DISTRIBUTION OF URANIUM IN ROCKS AND RADON LEVELS IN WATER IN THE SAN CARLOS - SAFFORD - DUNCAN NONPOINT-SOURCE MANAGENENT ZONE

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INTRODUCTION

As part of a study of potential non-point-source impacts on water quality, this report discusses the nature and distribution of uranium and radon in rocks, sediments, soils, and water in the San Carlos-Safford-Duncan Nonpoint-Source Management Zone (Figure 1). This study relies on previously published information, and for much of the Management Zone, this information is not detailed, or is not available.

Uranium is a naturally occurring element, found in all rocks and soils, as well as in all natural surface and groundwaters. Average values for typical crustal rocks are 4.4 ppm for granite, 0.8 ppm in basalt, and 3.8 ppm in shale (Brownlow, 1979, p. 43). The range of uranium concentrations within each rock type commonly varies by factors of 2 to 10.

Granites in Arizona, for example, have background levels of uranium ranging from 1.17 ppm in the Wilderness Granite, Santa Catalina Mountains, to 10 ppm in the Stronghold Granite in the Dragoon Mountains, and up to 51 ppm in the Lawler Peak Granite in Yavapai County (Duncan and Spencer, 1993b).

Radon is a naturally occurring gas produced from the radioactive decay of uranium. ^{222}Radon, the isotope of interest, is a daughter of ^{238}U (via ^{226}Ra). ^{222}Radon decays with a half life of 3.82 days, emitting an alpha particle.

Radon is highly soluble in water, and consequently is found in all natural waters. Radon may degas from domestic water, accounting for some of the indoor radon found in buildings. The U.S. Environmental Protection Agency has proposed, but not yet enforced, a limit of 300 picocuries per liter (pCi/l) for radon in water.

URANIUM DISTRIBUTION

Uranium in rocks

Uranium resources in the United States were evaluated by the U.S. Department of Energy (DOE) in the late 1970s and early 1980s and a series of reports detailing the results of this National Uranium Resource Evaluation (NURE) were published. Pertinent to the Management Zone are studies of the Mesa 1° x 2° quadrangle (Luning and others, 1982); Douglas 1° x 2° quadrangle (May and others, 1982); Silver City 1° x 2° quadrangle (O'Neill and Thiede, 1982); and Clifton 1° x 2° quadrangle (White and Foster, 1982). Results of their uranium analyses are shown on Plate 1.

The DOE studies sought to find economic resources of uranium (for the nuclear weapons program and nuclear power), and their shotgun approach to reconnaissance included sampling of areas known or suspected to have higher-than-background levels of uranium as well as some background sampling. The results shown should not, therefore, be taken as a truly random sampling, nor as reflecting the average background abundance of uranium in the rocks in the area around the actual sample location.

Locations of elevated uranium content were also identified in reconnaissance surveys by the U.S. Atomic Energy Commission (U.S. Atomic Energy Commission and U.S. Geological Survey, 1970a; 1970b; 1970c; 1970d). These surveys were preliminary, cursory evaluations of mines and prospect known or suspected of having above-background levels of uranium. Most analyses were field measurements by hand-held instruments, and results were generally presented as amount above background (e.g. 2X or 4X background). Absolute concentrations of uranium in the prospects and surrounding areas were generally not reported, so evaluation of true anomalies is difficult, considering the natural variations in uranium concentrations even within a given rock type.

