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RADON STUDIES IN UTAH AND THE STATE INDOOR RADON GRANT PROGRAM

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&
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INTRODUCTION

Radon is an odorless, tasteless, colorless radioactive gas which forms primarily by decay of uranium (^{238}U). One radon isotope, ^{222}Rn, is the most significant contributor to the indoor radon problem and may accumulate indoors in concentrations sufficient to pose a significant health hazard. The U.S. Environmental Protection Agency (EPA) estimates that from 8,000 to 40,000 Americans will die each year from lung cancer caused by long-term inhalation of radon gas (Schmidt and others, 1990; figure 1). The EPA (1986) has established 4 pCi/l as the indoor radon concentration above which mitigation is recommended.

Concentrations of indoor radon are a function of a number of variables, including presence of a significant radon source, weather, building construction, and ventilation. The source of most radon is uranium in the geologic materials surrounding a building's foundation. Radon migration from the ground into buildings is affected by geologic factors such as soil or rock permeability. The Utah Geological Survey (UGS), in cooperation with the Utah Division of Radiation Control (UDRC), Department of Environmental Quality, is investigating the relationship between geology and the indoor radon hazard by participating in a statewide radon study under grants from the EPA.

EPA PROGRAM OBJECTIVES AND UTAH ACTIVITIES

In 1988, in response to the growing national concern over the threat of radon gas, Congress enacted Title III, Indoor Radon Abatement Act (IRAA), as an amendment to the Toxic Substances Control Act. The IRAA has the overall goal of reducing public health risks from radon gas by rendering air within buildings in the United States free of radon. Section 306 of the IRAA, the State Indoor Radon Grant (SIRG) Program, authorizes the EPA to provide grants to states to support the development and implementation of State radon assessment and mitigation programs (EPA, 1989).

The goals of the SIRG Program are to achieve widespread participation by states in radon programs, establish basic radon response capabilities in states that have not yet developed radon programs, stimulate innovation and expansion in states with established radon programs, foster radon program development within the states, and strengthen federal/state partnerships by helping states develop programs for communicating and reducing the radon risk beyond the life of the SIRG Program (EPA, 1989). All of these goals are considered equally important by the EPA for success of the program.

The SIRG Program is to be conducted over a period of 3 years. During the first grant year in Utah (1990), two principal activities were conducted. The first activity, coordinated by the UDRC, involved soliciting volunteers from the Sandy and Provo areas to monitor their homes for indoor radon over a one-year period. A survey to assess indoor radon levels statewide, conducted by the UDRC in the fall of 1987, indicated that there were indoor radon levels in these cities higher than the statewide average (Sprinkel and Solomon, 1990). In the second activity, the UGS and University of Utah Research Institute (UURI) conducted a detailed geologic study of the factors that influence indoor radon concentrations by reinterpretation of National Uranium Resource Evaluation (NURE) aerial radiometric data, collection of field radiometric data, and physical characterization of soils (Solomon and others, 1991). The first grant year provided valuable information required to examine the relationships between geology and elevated indoor radon levels, and developed geologic techniques for assessing radon hazard potential.

Second grant year activities, now in progress, include detailed indoor radon surveys and radon-hazard-potential investigations in the Ogden Valley and St. George areas, as well as an update of the statewide radon-hazard map. The Ogden Valley and St. George areas were identified by the UDRC as having indoor radon concentrations higher than the statewide average (Sprinkel and Solomon, 1990). In these areas, the radon-hazard-potential investigations will consist of collection of field radiometric data and physical characterization of soils. The statewide radon-hazard map will be updated by compiling outcrop data of uranium concentrations from the NURE program and other uranium resource studies, and will show which geologic units in the state have the highest potential as uranium source areas.

Planned for the third grant year, if funded, are a detailed indoor radon survey and radon-hazard-potential investigation of the Sevier Valley area, and a radon-hazard-potential investigation of part of the Weber River flood plain west of the Wasatch Range. The Sevier Valley area, from Richfield to Monroe, was also identified as having indoor radon levels higher than the statewide average (Sprinkel and Solomon, 1990). The Weber River flood plain, a populous and rapidly growing suburban area near Ogden, was selected due to a cluster of high indoor radon measurements, ranging from 10.9 pCi/l in South Weber and 15.0 pCi/l in Roy to 68.2 pCi/l in Uintah (the highest value recorded in Utah) (Sprinkel and Solomon, 1990). The radon-hazard-potential investigations will be conducted in the same manner as the second grant year investigations.

GEOLOGIC INVESTIGATIONS OF RADON-HAZARD POTENTIAL DURING THE FIRST GRANT YEAR

In 1990, the UGS investigated the radon-hazard potential of the east Sandy and east Provo areas. The hazard potential was estimated by determining three geologic factors: (1) uranium content of soils, (2) concentration of radon in soil gas, and (3) depth to ground water (Solomon and others, 1991). Numerical scores were applied to each rating factor, and composite ratings were calculated to estimate the hazard potential for each major Quaternary (unconsolidated, basin-fill) geologic unit (Solomon and others, 1991). The objectives were: (1) to define geologic factors which influence radon distribution, (2) to establish rapid and inexpensive field techniques to delineate radon-hazard areas, and (3) to achieve more efficient testing and mitigation in existing construction, and hazard prevention in new construction by identifying hazard areas (Solomon and others, 1991). Airborne radiometric measurements were interpreted for the east Sandy area and adjacent Wasatch Range and field data were collected in both study areas.

The east Sandy study area is in southeastern Salt Lake County, extending from the mouth of Big Cottonwood Canyon on the north to Draper on the south, and from approximately State Street on the west to the Wasatch Range on the east (figure 2). The average indoor radon level in the east Sandy study area is 3.2 pCi/l, with 17 percent of measurements greater than 4 pCi/l (Solomon and others, 1991).

The Wasatch fault zone separates unconsolidated deposits in Salt Lake Valley from bedrock in the Wasatch Range. The valley is underlain by a complex sequence of unconsolidated Quaternary alluvial, deltaic, lacustrine, and eolian basin-fill deposits (Personius and Scott, 1990). Although a wide variety of bedrock types occur in the Wasatch Range east of Sandy, only some lithologies have the potential to provide source material with elevated uranium levels to the Quaternary deposits in the study area. They are: (1) Oligocene granitic rocks of the Little Cottonwood, Alta, and Clayton Peak stocks (Crittenden, 1976); and (2) Precambrian metamorphic rocks, including the Mineral Fork Formation (Condie, 1967). Quartzite, shale, and slate of the Precambrian Big Cottonwood Formation (James, 1979) has low uranium levels. Ground water occurs at depths greater than 50 feet (15 m) in the eastern part of the study area, but is less than 10 feet (3 m) deep to the west (Anderson and others, 1986b).

