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Mineral resource assessment of undiscovered solution-collapse breccia pipe uranium deposits in the Coconino National Forest, Arizona

by

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EXECUTIVE SUMMARY

Uranium resources of the Coconino National Forest, Arizona
Assessment by the U.S. Geological Survey, 1994

- The Coconino National Forest (CNF), as shown in figure 1, has areas permissible for solution-collapse breccia pipe uranium deposits.

- Quantitative assessment of uranium in undiscovered solution-collapse breccia pipe deposits was made using the deposit-size-frequency method (DSF, option C), a modification of a technique developed for NURE (National Uranium Resource Evaluation).

- The mean endowment of 77,300 metric tons (t) (85,200 short tons (st)) U_3O_8 for undiscovered solution-collapse breccia pipe uranium deposits in the CNF is 6.4 percent of the total mean uranium endowment previously predicted for the Colorado Plateau. Mean uranium endowments and an estimated number of undiscovered deposits (calculated from contained U_3O_8 using grade and tonnage data) are as follows:

Ranger District	U_3O_8(t)	Number of Deposits
Beaver Creek	8,700	3
Blue Ridge	4,040	1
Long Valley	4,990	2
Mormon Lake	17,400	6
Peaks (Elden & Flagstaff)	39,500	13
Sedona	2,570	1

- Of the 26 undiscovered deposits predicted in the CNF, 21 are covered by basalt and 5 are not. Those covered with basalt flows, etc. are currently not economically viable.

- Only a few sites are likely to be targeted for examination in the CNF even if suitable conditions (societal, economic, environmental, etc.) were present for exploration and development of solution-collapse breccia pipe uranium deposits.

- The uranium endowment for the CNF is a portion of the total endowment previously predicted for the Grand Canyon region; **not** an additional endowment.