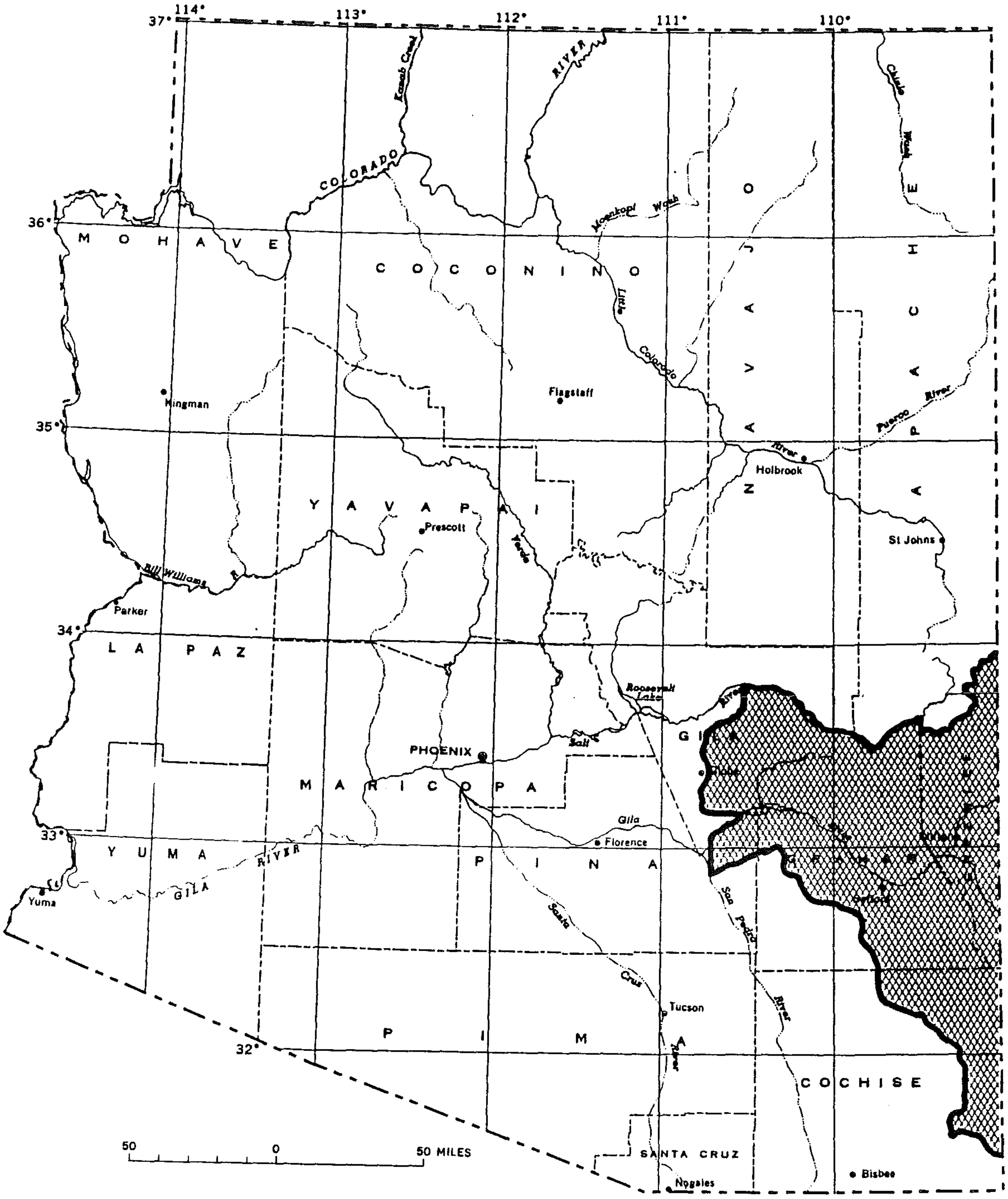

Figure 1. Location of San Carlos-Safford-Duncan Nonpoint-Source Management Zone.

Scarborough (1981) compiled all of the available AEC site reports and evaluated the potential for uranium deposits for parts of the Management Zone. His conclusion was that the lacustrine deposits in southeast Arizona containing elevated uranium levels were too small and too low grade to be of commercial interest. The AEC reconnaissance results are not plotted on Plate 1.

The U.S. Bureau of Mines conducted a detailed evaluation of the mineral resource potential of the Coronado National Forest, parts of which are in the Management Zone. Areas within the Management Zone include the Santa Teresa Mountains (Brown, 1993a), Pinaleno Mountains (Brown, 1993b), and Chiricahua Mountains (Brown, 1993c). These evaluations only looked at known mineralized areas (i.e., abandoned mines and prospects). Although each sample was analyzed for 52 elements, including uranium, the project did not include sampling for background levels of elements away from the mineralized zones. Owing to the non-random nature of the sampling, and lack of background samples, the Bureau of Mines analyses are not included on Plate 1.

Uranium in sediments of the Safford and Duncan basins

Uranium content of surficial sediments in the Safford and Duncan Valleys has been measured in several studies (Scarborough, 1981; Duncan and Spencer, 1993a; Harris, 1994). Generally, basin fill sediments are low in uranium, averaging about 1.6 ppm for the entire state (Duncan and Spencer, 1993b) and 3.6 ppm for the Safford-San Simon basin (Harris, 1994).

