URANIUM DISTRIBUTION IN SEDIMENTS OF THE SAFFORD AND DUNCAN BASINS, SOUTHEAST ARIZONA, AND IMPLICATIONS FOR INDOOR RADON

by

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INTRODUCTION

Radon is a colorless, odorless gas produced by the radioactive decay of uranium. The U.S. Environmental Protection Agency has determined that indoor radon at elevated levels is a significant health risk to humans. Indoor-radon levels generally correlate with uranium concentration in underlying rocks, and some areas of Arizona are known to have elevated levels of uranium.

This study is part of an ongoing evaluation of potential radon hazards in Arizona by the Arizona Geological Survey and the Arizona Radiation Regulatory Agency. This report presents results of a study of the distribution of uranium in upper Cenozoic sediments of the Safford and Duncan basins and describes the nature of a notable uranium anomaly in the area of the 111 Ranch, near Safford.

Uranium concentrations were measured using a portable gamma-ray spectrometer and were confirmed with analyses performed by a commercial laboratory. The spectrometer survey followed the methods outlined in Duncan and Spencer (1993) and the same equipment was used during both investigations. Indoor-radon data were supplied by the Arizona Radiation Regulatory Agency and well water-radon data were taken from Duncan and others (1993).

LOCATION

The Safford basin (also known as the San Simon basin) is a large, elongate valley in southeast Arizona, extending from the Miami-Globe area southeast for more than 130 miles to near Rodeo, New Mexico (Figure 1). Safford is at the center of the valley and is the largest town in the region. Other communities in the valley include San Simon, Bowie, Solomon, San Jose, Thatcher, Pima, Fort Thomas, and San Carlos. The valley is drained by the San Simon River, an intermittent stream, which flows northwest to Safford, where it joins the Gila River which flows northwest to San Carlos Lake.

The Duncan basin is situated along the upper Gila River, adjacent to the Arizona-New Mexico border. The Gila River flows northwest from Duncan almost to Clifton, where it turns southwest, cuts across the Gila Mountains and enters the Safford basin east of Safford. The valley includes the small towns of Duncan, Franklin, Sheldon, and York.

GEOLOGY

Safford Basin

The Safford basin is an extensive structural trough, 10 to 20 miles wide and over 130 miles long, formed during the late Tertiary Basin and Range disturbance. The basin is bounded on the northeast by the Gila and Peloncillo mountains, consisting largely of Tertiary mafic to silicic volcanic rocks, and on the southwest by the Santa Teresa, Pinaleño (Graham), Dos Cabezas, and Chiricahua mountains. Precambrian metamorphic and granitic rocks and Tertiary granitic rocks comprise the bulk of the Santa Teresa and Pinaleño mountains, with Tertiary volcanic rocks forming the southern tip of the Pinaleños. The Dos Cabezas Mountains contain Precambrian metamorphic and plutonic rocks, Paleozoic and Mesozoic sedimentary rocks, and Cretaceous to mid-Tertiary silicic volcanic and plutonic rocks. Paleozoic and Mesozoic sedimentary rocks and mid-Tertiary rhyolitic rocks make up the northeast Chiricahua Mountains.

