DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

MISCELLANEOUS FIELD STUDIES
MAP MF-956
POWDER RIVER BASIN, WYO.
SHEET 1 OF 2

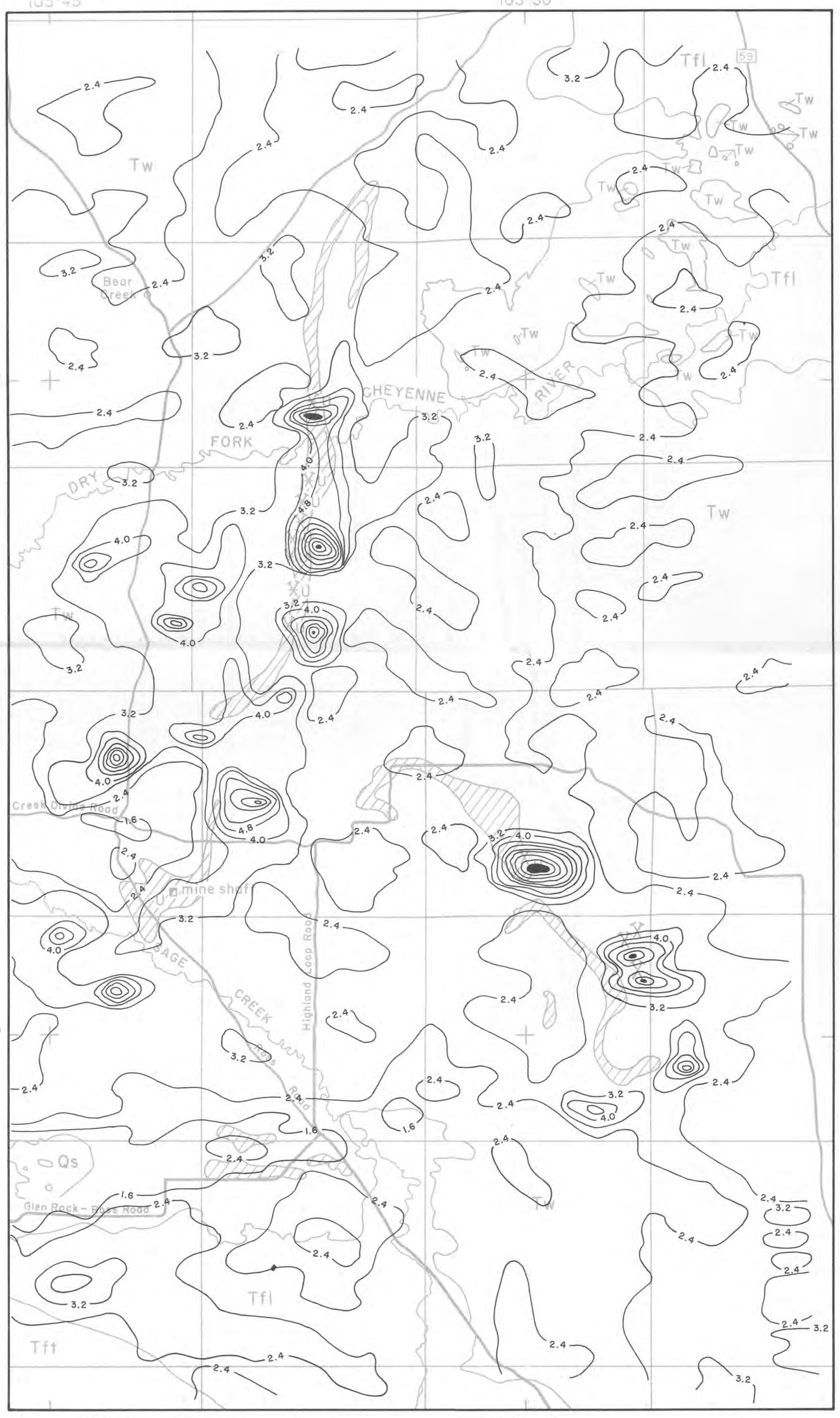

FIGURE 1.--Radiometric map showing fully corrected count-rate data converted to apparent surface concentrations of eU in parts per million. Contour interval 0.8 ppm eU.

