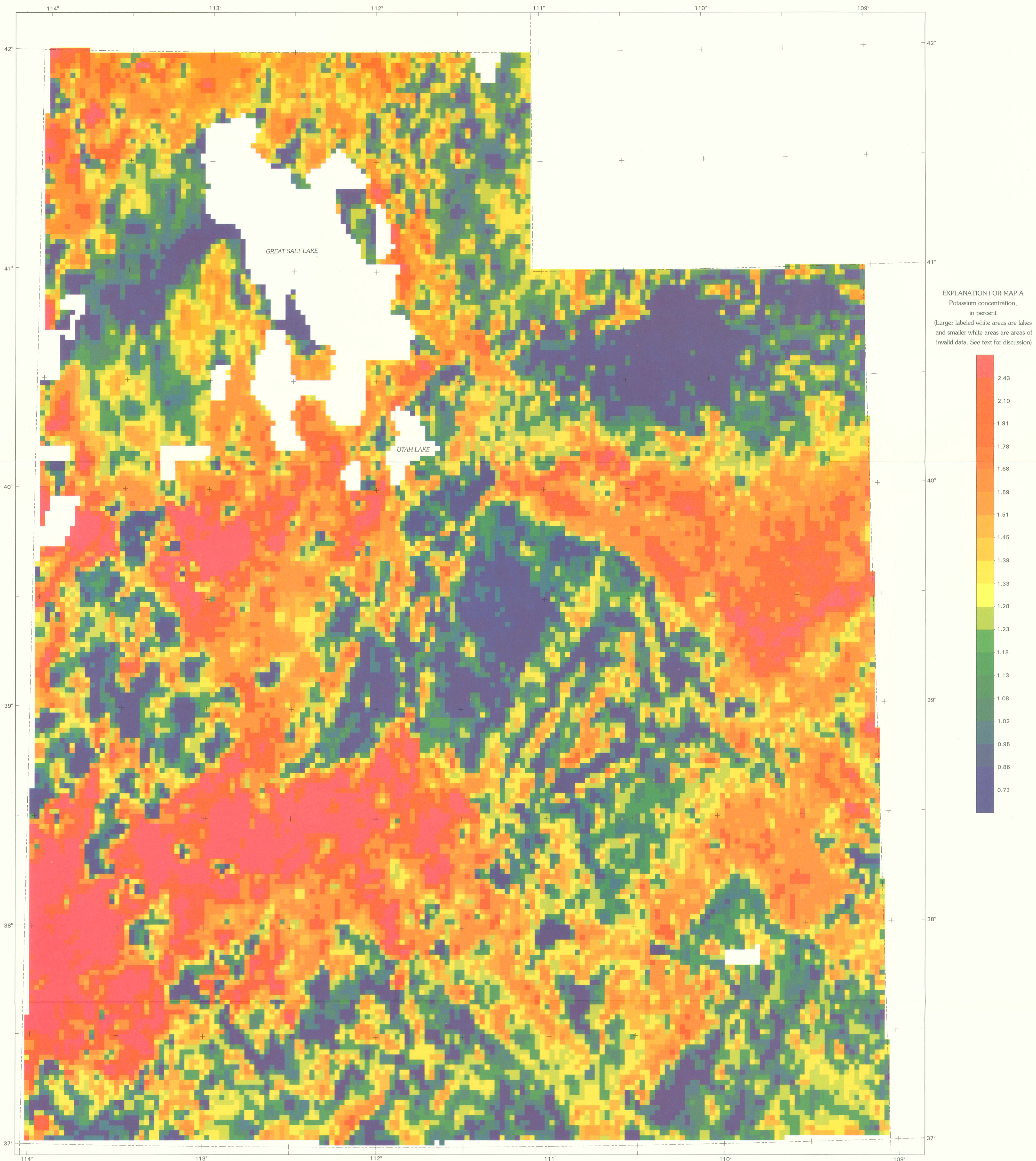