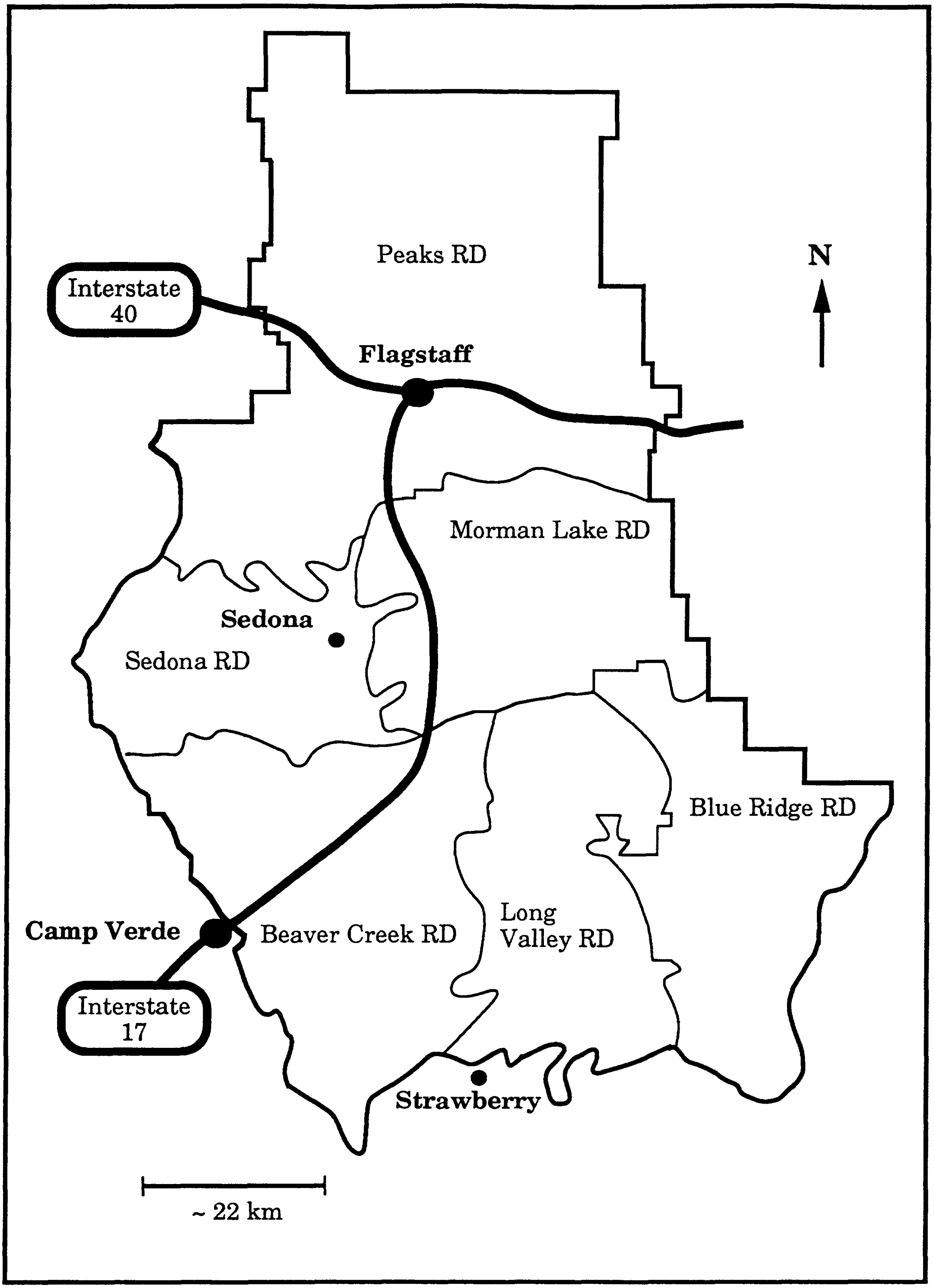

Fig. 1. Location of the six ranger districts of the Coconino National Forest, Arizona.

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INTRODUCTION

The Coconino National Forest (CNF), Arizona, contains approximately 814,000 hectares (ha) (2 million acres) in six Ranger Districts (RD) (fig. 1). The purpose of this assessment by RDs is to provide information useful to the Forest Service land managers concerning the quantity of uranium in solution-collapse breccia pipe uranium deposits **yet to be discovered in the CNF**. The assessment of metals and industrial minerals is addressed in a separate report. The predicted undiscovered uranium given here does not represent uranium endowments additional to those reported by Finch and others (1990) for the Grand Canyon region but it suggests what portion of their endowment is found within each of the ranger districts in the CNF and the forest as a whole. Included in this study are minor amounts of privately-held land (around Flagstaff, Sedona, Cornville), U.S. Park Service land (Sunset Crater National Monument, Walnut Canyon National Monument, Montezuma Castle National Monument), military land (part of Navajo Army Depot), and State of Arizona land.

Geology

To date, the Colorado Plateau is the only region where solution-collapse breccia pipe uranium deposits have been found. Both the deposits and associated geology have been intensely studied (see Van Gosen, and Wenrich, 1989; Wenrich and others, 1988; Wenrich, 1985; Wenrich, and Palacas, 1990). Deposits occur in solution collapse structures that are the result of upward stoping from caves developed in the Redwall Limestone. Pipes can extend upward for more than 1000 feet (300 m) (Finch, 1992) passing through the overlying Pennsylvanian, Permian, and Triassic rocks. The structures (pipes) are between 30 - 175 ft (9 - 51 m) in diameter (Finch, 1992). Initiation of upward stoping is less frequent if the Redwall Limestone is less than 50 ft (15 m) thick. Mineralization within the pipes is found adjacent to the Supai Formation, the Hermit Shale, and the Coconino Sandstone (Finch and others, 1990); for most areas mineralization is at a depth of 500-2000 ft (150-600 m) below the surface.

Previous assessment

The United States Geological Survey, in accordance with a Memorandum of Understanding, dated September 20, 1984, between the U.S. Department of Interior and the U.S. Department of Energy, provided an estimate of undiscovered uranium endowment in solution-collapse breccia pipe uranium deposits in the Grand Canyon region of northern Arizona and adjacent Utah (Finch and others, 1990). The deposit-size-frequency method (DSF, option C) used to make this assessment was a modification of one developed for NURE (National Uranium Resource Evaluation) as described by Finch and McCammon (1987), McCammon and others (1988), and McCammon (1990). The Hack-Pinenut area (which is just off the western edge of the North Kaibab Ranger District (RD), Kaibab National Forest) is used as a control (Finch and others, 1990) and is on the north side of the Grand Canyon National Park.