Geology from Denson and Horn, 1975

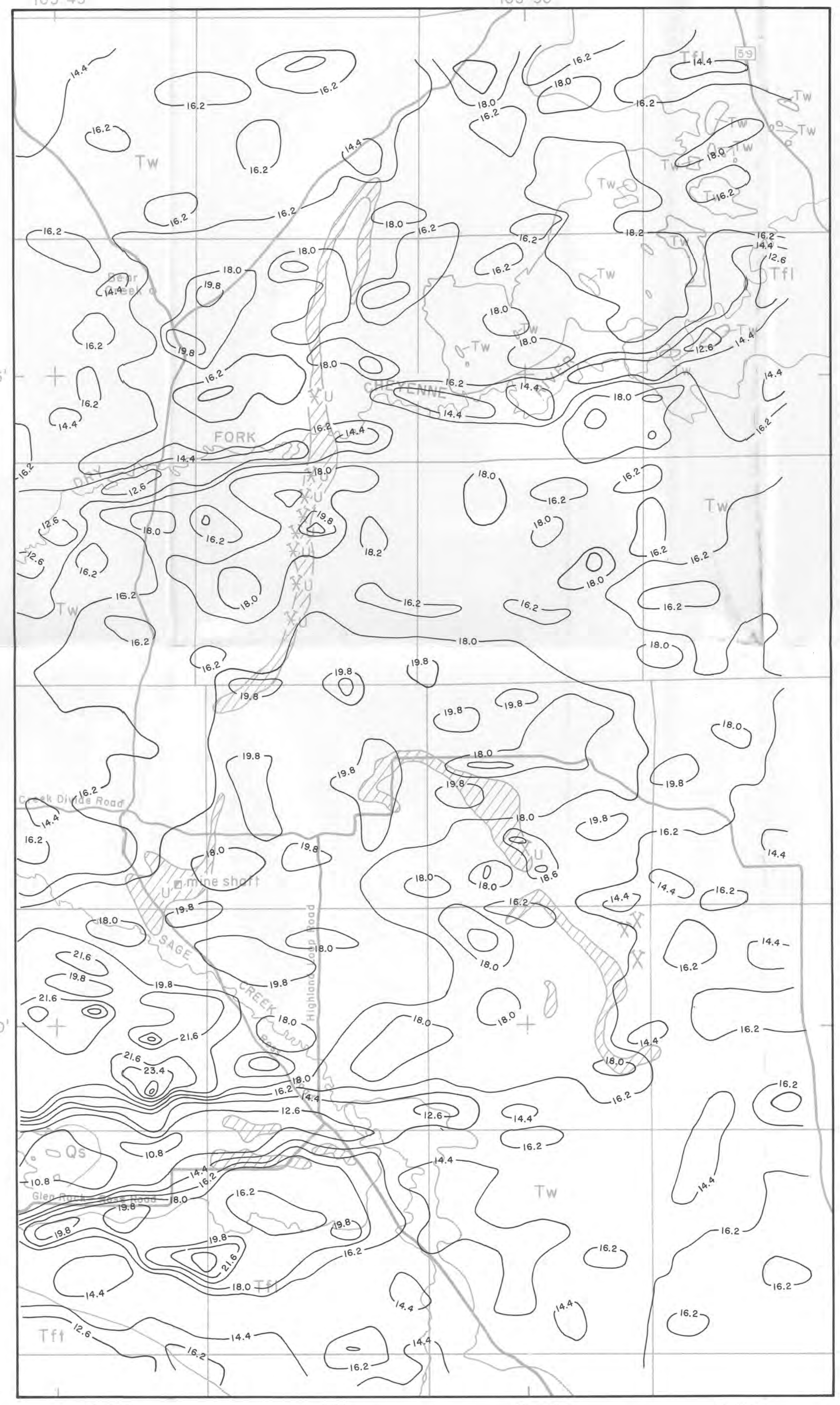

FIGURE 2.--Radiometric map showing fully corrected count-rate data converted to apparent surface concentrations of eTh in parts per million. Contour interval 1.8 ppm eTh.