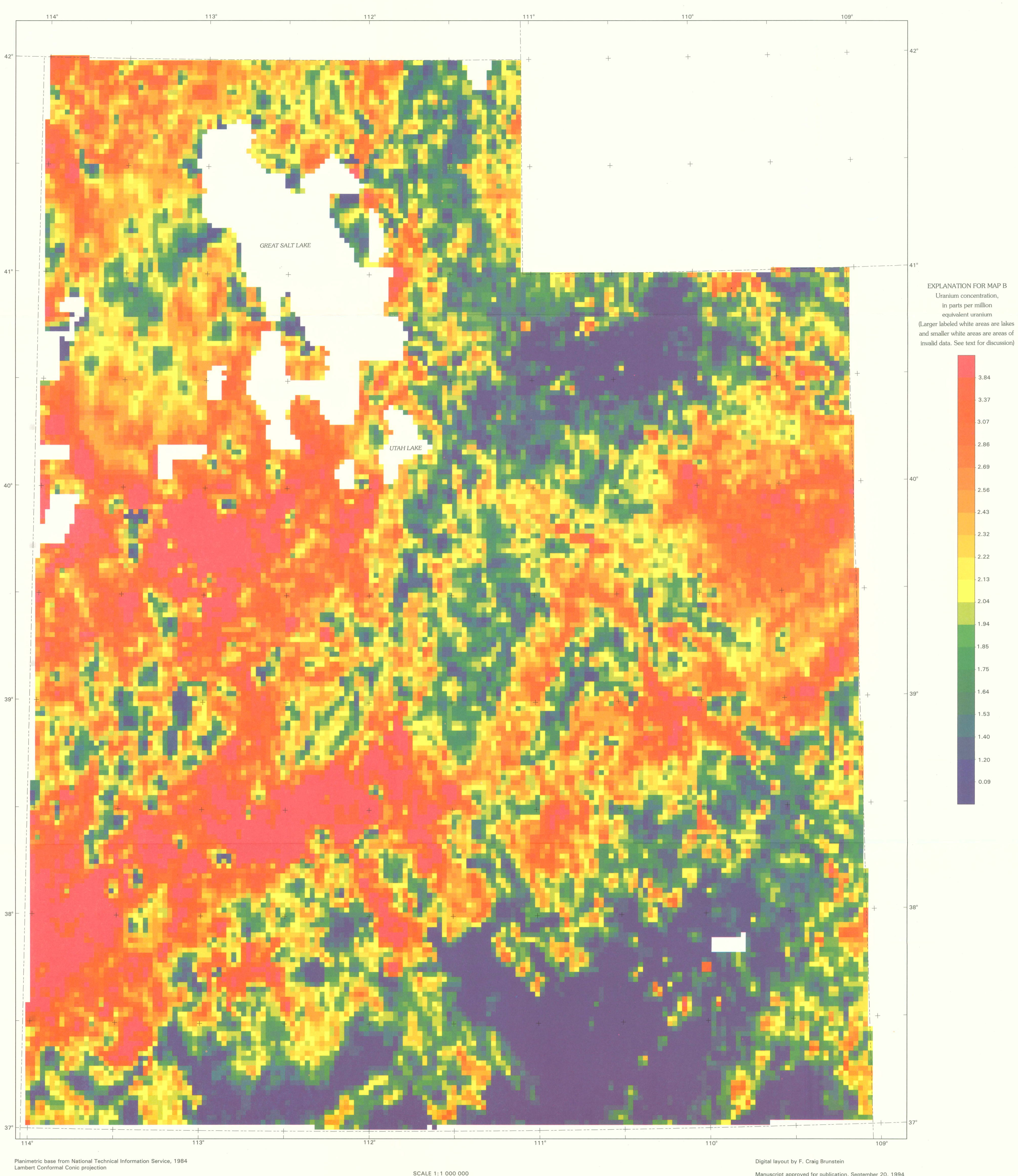