The east Provo study area is in Utah County, extending from Orem on the north to Provo on the south, and from approximately Interstate 15 on the west to the Wasatch Range on the east (figure 2). The average indoor radon level within the east Provo study area is 2.6 pCi/l, with 12 percent of the measurements greater than 4 pCi/l (Sprinkel and Solomon, 1990). Although the indoor radon level in this study area is lower than the statewide average, Sprinkel and Solomon (1990) demonstrated that the east Provo area does contain anomalous areas with indoor radon levels in excess of the statewide average.

Like the east Sandy study area, the Wasatch fault zone separates unconsolidated deposits in Utah Valley from the bedrock in the Wasatch Range. The study area is underlain by Quaternary sediments similar in origin to those of east Sandy (Machette, 1989). Bedrock with the potential to provide source material with elevated uranium levels to the unconsolidated deposits in the valley includes: (1) the Pennsylvanian to Mississippian Manning Canyon Shale, a dark shale that underlies much of the range front, and (2) diamictite of the Precambrian Mineral Fork Formation, which underlies the drainage basins of Rock and Slate Canyons (Baker, 1964, 1972, 1973). Limestone and quartzite of the Pennsylvanian and Permian Oquirrh Formation transported from the interior of the Wasatch Range by drainage through Provo Canyon has low uranium levels. Ground water occurs at depths greater than 50 feet (15 m) to the east, but is less than 10 feet (3 m) deep to the west (Anderson and others, 1986a).

The airborne radiometric survey completed under the NURE program delineates large areas of high surface uranium concentrations, which also serves as an indicator of areas that may have a potential indoor radon hazard (Duval and Otton, 1990). A contour map of equivalent uranium (eU) was generated by UURI from data compiled from the NURE radiometric survey for a part of the Salt Lake City 1:250,000 quadrangle, which covers the east Sandy study area (Solomon and others, 1991; figure 3). The average uranium concentration for the entire quadrangle is 1.65 parts per million (ppm) (EG&G Geometrics, 1979). The map shows three anomalous areas of uranium concentrations greater than 3.2 ppm. Area A is in the east Sandy study area and is associated with high indoor radon levels in the Sandy area. Anomalies with high uranium values (B and C) in the Wasatch Range east of anomaly A are located over the granitic stocks of Little Cottonwood, Alta, and Clayton Peak.

Field data were collected from both the east Sandy and east Provo areas. Four types of field data were collected during the study: (1) gamma-ray spectrometry, (2) levels of radon in soil gas, (3) soil moisture and density, and (4) soil texture (Solomon and others, 1991). Gamma-ray spectrometry determines the concentration of radioactive parent material in the soil available for decay into radon gas. The level of radon in soil gas measures the amount of radon available for migration into buildings. Soil moisture, density, and texture all affect the mobility of radon gas.

Gamma-ray spectrometry showed that average uranium levels were significantly higher in the east Sandy area (5.6 ppm) than the east Provo area (2.6 ppm) (Solomon and others, 1991). In east Sandy, the highest average uranium levels (7.1 ppm) were found in upper Pleistocene sand and gravel of the Provo (regressive) shorelines of the Bonneville lake cycle (Solomon and others, 1991). High levels (6.9 ppm) were also found in the upper Pleistocene gravelly alluvium of terraces graded to the Provo shoreline near Little Cottonwood Canyon. In east Provo, the highest average uranium levels (3.1 ppm) were found in upper Pleistocene lacustrine gravel of the Bonneville (transgressive) shoreline (Solomon and others, 1991).

Measurement of radon in soil gas showed that average levels of radon were also higher in east Sandy (528 pCi/l) than in east Provo (449 pCi/l) (Solomon and others, 1991). In east Sandy, the highest average levels of radon in soil gas (641 pCi/l) were found in the upper Pleistocene terrace deposits noted above (Solomon and others, 1991). In east Provo, the highest levels of radon in soil gas (679 pCi/l) were found in middle Holocene to upper Pleistocene alluvial fans (Solomon and others, 1991).

Once radon gas is formed, it can migrate into buildings through the soil. The rate of migration depends on soil permeability, which is affected by moisture content, density, and soil texture. Soil in east Sandy is generally gravelly sand, and is more permeable than the gravelly loam of the east Provo area (Solomon and others, 1991). Because pore water effectively traps radon and inhibits movement through the soil, low water content above the ground-water table facilitates the movement of radon. This phenonemon is graphically illustrated in east Sandy where Quaternary units high in uranium, but with shallow ground water, have low levels of soil gas (Solomon and others, 1991).

The relative radon-hazard potential of geologic units in the east Sandy and east Provo areas was estimated by three factors: (1) soil uranium concentration, (2) concentration of radon in soil gas, and (3) ground-water level (Solomon and others, 1991). Each geologic unit was assigned a hazard rating using a numerical rating scheme based on the field data. Using this hazard rating, radon-hazard-potential maps for the east Sandy and east Provo areas were constructed (figures 4 and 5). For a discussion of the methodology used consult Solomon and others (1991).

In both study areas, geologic units with the highest hazard rating were upper Pleistocene lacustrine sediments related to the transgressive phase of the Bonneville lake cycle, as well as younger deposits overlying the transgressive units (Solomon and others, 1991). However, the hazard rating is not indicative of actual indoor radon levels because a quantitative relationship does not exist between factors measured in the field and indoor radon. Factors not considered include building construction techniques, lifestyle, and weather, all of which can strongly affect indoor radon levels. Small localized areas of higher or lower indoor radon levels may still occur.

The indoor radon hazard potential of geologic units in the east Sandy and east Provo areas reflects common depositional patterns and physical conditions. Such patterns and conditions, as well as the techniques used to identify them, are applicable to identification of other indoor radon hazard areas along the Wasatch Front.

In east Sandy, drainage from Little Cottonwood Canyon transported material derived from Oligocene granitic rocks with relatively high uranium content to the Little Cottonwood delta at both the Bonneville (transgressive) and Provo (regressive) levels (Solomon and others, 1991; figure 6). Material transported through Big Cottonwood Canyon to the Big Cottonwood delta is relatively deficient in uranium, but is also derived in part from Oligocene granitic rocks and Precambrian metamorphic rocks with higher uranium contents. Below the Provo (regressive) level, sediments are not well drained and a significant part of radon gas at this level migrates with shallow ground water rather than with soil gas.