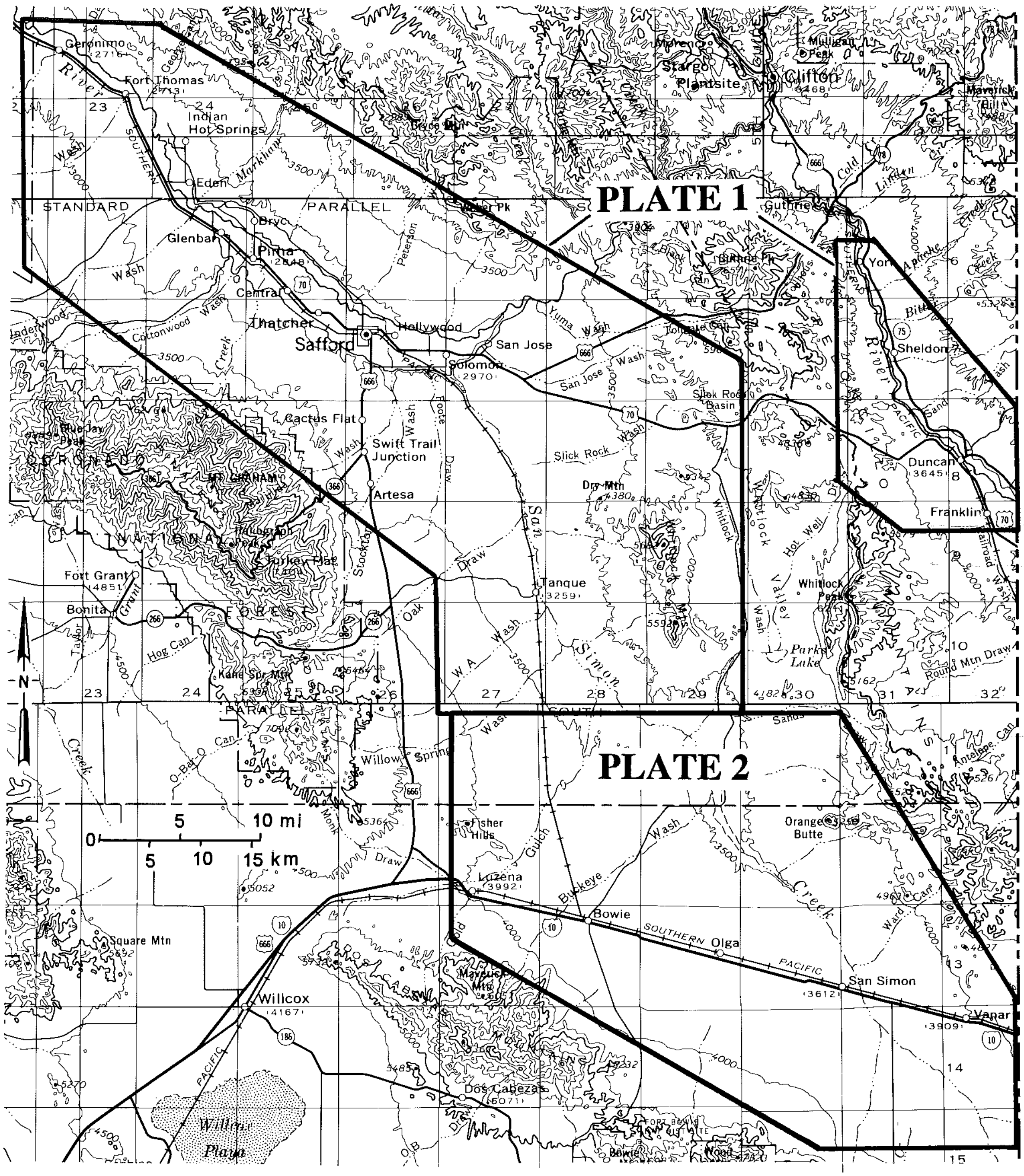

Figure 1. Location of study area. Outlined areas show coverage of Plates 1 and 2.

A thick sequence of unconsolidated mid- to late-Tertiary sediments fills the basin. The sediments consist of alluvial and fluvial silt, sand, and gravel interfingered with lacustrine deposits and evaporite layers. Detailed investigations of the basin-fill sediments were conducted by Heindl (1958) and Harbour (1966). The surficial geology of the Safford area has been mapped by Houser and others (1985) and Richter and others (1983).

Well logs and geophysical data indicate the presence of three semi-independent depositional sub-basins. The northwestern part of the Safford basin, from Miami-Globe to the vicinity of Fort Thomas is referred to as the lower Safford sub-basin, and from Fort Thomas southeast to the southern tip of the Whitlock Mountains is known as the upper Safford sub-basin. The portion south of this point is the San Simon sub-basin. Gravity models (Oppenheimer, 1980) suggest that the upper Safford sub-basin reaches a depth of nearly 10,000 feet in the Safford-Thatcher area and the San Simon sub-basin may be close to 9000 feet deep east of Bowie. Erosion since the mid-Pleistocene has exposed almost 1000 feet of the basin fill.