MAP A. SURFACE CONCENTRATIONS OF POTASSIUM



Planimetric base from National Technical Information Service, 1984
Lambert Conformal Conic projection

Digital layout by F. Craig Brunstein

Manuscript approved for publication, September 20, 1994

SCALE 1:1 000 000
25 0 25 50 75 100 MILES
25 0 25 50 75 100 KILOMETERS

MAP B. SURFACE CONCENTRATIONS OF URANIUM

DISCUSSION

INTRODUCTION

Maps of the surficial concentrations of the radioactive elements potassium, uranium, and thorium were prepared for the State of Utah. Data for these maps are from Duval and others (1989, 1990), who compiled a data base of these elements for the conterminous United States from original gamma-ray data obtained from the Department of Energy (DOE) as part of the National Uranium Resource Evaluation (NURE) program.

POTASSIUM, URANIUM, AND THORIUM IN ROCKS

Discussions of the geochemistry of the three radioelements can be found in Hansen (1980), Adams and Gasparini (1970), and Faul (1954). The principal potassium-bearing minerals of igneous rocks are the potassium feldspars, orthoclase and microcline; biotite; and muscovite. Hornblende and plagioclase may contain as much as 1 percent potassium (Adams and Lowder, 1964). The potassium content of igneous rocks usually increases with silica content. Dunite and serpentine are virtually free of potassium and the other alkali elements, and, in general, the mica- and feldspar-free igneous rocks, such as gabbro and peridotite, have very low concentrations of potassium. Granite has the highest content of potassium, ranging from 2.0 to 6.0 percent (Hansen, 1980). The variation in potassium content of basalt is quite high, ranging from about 0.2 percent to more than 2 percent (Hansen, 1980). The potassium content of detrital sedimentary rocks depends upon the relative amounts of feldspar, mica, and clay minerals that form the aggregate sediments. The average potassium content of shale and other argillaceous sediments is about 3 percent, of sandstone about 1 percent, and of limestone a few tenths of a percent (Faul, 1954).

Uranium and thorium contents of igneous rocks also increase with silica content. These elements are concentrated in the common accessory minerals such as zircon, sphene, allanite, monazite, thorite, and apatite. For basaltic rocks, the average content of uranium is 1.0 parts per million (ppm) and of thorium, 4.0 ppm; for granitic rocks, the averages are 3.0 ppm and 12.0 ppm, respectively (Hansen, 1980). The average uranium and thorium contents of chemical sedimentary rocks (including carbonate rocks) are 3.6 ppm and 14.9 ppm, respectively, and for detrital sedimentary rocks, the averages are 4.8 ppm and 12.4 ppm, respectively (Killeen, 1979).

The radioelement content of metamorphic rocks reflects the potassium, uranium, and thorium contents of the original sedimentary or igneous rock, unless radioelements were removed or added during metamorphism.

When potassium minerals weather, the liberated potassium is either used in the formation of potassium soil minerals, such as illite; adsorbed onto other clays; utilized in the metabolism of plants and animals; or is carried away in the ground-water solution. In reducing environments, uranium and thorium are both insoluble ions and tend to remain together in geologic processes occurring under reducing conditions. In oxidizing environments, however, thorium remains insoluble, whereas uranium becomes soluble (Adams and Gasparini, 1970) and is dissolved in surface and ground waters to be redeposited if it encounters reducing material, such as organic matter, or is carried away in the ground-water solution. Zircon and monazite are highly resistant to chemical decomposition and accumulate in placers and the heavy-mineral fraction of clastic sediments.

