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National Uranium Resource Evaluation

SHERIDAN QUADRANGLE WYOMING AND MONTANA

MASTER

Bendix Field Engineering Corporation
Grand Junction, Colorado

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PREPARED FOR THE U.S. DEPARTMENT OF ENERGY
Assistant Secretary for Nuclear Energy
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NATIONAL URANIUM RESOURCE EVALUATION
SHERIDAN QUADRANGLE
WYOMING AND MONTANA

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Grand Junction, Colorado 81502

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PREPARED FOR THE U.S. DEPARTMENT OF ENERGY
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This is the final version of the subject-quadrangle evaluation report to be placed on open file. This report has not been edited. In some instances, reductions in the size of favorable areas on Plate 1 are not reflected in the text.

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ABSTRACT

The Sheridan Quadrangle of north-central Wyoming was evaluated for uranium favorability according to specific criteria of the National Uranium Resource Evaluation program. Procedures consisted of geologic and radiometric surveys; rock, water, and sediment sampling; studying well logs; and reviewing the literature. Five favorable environments were identified. These include portions of Eocene Wasatch and Upper Cretaceous Lance sandstones of the Powder River Basin and Lower Cretaceous Pryor sandstones of the Bighorn Basin.

Unfavorable environments include all Precambrian, Cambrian, Ordovician, Permian, Triassic, and Middle Jurassic rocks; the Cretaceous Thermopolis, Mowry, Cody, Meeteetse, and Bearpaw Formations; the Upper Jurassic Sundance and Morrison, the Cretaceous Frontier, Mesaverde, Lance, and the Paleocene Fort Union and Eocene Willwood Formations of the Bighorn Basin; the Wasatch Formation of the Powder River Basin, excluding two favorable areas and all Oligocene and Miocene rocks. Remaining rocks are unevaluated.

INTRODUCTION

PURPOSE

The Sheridan NTMS 1° by 2° Quadrangle (Fig. 1) in north-central Wyoming was evaluated to identify geologic environments that have characteristics favorable for uranium deposition. The selection of an environment as favorable was based on the similarity of its geologic characteristics to the recognition criteria of the National Uranium Resource Evaluation (NURE) program, as described by Mickle and Mathews (eds., 1978). Areas are considered favorable if they have the potential to contain at least 100 t of U_3O_8 with an average grade of 0.01% or higher. Only environments to a depth of 1500 m have been evaluated for this project. This study was conducted by Bendix Field Engineering Corporation (BFEC) for the NURE program, managed by the Grand Junction office of the U.S. Department of Energy (DOE).

SCOPE

The quadrangle evaluation consisted of three separate phases, beginning in April 1980, and ending in March 1981. Approximately 80 man-days were spent in Phase I of the evaluation, which consisted of a literature search and compilation and review of all pertinent maps and data. Phase II included field work and data compilation and analysis. Field work, consisting of geologic reconnaissance and uranium-occurrence visitations, required 180 man-days. Compilation and analysis of data after the end of the field season took 90 man-days. Phase III, which included the writing of the final report and preparation of the accompanying plates and figures, required 110 man-days. This amount of time was clearly insufficient for evaluation of all environments. We therefore studied only environments that we deemed favorable during Phase I. Unfavorable environments were selected mostly on the basis of a literature search. Environments that could be favorable, but which we could not study because of time limitations, were classified as unevaluated.

PROCEDURES

The evaluation of the Sheridan Quadrangle involved both surface and subsurface geological investigations. In the surface investigation, all uranium occurrences listed in open-file Atomic Energy Commission (AEC) Preliminary Reconnaissance Reports (PRR's) and other sources (App. A) were examined in the field. Aerial radiometric anomalies (geoMetrics, 1979) were field checked, and hydrogeochemical anomalies (Morris, 1977) were resampled. Potentially favorable geologic environments were examined in the field by geologic and radiometric surveys. Radiometric reconnaissance was conducted using Mount Sopris Model 132 scintillometers; scintillometer readings in counts per second (cps) were converted into units of radioactivity (UR); (Darnley, 1977; International Atomic Energy Agency, 1976). A Scintrex Model GAD-6 four-channel spectrometer was used in crystalline terranes.