An assessment of undiscovered uranium endowment in solution-collapse breccia pipe uranium deposits in CNF can be made using the same favorable areas used by Finch and others (1990). The elicitations by a principal scientist in the previous assessment (as required to make a DSF, option C type assessment) are used here as well. The only modification one needs to make to the Grand Canyon region assessment are adjustments of the area of the favorable area classes (Finch and others, 1990; fig. 2) within each RD in the CNF. The same strategy used here has been previously used by Finch and others (1990) to give the the uranium endowment for the Grand Canyon, Williams, Flagstaff, Marble Canyon, and Holbrook 1^{o} x 2^{o} quadrangles. The Kaibab National Forest was also assessed the same way (Bliss and Pierson, 1993). The following types of areas may be classified in the CNF; the codes, with the exception of NP and V, are the same as in Finch and others (1990):

A--most favorable (comparable to the Hack-Pinenut control), area capped by the Kaibab Formation (only a small area in the northeast corner of Peaks RD);

B--less favorable but does contain the full section of Paleozoic formations which hosts deposits; Redwall Limestone thinner but still is likely greater than 50 ft (15 m) thick;

C--very low favorability with Paleozoic section present but the Redwall Limestone is less than 50 ft (15 m) or may be absent;

NP--not permissible for solution-collapse breccia pipe uranium deposits; Redwall Limestone clearly absent--areas will not contain undiscovered deposits of this type (included much of the Sedona RD, a part of the Beaver Creek RD and a little of the Long Valley RD); and

V--volcanic vents not permissible for undiscovered solution-collapse breccia pipe uranium deposits (significant part of the Peaks RD).

(Area classifications D and E used in the assessment of the Grand Canyon region are not found in the CNF--see Finch and others (1990) for discussion.)

Areas covered with basalt include B and C (designated as B(b) and C(b)). This type of cover would hide any deposits and would make them difficult to detect using existing geophysical methods (Finch and others, 1990). Although the assessment by Finch and others (1990) included areas with basalts from 5 ft (1.5 m) to 300 ft (90 m) thick, they clearly stated that most of these deposits were "essentially nonviable resources under present conditions" (Finch and others 1990, p. 12).

Magma rising to the surface and forming larger cones and vents of the San Francisco volcanic field likely has destroyed any deposits nearby. These areas were excluded from the assessment by Finch and others (1990) and designated as V herein. See Finch and others (1990, Plate 1) for the extent of areas not permissible (including vents) and favorable areas (with and without basalt) used in this study.

Using the same input variables used by Finch and others (1990), but with modified area class sizes, the probability distribution of undiscovered uranium endowment was calculated using the TENDOWG program (McCammon and others, 1988). Probability distributions were calculated for each of the favorable areas within each of the RD in the CNF (Beaver Creek, Blue Ridge, Long Valley, Mormon Lake, Peaks, Sedona).

Favorable area types in RDs

Beaver Creek RD

The following is the division of the 128,000 ha (316,000 acres) of the Beaver Creek RD into classified areas:

Area Type	Estimated Area (ha)	Square miles
B	424	1.6
B(b)	36,100	139
C(b)	2,440	9.4
V	570	2.2
NP	88,880	343

The NP area is the western 69 percent of the Beaver Creek RD.

