DESCRIPTIVE MODEL OF SOLUTION-COLLAPSE BRECCIA PIPE URANIUM DEPOSITS

By Warren I. Finch

BRIEF DESCRIPTION

SYNONYM: Collapse breccia pipe deposits, sedimentary breccia pipe deposits, Orphan Lode–type deposit.

DESCRIPTION: Uraninite and associated sulfide, arsenide, sulfate, and arsenic-sulfosalt minerals as disseminated replacements and minor fracture fillings in distinct bodies in near-vertical cylindrical solution-collapse breccia pipes, 30–175 m in diameter and 1,000 m in length. Pipes located in flat-lying upper Paleozoic and Triassic rocks restricted to the Grand Canyon region in the southwestern part of the Colorado Plateau.

TYPICAL DEPOSITS: Orphan Lode (Chenoweth, 1986; Gornitz and others, 1988), EZ-2 (Krewedl and Carisey, 1986), Pigeon (Schafer, 1988), all in Arizona.

RELATIVE IMPORTANCE: One of two dominant high-grade sources of United States uranium production in 1987; expected to be major source of future uranium production within the United States.

COMMODITIES: U

OTHER COMMODITIES: ± Cu± V± Ag± Au

ASSOCIATED DEPOSIT TYPES (*suspected to be genetically related): *Sandstone uranium; supergene enrichment of Cu and V and depletion of U in deeply eroded and weathered pipes—typical example, Ridenour, Arizona (Chenoweth, 1988); Apex germanium- and gallium-bearing breccia pipe nearby in Basin and Range province (Wenrich and others, 1987).

REGIONAL GEOLOGIC ATTRIBUTES

TECTONOSTRATIGRAPHIC SETTING: Pipes found within and along the southwest margin of the Colorado Plateau, in a stable block existent since the Precambrian and resistant to tectonic forces acting on the western part of the North American plate. Wall rocks of pipes were deposited on a stable marine platform. Pipes apparently originated along and at intersections of N. 50° E.- and N. 45° W.-trending joint or fracture sets (Wenrich and Sutphin, 1989), roughly parallel to orthogonal Colorado River (N. 45° E.), Zuni (N. 45° W), and related lineaments shown by Green (1988, fig. 4) that developed in the Precambrian and rejuvenated in later periods. No igneous rocks are found in the pipes.

REGIONAL DEPOSITIONAL ENVIRONMENT: Breccia pipes developed from solution collapse within the thick Mississippian Redwall Limestone (0–210 m) beginning in the Late Mississippian and propagated upward into overlying strata of carbonate-cemented sandstone, siltstone, limestone, and conglomerate for at least 1,000 m, apparently only where the Redwall is >15 m thick. Stoping was intermittently active and reached the lower members of the Chinle Formation in Late Triassic time.

AGE RANGE: Host wall rocks for pipes: Late Mississippian to Late Triassic. Ores: 260–200 Ma (Ludwig and Simmons, 1988).

LOCAL GEOLOGIC ATTRIBUTES

HOST ROCKS: Karst-collapse breccia. Breccia clasts as wide as 10 m across, consisting mainly of sandstone (~90 percent) and siltstone (~10 percent), occur in a matrix of quartz grains that is commonly well cemented with carbonate minerals. Minor claystone and limestone clasts.

ASSOCIATED ROCKS: Unbrecciated flat-lying sandstone, siltstone, and limestone.

ORE MINERALOGY: Principal ore minerals: uraninite±roscoelite± tyuyamunite*±torbernite*±uranophane*±zeunerite* ±chalcopyrite±bornite*±chalcocite*±malachite*±azurite *±brochantite *±volborthite±naumannite. Associated base-metal minerals: ±sphalerite ±galena±bravoite± rammelsbergite±stibnite ±molybdenite±skutterudite. An asterisk indicates sugergene origin. Pre-uraninite mineral assemblages resemble those of Mississippi Valley–type deposits. Unusual complexity of mineralogy shown in appendix E.

GANGUE MINERALS: Pyrite+marcasite+calcite+dolomite+barite+anhydrite±siderite±hematite±limonite±goethite ±pyrobitumen (see app. E).

TEXTURE AND MINERAL ZONING: Orebodies occur as discontinuous pods mainly in the core of the breccia pipe, but some are also found in the annular-ring structure and may occupy as much as a 200-m vertical interval (fig. 20). Mainly replacement and sparse open-space filling. Pyrite/marcasite and base-metal sulfides, locally associated with pyrobitumen, form a discontinuous "massive sulfide cap" above the uranium deposits in many pipes. Uranium, vanadium, and copper roughly zoned within some deposits.