In sediments deposited in Pliocene-Pleistocene lakes, however, U levels can be greatly elevated. These lacustrine sediments consist of clay, silt, diatomite, and marls (impure limestone) and are found throughout the San Carlos, Safford-San Simon, and Duncan valleys. Uranium concentrations as high as 133 ppm in diatomite (Harris, 1994) and 444 ppm in marl (Duncan and Spencer, 1993b) have been measured in the 111 Ranch lake beds southeast of Safford.

Anomalous uranium concentrations also have been found in lacustrine deposits of tuffaceous marl and diatomite in the Duncan area (Scarborough, 1981; Harris, 1994). Uranium levels of up to 34 ppm were encountered in tuffaceous marls and 15 ppm in diatomites (Harris, 1994).

Several weak anomalies have been found in the San Simon Valley in tuffaceous sediments. Carlisle and others (1978) describes an anomaly 10 miles east of Bowie and north of San Simon of about three times background in lacustrine tuffaceous clays. Harris (1994) found levels of 10 to 24 ppm in lacustrine deposits at several locations along the axis of the valley.

Uranium levels in the widespread lacustrine sediments within the San Carlos Indian Reservation have not been measured in detail. A few analyses of lacustrine sediments near San Carlos Lake are given in Luning and others (1982) and are shown on Plate 1.

NURE airborne radiometric survey

During the period 1975-83, the U.S. Department of Energy conducted the National Uranium Resource Evaluation (NURE) Program, which included aerial gamma-ray surveys of most of the conterminous United States. Estimated uranium concentrations over the Management Zone are shown on Plate 3. The data, available from the U.S. Geological Survey (Phillips and others, 1993), was processed and contoured by the AZGS using Surfer™ software. Meaurements were taken along north-south flight lines spaced two kilometers apart, at a ground-clearance between 400 and 1100 feet.

Aerial gamma-ray surveys measure the gamma-ray flux produced by the radioactive decay of the naturally occurring U-238 in the top few centimeters of rock or soil. If the detector is properly calibrated, the data can be expressed in terms of the estimated concentrations of the radioactive element. The concentration of uranium is usually expressed in units of parts per

Table 1. Air Radiometric Data, Averages for Rock Units

All Points

Map Unit	*Rock type*	*samples*	*eU (ppm)*	*eTh (ppm)*	*%K*
KJs	Sedimentary rocks with local volcanic units (Cretaceous to Late Jurassic)	49	1.94 ± 0.74	6.46 ± 3.01	1.78 ± 0.55
Ks	Sedimentary rocks (Cretaceous)	13	2.44 ± 0.64	7.83 ± 3.16	2.11 ± 0.73
Kv	volcanic rocks (Late Cretaceous (early Tertiary near Safford))	92	2.03 ± 0.75	6.67 ± 3.94	1.74 ± 0.63
MC	Seidmentary rocks (Mississippian to Cambrian)	154	2.04 ± 0.52	6.40 ± 2.18	1.52 ± 0.57
PP	Sedimentary rocks (Permian and Pennsylvanian)	169	2.05 ± 0.56	6.06 ± 2.09	1.26 ± 0.58
Pz	Sedimentary Rocks (Paleozoic)	33	2.29 ± 0.53	7.42 ± 2.24	1.87 ± 0.49
Q	Surficial Deposits (Holocene to middle Pleistocene)	1003	2.49 ± 0.54	8.50 ± 2.18	2.48 ± 0.48
Qo	older surficial deposits (middle Pleistocene to latest Pliocene)	571	2.28 ± 0.59	8.00 ± 2.34	2.15 ± 0.54
QTb	Basaltic rocks (Holocene to late Pliocene (< 4 Ma))	222	1.75 ± 0.60	5.92 ± 2.09	1.45 ± 0.38
Qy	Young alluvium (Holocene to latest Pleistocene)	206	2.59 ± 0.56	8.35 ± 1.85	2.27 ± 0.40
Tb	basaltic rocks (late to middle Miocene (8-16 Ma))	7	2.12 ± 0.36	6.41 ± 2.20	1.39 ± 0.63
Tg	granitoid rocks (early Miocene to Oligocene (18-38 Ma))	100	2.87 ± 0.60	10.82 ± 2.86	2.27 ± 0.43
Ti	subvolcanic intrusive rocks (middle Miocene to Oligocene)	44	2.60 ± 0.44	10.61 ± 2.38	2.44 ± 0.53
TKg	granitoid rocks (early Tertiary to late Cretaceous (55-85 Ma))	36	2.29 ± 0.59	7.06 ± 2.85	1.76 ± 0.41

Airborne radiometric data from National Geophysical Data Grid (Phillips et al, 1993). Averages are for data from all grid points that fall within each unit on the 1:1,000,000 scale Geologic Map of Arizona (Reynolds, 1988) within the study area and a 15 km-wide buffer zone around the study area.