Geology from Denson and Horn, 1975

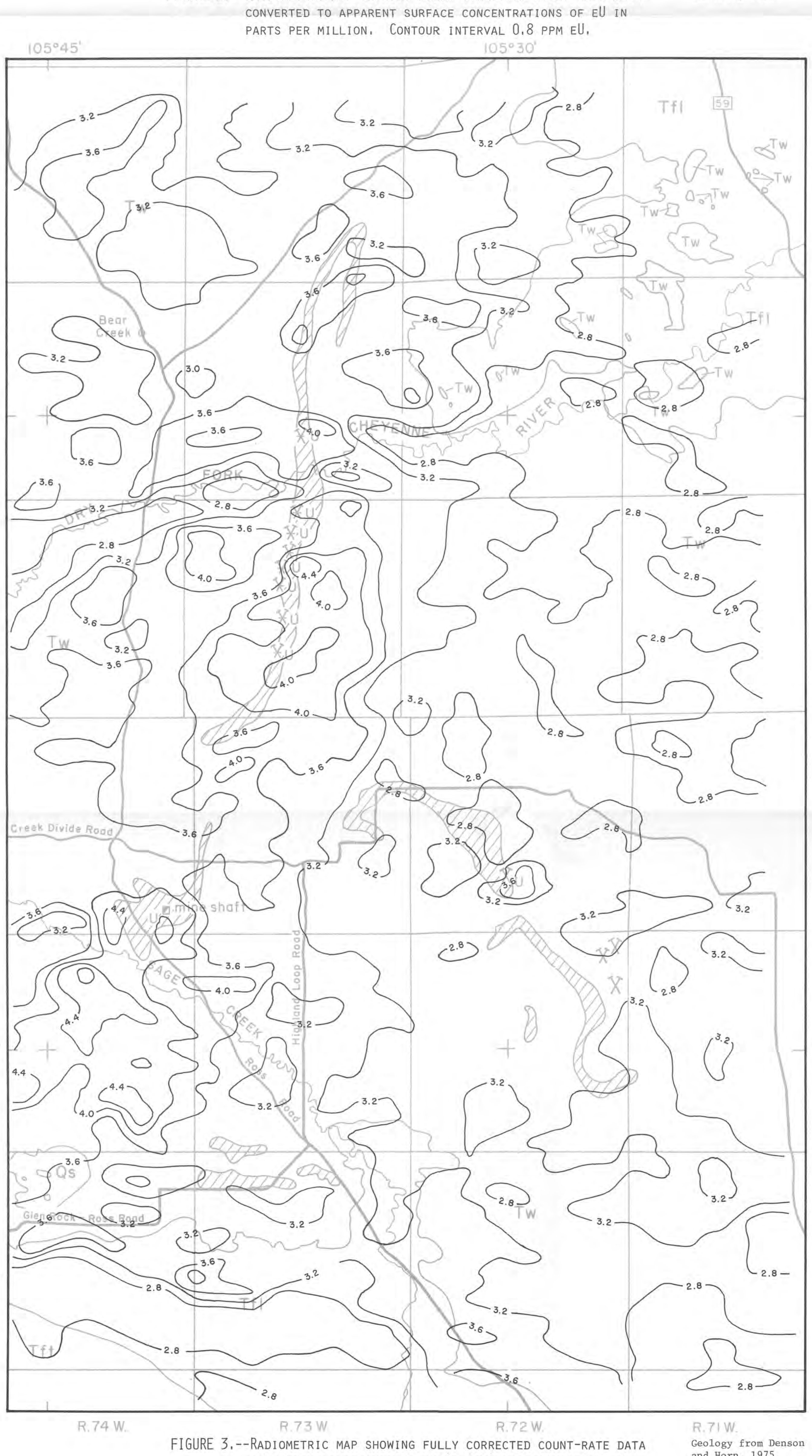

FIGURE 3.--Radiometric map showing fully corrected count-rate data converted to apparent surface concentrations of K in percent. Contour interval 0.4 percent K.