GAMMA-RAY SURVEYS AND DATA PROCESSING

Aerial gamma-ray surveys measure the gamma-rays produced by the radioactive decay of the naturally occurring elements potassium (^{40}K), uranium (^{238}U), and thorium (^{232}Th) in the top few inches (centimeters) of rock or soil (Duval and others, 1971). If the gamma-ray measuring system is properly calibrated (for example, see Grasty and Darnley, 1971), the gamma-ray data can be expressed in terms of the estimated concentrations of the radioactive elements. Potassium concentrations are usually expressed in units of percent (percent K); thorium concentrations are expressed in parts per million equivalent thorium (ppm eTh); and uranium concentrations are expressed as parts per million equivalent uranium (ppm eU). The term "equivalent" is used because the technique measures gamma-rays from the decay series of thallium (^{208}Tl), which is a decay product of thorium (^{232}Th), and bismuth (^{214}Bi), which is a decay product of uranium (^{238}U). Radioactive disequilibria in the decay series of uranium and thorium may make the equivalent concentrations differ from the actual concentrations of these elements present in the rock or soil (Adams and Gasparini, 1970), although the geochemical immobility of thorium usually inhibits disequilibrium.

From 1975 through 1983, aerial gamma-ray surveys of most of the conterminous United States were conducted as part of the NURE program (see index map). The NURE aerial gamma-ray data were collected by several private contractors who used high-sensitivity measuring systems. These systems used gamma-ray spectrometers that contained 2,000 to 3,300 in.^{3}(33-54 dm^{3}) of sodium iodide detector crystals. All of the systems also included electronic navigation equipment, radar altimeters, magnetometers, and upward-looking gamma-ray detectors. The purpose of the upward-looking detectors was to measure the amount of radiation from bismuth (^{214}Bi) in the atmosphere, which results from the escape of radon (^{222}Rn) into the atmosphere from the ground, and to use that information to correct the estimated ground concentrations of uranium (^{238}U). The reader is directed to Adams and Gasparini (1970) for a complete discussion of the decay series of uranium. The contractors corrected the data for background radiation from aircraft contamination and cosmic rays, Compton scattering effects, altitude variations, and airborne bismuth (^{214}Bi) radiation. The gamma-ray systems were calibrated using the DOE calibration pads at Grand Junction, Colo. (Ward, 1978), and the DOE dynamic test strip at Lake Mead, Ariz. (Geodata International, Inc., 1977). The gamma-ray surveys were flown at a nominal altitude of 400 ft (122 m) above the ground. Flightline spacing for all of the data for Utah was 3 mi (4.8 km), except for the Tooele and Brigham City quadrangles, where a combination of 3- and 6-mi (4.8 and 9.6 km) spacing was used.

Duval and others (1989, 1990) applied two additional corrections to the data. The initial correction was to individual flightlines within a given quadrangle. The data were converted to a grey-tone image and displayed on a television monitor. The image was examined for linear features along flight paths, which would indicate a significant difference with the flightlines adjacent to the linear feature. The data for the flightline identified as needing correction were multiplied by an appropriate constant so that the linear feature could no longer be seen in the grey-tone image. The second correction was applied to an entire quadrangle after individual flightline adjustments within that quadrangle were completed. The data for several adjacent quadrangles were displayed as grey-tone images and examined for inconsistencies in data values occurring at boundaries between quadrangles. The data for a quadrangle identified as needing correction were multiplied by an appropriate constant so that differences at the quadrangle boundaries were no longer visible in the grey-tone image.

RADIOELEMENT MAPS

In the following general discussion, all averages of radioelement concentrations were estimated by visual inspection of the maps. The large white areas in the northwestern part of the State coincide with the Great Salt Lake and Utah Lake where no data were collected, because three or more feet of water effectively block the gamma-rays. The smaller white areas labeled "No data" correspond to areas where the data were determined to be invalid due to survey altitudes greater than 600 feet (182.9 m) where the gamma-ray flux is completely attenuated by the atmosphere. The color intervals for the three individual radioelement maps discussed below were chosen so that each color interval contains 5 percent of the total number of data points. The reader is referred to the geologic map of Utah (Hintze, 1980) for information on and the location of geologic units discussed below.