Map Unit	*Rock type*	*samples*	*eU (ppm)*	*eTh (ppm)*	*%K*
TKgm	granitic rocks (early Tertiary to Late Cretaceous (45 to 75 Ma))	1	4.57	14.10	3.36
Tsm	Sedimentary rocks (middle Miocene to Oligocene (15-38 Ma))	106	2.78 ± 0.56	10.21 ± 2.45	2.22 ± 0.45
Tso	sedimentary rocks (Oligocene to Eocene or locally Paleocene)	215	1.58 ± 0.54	5.27 ± 1.32	1.30 ± 0.31
Tsy	Sedimentary rocks (Pliocene to middle Miocene)	1187	2.30 ± 0.63	8.02 ± 2.58	2.11 ± 0.46
Tv	Volcanic rocks (middle Miocene to Oligocene; 15-38 Ma)	2628	1.82 ± 0.63	6.67 ± 2.45	1.81 ± 0.59
W	water (recent)	12	2.27 ± 0.41	9.44 ± 1.42	1.70 ± 0.35
Xg	granitoid rocks (Early Proterozoic (1650-1750 Ma))	31	2.79 ± 0.76	10.78 ± 3.10	2.30 ± 0.51
Xm	metamorphic rocks (Early Proterozoic (1650-1800 Ma))	162	2.24 ± 0.59	8.28 ± 2.50	2.19 ± 0.40
Xms	metasedimentary rocks (Early Proterozoic (1650-1800 Ma))	41	2.36 ± 0.26	8.77 ± 1.50	1.92 ± 0.29
Xmv	metavolcanic rocks (Early Proterozoic (1650-1800 Ma))	11	3.15 ± 0.35	13.41 ± 1.42	1.92 ± 0.18
Xq	quarzite (Early Protoerozic (1700 Ma))	9	3.03 ± 0.58	14.75 ± 2.58	2.08 ± 0.29
Yd	diabase (Middle Proterozoic (1100 Ma))	113	2.11 ± 0.47	7.78 ± 2.58	1.75 ± 0.52
Yg	granitoid rocks (Middle Proterozoic (1400 Ma))	294	2.60 ± 0.66	10.04 ± 3.04	2.35 ± 0.53
Ys	sedimentary rocks (Middle Proterozoic)	185	2.18 ± 0.48	7.64 ± 2.60	1.80 ± 0.50
YXg	granitoid rocks (Middle or Early Proterozoic (1400 Ma or 1650-1750))	23	1.72 ± 0.45	5.52 ± 2.20	1.92 ± 0.42

Airborne radiometric data from National Geophysical Data Grid (Phillips et al, 1993). Averages are for data from all grid points that fall within each unit on the 1:1,000,000 scale Geologic Map of Arizona (Reynolds, 1988) within the study area and a 15 km-wide buffer zone around the study area.