Geology from Denson and Horn, 1975

EXPLANATION

Qs	WIND-BLOWN SAND (HOLOCENE AND PLEISTOCENE)
Tw	WASATCH FORMATION (EOCENE)
	FORT UNION FORMATION (PALEOCENE)
Tft	Lebo Member
Tfl	Tullock Member
—3.2—	AERORADIOACTIVITY CONTOUR
(hachured area)	LOCATION OF MINERALIZATION TREND-- Generalized from surface and subsurface investigations
(mine symbols)	ABANDONED AND ACTIVE OPEN-PIT URANIUM MINES
U	URANIUM MINE SHAFT

Index map of Wyoming showing the location of study area

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13.5°
Magnetic north
Inclination 70°
1975

Introduction

An aerial survey of the southern Powder River Basin from T. 34 N. to T. 39 N. and from R. 71 W. to R. 74 W. in Converse County, Wyoming (fig. 1) was flown on June 21 and July 31, 1975 by Geodata International on behalf of the U.S. Geological Survey. Equivalent uranium (eU), equivalent thorium (eTh), potassium and gross-count gamma-ray data were measured as part of a program of geophysical investigation designed to monitor the radioactive signatures of known near-surface uranium ore zones, and the surrounding geologic units.

A total of 29 flight lines covering an area of approximately 1,950 sq km were flown at 1.2 km spacing. The flight lines are oriented north-south and are each approximately 56 km long. Two tie-lines approximately 34 km long were flown perpendicular to the survey lines. During the survey the aircraft maintained a nominal altitude of 120 m above ground level with a ground speed of about 192 km per hour.

The spectrometric data were obtained using a high sensitivity gamma-ray spectrometer with nine 29.2 cm diameter by 10.2 cm thick NaI(Tl) (thallium-activated sodium iodide) detectors, each having a volume of 6.8 L. Eight detectors were used for ground radiometric data measurements. The ninth detector was shielded from ground radiation by about 10 cm of lead and was used to monitor ^{214}Bi (bismuth-214) in the atmosphere. A radar altimeter was used to measure the altitude of the aircraft above the ground surface. A 35 mm camera took pictures of the ground below the aircraft; Doppler radar data were merged with photographs along the flight lines to determine the actual flight path of the aircraft.

The Geodata system utilizes energy windows centered at 1.12 MeV (million electron volts) and 1.76 MeV to measure gamma radiation from the decay of ^{214}Bi, a ^{238}U (uranium-238) daughter product. Equivalent thorium concentrations were measured with an energy window centered at 2.615 MeV to measure decay of ^{208}Tl (thallium-208), a daughter product of ^{232}Th (thorium-232). Potassium concentrations were determined using a window centered about the ^{40}K (potassium-40) 1.46 MeV peak. Widths of energy windows used are given by Duval and Schulz (1977). The term equivalent, abbreviated e, is used to denote U and Th concentrations measured by gamma-ray emissions of daughter isotopes because of the potential for disequilibrium in the U and Th decay series.

A gamma-ray background composed of cosmic radiation, aircraft contamination and atmospheric ^{214}Bi was subtracted from the observed radiometric data. The component due to cosmic radiation was determined using the shielded detector to monitor the gamma-ray spectrum from 3.0 to 6.0 MeV. Aircraft contamination was determined by flying the aircraft in excess of 1,000 m above the ground surface. The radiometric data were also corrected for Compton-scattered gamma rays in the ^{40}K and ^{214}Bi energy windows. The adjustment to a common altitude of 122 m above the ground surface using standard gamma-ray attenuation equations was the final correction applied to the data.

The radiometric maps presented here represent fully corrected count-rate data converted to apparent surface concentrations of ppm eU, ppm eTh, and percent K (figs. 2, 3, and 4, respectively). The data for the contour maps was smoothed with a nine-point (approximately 300 m) sliding average, and gridded at 400 m intervals before contouring. The units of the ratio maps are ppm eU/ppm eTh, ppm eU/percent K, and ppm eTh/percent K (figs. 5, 6, and 7, respectively). Calibration constants used to calculate the concentrations are given by Duval, Schulz, and Pitkin (1977). The units used for the gross-count maps (fig. 8) are such that 1 ur (radioelement unit, International Atomic Energy Agency, 1976) is equal to the gross-count rate that would be measured flying at an altitude of 122 meters over an infinite source with an apparent surface concentration of 1 ppm eU with no K and no eTh. That 1 ur equals 55 cps (counts per second) for this aerial survey was determined by using a linear regression fit to establish the relationship between the gross count and the radioelement concentrations (Duval and Schulz, 1977). The calibration factors for the elements and gross count data are considered to be correct within ±25 percent.