111 Ranch area

An unusually extensive and thick sequence of lacustrine and paludal sediments occurs 15 miles southeast of Safford at the abandoned 111 Ranch. Here, tuffaceous silt, clay, marl, limestones and diatomite crop out over an area of about 10 square miles and form a stratigraphic sequence up to 210 feet thick. The deposits wrap around the north and west sides of Dry Mountain, a rhyolitic outlier of the Whitlock Mountains, which are themselves an outlier of the Peloncillo Mountains to the east. South of Dry Mountain, the beds continue along the west flank of the Whitlock Mountains, then grade into the more massive silts and sands that characterize the rest of the basin. The geology of the Whitlock Mountains and vicinity has been mapped by Richter and others (1981). Sediments of the 111 Ranch area are described in detail by Clay (1960), Seff (1962), and Van Horn (1957).

Duncan Basin

The Duncan basin is part of a fault-bounded trough extending from near Clifton southeast to near Lordsburg, New Mexico, where the basin continues as the Animas Valley. Tertiary mafic to silicic volcanic rocks make up the Peloncillo Mountains, which lie to the southwest of the valley. The basin is flanked on the northeast by Tertiary volcanic rocks of the Mule, Summit, and Black mountains in New Mexico.

Basin fill consists of alluvial and fluvial sand, silt, and gravel, and fine grained lacustrine sediments similar to those of the Safford basin. The sediments were deposited in a closed basin that at times contained lakes or playas (Heindl, 1958).

GAMMA-RAY SPECTROMETER SURVEY

Methods

The Arizona Geological Survey conducted a survey of the Safford and Duncan basins using an EG&G geoMetrics model GR-310 portable gamma-ray spectrometer. The machine employs an external detector containing a 347-cm^3, thallium-doped, sodium iodide crystal and a high-gain photomultiplier tube. Four independent channels provide measurements of the diagnostic gamma radiation for uranium (via bismuth-214, 1.76 million electron volts [MeV]), thorium (via thallium-208, 2.62 MeV), needed for uranium assay corrections, as well as total gamma radiation (0.4 to 4.0 MeV) and potassium.

Count times of 1, 10, 100, or 1000 seconds may be selected, and due to the random nature of radioactive decay, longer count times generate less statistical error and greater precision. Periodic comparisons of 100- versus 1000-second count times confirmed that the shorter count time was sufficiently accurate for the purposes of this study and so was used for data acquisition.

Uranium concentrations in parts per million (ppm) were calculated from the field data using correction factors and assay equations developed by Duncan and Spencer (1993).

Results

Figure 2 is a histogram of uranium concentrations determined by spectrometer measurements. The mean for 138 samples in the Safford basin, excluding the anomalous sediments of the 111 Ranch area, is 3.6 ppm. Uranium concentrations greater than 6 ppm are considered anomalous (Duncan and Spencer, 1993). Locations of spectrometer measurements and uranium concentrations are shown on plates 1 and 2.

Uranium concentrations in the sediments of the 111 Ranch area (Plate 1, Figure B) are significantly higher than elsewhere in the Safford valley. The mean uranium level at 76 sites tested (nonrandomly chosen) is about 12.7 ppm. The highest uranium concentrations measured in this study were 90 ppm (spectrometer reading at a diatomite deposit) and 133 ppm (commercial analysis of a marl).

Several anomalous areas were found near San Simon wash in the southern part of the Safford valley. One area is in some low road cuts in section 6, T. 11 S., R. 28 E., about one mile northwest of where the main road crosses San Simon wash. Readings up to 24 ppm were found in one road cut, but the anomaly tapered off to normal levels within 100 yards. Another area with slightly anomalous readings is at the northernmost chabazite mine in section 2, T. 12 S., R. 29 E. A white tuff below the chabazite layer gave a reading of 10 ppm uranium. Slightly anomalous levels of uranium were found on the east bank of San Simon wash one-half mile east of the town of San Simon, and also one mile north of town.