Potassium Map (A)

In the northeastern part of Utah, the rocks of the Uinta Mountain Group are characterized by very low potassium concentrations, averaging about 0.9 percent. A small area of glacial deposits in the south-central part of the Uinta mountains has similar concentrations. The rocks of the Uinta Basin are characterized by moderate to high concentrations that range from about 1.2 to 2.4 percent. The Uinta Formation, in the northern part of the basin, coincides with a west-trending linear band of potassium concentrations averaging about 1.5 percent. The Green River Formation, in the southern part of the basin, coincides with a rough triangularly shaped area of concentrations ranging from about 1.6 to 2.4 percent, with the highest concentrations found along its southeastern edge. Southwest of the Green River Formation, the area of the San Rafael Swell is outlined by a narrow oval-shaped ring of low (<1.0 percent) potassium values.

In the southeastern part of the State, the shale and sandstone of the Cutler Group in the area of the Monument Uplift can be discerned by their low (about 0.7 to 1.4 percent) potassium levels. The western and northern edges of the uplift are more distinct due to the contrast with the rocks of the Glen Canyon Group, which locally have potassium concentrations of about 1.6 to 2.1 percent in those areas.

The largest area of high potassium concentrations (>2.1 percent) is found in the southwestern part of Utah and is associated with Tertiary volcanic rocks of the Marysvale volcanic field. The northern edge of the volcanic field is well defined, with concentrations of about 2.1 percent to > 2.4 percent. The southern edge of the field is not as well defined, because here the volcanic rocks have potassium levels only slightly higher than the sandstone and shale to the south. Adjoining the western edge of the Marysvale volcanic field is a second area of high (2.4 percent) potassium levels that is associated with volcanic centers in the Mineral Mountains. In the southwestern corner of the State is a large area with potassium levels of >2.1 percent that is roughly coincident with the easternmost extent of a large Tertiary volcanic field located in adjacent southeastern Nevada. Another area characterized by high (>2.1 percent) potassium levels is found in the vicinity of Keg Mountain and corresponds to Tertiary rhyolite and other volcanic rocks in this area.

In the northwestern part of the State, the Quaternary deposits of the Great Salt Lake Desert are marked by a wide band of low to moderate potassium levels averaging about 1.5 percent which trends in a northeasterly direction. A narrow band of very low concentrations (0.7 percent or less) is found in the center of this band.

Uranium Map (B)

In the northeastern part of the State, the rocks of the Uinta Mountain Group in the western part of the Uinta Mountains have uranium concentrations of <1.2 ppm eU. These low areas appear to correlate with areas of glacial deposits. In the eastern part of the mountains, the Uinta Mountain Group has higher uranium levels (about 2.0 ppm eU), similar to the rocks immediately south of the mountains.

In the eastern part of the Uinta Basin, the Green River and Uinta Formations are characterized by uranium concentrations of >2.6 ppm eU. In the western part of the basin, these same rocks have uranium concentrations that average about 2.0 ppm eU. South of the basin, the Mancos Shale is marked by a diffuse sinuous band of high uranium levels of >2.6 ppm eU. In the central part of the State, the Mancos Shale ranges from about 2.0 to 3.1 ppm eU.

In the southeastern part of the State, sediments of the Glen Canyon Group are well delineated by a roughly v-shaped area of uranium concentrations of <1.4 ppm eU. To the east of these rocks, shale and sandstone of the Cutler Group in the area of the Monument Uplift are characterized by concentrations of <2.0 ppm eU. These two areas have the largest extent of low uranium levels in the State.