Rock and sediment samples were collected and analyzed for uranium and associated trace elements by fluorometry, colorimetry, gamma spectrometry, and loss on ignition. Thin sections of selected samples were prepared and

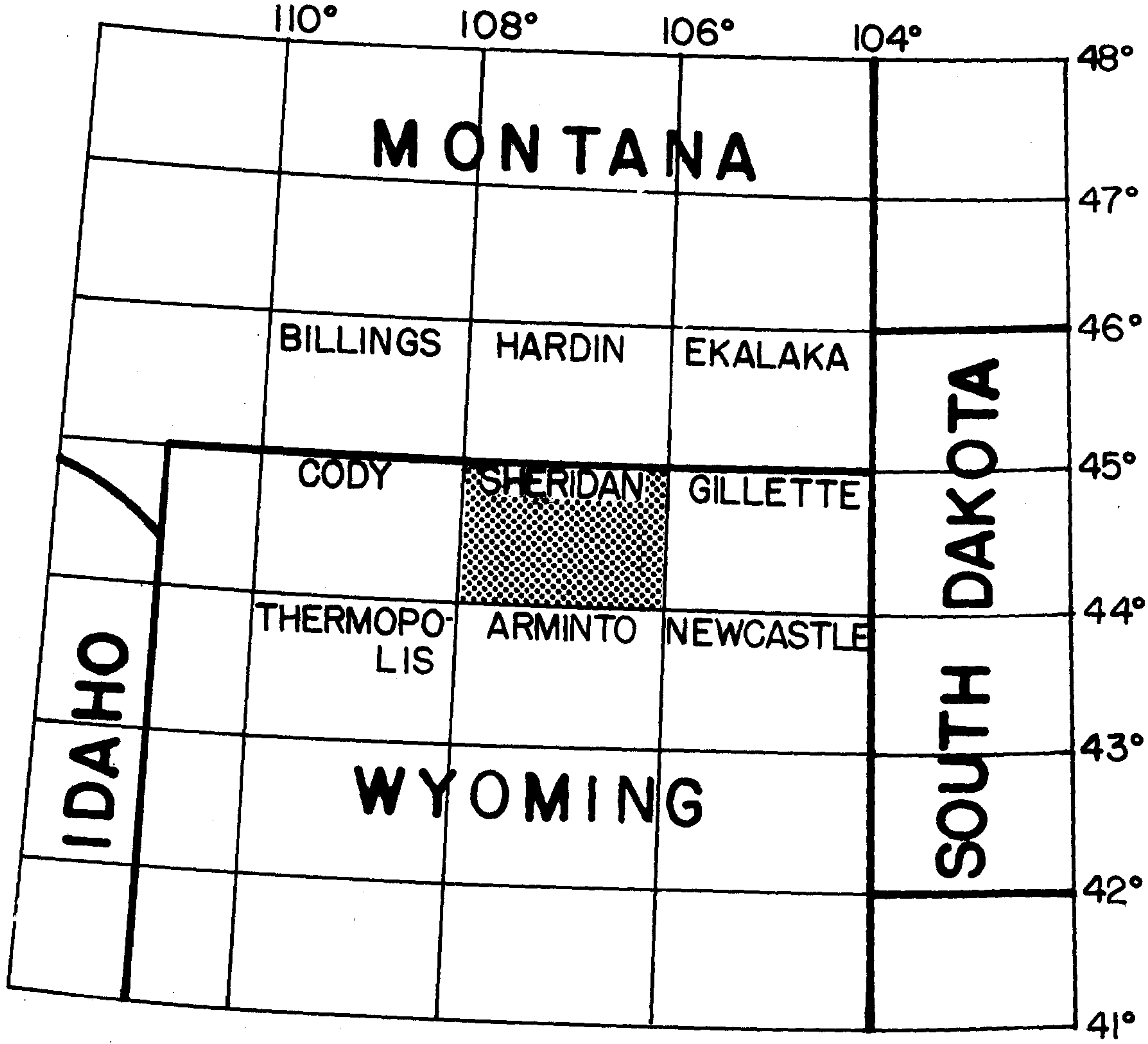

Figure I. Location of Sheridan Quadrangle analyzed by petrographic methods, x-ray diffraction, and scanning electron microscopy (SEM). Alpha-track studies of 28-days duration were conducted on some thin-section samples. Water samples were analyzed for uranium and conductivity (CDT) using a Scintrex UA-3 analyzer. Using an RE-350 radon emanometer (developed under contract for Bendix Field Engineering Corporation by TSA Systems, Inc., Boulder, Colorado), most water samples were also analyzed in the field for radon gas. All petrographic work and chemical analyses of the samples were done by BFEC personnel at laboratories in Grand Junction.

The subsurface geologic investigation involved the study and correlation of geophysical and lithologic logs of oil wells, gas wells, and coal exploration holes. Maps showing sand trends, subsurface structure, thickness of stratigraphic units, and subsurface gamma-ray anomalies were constructed.

GEOLOGIC SETTING

The Sheridan Quadrangle in north-central Wyoming includes an area of about 18,000 km^2 between lat 44° and 45° N. and long 106° and 108° W. (Fig. 1). Major towns in the quadrangle are Sheridan and Buffalo, located in the north-central and south-central portions of the quadrangle respectively, and Worland located in the extreme southwest corner of the quadrangle. The remainder of the quadrangle contains scattered ranches and a few small towns.

The Sheridan Quadrangle consists of three basic structural elements: the Bighorn Mountains, and the Bighorn and Powder River Basins. The Bighorn Mountains, which run diagonally from the northwest corner to the south-central edge of the quadrangle, separate the Bighorn Basin to the west from the Powder River Basin to the east.