In east Provo, uranium-enriched sediment was derived from the Mineral Fork Formation and Manning Canyon Shale, transported locally through Rock and Slate Canyons and deposited at the Bonneville (transgressive) level along the range front (Solomon and others, 1991; figure 7). Material derived from the Oquirrh Formation, transported through Provo Canyon and deposited on the Provo River delta, is deficient in uranium. As in east Sandy, the units with the highest potential for an indoor radon hazard are well-drained sediments that allow soil gas migration rather than migration with shallow ground water. Lower uranium levels in east Provo compared to east Sandy reflect the differences in source material.

GEOLOGIC INVESTIGATIONS OF RADON-HAZARD POTENTIAL DURING THE SECOND GRANT YEAR

In 1991, the UGS investigated the radon-hazard potential of the Ogden Valley and St. George basin. Three geologic factors were used to estimate the radon hazard potential of these areas: (1) uranium content of soils, (2) soil permeability, and (3) depth to ground water. Unlike the first grant-year investigations, soil gas concentration has been replaced by soil permeability as a factor in determining the hazard potential, because permeability is a primary factor whereas soil gas concentration is derivative and depends on primary geologic factors. However, because the field work and analysis of data is not complete at this time, no hazard ratings have been assigned and the hazard potential of these areas is not yet determined.

The Ogden Valley study area is in Weber County, about 12 miles (19 km) east of Ogden, and includes the towns of Huntsville, Liberty, and Eden (figure 8). Indoor radon levels in the Ogden Valley area range from 2.1 pCi/l to 17.6 pCi/l (Sprinkel and Solomon, 1990). Only four indoor radon levels from the statewide radon survey were measured in Ogden Valley; two were higher than 4 pCi/l (Sprinkel and Solomon, 1990).

Ogden Valley is a northwest-trending valley east of the Wasatch Range front, and is bounded on the east and west by faults that dip toward the valley (Leggette and Taylor, 1937). The valley is underlain by a thick sequence of sedimentary basin-fill deposits that have accumulated since early Tertiary time (Lofgren, 1955). Bedrock lithologies in the Wasatch Range surrounding Ogden Valley with a potential to provide source material with elevated levels of uranium are: (1) the Tertiary Norwood Tuff, which underlies many of the western and southwestern slopes bordering the valley, and (2) argillite weathered from the Precambrian Inkom, Kelley Canyon, and Maple Canyon Formations and transported to the valley by drainage through the North Fork, Middle Fork, and South Fork of the Ogden River (Crittenden, 1972; Crittenden and Sorensen, 1979). Ground water occurs at depths greater than 50 feet (15 m) around the edges of the valley, but is less than 10 feet (3 m) in much of the valley interior.

Three types of field data were collected in Ogden Valley: (1) gamma-ray spectrometry, (2) levels of radon in soil gas, and (3) soil texture. Gamma-ray spectrometry showed that uranium concentrations were higher in the north and west part of Ogden Valley (figure 9). High uranium levels occurred generally in Quaternary alluvial sediments derived from bedrock with elevated uranium levels (Lowe, in prep.). High soil-gas measurements occurred generally in uranium-rich, permeable, and well-drained alluvial sediments. Preliminary data analysis indicates that the potential for elevated indoor radon levels in the Ogden Valley is highest in the northwestern part of the valley, north and west of Liberty, and is lowest to the southeast, east of Huntsville.

The St. George study area is in Washington County, and includes Santa Clara, Middleton, Washington, Bloomington, and St. George (figure 10). Indoor radon levels ranged from 0.8 pCi/l to 6.2 pCi/l (Sprinkel and Solomon, 1990). Like Ogden Valley, only four indoor radon levels were measured in the statewide survey in the St. George area; one was greater than 4 pCi/l (Sprinkel and Solomon, 1990).

The St. George basin is centered on the confluence of the Virgin and Santa Clara Rivers. Population centers lie in the river valleys, which are underlain by Quaternary alluvium. Bedrock units with the potential to provide source material with elevated levels of uranium are: (1) the Triassic Moenave Formation, which was mined for uranium in the nearby Silver Reef mining district, (2) the Triassic Chinle Formation, a prolific producer of uranium ore in Utah, and (3) the Triassic Moenkopi Formation (Doelling, 1974). These units crop out over a large area in the southern part of the study area and alluvium derived from them has uranium levels of up to 4.7 ppm. Distribution of uranium in alluvium derived from these bedrock sources is governed by Quaternary sedimentation patterns. The Navajo Sandstone of Jurassic age is common to the north part of the study area and is exceptionally deficient in uranium, with levels generally below 1.5 ppm.

Field data collected in the St. George area included 1) gamma-ray spectrometry, 2) levels of radon in soil gas, and 3) soil texture. Airborne radiometric surveys of the area, conducted for the NURE program, indicate that the St. George basin has low average apparent uranium concentrations. However, because the resolution of these surveys is insufficient to detect localized concentrations of uranium, ground-based gamma-ray spectrometry will determine the detailed distribution of uranium in the area. The field data, combined with evaluation of ground-water depth and distribution of surficial geologic units, will be used to evaluate the radon-hazard potential of the St. George basin.

GEOLOGIC INVESTIGATION OF RADON-HAZARD POTENTIAL DURING THE THIRD GRANT YEAR

In 1992, the UGS plans to investigate the radon hazard potential of the Sevier Valley area and Weber River flood plain, using techniques similar to those used in the Ogden Valley and St. George study areas.

The Sevier Valley study area is in Sevier County and includes Monroe, Joseph, Richfield, and Sevier. Indoor radon levels in the Sevier Valley area ranged from 0.8 pCi/l to 22.4 pCi/l, with 35 percent of the measurements greater than 4 pCi/l (Sprinkel and Solomon, 1990). Geologic units with the potential to provide source material with elevated levels of uranium to the unconsolidated valley fill may be calc-alkaline volcanic flows and tuff bedrock of the Marysvale volcanic field (Cunningham and others, 1983).

The Weber River flood plain is in Weber County, and includes Uintah, South Weber, and Roy. Indoor radon levels in the Weber River flood plain ranged from 0.8 pCi/l to 68.2 pCi/l (the highest value recorded in Utah), with 35 percent of the measurements greater than 4 pCi/l (Sprinkel and Solomon, 1990). Only four indoor radon levels were measured in the statewide survey in the Weber River flood plain; three were greater than 4 pCi/l (Sprinkel and Solomon, 1990). A geologic unit that may have potential to provide source material with elevated levels of uranium to the Quaternary deposits in the area is the Precambrian Farmington Canyon Complex, which consists of argillite, gneiss, and schist (Davis, 1985; Nelson and Personius, 1990).

CONCLUSION

Radon is an environmental concern throughout the country because of its suspected link to lung cancer. The SIRG Program developed by the EPA has been successful in fostering an indoor radon program in Utah. Because of the complex relationship between geologic and non-geologic factors that control radon levels, successful interagency cooperation between the UGS and the UDRC has played an important role in the indoor radon program. Additional grants by the EPA will strengthen federal/state partnerships and continue to provide valuable information for communicating and reducing the radon risk in the state.