In the southwestern part of the State, the Kayenta and Moenave Formations (sandstone) and the Navajo Sandstone are well marked by a crescent-shaped area with uranium concentrations ranging from about 1.0 to 1.9 ppm eU. The largest area of high uranium levels in Utah is found in the southwest and is associated with Tertiary volcanic rocks of the Marysvale volcanic field. In the northern part of the Marysvale area, concentrations are >3.1 ppm eU, but in the southern part the volcanic rocks have uranium levels similar to the shale and sandstone that underlie the volcanics, averaging about 2.0 ppm eU. Adjoining the northwest edge of the Marysvale area is a second area of high (about 3.1 ppm eU) uranium concentrations that is associated with volcanic centers in the Mineral Mountains. In the southwestern corner of Utah is a large area of high (about 3.4 ppm eU) uranium concentrations which represents the easternmost extent of a large Tertiary volcanic field located in southeastern Nevada. Another smaller volcanic center, in the vicinity of Keg Mountain, is characterized by uranium levels of about 3.1 ppm eU and higher. North of Keg Mountain, the Quaternary deposits of the Great Salt Lake Desert are marked by a broad area of moderate (averaging about 2.0 ppm eU) uranium levels that trends in a northeasterly direction.

Thorium Map (C)

The rocks of the Uinta Mountain Group, in the northeastern part of Utah, are distinguished by very low thorium levels of <4.2 ppm eTh. A small area of glacial deposits in the south-central part of the Uinta Mountains has similar thorium concentrations. The rocks of the Uinta Basin are characterized by thorium concentrations that range from about 5.6 to 12.1 ppm eTh. In the northeastern part of the basin, the Uinta Formation can be distinguished from the Green River Formation by its slightly higher thorium content of approximately 9.1 ppm eTh; this difference is less distinct in the western part of the basin. The Mancos Shale, which borders the basin on the south, appears as a sinuous band of moderate concentrations of about 7.4 to 10.2 ppm eTh. Southwest of the Green River Formation, the area of the San Rafael Swell is outlined by a narrow oval-shaped ring of low (<4.2 ppm eTh) thorium values.

In the southeastern part of Utah, the Cutler and the Glen Canyon Groups are characterized by very low thorium levels of <4.2 ppm eTh. Within this large low area, outcrops of the Moenkopi Formation and the Mancos Shale appear as distinct high areas with thorium levels ranging from about 5.6 to 10.2 ppm eTh.

The largest area of high thorium concentrations is found in the southwestern part of Utah and is associated with Tertiary volcanic rocks of the Marysvale volcanic field. The northern edge of the volcanic field is well delineated and has thorium levels of 12.1 ppm eTh or higher. The southern edge of the basalts is not as well defined, because here the volcanic rocks have thorium levels very similar to the sandstone and shale to the south. Adjoining the northwest edge of the Marysvale volcanic field is a second area of high thorium levels (averaging about 14 ppm eTh) that corresponds to volcanic centers in the Mineral Mountains. In the southwestern corner of the State is an area with thorium concentrations of >12.1 ppm eTh that represents the easternmost extent of a large Tertiary volcanic field located in adjacent southeastern Nevada.

In the northwest part of the State, the Quaternary deposits of the Great Salt Lake Desert are marked by a wide band of low to moderate thorium levels, ranging from <3.3 ppm to about 6.6 ppm eTh, which trends in a northeasterly direction. South of the Great Salt Lake Desert is a small volcanic center near Keg Mountain that is characterized by thorium concentrations of >10.2ppm eTh.

Color-Composite Map (D)

Duval (1983) developed a technique that combines measurements of the three radioelements as varying shades of the primary colors (red, green, and blue) to make color-composite maps. Such a map is presented here to show the relative proportions of the three radioelements, with K as shades of green, eU as shades of red, and eTh as shades of blue. Of course, there are an unlimited number of combinations of concentrations of the three radioelements leading to an unlimited number of color permutations; however only the basic combinations are explained on this map. A map of this type provides a qualitative synthesis of the radiometric data, showing the geochemical signature of the surface materials and the distribution of areas of similar and dissimilar geochemical compositions.