The Bighorn Mountains, a broad anticlinal uplift of Laramide age, may be divided structurally into three separate blocks. The central block has been uplifted the highest. Precambrian granitic and metamorphic rocks are exposed in this central portion, which culminates in rugged glaciated mountains 4000 m above sea level. Parts of this central section have been thrust eastward along the Piney Creek and Clear Creek Thrusts. The western slope of this segment is characterized by gentle westward dips. The central uplifted block is bounded on the south by the Tensleep Fault (Osterwald, 1959) and on the north by the Tongue River Lineament (Wilson, 1938). The northern and southern blocks of the Bighorns are anticlinal folds with steeply dipping or overturned western limbs and more gently dipping eastern flanks (Wilson, 1938). Mostly Paleozoic rocks are exposed in the northern and southern sections; erosion has breached the Precambrian only in small areas.

Flanking the Bighorn Mountains are deep structural basins: the Bighorn Basin on the west and the Powder River Basin on the east. Both basins are floored with Precambrian rocks that are overlain by sediments ranging in age from Cambrian to Tertiary. All units have steep dips and are folded adjacent to the Bighorn uplift.

The Paleozoic formations (Fig. 2) include the Cambrian Flathead, Gros Ventre, and Gallatin; the Ordovician Bighorn; the Mississippian Madison; the Pennsylvanian Amsden and Tensleep; and the Permian Phosphoria in the Bighorn

SYSTEM	SERIES	FORMATION	LITHOLOGY	DESCRIPTION
TERTIARY	MIOCENE	Unnamed		Claystone, ashy sandstone, arkosic conglomerate, siltstone, boulder beds; oxidized; 0-50 m
TERTIARY	OLIGOCENE	White River		Limestone, arkosic conglomerate, sandstone, volcanic ash, boulder beds; oxidized; 0-15 m
TERTIARY	EOCENE (lower)	Wasatch* (Powder River Basin)		Arkose, mudstone, siltstone, coal, clinker; oxidized and reduced; 0-450 m
TERTIARY	EOCENE (lower)	Willwood (Bighorn Basin)		Subarkose, quartz arenite, variegated mudstone; oxidized and reduced; 0-760 m
TERTIARY	PALEOCENE	Fort Union		Quartz and lithic arenite, arkose, mudstone, siltstone, coal; reduced; 760-1500 m
CRETACEOUS	UPPER CRETACEOUS	Lance*		Quartz and lithic arenite, shale, coal, siltstone; reduced; 300-600 m
CRETACEOUS	UPPER CRETACEOUS	Meeteetse (Bighorn Basin) Bearpaw (both basins)		Shale, thin sandstone, siltstone, clinker; reduced; 60-250 m
CRETACEOUS	UPPER CRETACEOUS	Mesaverde		Quartzose sandstone, shale, siltstone, coal; reduced; 0-200 m
CRETACEOUS	UPPER CRETACEOUS	Cody		Shale, thin sandstone, bentonite; reduced; 750-1400 m
CRETACEOUS	UPPER CRETACEOUS	Frontier		Quartz and lithic arenite, shale, bentonite, minor lignite; reduced; 60-300 m
CRETACEOUS	LOWER CRETACEOUS	Mowry		Siliceous shale, bentonite; reduced; 60-150 m
CRETACEOUS	LOWER CRETACEOUS	Muddy		Sandstone, siltstone, minor shale; reduced; 0-30 m
CRETACEOUS	LOWER CRETACEOUS	Thermopolis		Dark shale; reduced; 60-90 m
CRETACEOUS	LOWER CRETACEOUS	*Cloverly**		Bentonitic mudstone, chert-pebble conglomerate,oxidized and reduced; 40-120 m
JURASSIC	UPPER JURASSIC	Morrison		Siltstone, mudstone, sandstone; oxidized and reduced; 30-90 m
JURASSIC	UPPER JURASSIC / MIDDLE JURASSIC	Sundance		Glauconitic sandstone, shale, limestone; reduced; 60-110 m
JURASSIC	MIDDLE JURASSIC	Gypsum Spring		Evaporite, shale, siltstone; oxidized and reduced; 0-50 m
TRIASSIC		Chugwater		Shale, siltstone, sandstone, carbonates; oxidized; 180-300 m
PERMIAN		Phosphoria / Goose Egg		Dolomite, siltstone, sandstone, evaporite, shale; oxidized and reduced; 60-110 m
PENNSYLVANIAN		Tensleep		Quartz arenite, limestone, dolomite, chert; reduced; 30-120 m
PENNSYLVANIAN / MISSISSIPPIAN		Amsden		Cherty limestone and dolomite, sandstone, siltstone, shale; oxidized and reduced; 0-60 m
MISSISSIPPIAN		Madison		Limestone, dolomite, shale; karstic in upper third; oxidized(?) and reduced; 60-300 m
ORDOVICIAN		Bighorn		Dolomite, sandstone, siltstone; reduced; 0-150 m
CAMBRIAN	UPPER CAMBRIAN	Gallatin		Limestone, siltstone, conglomerate; reduced; 10-120 m
CAMBRIAN	MIDDLE CAMBRIAN	Gros Ventre		Limestone, siltstone, sandstone, conglomerate; reduced; 15-110 m
CAMBRIAN	MIDDLE CAMBRIAN	Flathead		Conglomerate, sandstone, siltstone; oxidized and reduced; 5-15 m
PRE-CAMB.		Igneous and metamorphic rock		Quartz diorite, granodiorite, granite, quartzofeldspathic gneiss, amphibolite, quartzite, marble, diabase dikes