Geology can be successfully used as a predictor of areas with elevated indoor radon levels. Airborne radiometric surveys can be used in conjunction with regional geologic maps to identify regional uranium anomalies. Ground surveys then determine detailed uranium distribution in geologic units and identify other geologic factors such as shallow ground water and soil permeability. This combination of airborne and ground studies enables identification of areas that have a higher potential for elevated indoor radon levels.

Although geologic investigations can show the relative hazard potential of an area, indoor testing is still the only reliable way to determine indoor radon levels in an individual building. Non-geologic factors such as weather, lifestyle, and building construction and design make predicting radon levels from building to building difficult even in areas of high geologic potential for radon. In the past 15 years, the building industry has made structures more energy efficient by restricting ventilation and air flow, which has to some extent increased the indoor radon hazard. Indoor testing can be used in existing structures to monitor indoor radon levels and show which buildings may require mitigation. However, it is still important to determine the indoor radon hazard potential of an area so that in high-hazard areas, mitigation techniques can be incorporated into building design prior to construction.

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Radon Risk Evaluation Chart

pCi/l	Estimated number of lung cancer deaths due to radon exposure (out of 1000)	Comparable exposure levels	Comparable risk
200	440-770	1000 times average outdoor level	More than 60 times non-smoker risk
			4 pack-a-day smoker
100	270-630	100 times average indoor level	20,000 chest x-rays per year
40	120-380		
			2 pack-a-day smoker
20	60-210	100 times average outdoor level	
			1 pack-a-day smoker
10	30-120	10 times average indoor level	
			5 times non-smoker risk
4	13-50		
			200 chest x-rays per year
2	7-30	10 times average outdoor level	
			Non-smoker risk of dying from lung cancer
1	3-13	Average indoor level	
			20 chest x-rays per year
0.2	1-3	Average outdoor level	

Figure 1.

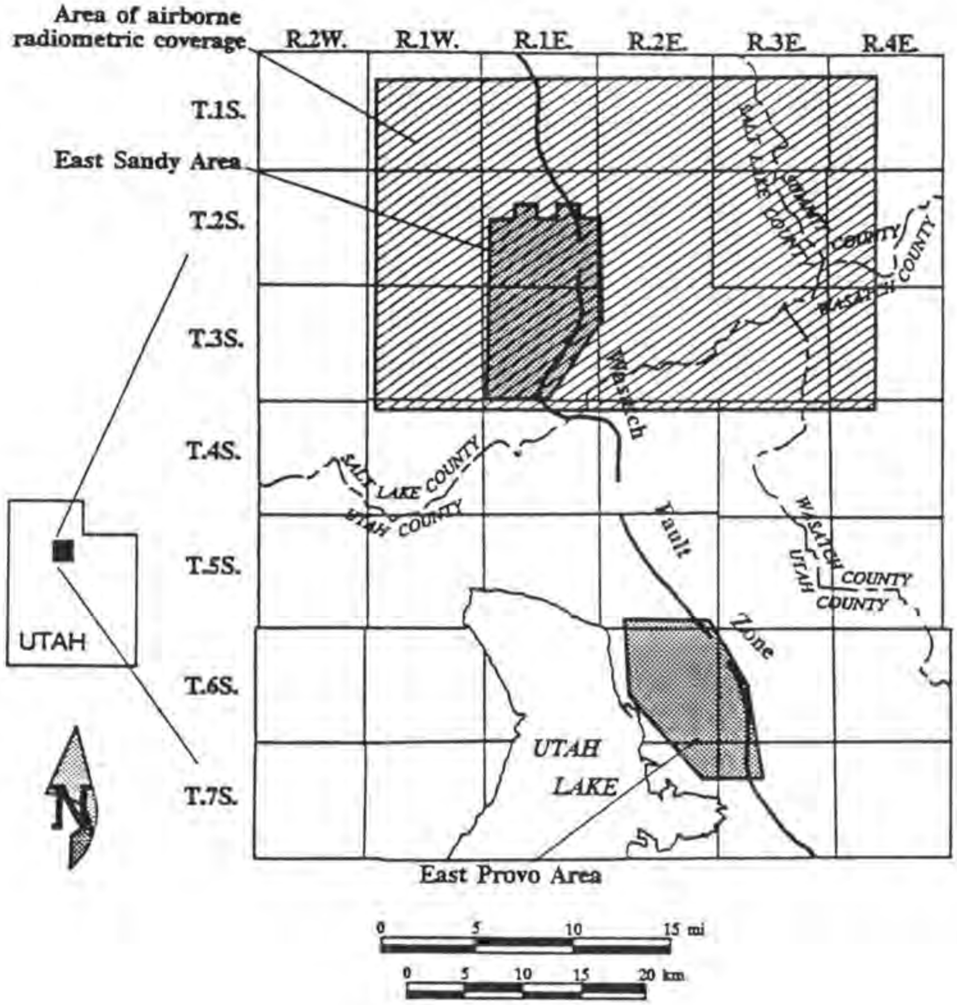
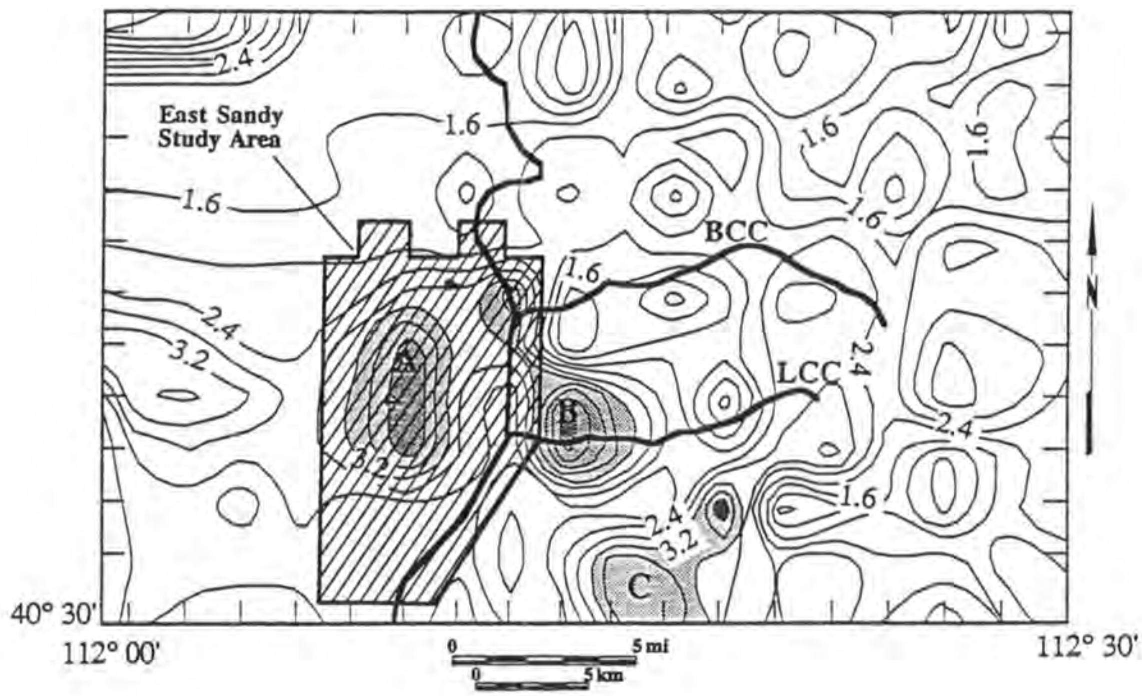