ORE CONTROLS: Fractured, permeable rock within breccia pipe. Nearly all primary ore confined to the breccia pipe: rarely, a little uranium ore is reported in relatively undisturbed beds outside the ring structure. Vertically, most primary ore is below the Coconino Sandstone and at the level of the Hermit Shale and the Esplanade Sandstone of the Supai Group (fig. 20).

ISOTOPIC SIGNATURES: See Age Range above.

FLUID INCLUSIONS: Fluid-inclusion-filling temperatures of 80–173 °C for ore-related sphalerite, dolomite, and calcite. Salinities (in weight percent NaCl equivalent) are for sphalerite, ≥9, for dolomite, ≥17, and for calcite, ≥4 (Wenrich, 1985; Wenrich and Sutphin, 1988).

STRUCTURAL SETTING: All ore associated with solution-collapse breccia pipes.

ORE DEPOSIT GEOMETRY: Orebodies develop in annular-ring structures and in the core (fig. 20). At Orphan Lode, orebodies in core range from 15 to 60 m in diameter and from 30 to 90 m high; annular-ring orebodies are 5–20 m wide and a few tens of meters high, and extend variably part way around ring circumference (Chenoweth, 1988).

ALTERATION: Characteristic bleaching by reduction (some extends locally outward into wall rocks as much as 30 m); common carbonate recrystallization and calcification, local dolomitization and kaolinization, some weak silicification. Calcified rock extends outside boundary shears, completely surrounding the Orphan Lode pipe. Malachite, azurite, goethite, and other secondary minerals on surface outcrops of eroded pipes.

EFFECT OF WEATHERING: Leaching of U and enrichment of Cu and V, particularly in those pipes deeply weathered. "Massive sulfide cap" apparently prevented oxidation prior to erosion and exposure.

EFFECT OF METAMORPHISM: Not applicable.

GEOCHEMICAL SIGNATURES: Enrichment of Ag, As, Ba, Cd, Co, Cr, Cs, Cu, Hg, Mo, Ni, Pb, Sb, Se, Sr, U, V, Y, Zn, Zr, and REE; indicator elements are Ag, As, Co, Cu, Ni, Pb, and Zn (Wenrich, 1985).

GEOPHYSICAL SIGNATURES: Electrical conductivity and magnetic properties of the pipes are significantly greater than for unbrecciated rocks; diagnostic differences in conductivity shown by scalar audiomagnetotelluric (AMT) and E-field telluric profile data for one pipe (Flanigan and others, 1986). Ground magnetometer surveys show subtle low magnetic values over several pipes (Van Gosen and Wenrich, 1989).

SPATIAL EXPLORATION GUIDES: Collapse features recognized by concentrically inward-dipping beds, circular concave topography, circular patches of brecciated and (or) bleached or iron-stained rock (related to "massive sulfide cap"), and differences in vegetation. In well-exposed areas of the Marble Plateau, collapse breccia pipe densities are 0.11 pipes per square kilometer. Marked tendency for pipes to occur in clusters as small as 3 km^2 in diameter. The presence of one pipe indicates a high probability for other pipes nearby.

OTHER EXPLORATION GUIDES: For a new area outside of the Grand Canyon region, a thick (>15 m) flat-lying, karst-forming limestone overlain by a thick sequence of predominantly carbonate-cemented sandstone and siltstone within a perpetually stable cratonic environment and a post-pipe formation volcanic source for uranium. Preexisting Mississippi Valley-type Cu-Co-Ni-Pb-Zn sulfide-rich ore may be required as a reductant for uranium deposition.

OVERBURDEN: Favorable area on Coconino Plateau (fig. 20): depths to mineralized portion of pipes are 150–600 m. Area exposed on Esplanade surface (fig. 20): depths are 0–120 m. Additional cover by basalt, 0–100 m thick, around San Francisco and Mt. Floyd volcanic fields. Quaternary and Tertiary sediments, 0–50 m thick, cover a few areas.

OTHER: Tectonic stability required for preservation. "Massive sulfide cap" prevented and delayed oxidation of some breccia pipe ores. Goethite possible pathfinder mineral for recognition of concealed pipe.