*Favorable for uranium deposition

Figure 2. Stratigraphic column of the Sheridan Quadrangle.

Basin and Goose Egg in the Powder River Basin. These rocks consist of interbedded sandstones, shales, and carbonates that record a series of marine transgressions and regressions across a continental shelf with a source area to the east.

Mesozoic rocks (Fig. 2) in the Bighorn and Powder River Basins, representing a continuation of alternating transgressive and regressive conditions, also include some deposits of continental origin. Mesozoic formations include the Triassic Chugwater; Jurassic Gypsum Spring, Sundance, and Morrison; and the Cretaceous Cloverly, Thermopolis, Mowry, Frontier, Cody, Mesaverde, Meeteetse, Bearpaw, and Lance. The pre-Morrison rocks consist of shales, evaporites, and thin carbonates deposited under marine-platform conditions. The Morrison and Cloverly Formations are continental deposits and contain shales, sandstones, and mudstones of fluvial and lacustrine origin. Significant amounts of volcanic debris are present in the mudstones of the Cloverly. Thermopolis through Bearpaw Formations represent a long period of dominately marine deposition, consisting mostly of thick accumulations of shale. Periods of marine regression are represented by westerly-derived sandstones interbedded within the shale sequence. The Lance Formation, consisting of fluvial, flood-plain, and coastal-plain sediments, marks the end of marine deposition in both the Bighorn and Powder River Basins (Wyoming Geological Association Technical Studies Committee, 1965).

Cenozoic rocks (Fig. 2) include the Paleocene Fort Union, Eocene Wasatch and Willwood, and the Oligocene White River Formations. The Laramide orogeny, which produced the major structural elements now present in the Sheridan Quadrangle, took place from latest Cretaceous through Eocene time. The initial subsidence of the Powder River and Bighorn Basins is recorded by the fluvial sands and shales of the Fort Union Formation. Uplift of the Bighorn Mountains did not occur until late Paleocene and, along with basin subsidence, continued into the Eocene (Curry, 1971). The subsiding basins were filled with lower Eocene fluvial sediments derived from the adjacent highlands. These sediments are included within the Willwood Formation in the Bighorn Basin and the Wasatch Formation in the Powder River Basin. Significant amounts of coarse material were shed eastward from the Piney Creek and Clear Creek Thrusts during Wasatch deposition. These coarse-grained rocks, the Moncrief and Kingsbury Conglomerate Members of the Wasatch, intertongue with finer- grained sediments a short distance east of the mountain front.

Laramide deformation ceased by middle Eocene time. During the Oligocene period, volcanic-rich sediments of the White River Formation buried both basins and much of the Bighorn Mountains (Curry, 1971). Major regional uplift in Pliocene time initiated a period of erosion and basin excavation, which has resulted in the present-day topographic features of the Sheridan Quadrangle (Wyoming Geological Association Technical Studies Committee, 1965).

ENVIRONMENTS FAVORABLE FOR URANIUM DEPOSITS

The Sheridan Quadrangle contains five favorable areas. Theses include environments favorable for Wyoming roll-type deposits (Subclass 241, Austin and D'Andrea, 1978) in the Wasatch, Lance, and Cloverly Formations; channel-controlled peneconcordant deposits (Subclass 243, Austin and D'Andrea, 1978) in the Cloverly Formation; and uraniferous coal and carbonaceous shale deposits (Class 210, Jones, 1978) in the Wasatch Formation. Favorable environments in the Wasatch and Lance Formations occur in the Powder River Basin; favorable environments in the Cloverly Formation occur in the Bighorn Basin.

AREA A - FLUVIAL FACIES OF THE WASATCH FORMATION

The lower Eocene Wasatch Formation of Area A (Pl. 1) is favorable for Wyoming roll-type deposits (Subclass 241) because it meets the following criteria:

- It consists of a permeable, arkosic-sandstone facies that was deposited by the ancestral Powder River.
- It was once directly overlain by tuffaceous sediments of the Oligocene White River Formation, a possible source of uranium.
- Arkoses, which host uranium deposits in the Pumpkin Buttes District, belong to the same depositional sand trend as those of Area A. (The Pumpkin Buttes are immediately south of Area A, in the Arminto Quadrangle.)
- It contains numerous uranium occurrences and ground-water uranium anomalies.
- It contains reduced sandstones with carbonaceous material, possibly important in precipitating uranium.