Limited reconnaissance sampling of the Duncan valley (Plate 1, Figure C) indicated that the sediments in the basin may contain uranium in amounts slightly higher than sediments of the Safford basin. The mean uranium content for all samples (total of 13) in the Duncan valley is 5.5 ppm. One anomalous area, adjacent to highway 70 about three miles west of Duncan, contains a section of tuffaceous lacustrine rocks with 15 ppm uranium. Another anomaly, adjacent to Highway 75 six miles north of Duncan, consists of a four-inch-thick cherty tuff layer with 34 ppm uranium.

Analyses of 12 samples were performed by a commercial lab to check the quality of the spectrometer data. Figure 3 shows the results of laboratory analyses versus spectrometer measurements. The correlation is strong, although two of the laboratory analyses showed higher uranium concentrations than the spectrometer. A similar trend is apparent in the data of O'Neill and Thiede (1980) for samples from the 111 Ranch area. Several factors may be responsible for the lower spectrometer results. First, the spectrometer measures radiation from a large area, which may contain many rock types containing normal as well as anomalous levels of uranium. Samples collected for chemical analyses, on the other hand, are typically from a single layer or specific rock type (often known to be anomalous by spectrometer readings). Also, chemical analyses measure uranium in samples directly, whereas spectrometers measure gamma rays emitted from near the surface by bismuth-214, a daughter of radon. If radon, a gas, is lost from the surface, as could happen in the case of unconsolidated sediments in the Safford Basin, the full amount of uranium in the sediment may not be accounted for in measurements of bismuth-214. Furthermore, samples collected for laboratory analyses may be taken from below the surface, where the rock is relatively fresh (unweathered) and where loss of uranium by leaching and loss of radon gas by diffusion are