Area of airborne radiometric coverage
East Sandy Area
R.2W.
R.1W.
R.1E.
R.2E.
R.3E.
R.4E.
T.1S.
T.2S.
T.3S.
T.4S.
T.5S.
T.6S.
T.7S.
SALT LAKE COUNTY
UTAH COUNTY
SUMMIT COUNTY
WASATCH COUNTY
Wasatch
Fault
Zone
UTAH LAKE
UTAH
N
East Provo Area
0 5 10 15 mi
0 5 10 15 20 km

Figure 2.



East Sandy
Study Area
BCC
LCC
A
B
C
1.6
2.4
3.2
40° 30'
112° 00'
112° 30'
0
5 mi
0
5 km

Figure 3.

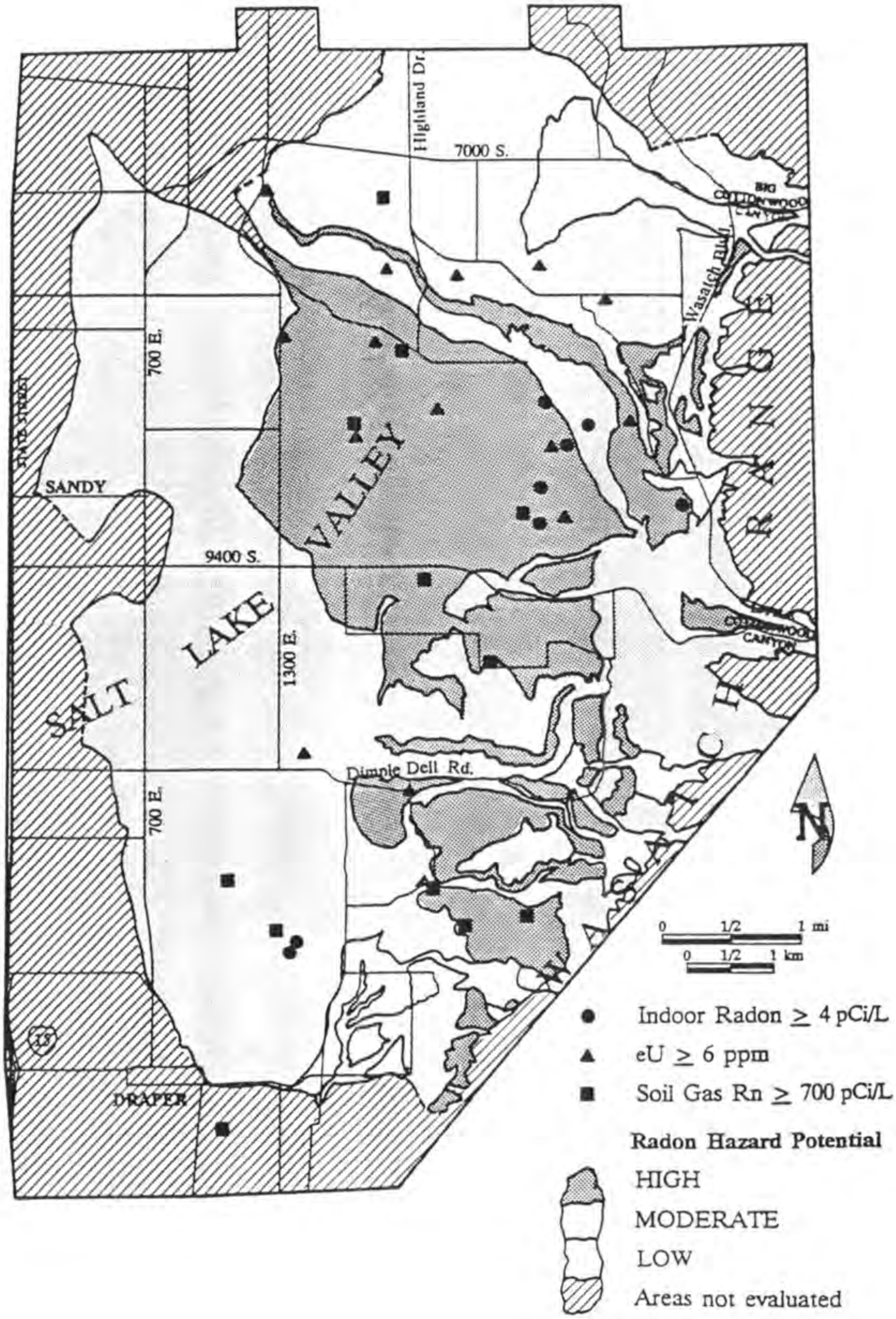

Highland Dr.
7000 S.
Wasatch Blvd.
700 E.
STATE STREET
SANDY
SALT LAKE VALLEY
9400 S.
1300 E.
Dimple Dell Rd.
700 E.
DRAPER
WASATCH RANGE
N
0 1/2 1 mi
0 1/2 1 km
Indoor Radon ≥ 4 pCi/L
eU ≥ 6 ppm
Soil Gas Rn ≥ 700 pCi/L
Radon Hazard Potential
HIGH
MODERATE
LOW
Areas not evaluated

Figure 4.