Area A encompasses 1985 km^2. On the average, total sandstone thickness is 60 m, yielding a volume of 119 km^3 of favorable rock. Area A includes all sandstones of the Wasatch Formation, where the Wasatch is composed of greater than 10% sandstone and where this sandstone was deposited as part of the ancestral Powder River fluvial system (Pl. 9). The northern limit of Area A is defined by the zone where fluvial sands become very silty and less permeable.

Host Rocks

General Statement. The lower Eocene Wasatch Formation consists of 0 to 500 m of almost horizontally bedded sandstone, siltstone, mudstone, and coal that fill an asymmetrically shaped intermontane basin. Except along the basin margin, it unconformably overlies the Tongue River Member of the Paleocene Fort Union Formation. Along the eastern flank of the Bighorn Mountains, alluvial-fan members of the Wasatch overlie steeply dipping truncated beds of Paleocene and Cretaceous units. Younger formations do not directly overlie the Wasatch Formation in the Sheridan Quadrangle. Thirteen miles south of the southeastern corner of the Sheridan Quadrangle, at Pumpkin Buttes, the Wasatch is unconformably overlain by a remnant of the Oligocene White River Formation. At Pumpkin Buttes, the Wasatch-White River contact is placed at 1800 m above sea level (Sharp and others, 1964). Using this datum, we estimate that 450 m to 600 m has been eroded from the Wasatch Formation in the Sheridan Quadrangle.

The Wasatch Formation consists of fluvial, flood-plain, paludal, and alluvial-fan deposits. Sedimentation occurred in early Eocene time during the main basin-filling episode in the Powder River Basin. Active subsidence and uplift throughout Wasatch time have been the principal depositional controls. Alluvial fans developed along the Bighorn Mountain front in response to uplift. Separate and distinct orogenic pulses are represented by the Kingsbury and Moncrief Members, which consist of conglomerates and are identified only along the northwestern margin of the Powder River Basin. Along the axis of the subsiding basin, thick coal beds, individually greater than 60 m (200 ft) thick, were deposited (Mapel, 1959). Kingsbury and Moncrief conglomerates are in lateral contact with coals along the west edge of the basin.

Elsewhere in the basin, extensive gray, fine-grained, cyclical flood-plain deposits characterize the Wasatch and rarely contain more than 20% sandstone. Red-banded mudstones, which occur sporadically in the southern Powder River Basin, are unknown. Their absence in the Sheridan Quadrangle suggests a regionally high, stable, ground-water table during deposition. During deposition, if the ground-water table had been lower or had fluctuated in response to a savannah climate, then flood-plain sediments deposited above the ground-water table would be red, in part, due to primary oxidation.

The ancestral Powder River, which originated in the southern end of the Powder River Basin, entered the Sheridan Quadrangle in its southeastern corner. Channel sandstones deposited by this river system can be mapped with electric logs from the southeast corner of the quadrangle northward to near the town of Ucross (Pl. 16); here the sandstones grade into massive siltstone. Channel facies of this fluvial system constitute 10% to 50% of the total Wasatch thickness, and their areal extent is defined as Area A.

Fluvial Facies of Area A. The Wasatch Formation of Area A varies from 120 m to 460 m in thickness; 19% to 50% of the Wasatch is channel sandstone. As stated above, this sandy facies was deposited by a major northward-flowing drainage system that appears to have been persistent throughout Wasatch time. Sand isoliths on Plate 9 indicate a gradual, lateral decrease in sand percent on the western margin of the system and an abrupt decrease on the east. Outcrop studies indicate a multiplicity of channels along the axis of the sand system. The axial portion of this sand system is identified on Plate 9 as that area with greater than 40% sand. Channels scour into each other and are, in general, laterally and vertically interconnected. Interconnected channel sandstones can be traced laterally for hundreds of meters. Sandstone outcrops have observable thicknesses of 30 m, with individual 10-m-thick sands being very common. Sandstones are generally fine- to medium-grained, but occasionally contain local lenses of coarse- to very coarse-grained sand. No conglomeratic material was observed. Sand bodies are typically thick and lack shale interbeds. Trough cross-stratification is common.

Peripheral to the axis of major sand buildup, however, channel sands appear to be vertically and laterally isolated by banded mudstone deposits. These isolated sands occupy the area on Plate 9 between the 10% and 40% sand contours. These sandstones appear to be of grain size and texture similar to sandstones in the central trend, but differ in that channels are not scoured into each other. These isolated channel sands attain observed thicknesses of 15 m and widths of about 60 m or more. The degree of sandstone isolation decreases gradually toward the center of the sand complex.