Bedrock geology

Bedrock in the Powder River Basin study area consists of fluvial and paludal sedimentary rocks of Paleocene and Early Eocene age. The Wasatch Formation of Early Eocene age and latest Paleocene age, underlies most of the area. The Paleocene Fort Union Formation underlies only a portion of the northeastern corner and extreme southern end of the area. All sediments in the Powder River Basin are poorly to only semi-consolidated, and due to similar origin, are difficult to differentiate. Denson and Horn (1975) have recognized distinctions between the Fort Union and Wasatch Formations such as heavy minerals. They divided the Fort Union in this area into two members, the Tullock (lower) and Lebo (upper) Members.

The Tullock Member of the Fort Union Formation consists of 300-475 m of interbedded sandstone, siltstone, shale, carbonaceous shale, and thin coals conformably overlying the Upper Cretaceous Lance Formation. The drab appearance and massive sandstones of the Tullock and its generally darker overall aspect distinguish it from the overlying Lebo Member.

The Lebo of the Fort Union consists of 518-853 m of light- to dark-gray, very fine grained to conglomeratic sandstone, carbonaceous shale, and coal. The Lebo contains thin-bedded ironstone concretions, interbedded with massive, white sandstone and light- to dark-gray slightly bentonitic shale throughout the member (Denson and Horn, 1975).

The rocks of the Wasatch Formation attain a maximum thickness of about 500 m in the Powder River Basin and consist of gray, brown, and reddish pink conglomeratic to fine-grained arkosic sandstone, siltstone, carbonaceous shale, and coal, which are poorly to semi-consolidated. In general, the Wasatch is coarser grained than the underlying Fort Union rocks. Sandstones generally occur as coarse, crossbedded arkosic lenses within the clay and stilstone units. Many of the sandstone lenses are rich in clay, frequently white montmorillonite, apparently derived from volcanic ash. Although no formal stratigraphic divisions have been made in the Wasatch, Sharp and Gibbons (1964, p. D-7) have separated the formation areally into a dominantly fine grained facies which flanks the basin on three sides and a dominantly coarse grained facies in the central and southern parts of the basin. The Wasatch unconformably overlies the upper member of the Fort Union (Denson and Horn, 1975).

The Wasatch and Fort Union should have detectable differences in their radiometric character due to the differences in source rocks (Denson and Chisholm, 1971, p. C123), the coarser, more arkosic nature of the Wasatch, and its higher content of clay derived from volcanic ash (Sharp and Gibbons, 1964). However, because of the similarity of depositional environments and distance of sediment transport, like lithologies in the Fort Union and Wasatch Formation should not be expected to differ greatly in radiometric signature (Adams and Weaver, 1958).

Genesis of uranium deposits

There is no general agreement on the question of genesis of the Powder River Basin uranium deposits. Houston (1969, p. 25) summarizes the work done during the 1950's and 1960's on the geology and genesis of Wyoming uranium deposits. Investigations conducted since 1969 still present a wide array of hypotheses to explain uranium genesis. The deposits have been described as syngenetic, penesyngenetic, epigenetic lateral-secretion (Finch, 1967), and combinations of these.

Sharp and Gibbons (1964, p. D-32) give radiometric age dates for uranium in the southern Powder River Basin with the range of 7 to 13 m.y.b.p. (million years before present). Davis (1970, p. 24) gives a time of about 10 m.y.b.p. for mineralization. K. Ludwig of the U.S. Geological Survey has determined ages of 1 and 3 m.y.b.p. for ore at the Highland mine (oral commun., 1977).