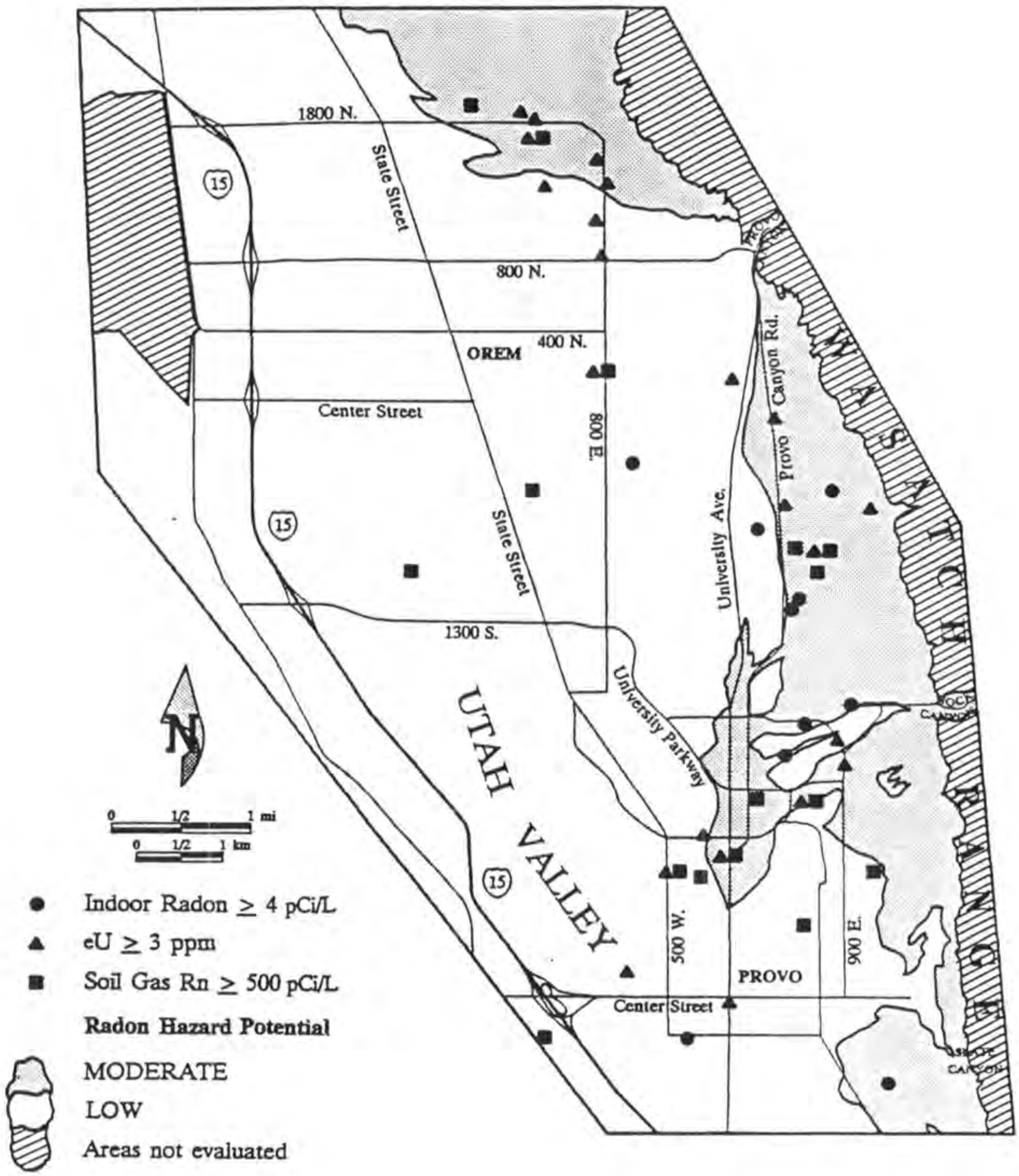

1800 N.
State Street
15
800 N.
400 N.
OREM
Center Street
800 E.
15
State Street
University Ave.
Provo Canyon Rd.
WASATCH RANGE
1300 S.
UTAH VALLEY
University Parkway
N
0 1/2 1 mi
0 1/2 1 km
15
500 W.
900 E.
PROVO
Center Street
Indoor Radon ≥ 4 pCi/L
eU ≥ 3 ppm
Soil Gas Rn ≥ 500 pCi/L
Radon Hazard Potential
MODERATE
LOW
Areas not evaluated