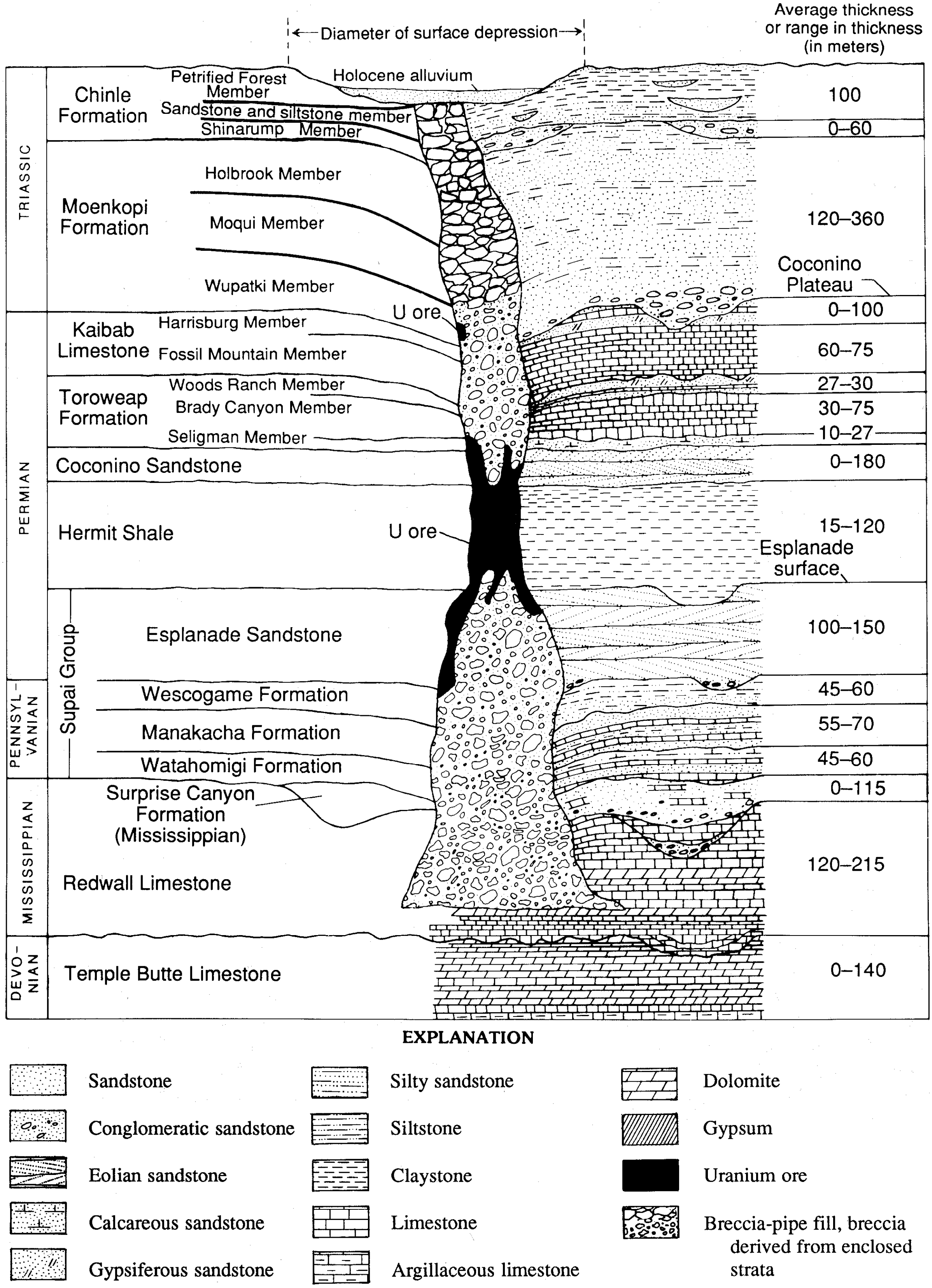

Figure 20. Schematic cross section of a solution-collapse breccia pipe in the Grand Canyon region, showing the general distribution of uranium ore within the pipe (stratigraphic section modified after Van Gosen and Wenrich, 1989).

