141,345 |

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Table II. Index cases or calibration standards for the northern Arizona uranium-mineralized collapse breccia pipe production function.
Field Tests of the TPF Uranium Resource Predictions

Quaterra Resources (2009) published maps showing the general findings for the extensive historical exploration drilling carried out by the original Energy Fuels Corporation and others. By also employing the pipe location map published by the USGS (Sutphin and Wenrich, 1989), it was possible to locate and then surface sample a respectable number (n = 23) of previously drill-tested breccia pipes in order to conduct a comparison of DIR’s geochemical surface sampling uranium resource predictions with published drill-based uranium mineralization data about these pipes.

Table IV (on page 8) provides the data comparisons. Comparative cases 1-6 are breccia pipes that were intensely surface-drilled (Moreton and Ross, 2009; Pool and Ross, 2007) in order to determine whether uranium reserves there were sufficient to support mine development. There is a 67% agreement between drilling results and surface sampling results for these six test cases. Assuming a minimum of about 1,200,000 pounds U₃O₈ in reserves are required to bring a pipe into production at recent yellowcake price levels, only the Canyon Mine breccia pipe was shown by both drilling assessment and surface sampling assessment to be a likely candidate for mining. On the other hand, surface geochemical data suggest that the WHAT and Kanab South pipes also contain economic amounts of ore, and that these breccia pipes should be drill-explored further. The other three (EZ-1, EZ-2, and DB-1) ore body discoveries in cases 1-6 are shown by both drilling and surface geochemistry to currently be too small to be paying propositions on a standalone basis.

Comparative cases 7-23 in Table IV (shaded rows in Table) are breccia pipes that were tested with light to moderately dense surface drilling work (Sutphin and Wenrich 1989; Quaterra 2009). Assuming a 140,000 pound U₃O₈ mineralization detection limit (i.e., the Table II average relative deviation for resource estimations) for the surface sampling resource assessment method, there is a 71% “mineralized vs. barren” agreement between drilling results and surface sampling results for these seventeen test cases. However, the surface sampling geochemical results indicate that the PIPE, Smugg, RA-08, and Rim pipes are not barren, contrary to drilling results obtained to date. Conversely, the surface sampling uranium resource evaluation method suggests that the reportedly mineralized Peace pipe is actually barren.

These last seventeen pipes in Table IV, partially tested by exploration drilling, have no published drill-based uranium resource estimates attached to them. According to surface sampling geochemical results, however, eight (47%) of these structures probably contain more than 1,200,000 pounds of U₃O₈ and will likely therefore eventually become mine development candidates. The pipes concerned are PIPE, South Antelope, Clearwater, Smugg, Grama, RA-08, Black Box, and New Year. The geochemically-predicted resource for all eight pipes totals about 22 million pounds U₃O₈.

Conclusion

This report shows that geochemical modeling of surface sample data can be used as a far cheaper and much more rapidly deployed substitute for much of the exploration drilling historically used to determine the economic potential of uranium-bearing Arizona breccia pipes. Applying this exploration approach involves partially reversing a long-standing
In the second, shaded part of this Table, "mineralized" means that a drill intercept greater than or equal to one vertical foot of 0.01% eU3O8 has been reported for the pipe concerned.

### Table IV. Surface sampling resource size assessment of historically drilled breccia pipes.

<table>
<thead>
<tr>
<th>Case</th>
<th>Surface Drill-Explored Breccia Pipes</th>
<th>Input Factors</th>
<th>Published Drill Resource</th>
<th>PREDICTED-DRILLED</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>ORE</td>
<td>LKG</td>
<td>AB</td>
</tr>
<tr>
<td>1</td>
<td>What (18 DHs)</td>
<td>30.62</td>
<td>266.22</td>
<td>0.50</td>
</tr>
<tr>
<td>2</td>
<td>EZ-2B (47 DHs)</td>
<td>13.44</td>
<td>206.64</td>
<td>1.10</td>
</tr>
<tr>
<td></td>
<td>EZ-2A</td>
<td>17.70</td>
<td>239.15</td>
<td>0.86</td>
</tr>
<tr>
<td>3</td>
<td>EZ-1A (34 DHs)</td>
<td>73.10</td>
<td>431.00</td>
<td>0.34</td>
</tr>
<tr>
<td></td>
<td>EZ-1B</td>
<td>103.10</td>
<td>1,599.45</td>
<td>0.87</td>
</tr>
<tr>
<td>4</td>
<td>EZ-1B</td>
<td>94.94</td>
<td>1,409.92</td>
<td>0.86</td>
</tr>
<tr>
<td>5</td>
<td>EZ-1A (47 DHs)</td>
<td>36.33</td>
<td>77.23</td>
<td>0.12</td>
</tr>
<tr>
<td>6</td>
<td>EZ-1A</td>
<td>40.36</td>
<td>108.98</td>
<td>0.15</td>
</tr>
<tr>
<td>7</td>
<td>EZ-1A</td>
<td>83.54</td>
<td>544.93</td>
<td>0.19</td>
</tr>
<tr>
<td>8</td>
<td>Ez-2B</td>
<td>73.10</td>
<td>431.00</td>
<td>0.34</td>
</tr>
<tr>
<td>9</td>
<td>Ez-2A</td>
<td>103.10</td>
<td>1,599.45</td>
<td>0.87</td>
</tr>
<tr>
<td>10</td>
<td>Ez-2B</td>
<td>94.94</td>
<td>1,409.92</td>
<td>0.86</td>
</tr>
<tr>
<td>11</td>
<td>Ez-2A</td>
<td>40.36</td>
<td>108.98</td>
<td>0.15</td>
</tr>
</tbody>
</table>