Radioelement data

Using calibration constants of Duval and Schulz (1977), average radioelement concentrations have been calculated from the aerial gamma-ray data. The average concentrations for the Wasatch are 16.7 ppm eTh, 2.6 ppm eU, and 3.2 percent K. Average concentrations for the Tullock Member of the Fort Union are 13.8 ppm eTh, 2.3 ppm eU, and 2.8 percent K, and for the Lebo Member, 16.1 ppm eTh, 2.4 ppm eU, and 2.8 percent K. The differences in these mean values are small and are not sufficient to enable significant distinctions between the geologic units. The mean values are useful only for defining expected values for a given geologic unit. Separation of the geologic units on the basis of their radiometric character requires a method which presents a synthesis of the radiometric data such as the composite images presented by Duval, Pitkin, and Macke (1977).

Two strong linear features related to surficial geology are present in the radiometric data. The first of these is an east-west-trending feature just south of 43°15' N. This feature marks the alluvial fill along the Dry Fork of the Cheyenne River. Within the total count data it appears as an area of generally less than 49.1 ur, and generally has less than 16.3 ppm eTh, and less than 2.83.6 percent K. It does not, however, figure prominently in the eU data, with values in the range 2.43.2 ppm eU. The second linear feature trends east-west south of 43° N. It is an eastward extension of the Sand Hills to the west, and has total count values less than 47.3 ur, from 1.6 to 2.4 ppm eU, less than 14.4 ppm eTh, and shows no strong trend in the K data, with values generally less than 3.2 percent K.

Other obvious features which dominate the contour maps are uranium mines. The location of these is given on the geologic base for the contour maps.

An elliptical area in the southwestern portion of the study region appears as a high on the eTh, K, and total count maps, but is less prominent in the eU and the ratio maps. Topographic maps and aerial photography show this to be the highly dissected drainage of Sage Creek. Here total count values are in the range of 49.1 to 56.4 ur, eTh values about 16.223.4, and K values in the range of 3.64.4 percent. High values are indicated within the uranium data but this is not as conspicuous as in the other radiometric data. Examination of the ratio maps shows little difference between this region and adjacent areas underlain by the Wasatch Formation. There is, then, an increase in radioelement concentrations with little change in the radioelement ratios. One possible explanation is that these locations represent the same source material, but that the dissection of the Sage Creek drainage has led to the exposure of relatively fresher and (or) drier material (drier due to the increase in valley side slope, and therefore an increase in runoff). However, intensity of active drilling in this area suggests that the subtle change in the character of the gamma-ray signature may in fact be related to mineralization at depth.

The mapped outcrop of the Fort Union differs in radiometric character in the northern and southern parts of the study area. In the north, there are higher concentrations of eTh (16.2-18.0 ppm), lower concentrations of eU (about 2.4 ppm) when compared to the Fort Union in the south. The total count data are nearly the same in both areas (approximately 50 ur) as are eU to eTh ratios (about 2.4). However, the eTh to K and eU to K ratios show higher values in the north (to the north, eTh to K is greater than 6.3, and eU to K is 0.8-1.2; in the south, eTh to K is 4.5-5.4, and eU to K is less than 0.8). These data suggest a difference in lithologies between the north and south. However, the radiometric signature of the northern exposure may not be representative of the unit's radiometric character. The Fort Union exposed in the north occupies a broad topographic low which is part of the valley of the Dry Fork of the Cheyenne River. Only the uppermost Fort Union is exposed and in places is capped by basal Wasatch sediments. There is vertical displacement of as much as 75 m between the contact in the valley and the main contact to the north, apparently due to relief on the unconformity surface. The streams draining into the valley from the north and the south carry detritus from Wasatch uplands and in many places thick alluvial fills composed of predominantly Wasatch-derived detritus have been deposited. In contrast, the streams draining the southern exposure of the Fort Union widen to form broad alluvial valleys to the south of the study area boundary, and no major outliers of Wasatch caprock are preserved in this area.