Figure 5

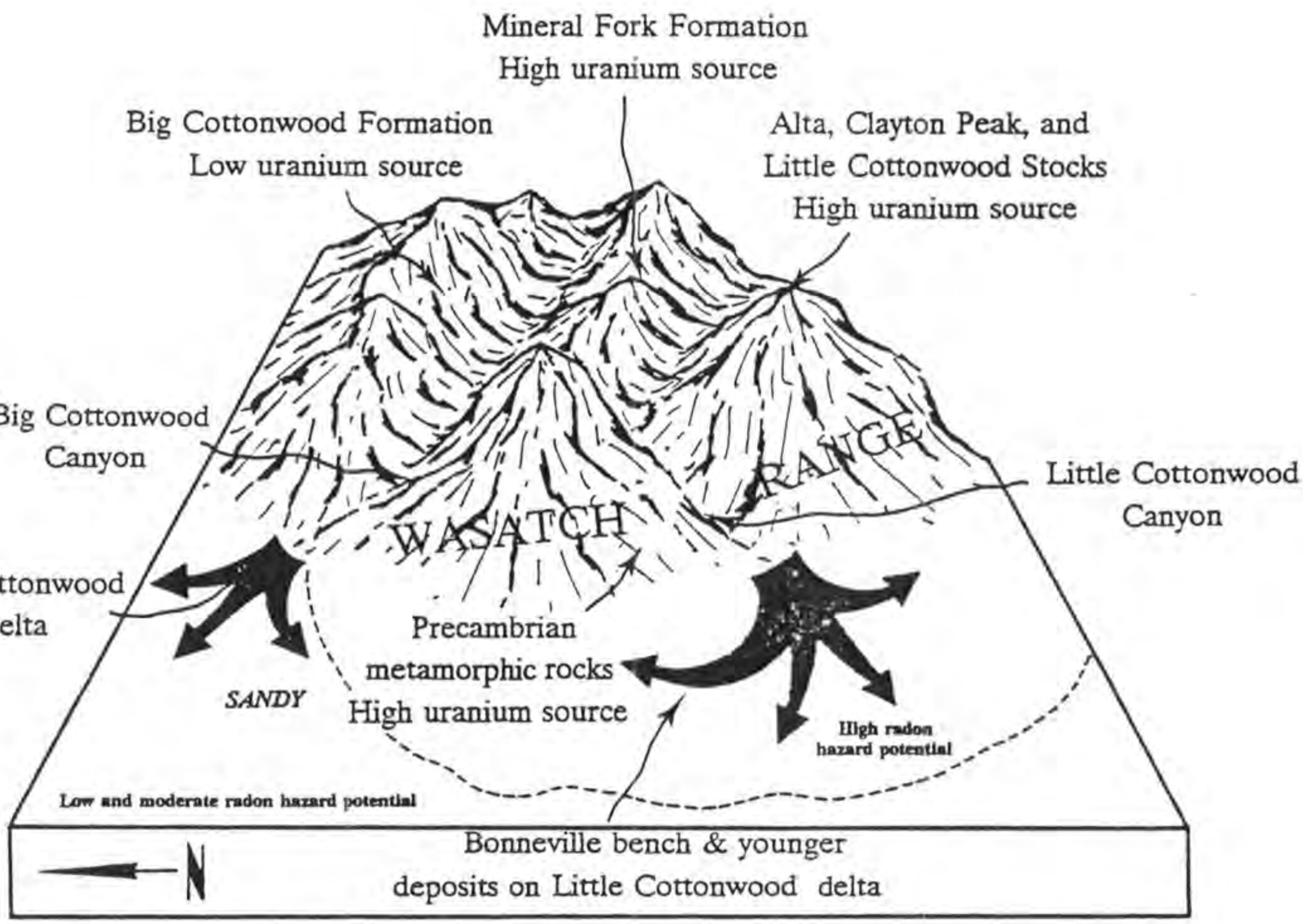
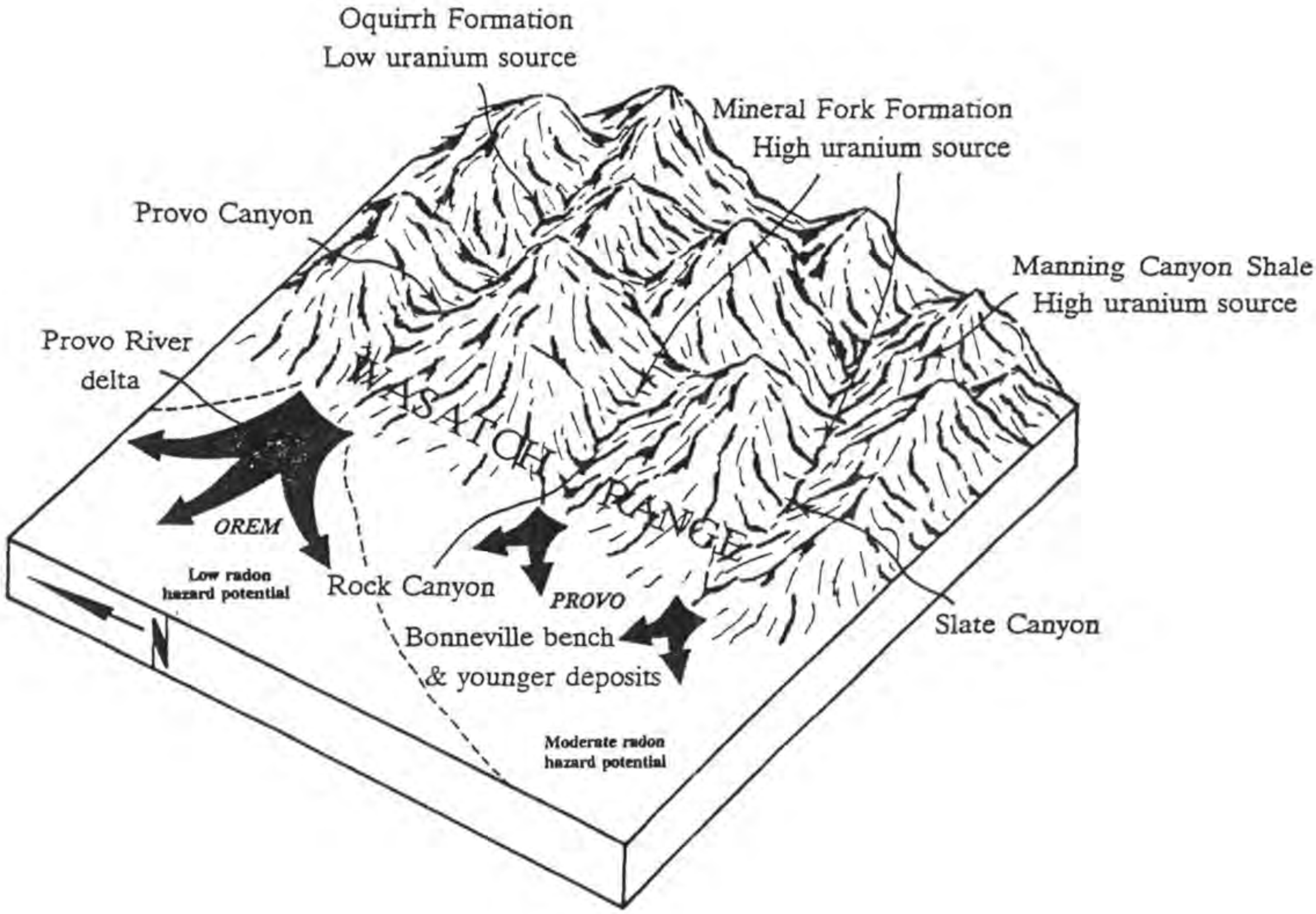

Mineral Fork Formation
High uranium source
Big Cottonwood Formation
Low uranium source
Alta, Clayton Peak, and
Little Cottonwood Stocks
High uranium source
Big Cottonwood
Canyon
RANGE
Little Cottonwood
Canyon
WASATCH
Big Cottonwood
delta
Precambrian
metamorphic rocks
High uranium source
SANDY
High radon
hazard potential
Low and moderate radon hazard potential
Bonneville bench & younger
deposits on Little Cottonwood delta
N

Figure 6.



Oquirrh Formation
Low uranium source
Mineral Fork Formation
High uranium source
Provo Canyon
Manning Canyon Shale
High uranium source
Provo River
delta
WASATCH RANGE
OREM
Low radon
hazard potential
Rock Canyon
PROVO
Bonneville bench
& younger deposits
Slate Canyon
N
Moderate radon
hazard potential

Figure 7.

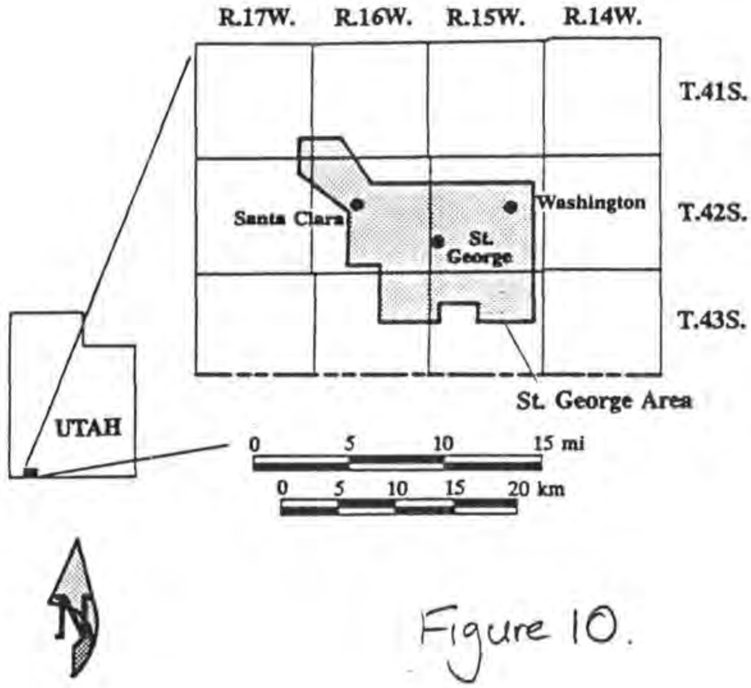


Figure 10.