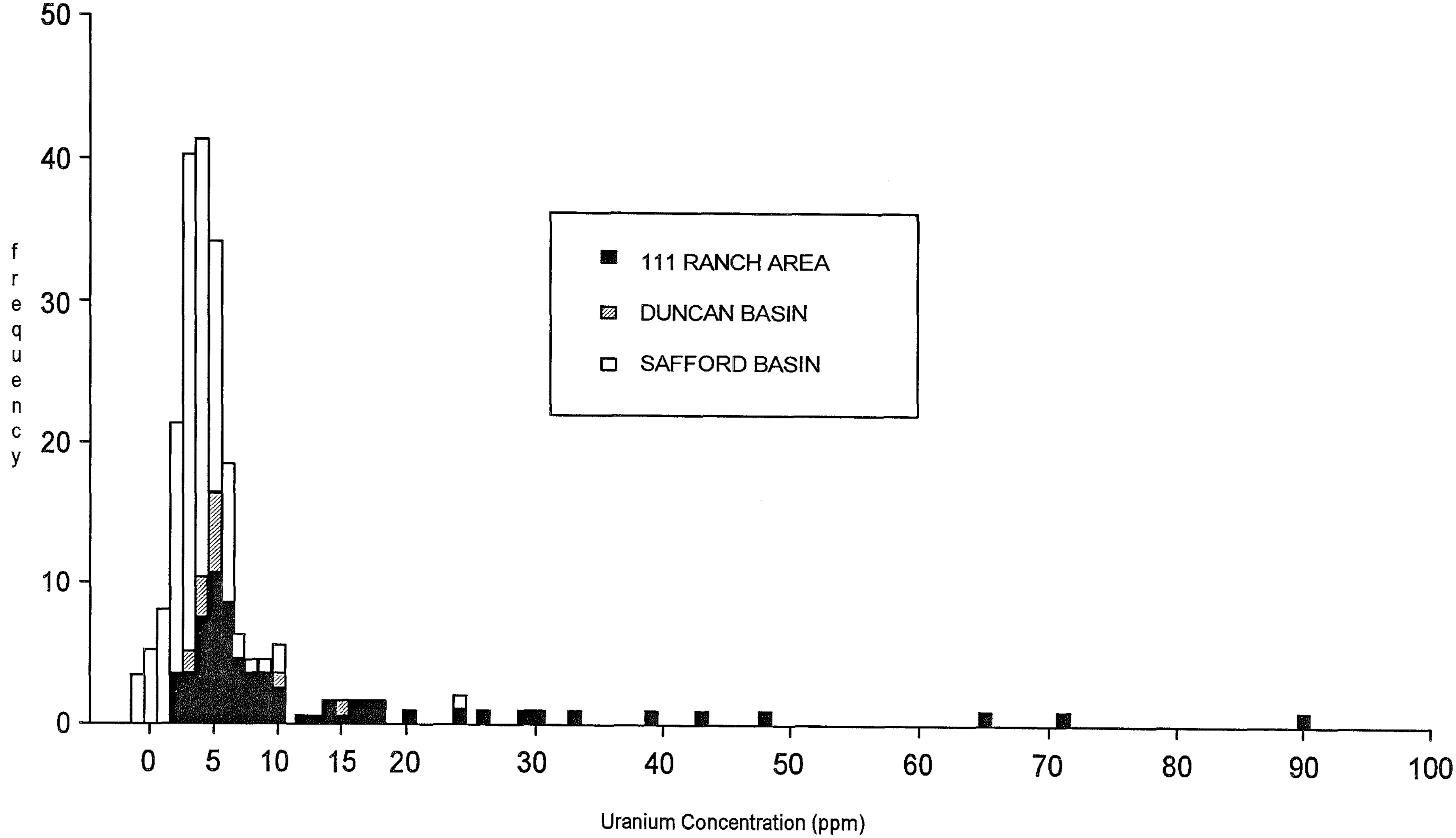

Figure 2. Histogram of uranium concentrations in the Safford and Duncan basins. Concentrations greater than 6 ppm are considered anomalous.