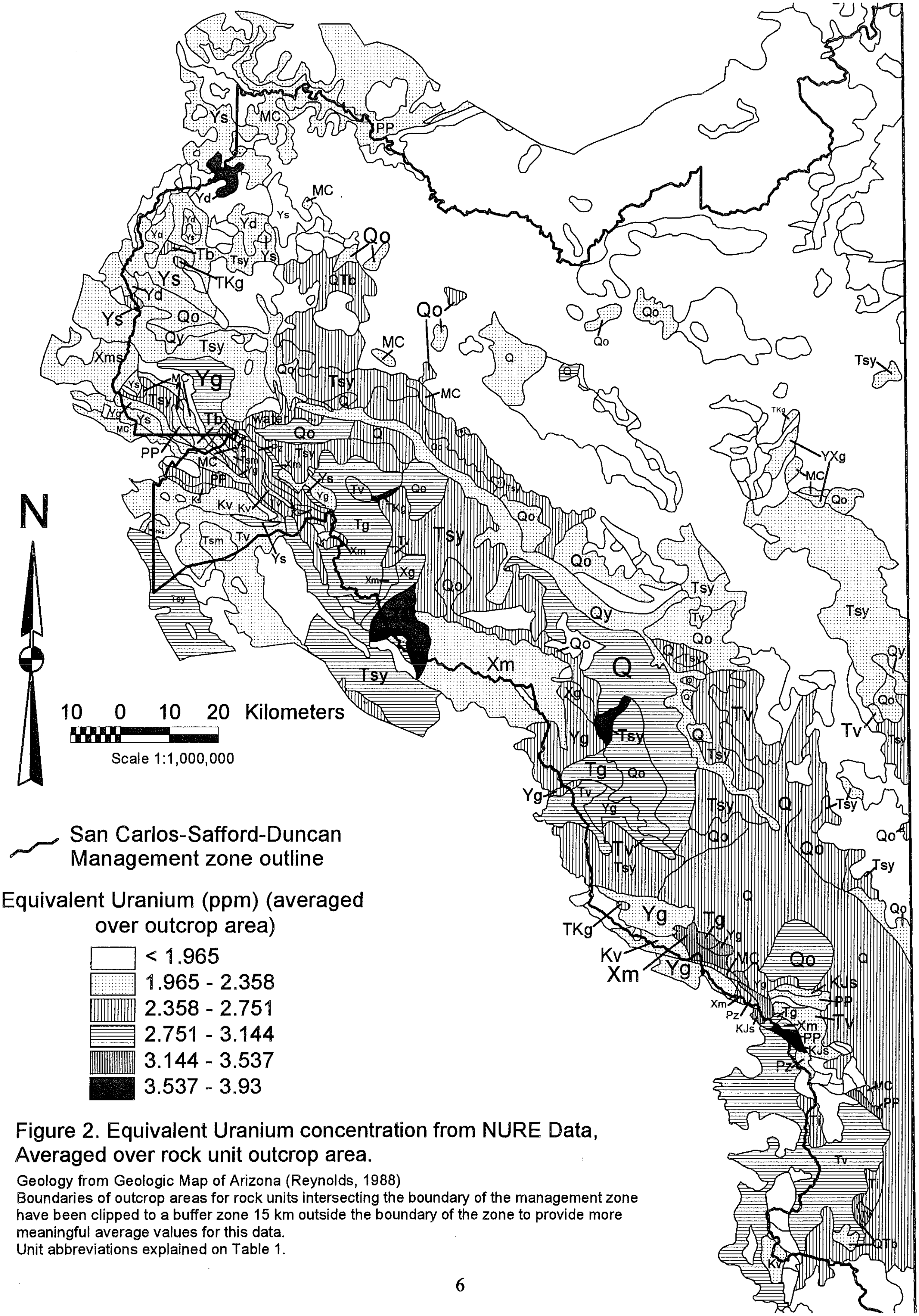

Figure 2. Equivalent Uranium concentration from NURE Data, Averaged over rock unit outcrop area.

Geology from Geologic Map of Arizona (Reynolds, 1988)
Boundaries of outcrop areas for rock units intersecting the boundary of the management zone have been clipped to a buffer zone 15 km outside the boundary of the zone to provide more meaningful average values for this data.
Unit abbreviations explained on Table 1.

million equivalent uranium (ppm eU). The term equivalent is used because the technique actually measures the gamma rays from the decay of bismuth (Bi-214), which is a decay product of U-238. Radioactive disequilibrium in the uranium decay series, caused by the loss of any daughter products, may result in the measured equivalent uranium being different from the actual uranium present in the surface rocks and soils.

Results of the NURE survey are presented in Table 1 and Figure 2 by rock type. All rock types are within the normal range of uranium concentrations and no anomalies are revealed at the coarse scale of the survey. In general, uranium levels are higher over the southwest part of the Management Zone versus the northeast part. All of the areas over 3 ppm are far from population centers, and all are still within the natural variability for the host rock types.

RADON AND URANIUM IN WATER

A survey of radon in Arizona ground water was conducted by the Arizona Geological Survey (Duncan and others, 1993) to establish baseline data and determine if measurements of uranium in rocks and sediments could be used to predict associated levels of radon in groundwater derived from those rocks and sediments. Four wells in the Safford area were tested for radionuclides. Results, in picocuries per liter (pCi/l), are presented in Table 2, and radon levels are plotted on Plate 2 (From Duncan and others, 1993):

Table 2. Radionuclides in Safford area water wells.