Blue Ridge RD

The following is division of the 109,000 ha (247,000 acres) of the Blue Ridge RD into classified areas:

Area Type	Estimated Area (ha)	Square miles
C	85,300	329
C(b)	23,800	91.8

Long Valley RD

The following is the division of the 100,000 ha (248,000 acres) of the Long Valley RD into classified areas:

Area Type	Estimated Area (ha)	Square miles
NP	592	2.29
B	3,110	12
B(b)	3,520	13.6
C	29,400	114
C_b	62,800	242
V	924	3.57

Mormon Lake RD

The following is the division of the 138,000 ha (340,000 acres) of the Mormon Lake RD into classified areas is suggested:

Area Type	Estimated Area (ha)	Square miles
B	3,040	11.7
B(b)	59,800	231
C	12,300	47.4
C(b)	57,500	222
V	5,240	20.2

Peaks RD

The Peaks RD is the combined of the former Flagstaff RD and Elden RD. The following is the division of the 247,000 ha (610,000 acres) of the Peaks RD into classified areas:

Area Type	Estimated Area (ha)	Square miles
A	1,950	7.53
B	53,800	208
B(b)	109,000	421
C	7,660	29.6
V	72,600	280
NP	1,580	6.1

Sedona RD

The following is the division of the 91,500 ha (226,000 acres) of the Sedona RD into favorable areas:

Area Type	Estimated Area (ha)	Square miles
NP	80,600	311
B	1,000	3.86
B(b)	9,870	38.1

Predicted uranium endowment

Probability distributions in 5 and 10 percentile increments of the undiscovered uranium endowment for favorable areas within the six RDs are given in table 1. The undiscovered mean uranium endowment (in metric tons (t)) by RDs are:

Beaver Creek	8,700
Blue Ridge	4,450
Long Valley	4,990
Mormon Lake	17,400
Peaks	39,500
Sedona	2,570

The forecasts made in this report do not represent additional uranium endowments to those reported by Finch and others (1990) but rather they suggest what portion of that endowment is found within the six RDs of the CNF. The calculation was made using the computer program TENDOWG (McCammon and others, 1988). See Finch and others (1990, tables 1-2) for size-frequency distribution and listing of L factors of favorable areas used in these calculations.

The total mean endowment of 77,300 t (85,200 short tons (st)) U_3O_8 for the CNF (table 1) is 6.4 percent of the total mean endowment of 1,200,000 t (1,320,000 st) estimated for solution-collapse breccia pipes in the Grand Canyon Region of Northern Arizona and adjacent Utah (Finch and others, 1990). Most of the undiscovered U_3O_8 endowment in this region for this deposit type is expected to be found in areas **outside** of the CNF. Of the six ranger districts evaluated, the Peaks RD is expected to contain approximately 50 percent of the undiscovered uranium endowment (mean of 43,600 st (39,500 t) U_3O_8) predicted to be within the CNF.

Predicted numbers of undiscovered deposits

Introduction

Another way to visualize the amount of U_3O_8 endowment is using the estimated number of undiscovered deposits. An estimate of the number of undiscovered of solution-collapse breccia pipes is possible using grade and tonnage models (Finch and others, 1992, figs. 21-23) together with mean uranium endowment given herein.

Solution-collapse breccia pipes used to develop the grade and tonnage model have sizes between about 110,000 and 500,000 t based on data from eight deposits (Finch and others, 1992, fig. 21). The size range is quite narrow. The geometric mean deposit size of solution-collapse breccia pipes in the model is 230,000 t .

U_3O_8 grades in the model (Finch and others, 1992, fig. 22) are slightly higher than 0.40 percent or are less than 0.70 percent U_3O_8 using data from eight deposits. The mean U_3O_8 is 0.56 percent. U_3O_8 grade is not correlated with deposit size (Finch and others, 1992). Multiplying the mean grade by mean tonnage gives 1288 t of contained U_3O_8.

The number of deposits at various probabilities can be forecast by dividing the U_3O_8 endowment for each RD (generated by the deposit-size-frequency method). In this study, the uranium endowment at the 10th, 50th, and 90th percentiles as well as the mean values were divided by 1288 t of contained U_3O_8 (table 2). One problem of doing this is that the number of deposits estimated is too large. This is because the U_3O_8 cut off grades of 0.01 percent in the deposit-size-frequency method assessment is much lower than the lowest grade (i.e. 0.40 percent) for a deposit used in the grade and tonnage model. Extending the grade distribution to 0.01 percent U_3O_8 suggests that 57 percent of the endowment in deposits given by the deposit-size-frequency method will have U_3O_8 grades less than the lowest deposit grade in the model. The number of estimated undiscovered deposits in table 2 have been adjusted to be consistent with the grade and tonnage model by Finch and others (1992).