GRADE AND TONNAGE MODEL OF SOLUTION-COLLAPSE BRECCIA PIPE URANIUM DEPOSITS

By Warren I. Finch, Charles T. Pierson, and Hoyt B. Sutphin

COMMENTS All the deposits in this grade and tonnage compilation are from the Grand Canyon region of northwestern Arizona. From the many mineralized solution-collapse breccia pipes in the region, we have chosen eight deposits that contain mostly primary, unoxidized minerals and have complete, reliable grade and tonnage data. Other mineralized breccia pipes are deeply eroded, strongly weathered, depleted in uranium, and enriched by supergene processes to minable grades of copper, vanadium, and other metals. These remnant deposits are not considered here to be a separate, distinct class of deposits. Furthermore, grade and tonnage data of these remnant deposits (Chenoweth, 1988) are too incomplete to graph meaningfully either separately or combined with the primary deposits.

During the 1950–70 period when the Orphan Lode was mined, the cutoff grades were around 0.10 percent U_3O_8. Few, if any, breccia pipes were mined in the 1970's. In the 1980's, the cutoff grade was 0.20–0.35 percent U_3O_8 for the remaining seven pipes. The average grade of the Orphan Lode ore mined in the early period was 0.43 percent U_3O_8 (Chenoweth, 1986), whereas ores mined from other pipes in the 1980's averaged about 0.65 percent U_3O_8 (Mathisen, 1987). The grade and tonnage data used to plot the graphs in figures 21 and 22 are based on premining reserves calculated at a cutoff grade of 0.05 percent U_3O_8. Energy Fuels Nuclear, Inc., operators of all deposits but the Orphan Lode, kindly permitted the use of data from their properties. See appendix B for locality abbreviations. See introduction for explanation of the grade and tonnage model as shown in figures 21 and 22.

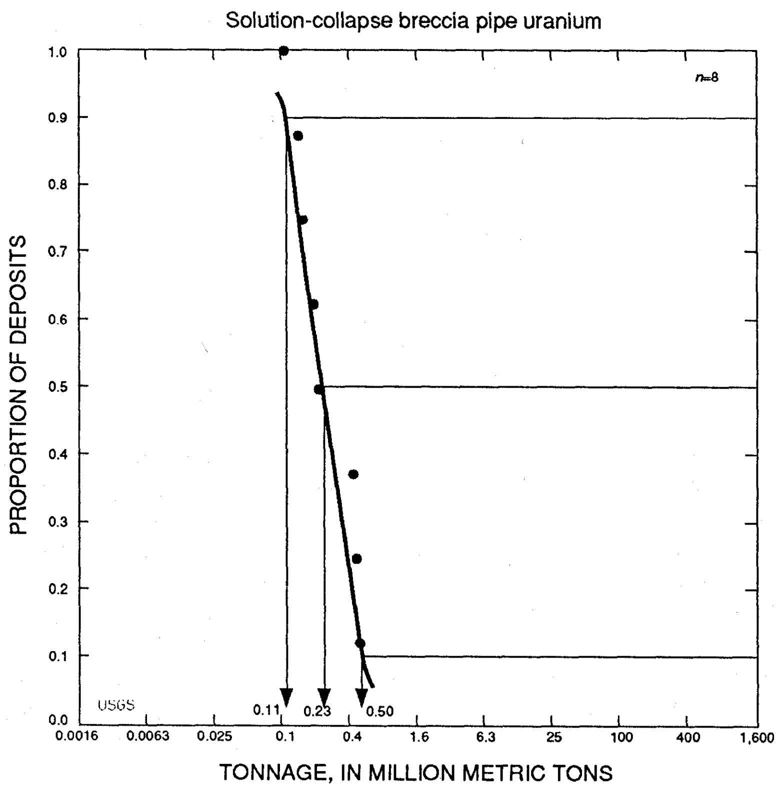

Figure 21. Tonnages of solution-collapse breccia pipe uranium deposits.