Well, location	**^{222}Rn**	**Gross α**	**Gross β**	**^{238}U**	**^{234}U**	**^{226}Ra**
1) D(8-26)19da	279± 2.6	<1.2	3.30±0.70	0.22±0.04	0.29±0.04	<0.10
2) D(7-26)13bad	461±28	9.60±1.0	7.70±1.0	1.80±0.20	3.40±0.20	<0.10
3) D(7-26)5dbd	476±28	3.70±0.60	3.80±0.80	0.80±0.09	1.70±0.10	<0.10
4) D(8-26)17cac	1,020±50	11.0±1.10	5.5±1.00	1.9±0.20	2.3±0.20	0.59±0.08

Well number 1 is at the Safford Federal Prison and penetrates granitic sand and gravel derived from the Pinaleno Mountains to the west. Wells 2 and 3 are in young river gravels (and possibly Late Tertiary alluvium) along the Gila River. Well 4 is screened in Late Tertiary lacustrine sediments, similar to those exposed to the east at 111 Ranch.

Radon and uranium content of water samples from wells and springs in the Silver City 1° x 2° quadrangle were measured by the U.S. Geological Survey (Scott and Barker, 1962; Hassemer and others, 1983). The results are informative in that they illustrate the enormous natural variation in radon and uranium in surface and groundwater. Scott and Barker (1962) consider water with uranium of more than 54 micrograms per liter (μg/l) to be anomalous. Sample locations and concentrations are shown on Plate 2. Table 3 summarizes the results of the USGS analyses for the entire quadrangle:

Table 3. Radon and uranium in wells and springs, Silver City 1°x2° quadrangle.

Element	number of samples	minimum value	maximum value	arithmetic mean	standard deviation
Radon	94	<5	24,000	1000	3100
Uranium	254	<1	550	11	48

Radon was determined by the alpha particle detection method and is reported as picocuries per liter. Uranium was determined using laser-excitation fluorescence and is reported in micrograms per liter. Data from Hassemer and others, 1983.

In studies across the nation, geologists have tried to correlate levels of uranium in rocks to levels of radon in water; uranium in rocks and soil to indoor air radon; and radon in water to indoor air radon. The study by Duncan and others (1993), which included wells near Payson, Sierra Vista, Paulden, Kingman, Yuma, Verde Valley, and New River, showed that the uranium content of surficial rocks was a poor predictor of radon levels in groundwater. Correlation between radon and the other radionuclides was very weak. In general, wells producing from granite had the highest radon levels.

Gundersen and others (1993) found that, regardless of rock type, the highest levels of radon were associated with sheared fault zones. In unsheared rocks, carbonates and shales produced less radon in water than igneous and metamorphic rocks. Their residential monitoring also found that up to 30% of indoor radon was from water usage.

Wanty and others (1993) found higher water radon levels in granites than in schists and gneisses, even when the metamorphic rocks contained higher concentrations of uranium. Significantly, all of their water samples exceeded the EPA's proposed limit of 300 picocuries per liter for radon in water. In the statewide study of Duncan and others (1993), 23 of the 32 samples (72%) exceeded the proposed EPA limit. Radon levels shown on Plate 2 (from Hassemer and others, 1983) exceed proposed standards in 10 of 34 samples (29%) tested for radon.

CONCLUSIONS

Uranium contents in the rock of the San Carlos-Safford-Duncan Nonpoint-Source Management Zone are typical for the various rocks types present. Elevated concentrations of uranium are found in scattered small prospects, generally in narrow veins or shear zones in weakly mineralized areas. None of these bedrock occurrences is large enough or of sufficient grade to be of economic interest. Owing to their very small size and relatively low U concentrations, these occurrences are not expected to contribute any more uranium to the surface or groundwater than the surrounding rocks.

Surficial basin fill sediments in the study area generally contain low concentrations of uranium. Some lacustrine deposits, however, have been found to have elevated levels of uranium. Water wells producing from lacustrine units have higher radon levels than wells in alluvial material, or in bedrock. The full extent and uranium content of subsurface lacustrine sediments in the study area (especially on the San Carlos Reservation) has not been determined. Lacustrine sediments may be an important source for uranium and radon in the groundwater of the Management Zone.

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