The distribution of numbers of undiscovered deposits in table 2 fails to represent the variability present in deposit sizes and U_3O_8 grades in the grade and tonnage model. Uncertainty also comes from the projection of RD boundaries onto the 1:500,000 scale map and boundaries of favorable areas using simplified geology of Finch and others (1990). The number of undiscovered deposits is a simple, easy to visualize guide, to the undiscovered uranium endowment, particularly for those deposits consistent with the grade and tonnage model (Finch and others, 1992).

The locations of these undiscovered solution-collapse breccia pipes within each RD are unknown. Their geologic expressions using geochemical techniques, etc., are more likely to be applicable to undiscovered deposits **not** covered by volcanic flows. Some RDs lack permissible tracts of any type, others have significant volcanic flows. Therefore, a brief discussion of the number and the general distribution of the **mean** undiscovered solution-collapse breccia pipes forecast in each of the six RDs (table 2) follows where particular favorable area types are noted by code (see above).

Beaver Creek RD

Areas not permissible for undiscovered solution-collapse breccia pipes are 69 percent of the RD, particularly in the western part. An insignificant portion of permissible areas contain volcanic vents, etc. which preclude the presence of deposits. Three undiscovered solution-collapse breccia pipes are likely present in permissible areas (Bb) in the district. All are probably in areas covered with basalt and would not be readily detected using currently available exploration methods.

Blue Ridge RD

All of the district is permissible (favorable area type C). One undiscovered solution-collapse breccia pipe is likely present. Chances are 2 out of 3 that the deposit is in an areas covered by basalt.

Long Valley RD

Areas not permissible for undiscovered solution-collapse breccia pipes are small, just 1.5 percent of the RD, in which there are predominantly volcanic vents, etc. Two undiscovered solution-collapse breccia pipes are predicted to be present in this RD. Of the four favorable area types, one deposit is likely to be in areas covered by basalt (Cb).

Mormon Lake RD

Areas not permissible for undiscovered solution-collapse breccia pipes are small, just 3.8 percent of the RD. Six undiscovered solution-collapse breccia pipes are predicted to be present in this RD (Bb, Cb) which ranks second for numbers of expected undiscovered deposits within the CNF. All are likely in areas covered by basalt.

Peaks RD

Areas not permissible for undiscovered solution-collapse breccia pipes are 30 percent of the RD. A total of 13 undiscovered solution-collapse breccia pipes are predicted to be present in this RD (most in favorable area B, Bb) which ranks first for numbers of expected undiscovered deposits within the CNF. Of these, nine are likely in areas covered by basalt. This RD is likely to be of particular interest to explorationists given suitable conditions to do so in the future.

Sedona RD

Most of the areas in the RD, or 88 percent, are not permissible for undiscovered solution-collapse breccia pipes. One undiscovered solution-collapse breccia pipe is predicted to be present in the east side of the RD and likely covered by basalt.

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Table 1. Undiscovered uranium endowment in the Coconino National Forest, Arizona.

[Values (short tons) of U_3O_8 are rounded to three significant figures. For each favorable area in a Ranger District (RD), the odds are 9 to 1 that the true unconditional endowment in tons of U_3O_8 is between the values given for a probability of 0.05 and 0.95. See text for explanation of favorable area type code.]