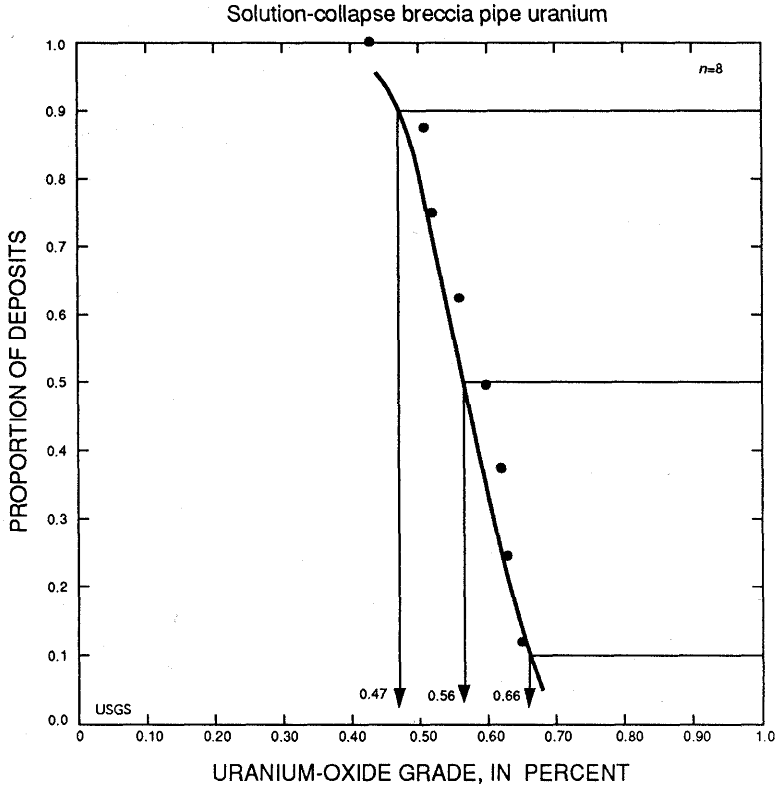

Figure 22. Uranium-oxide grades of solution-collapse breccia pipe uranium deposits.

DEPOSITS Name	Country	DEPOSITS Name	Country
Canyon	USAZ	Kanab North	USAZ
Hack No. 1	USAZ	Orphan Lode	USAZ
Hack No. 2	USAZ	Pigeon	USAZ
Hack No. 3	USAZ	Pinenut	USAZ

The scatter plot of the logarithms (to base 10) of grade and tonnage is shown in figure 23. This plot and the correlation coefficient of –0.122 suggest that the log-tonnage and log-grade are not correlated. Neither probability plots nor histograms of the grade and tonnage data demonstrate either normality or lognormality. Skewness is 0.13 for log-tonnages and –0.90 for log-grades. The mean tonnage and grade are 269,600 metric tons and 0.57 percent U_3O_8, with standard deviations of 157,370 metric tons and 0.07 percent U_3O_8, respectively.

Trace-element contents of five of the eight pipes are shown in table 9. Because the selected samples were high graded, these data do not represent the average grade for a given deposit. Hence, grade curves cannot be constructed from the data. Nevertheless, they do show that the mean value of the elements As, Co, Cu, Ni, Pb, U, and Zn are high locally within breccia pipe primary orebodies. Copper, vanadium, gold, and silver have been produced from some highly oxidized breccia pipe uranium ores (Chenoweth, 1986, 1988).

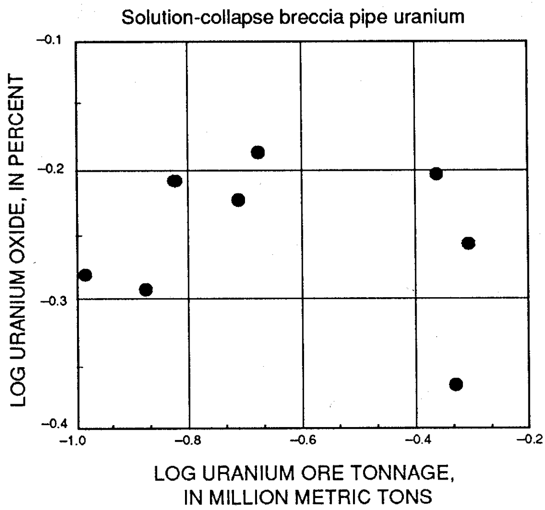

Figure 23. Scatter plot of logarithms of average uranium-oxide grade vs. tonnage of uranium ore.

Table 9. Summary statistics of chemical analyses of one selected sample from each of the five solution-collapse breccia pipe uranium deposits (based on analyses by Wenrich and Sutphin, 1989, and their unpublished data)

Element	Mean (ppm)	Standard deviation (ppm)
Ag	34	22
As	8,340	6,981
Ba	139	109
Cd	31	40
Ce	102	94
Co	2,044	3,795
Cr	51	68
Cu	11,440	9,340
Fe	4.7[1]	3.7[1]
Ga	21	9
La	17	7
Li	20	16
Mo	403	312
Ni	4,760	5,998
Pb	2,978	2,042
Sr	372	494
U	77,400	65,569
V	121	99
Y	124	112
Zn	9,584	11,469

[1]Both the mean and standard deviation for Fe are in percent.