In the northeastern part of the State, the Uinta Mountain group is characterized by low concentrations of all three radioelements. The eastern part of the mountains has a much less uniform signature, indicating a more varied mix of low radioelement mixtures. The rocks of the Uinta Basin are characterized by high concentrations of potassium and uranium, especially in the central part of the basin. The southeast edge of the basin is especially well defined by the Mesaverde Group which appears as a thin northwest-trending arcuate band of low radioelement concentrations.

The area around the San Rafael Swell is defined by an area of relative potassium dominance which is surrounded by a thin band of lower radioelement concentrations that is relatively higher in uranium. Immediately to the southeast of the San Rafael Swell is an area of mostly Quaternary sediments that has a distinctive signature indicating high potassium and uranium levels. Directly south of the San Rafael Swell is an area of the Mancos Shale that has a signature indicating relatively high uranium and thorium levels. South of the Mancos Shale, the Glen Canyon Group has a distinctive v-shaped signature that indicates high potassium levels. A similar signature, found at lat 37°05'N, long 112°30'W, marks the Navajo Sandstone. East of the Glen Canyon Group, the rocks of the Monument Uplift area have a signature indicating low levels of uranium and thorium and moderate levels of potassium.

The western part of the State has two areas that are high in all three radioelements. The larger of the two areas is in the southwest part of the State and corresponds to a large area of Tertiary volcanic rocks of the Marysvale volcanic field. The second smaller area, southwest of the Great Salt Lake, corresponds to Tertiary rhyolite and other volcanic rocks in the vicinity of Keg Mountain.

The Quaternary deposits of the Great Salt Lake Desert, in the northwest part of the State, are characterized by a relative uranium dominance, especially in a narrow northeast-trending band in the northern part of the Great Salt Lake Desert.

SUMMARY

The distributions of the three radioactive elements in Utah have similar overall patterns. The rocks of the Uinta Mountains are characterized by low levels of all three elements (<1.0 percent K, <1.3 ppm eU, and <4.2 ppm eTh). To the south of the Uinta mountains, the rocks of the Uinta Basin have moderate levels of thorium (about 5.6 to 12.1 ppm eTh) and moderate to high levels of potassium and uranium (about 1.2 to 2.4 percent K, 2.0 to 2.6 ppm eU). The rocks in the area of the Monument Uplift in the southeastern corner of the State have low levels of uranium (<2.0 ppm eU) and thorium (<4.2 ppm eTh) and moderate levels of potassium (about 0.9 to 1.5 percent). The large areas of volcanic rocks in the southwestern part of the State have relatively high levels of all three elements (>2.1 percent K,>2.0 ppm eU, and >12.1 ppm eTh). In the northwest, the Quaternary deposits of the Great Salt Lake Desert are characterized by moderate levels of uranium (averaging about 2.0 ppm eU) and low to moderate levels of potassium (about 1.5 percent) and thorium (<3.3 ppm to about 6.6 ppm eTh).