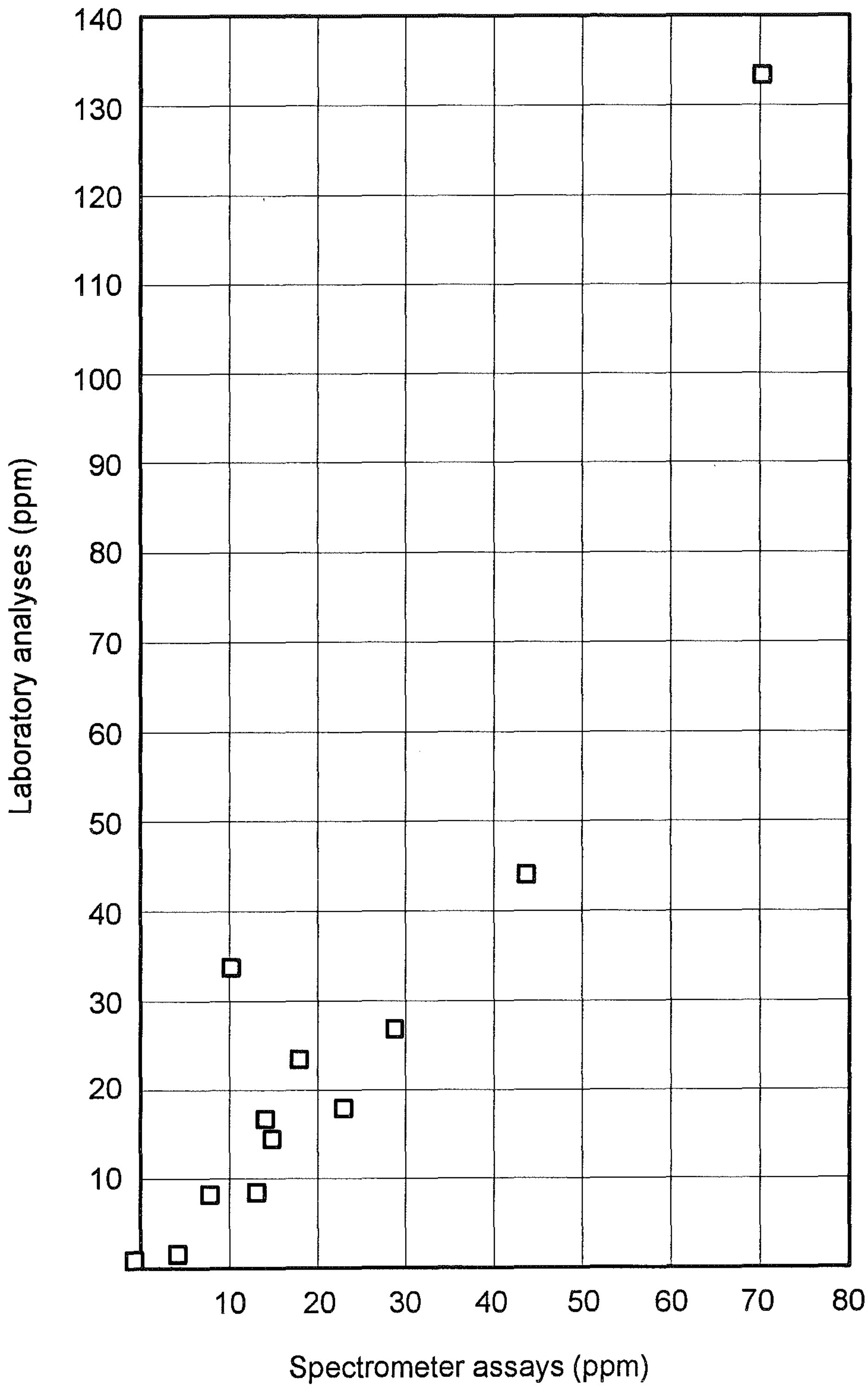

Figure 3. Plot of spectrometer assays versus commercial laboratory analyses of sediments in the Safford and Duncan basins.

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URANIUM GEOLOGY

Rock-type Associations

Uranium anomalies in the Safford and Duncan basins are restricted to marly, diatomaceous, and cherty lacustrine sediments. These types of sediments are characteristic of the 111 Ranch area near Safford, and are found in the vicinity of the town of Duncan, but are not as common (at least in the exposed sediments) elsewhere in the basins. Sandy or silty alluvial sediments that account for the bulk of the basin fill of the Safford and Duncan valleys typically have low levels of uranium.

Spectrometer measurements indicate that concentrations of uranium in bedrock surrounding the basin are highest (up to 10 ppm) in the silicic volcanic rocks of the Whitlock Mountains, especially Dry Mountain, on which the anomalous sediments of the 111 Ranch are deposited. Intermediate to mafic volcanic rocks of the Whitlock, Peloncillo, and Gila mountains contain average concentrations (2 to 4 ppm) of uranium and no anomalous levels were measured in these rock types with the spectrometer. Precambrian metamorphic and granitic rocks of the Pinaleño Mountains generally contain low concentrations of uranium (Reynolds and others, 1980). At the southern tip of the range, in the Greasewood Mountain area, a high radiometric background and several very small, low-grade uranium occurrences have been noted (Scarborough, 1981; O'Neill and Thiede, 1982).

Origin of Uranium Anomalies

While the location of the highest uranium concentrations in the sediments of the Safford Basin (111 Ranch area) coincides with that of higher-than-average levels in the adjacent bedrock, anomalous concentrations of uranium are probably more strongly controlled by the nature of the sediments than the amount of influx of uranium. Most of the sediments in the 111 Ranch area were deposited in lacustrine or paludal (swampy) environments. These conditions promote the deposition of fine-grained sediments, including carbonate, diatomite, and organic matter.

Although most carbonate rocks contain very little uranium, especially those deposited in oxidizing environments, some impure carbonates can contain considerably more uranium. Impurities such as clay, organic matter, and silica gel can absorb uranium (Jones, 1978; O'Neill and Thiede, 1982). Seff (1962), Harbour (1966), and O'Neill and Thiede (1982) emphasize the prevalence of a variably-altered tuffaceous component in the 111 Ranch sediments, important even in the limestone units. The tuffaceous sediment may be altered to clay and release silica shortly after deposition, providing sites for uranium adsorption (Zielinski, 1980).