RD (favorable area type)	Probability											
	.05	.10	.20	.30	.40	.50	.60	.70	.80	.90	.95	Mean
Beaver (B)................	27.5	37.8	53.7	67.7	81.4	96.0	112	131	156	194	230	109
Beaver (Bb)..............	2,390	3,280	4,660	5,880	7,080	8,340	9,740	11,400	13,500	16,900	20,000	9,390
Beaver (Cb)..............	14.9	23.6	38.4	52.4	67.0	82.7	101	122	152	1,980	24,300	99.6
											RD mean =	**9,600**
Blue Ridge (C)..........	521	826	1,340	1,840	2,340	2,890	3,520	4,290	5,310,	6,940	8,490	3,480
Blue Ridge (Cb)........	145	230	375	512	654	807	984	1,200	1,480	1,940	2,370	973
											RD mean =	**4,450**
Long Valley (B).........	206	284	402	508	611	720	840	983	1,170	1,460	1,730	811
Long Valley (Bb).......	234	321	456	575	693	816	952	1,110	1,320	1,650	1,960	919
Long Valley (C)........	180	286	466	640	812	1,000	1,220	1,490	1,840	2,400	2,940	1,210
Long Valley (Cb).......	383	607	988	1,350	1,720	2,130	2,590	3,150	3,900	5,100	6,240	2,560
											RD mean =	**5,500**
Mormon Lake (B).....	201	276	392	495	596	702	820	958	1,140	1,420	1,680	790
Mormon Lake (Bb)..	3,970	5,460	7,750	9,770	11,800	13,800	16,200	18,900	22,500	28,100	33,200	15,600
Mormon Lake (C)..	75.1	119	193	264	338	417	508	618	764	1,000	1,220	502
Mormon Lake (Cb)...	352	557	907	1,240	1,580	1,950	2,380	2,890	3,580	4,680	5,730	2,350
											RD mean =	**19,200**
Peaks (A)................	223	305	431	542	650	763	887	1,030	1,220	1,500	1,760	846
Peaks (B)................	3,580	4,920	6,980	8,800	10,600	12,500	14,600	17,000	20,200	25,300	29,900	14,000
Peaks (Bb)..............	7,240	9,950	14,100	17,800	21,400	25,200	29,500	34,400	41,000	51,200	60,600	28,400
Peaks (C)................	46.9	74.3	121	165	211	260	317	386	477	624	764	314
											RD mean =	**43,600**
Sedona (B)..............	66.4	91.2	129	163	196	232	270	316	376	469	556	260
Sedona (Bb).............	655	900	1,280	1,610	1,940	2,280	2,670	3,120	3,710	4,630	5,480	2,570
											RD mean =	**2,830**
Coconino Natioal Forest (forest-wide mean)..												**85,200**

Table 2. Estimated numbers of undiscovered solution-collapse breccia pipe uranium deposits in the Coconino National Forest, Arizona.

[Number of deposits calculated from estimated U_3O_8 endowment (see table 1) and estimated contained U_3O_8 in a deposit with mean grade and mean size (from grade and tonnage model, see text). The number of undiscovered deposits is equal to or greater than the value at the given probabilities for each favorable area in a Ranger District (RD). See text for explanation of favorable area type codes. Mean values of uranium endowment distribution can be greater than those at a probability of 0.50 and the mean number of deposits may also be greater. All fractional deposits rounded to whole numbers.]

RD (favorable area type)	Probabilities and number of deposits				
	.90	.50	.10	Mean	RD Mean
Beaver (B)	0	0	0	0	
Beaver (Bb)	1	3	5	3	
Beaver (Cb)	0	0	1	0	
Beaver RD					3
Blue Ridge (C)	0	1	2	1	
Blue Ridge (Cb)	0	0	1	0	
Blue Ridge RD					1
Long Valley (B)	0	0	0	0	
Long Valley (Bb)	0	0	0	0	
Long Valley (C)	0	0	1	0	
Long Valley (Cb)	0	1	2	1	
Long Valley RD					2
Mormon Lake (B)	0	0	0	0	
Mormon Lake (Bb)	2	4	9	5	
Mormon Lake (C)	0	0	0	0	
Mormon Lake (Cb)	0	1	1	1	
Mormon Lake RD					6
Peaks (A)	0	0	0	0	
Peaks (B)	1	4	8	4	
Peaks (Bb)	3	8	16	9	
Peaks (C)	0	0	0	0	
Peaks RD					13
Sedona (B)	0	0	0	0	
Sedona (Bb)	0	1	1	1	
Sedona RD					1
Coconino National Forest.(forest-wide total)					26