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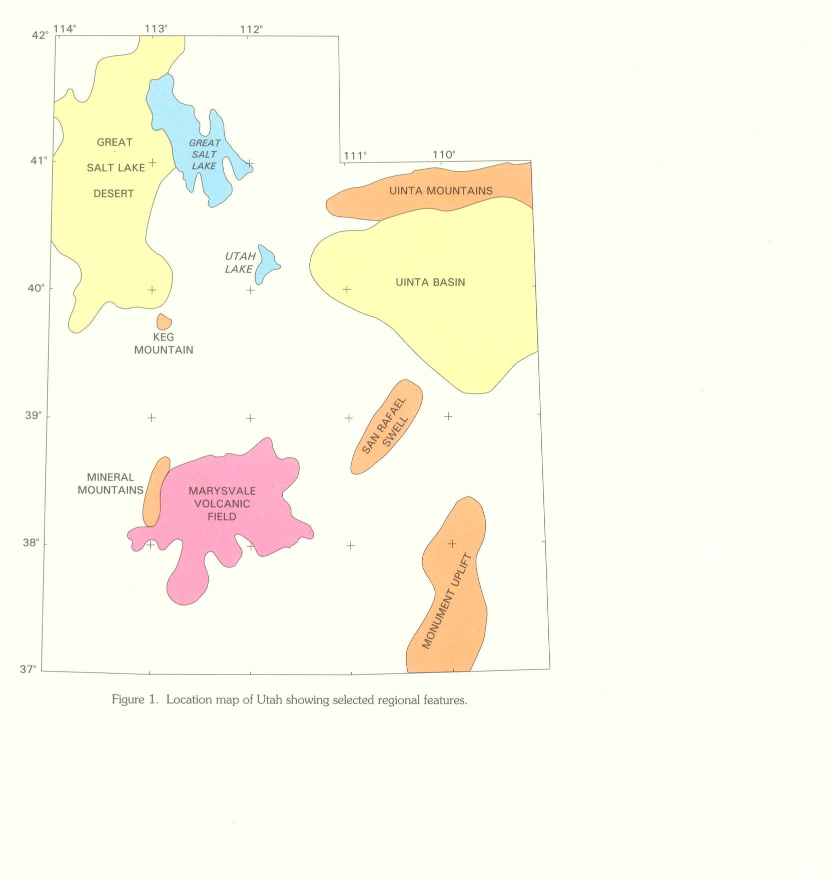
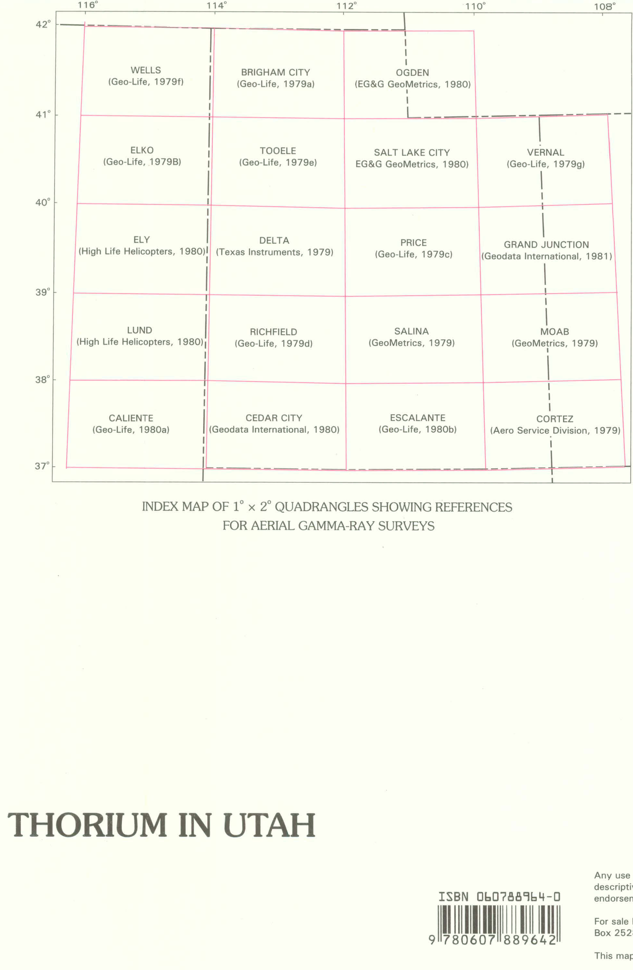


Figure 1. Location map of Utah showing selected regional features.



INDEX MAP OF 1° × 2° QUADRANGLES SHOWING REFERENCES FOR AERIAL GAMMA-RAY SURVEYS

AERIAL GAMMA-RAY MAPS OF REGIONAL SURFACE CONCENTRATIONS OF POTASSIUM, URANIUM, AND THORIUM IN UTAH

By
Kevin R. Bond and Joseph S. Duval
1998

ISBN 0-607-88964-0
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