Organic matter in the basin sediments would also contribute to an increased uranium content by reducing the soluble, oxidized form of uranium U(+6) to the insoluble U(+4) state. Despite the oxidizing conditions present today, and at the time of deposition, the 111 Ranch sediments contain a small amount of organic matter. Samples analyzed by the U.S Department of Energy (O'Neill and Thiede, 1982) contained 0.04 to 0.31% organic carbon. Organic matter content does not appear to correlate with sediment type. Mudstones, for example, contain both the lowest and highest amounts measured. Carbonate rocks contained 0.10 to 0.18 ppm organic matter. The same study found elevated levels of vanadium (135 to 648 ppm) in the sediments, which is believed to contribute to the stabilization of secondary uranium as carnotite.

Although the organic carbon content of the basin sediments is minute to nil, the presence of organic matter may increase the uranium content by a factor of 10,000 or more over that of the surface runoff or groundwater supplying uranium to the basin (Schmidt-Collerus, 1979).

Correlation with indoor-radon levels

Safford Basin. A residential indoor-radon testing program was performed by the Arizona Radiation Regulatory Agency from 1987 to 1989. The U.S. Environmental Protection Agency has set a guideline indoor radon limit of 4 picocuries per liter (pCi/l), above which mitigation is recommended. Charcoal canister results from 88 homes in the Safford area show a mean indoor radon level of 1.17 pCi/l, slightly above the average of about 1 pCi/l for all of Arizona. Fifty two homes (59%) registered below 1.0 pCi/l; only four homes (4.5%) had radon levels higher than 4.0 pCi/l, compared with 5.4% of homes statewide. The highest reading in the Safford area was 7.5 pCi/l.

Readings from homes in Bowie and San Simon were higher than the average home in the Safford area. The two canisters from Bowie recorded levels of 3.00 and 2.00 pCi/l, and the two from San Simon contained 3.40 and 3.30 pCi/l. Although radon levels were known and available from only four homes (average 2.93 pCi/l) in the Bowie-San Simon area, this average is more than twice that of the Safford area and may be statistically significant. Adding these results to those of the Safford area increases the average for the entire valley from 1.17 to 1.24 pCi/l.

Studies have shown that water may be a significant source of radon in the home, with up to one third of indoor radon coming from water usage, particularly showers (U.S. Department of Energy, 1993). A survey of four water wells in the Safford area (Duncan and others, 1993) found levels of 279 to 1020 pCi/l radon, compared to a mean of 1148 pCi/l for 32 wells sampled statewide. Thus, the contribution to indoor radon from water in the Safford area may be less significant than for other areas of the state. The U.S. Environmental Protection Agency has recently proposed a limit of 300 pCi/l for radon in water.

Duncan Basin. Charcoal-canister results from 26 homes in the Duncan area show an average indoor radon level of 1.43 pCi/l, slightly higher than that of the Safford area. However, none of the homes tested higher than 4 pCi/l (the highest level was 3.1 pCi/l) and 37% were below 1.0 pCi/l.

CONCLUSION

The Safford and Duncan Basins contain several occurrences of anomalous uranium levels, and the surficial sediments of the basins contain higher-than-average levels of uranium compared to levels determined by a statewide survey (Duncan and Spencer, 1993). Anomalous uranium is generally restricted to limy, diatomaceous, and cherty sediments, particularly in the 111 Ranch area. High background levels of uranium are also found in silicic volcanic rocks of the Whitlock Mountains near the 111 Ranch. Anomalies found in this study were generaly in unpopulated areas.

Homes tested for indoor radon in the Safford and Duncan basins have levels near the average for all homes in the state, and water wells near Safford on average have less radon than the state mean. However, considering the widespread distribution of lacustrine sediments in the basins, exposed and in the subsurface, the basin fill is a potentially significant source of indoor radon.

The possibility exists that small or low-level uranium anomalies are present that were not found during this survey. The distribution of uranium in the subsurface basin fill has not been determined. Many other late Tertiary basins in Arizona contain lacustrine sediments similar to those of the Safford and Duncan basins. Further study of these other basins may help characterize the potential radon hazard from Tertiary basin fill sediments.

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