- **Surface Drill-Explored Breccia Pipes**
- **Input Factors Predicted**
- **Predicted Drilled Resource**
- **Resource Size Assessment**
habitual reliance on the technical action of drilling to initially screen, prioritize, and/or decide when to terminate exploration work on Arizona breccia pipe uranium prospects, however.

Judging by the breccia pipe case study reported here, adaptation of the same geochemical approach to the exploration for other ore body types could rapidly and cost-effectively improve the declining economic mineral deposit discovery rate that is now plaguing the entire metals exploration and mining industry. In this regard, DIR Exploration, Inc., has more recently defined surface metal leakage TPFs for Carlin-type gold deposits and for bonanza grade low-S precious metal vein deposits, and anticipates doing the same for porphyry- and Mississippi Valley-type metal deposits.

Acknowledgments

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References


Larry D. Turner is a second-generation mineral exploration geologist. He graduated from Eastern Washington State College in summer 1975 with a BS in geology, and thereafter began employment as a uranium project geologist and program manager for Minatome Corporation, working throughout the western US. Following completion of an exploration geochemistry-focused MS geology degree at Eastern in 1981, he briefly worked in petroleum exploration geochemistry for CITGO and then returned to mineral exploration as Energy Fuels Nuclear’s chief geochemist in northern Arizona breccia pipe uranium exploration. In 1987, he, his father (co-author Irving L. Turner), and his MS thesis advisor, Dr. Mohammed Ikramuddin, formed DIR Exploration, Inc., in order to manage a breccia pipe uranium exploration joint venture between DIR and the Japanese company, PNC Exploration (USA), Inc. This JV ended in 1993 with the continued and chronic uranium price level slump. DIR worked until 2006 as a mineral
exploration contractor and as project generator. Over 1998-2000, Larry completed an MS in mineral economics at the Colorado School of Mines: some of the skills obtained in this graduate study led directly to the exploration innovation described in the current report. In 2006, DIR joined Takara Resources in a second northern Arizona uranium exploration JV. Work conducted during and immediately after this relatively short-lived JV (the region was effectively closed to uranium exploration in 2009) provided the data supporting the research and paper provided here. Larry D. Turner is currently conducting greenfields exploration for Au-Te deposits in central Colorado for DIR using a variation of the innovation described by the report.

DIR Exploration, Inc., 13960 W. 78th Avenue, Arvada, Colorado 80005, United States: AIPG CPG-11408.

Irving (Larry) Turner is a retired first-generation mineral exploration geologist who graduated from SIU-Carbondale (BS, geology/physics) and UT-Knoxville (MS, economic geology, 1960). He has two sons and two grandsons professionally involved in mineral exploration and mining, as well as a daughter and granddaughter who graduated from the Colorado School of Mines in other disciplines. After graduate school, I.L. Turner spent 10 years in underground and surface base metal exploration with St. Joe Lead, and then 4 years managing exploration programs for Vanguard Exploration in Washington State’s Metaline mining district. Following Vanguard, Larry senior became a consultant for several years, managed exploration for NL Industries in Idaho’s Bayhorse fluor spar mining district, and then joined Texasgulf Minerals, Inc. He retired from major mining company exploration work after working for a number of years as Leo Miller’s successor as Texasgulf’s VP of Exploration. In 1987, he, his son Larry, and Mohammed Ikramuddin, formed DIR Exploration, Inc., a company that has been active since that year in uranium and precious metals exploration.

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