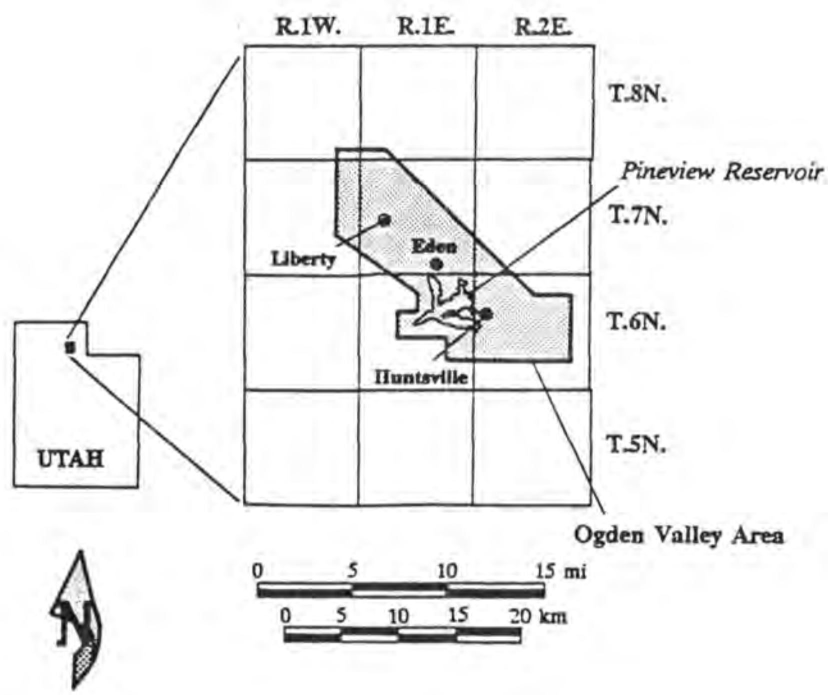
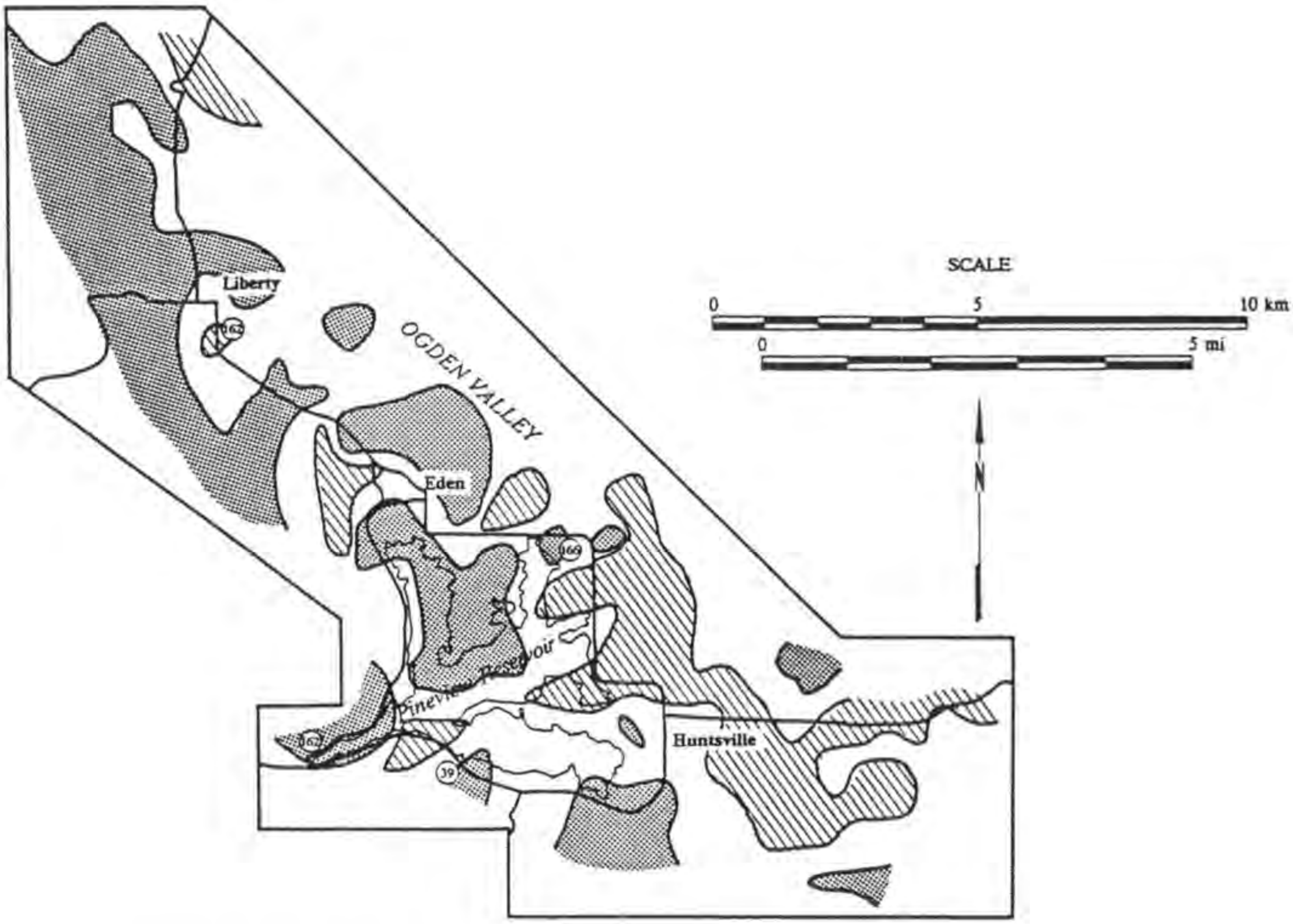


Figure 8.



URANIUM CONCENTRATION

- Greater than 3 ppm
- 2-3 ppm or areas with no available data
- Less than 2 ppm

Figure 9