Sharp and Gibbons (1964, Pl. 1, p. D8, D9) mapped three color zones within the Wasatch Formation in the southern Powder River Basin: red, white, and drab. The red color zones indicate oxidation of the sediments by ground water and formation of hematite by destruction of pyrite and other iron minerals within the host sediments. The white color is indicative of the formation of clays, principally from alteration of volcanic ash. The drab sediments represent material on the down-dip side of an oxidation-reduction interface, where the ground waters have lost their oxidizing capacity. Hydrated iron oxides are common in the drab lenses. Both the drab and red sandstones contain 13 percent iron. The clay content of the red and drab sandstones is generally less than 1 percent, while that of the white sandstone is from 2-4 percent. The nature of these color zones is important, because the standard exploration technique within the Powder River Basin is to search for the interface between the red and drab color boundaries, and then examine it for rollfront deposits (Sharp and Gibbons, 1964, p. D-54).

Radiometric values for the three color zones have been calculated for the map area. The entire outcrop of Wasatch has the following values: eTh, 16.7±2.7 ppm; eU, 2.6±0.7 ppm; K, 3.2±0.6 percent where the range of values has been calculated using an arbitrary measure of dispersion, defined as 0.75 times the full width of the histogram at one-half maximum value. The following radiometric values have been calculated for individual color zones:

	Red	White	Drab
eTh	15.9±2.0 ppm	15.2±2.0 ppm	16.7±1.0 ppm
eU	2.6±1.5 ppm	2.7±1.8 ppm	2.3±0.3 ppm
K	3.2±0.2 percent	3.6±1.2 percent	3.6±0.6 percent

The drab unit contains the highest concentrations eTh, the lowest concentrations of eU, and the same concentration of K as the white zones. This suggests that neither the thorium nor potassium minerals have been strongly affected by alteration. The red zones show values intermediate between the white and drab for both eTh and eU, while having the lowest K concentrations. The white units have the lowest concentrations of eTh, the highest concentrations of eU, and intermediate values for K. These data suggest that both the red and white zones have been the site of uranium enrichment relative to the drab zones, and that the uranium and possibly potassium within the white zones may be connected to the high clay content of these areas, although the actual site of concentration has not been determined. The red zones apparently have been subject to depletion of K and possibly eTh, while being enriched in eU. The differences in the radiometric end product of the red and white zones appear to be due to the higher clay content within the white areas. The white areas also have the highest variability of radiometric values, that is, are the least uniform in character.

The general trend of higher K values in the central part of the study area may reflect the presence of a coarser grained, more arkosic, facies along the basin axis. The occurrence of a coarser grained facies within the Wasatch, increasing in thickness and in grain size southward and toward the axis of the basin, has been discussed by Sharp and Gibbons (1964, p. D-7, D-8).

The differences in the radiometric data are subtle. The dominant influence appears to be related to the mineralization rather than to differences in original bedrock character. The radiometric differences between similar lithologies are expected to be slight, and are apparently altered to a large extent by later mineralization. The generally north-south alignment of radioelement trends supports the thesis of control of mineralization by a major fluvial system developed during Wasatch time (Seeland, 1976), with solution movement predominantly from south to north (Davis, 1970, p. 25).

The distribution of radioelements relative to color changes within the Wasatch suggests that a source of uranium other than the host rocks themselves must have supplied uranium to ground waters for the development of uranium mineralization. The enrichment of the red and white color areas suggests that uranium has been added, rather than leached, throughout the sediments updip of roll-front deposits.

Trends within the radiometric data are subtle and diffuse. The mineralization pattern appears to be confined to the major fluvial depositional system (Seeland, 1976), but in detail is more pervasive and does not reflect the dendritic pattern assumed for that system. This is most compatible with an epigenetic, lateral-secretion ore genesis model. Since the syngenetic and penesyngenetic mineralization hypotheses suggest more laterally and vertically restricted alteration, the radiometric data cast doubts on these models. This is supported by 1 to 3 m.y.b.p. age determinations for ore deposition at the Highland mine (K. Ludwig, U.S. Geol.Survey, oral commun., 1977).

SCALE 1:125 000
2 0 2 4 6 8 10 MILES
2 0 2 4 6 8 10 KILOMETERS

AERIAL GAMMA-RAY MAPS OF PART OF THE SOUTHERN POWDER RIVER BASIN IN CONVERSE COUNTY, WYOMING

By
D.L. Macke, J.S. Duval, and J.A. Pitkin

1978

INTERIOR—GEOLOGICAL SURVEY, RESTON, VIRGINIA—1978

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