All sandstones of Area A are clean and permeable. Calcite cement is common in elongate concretions, which trend northward, parallel to the paleocurrent direction. Light- to medium-gray and yellow-brown arkose is the principal rock type but some quartzose sands are seen occasionally. The arkose very commonly contains spotty and streaky yellow-brown and orange staining, which is within and adjacent to bleached sandstone. Ironstone concretions are common. Carbonaceous material is plentiful and is usually concentrated along ripple bedding planes associated with finer grained sediments.

Uranium Source

Three distinct sources have been proposed for the uranium districts in the southern Powder River Basin. These include:

- crystalline rocks of the Laramie and Granite Mountains, from which uranium may have been leached and carried in solution during or shortly after Wasatch deposition (Sharp and others, 1964);
- the overlying White River Formation, from which uranium may have been leached and carried downward through the unconformity during Oligocene or Miocene time (Mrak, 1958; Davis, 1969; Love, 1952);
- arkosic material indigenous to Wasatch sands (Seeland, 1976).

Ground water in sandstones of Area A was probably in hydrologic communication with both the granites and overlying tuffaceous sediments of the White River Formation. All three proposed sources could have supplied uranium to Area A.

Hydrology

Fluvial host sandstones of Area A possess excellent transmissivity, particularly where channel sands are stacked and multilateral. Although sandstone geometry would have affected flow of uranium-bearing ground waters, the overall direction of maximum transmissivity will be parallel to the axis of sandstone deposition, as dictated by the paleocurrent direction of the ancestral Powder River fluvial system. Of equal importance is that both the fluvial system and the hydrologic gradient trend toward the basin axis (Pl. 9).

If mineralization occurred during the Eocene, ground water would have been moving as an underflow to, and closely associated with, the ancestral Powder River and its tributaries. If mineralization was Oligocene or Miocene in age, then ground waters of Area A probably entered the basin from recharge areas at the southern end of the basin. In both cases, the regional hydrologic gradient was northward toward a discharge area in the central and northern portions of the Powder River Basin. The ground-water flow patterns of the Powder River Basin probably remained essentially constant from Eocene through Miocene time (Galloway and others, 1979).

Evidence that Uranium Moved from Source to Host

Evidence that uranium moved from a source to the host rocks of Area A includes:

- syngenetic and epigenetic uranium anomalies;
- alteration features, including solution banding, limonite staining, and limb mineralization;
- a radiometric anomaly in a drill hole;
- ground-water uranium anomalies; and
- anomalous concentrations of elements which, both locally and regionally, have been shown to correlate positively with uranium.

Uranium Anomalies. Several anomalous concentrations of uranium occur in Area A. Several of these are termed "occurrences" if they contain concentrations greater than 50 ppm U_3O_8. These are described in Appendix C. In addition, log 110 (App. D) shows a subsurface radiometric anomaly. Anomalies in rock samples are divided into syngenetic and epigenetic groups, based on our interpretation of their probable genesis.

Syngenetic concentrations (Table 1) are represented by samples that have several characteristics in common. All but sample MLK 112 are black, carbonaceous shales. They contain 2% to 3% organic carbon, except for MLK 110; it contains 14.8% organic carbon. As a group, they show a positive correlation of uranium with arsenic, selenium, and molybdenum (Pl. 10). All syngenetic concentrations show rather low-grade uranium concentrations of less than 50 ppm U_3O_8. The most important characteristic shown by these samples is that they were all collected from thinly bedded, cyclical, flood-plain sequences almost totally devoid of sandstones. In a few cases, where thin sandstone beds were adjacent to the radioactive shale, the most radioactive zone within the shale was not directly adjacent to the sand. Relatively nonradioactive black shales in the basin were not sampled but average about 10 UR.

That these radioactive shales are located within the ancestral Powder River fluvial system and are stratigraphically separated from sands or other permeable rock types suggests a syngenetic origin. Such an origin would indicate that uranium and other mobile elements were moving in rivers and in ground-water systems during early Eocene time and that their logical source was recently exposed granites of the Laramie or Granite Mountains. A similar model has been proposed for the Great Divide Basin by Masursky (1962), Bailey and Childers (1977) and Wyant and others (1956).

Four rock samples are thought to represent epigenetic uranium concentrations (Table 2). All but MLK 109 are of sufficiently high grade to be classified as uranium occurrences (Pl. 2). Detailed descriptions of these occurrences are found in Appendix C. The following general characteristics distinguish them from syngenetic uranium concentrations:

TABLE 1. ROCK SAMPLES REPRESENTING PROBABLE SYNGENETIC URANIUM CONCENTRATIONS IN AREA A

Sample no.	UR	U_3O_8 (ppm)
MLK 039	59	34
MLK 040	36	11
MLK 103	36	25
MLK 105	36	20
MLK 110	48	43
MLK 112	48	44

TABLE 2. ROCK SAMPLES REPRESENTING PROBABLE EPIGENETIC URANIUM CONCENTRATIONS IN AREA A

Sample no.	UR	U_3O_8 (ppm)
MLK 078	94	90 (occurrence 23)
MLK 097	82	73 (occurrence 18)
MLK 100	59	81 (occurrence 16)
MLK 109	36	36

- They occur in coals or lignitic mudstones that have 7.6% to 36.7% organic carbon content, significantly higher than the black shales discussed above.

- They occur immediately below thick, permeable sandstones, suggesting that uranium moved in ground water through the sand and was plated on its margins. These uranium occurrences could therefore represent limb mineralization associated with roll fronts down the hydrologic gradient.

- The grade of these occurrences ranges from 36 to 90 ppm U_3O_8. This is significantly higher than the 11 to 44 ppm range found in the syngenetic uranium concentrations.

- They have significantly higher concentrations of molybdenum and copper than the syngenetic anomalies.

Sample MLK 109 is interesting because of its high equivalent thorium content of 111 ppm. This sample is very similar to the other epigenetically enriched rocks however, in that it also occurs immediately below a massive, permeable sandstone. It contains significantly less uranium, molybdenum, arsenic, and vanadium than the other epigenetic occurrences, yet its organic carbon content is very high.

Alteration Features. A second line of evidence that uranium moved from a source rock into host rocks of Area A is the existence of alteration features typical of the updip, oxidized interior of Wyoming roll-front deposits. Features such as limb mineralization, solution banding, and limonite staining were observed.

Samples MLK 078, 097, 100, and 109 have been interpreted as representing limb mineralization because mineralization occurs in carbonaceous material that is immediately adjacent to permeable sandstone. For a more detailed discussion, see Uranium Occurrence Reports 16, 18, and 23 (App. C).

Solution banding, a commonly observed feature of altered sandstones in the southern Powder River Basin as far north as the Pumpkin Buttes, was rarely seen in Area A. Solution bands were observed in a massive arkosic sandstone at sample site MLK 107, but they were diffuse and lacked the sharp tonal contrasts of solution bands in the Pumpkin Buttes.

Limonite staining is ubiquitous in Area A. It includes yellow-brown, rusty yellow-brown, and orange-brown colors. In general, this staining occurs as spots and streaks within light- to medium-gray sands. Localized remobilization of iron from ferruginous concretions appears to be a likely explanation in many cases. Oxidation, due to normal surficial weathering of rock outcrops, can impart these limonitic colors on a rock simply by oxidizing indigenous pyrite to limonite. Traces of red hematitic staining were observed at occurrence 16.

If this limonite stain was due to alteration of sandstones by oxidizing solutions moving through Eocene ground-water systems, we would also expect destruction of indigenous carbonaceous material, particularly if the solutions were alkaline. Today, by contrast, carbonaceous material in outcrop is only slightly affected by slow surface weathering in Wyoming's dry climate. At occurrence 16, finely disseminated carbonaceous material is abundant in fine-grained silts and sands near the base of the sand, which also happens to be immediately above a highly mineralized coal. If oxidizing solutions moved through the sand here, they did not significantly destroy the carbonaceous material. In the sand adjacent to the mineralized coal of occurrence 23, however, no carbonaceous material was noted. The sandstone overlying the coal of MLK 109 was barren of carbonaceous material also. Uranium-bearing ground waters were probably not oxidizing enough to completely destroy carbonaceous material.

The red hematitic alteration colors characteristic of the Powder River Basin uranium deposits have not been recognized in Area A. Perhaps altered sands there have been re-reduced or are characterized by limonite rather than hematite staining.

Ground-water Anomalies. Several ground-water uranium anomalies support the idea that uranium moved from a source rock to host sandstones of Area A. Two clusters of ground-water anomalies (Pl. 4) occur in Area A. One is in T. 53 N., R. 80 W.; the other is in Tps. 47 and 48 N., and Rs. 78 and 79 W. Both clusters are characterized by high uranium values and high uranium-to-conductivity (U/CDT) ratios. This latter parameter normalizes uranium for the effects of saline variance. Samples with a U/CDT X 1000 value of greater than 15 are considered anomalous. This value is derived statistically by Texas Instruments, Inc. (1980a, b) for similar geochemical and geologic environments in the adjacent Arminto and Gillette NTMS 2° quadrangles. In those quadrangles, uranium values of greater than 34 ppb U are considered anomalous and values greater than 12 ppb U are considered threshold. These anomalous and threshold values are used in the Sheridan Quadrangle.

The northern cluster of anomalies is in the Double Crossing Creek area. Wells MLK 082 and MLK 083 are about 9 m deep. No depth data is available on the two anomalous Los Alamos Scientific Laboratory (LASL) wells 200759 and 200760 (Morris, 1977). The two BFEC samples, as well as LASL's 200760, are within the narrow flood plain of Double Crossing Creek. Sandstone outcrops were not seen in the area. Although these were among the most highly anomalous waters sampled in the Sheridan Quadrangle, no explanation is readily apparent. Subsurface data (Pl. 9) indicate that they fall near the zone where the fluvial sand system silts out northward. Perhaps this silt-out has affected ground-water flow. The Double Crossing Creek anomalies are taken as supportive evidence for uranium favorability.

The southern cluster of anomalous ground waters falls within a 50-km^2 area in the Coyer Reservoir and Bowman Flat USGS 7 1/2' quadrangles. Several LASL samples (201960, 201964, 201967, 201969, 201971, 201973, 201975) contained 40 to 60 ppb U (Morris, 1977). Of these, we re-sampled 201964, 201971, 201973, and 201975, but our results were all less than 1 ppb U_3O_8 (samples MLK 033 and 186; 036; 037; 185, respectively). We have no explanation for the contradiction in sample results. Sample MLK 038 is the only BFEC sample in the area to yield an anomalous uranium value (61 ppb U_3O_8).

This southern anomalous area falls near the 20% sand isolith on Plate 9 and is near the margin of the main sand trend. The area lies directly "on trend" with a linear belt of mineralization that includes the Irigaray orebody (T. 45 N., R. 77 W., Sec. 5). Oil-well-log coverage is not dense enough in this region to identify the specific Irigaray host sands nor to trace their courses northward into Area A. Detail-drilling patterns around Irigaray, though, suggest a remarkably straight ore trend along a channel margin (Intrasearch, 1977). If this trend continues northward, then the cluster of anomalies in Coyer Reservoir and Bowman Flat quadrangles may indicate roll-front development "down stream" of the Irigaray ore body.

Trace Elements. Nearly all rock samples in Area A that are anomalous in uranium are also anomalous in selenium, molybdenum, copper, arsenic, and vanadium (App. B1). Some samples are also anomalous in antimony, yttrium, zirconium, tungsten, lanthanum, phosphorus, and thorium.

Anomalous amounts of selenium are associated with altered sandstones at Pumpkin Buttes (Sharp and others, 1964); with vanadium, arsenic, and uranium at Irigaray (Noyes, 1978); and with uranium, arsenic, lanthanum, molybdenum, and yttrium in lignites and carbonaceous shales of the Williston Basin. The elements in the Williston Basin are thought to have been introduced from an outside source (Denson and Gill, 1965). Sharp and others (1964) noted that pyrite in mineralized sandstone in the Pumpkin Buttes district contains significantly more selenium than pyrite in barren, unaltered sandstone, which suggests that selenium has been mobilized along with uranium.

Plate 10 summarizes the relationship in Area A rock samples between uranium and various pathfinder elements in carbonaceous shales, coals, and one clinker. Although there are few samples, the graphs suggest a crude positive correlation between uranium and arsenic, selenium, molybdenum, and copper. No correlation was found between uranium and thorium or vanadium.

Abundant chemical analyses are available for Wasatch coals in the Wyarno, SR Springs, Ulm, Bar N Draw and Verona 7 1/2' USGS topographic quadrangles (Culbertson, 1975; Culbertson and Klett, 1975a, b; Mapel and Dean, 1976a, b; Mapel, 1976). These quadrangles are north of Area A and immediately east of the city of Sheridan. Although a few uranium anomalies exist there, the area is generally unmineralized, and lithologies are too fine grained for lateral secretion of mobile elements in ground waters. In 45 coal samples, arsenic averaged 10 ppm; selenium 1.3 ppm; uranium 2.5 ppm; and molybdenum 2.7 ppm. These data indicate that background concentrations of arsenic, selenium, uranium, and molybdenum in Wasatch coals are average for shales worldwide (Krauskopf, 1967) and that the anomalous concentrations of these elements in Area A were therefore most likely formed after deposition of the coals. We conclude that a geochemical province, characterized particularly by anomalous copper, uranium, selenium, arsenic, and molybdenum includes not only the southern Powder River Basin but also Area A. On geochemical grounds, therefore, the favorable uranium environment of the southern Powder River Basin can be extended northward into Area A of the Sheridan Quadrangle.

Precipitants

Wyoming roll-type deposits form at oxidation-reduction interfaces. The redox interface, or geochemical front, is the boundary between the oxidized sandstone and the original, reduced, carbonaceous sandstone. Diagenetic pyrite in the reduced sandstone is oxidized at the front and produces HS^-, which in turn acts as a reducing agent for uranium.

Carbonaceous plant material preserved in original reduced sandstones of the Wasatch Formation is available to reduce and adsorb uranium. Additionally, the strongly reducing environment created by coal beds may precipitate uranium. A particularly advantageous location for this to have occurred is in the northern end of Area A, where the fluvial sands intertongue with thick coal deposits along the basin axis.

Geography and Land Status

Area A is composed of about 85% federal land, 10% private land, and 5% state land. The area is covered by sage and grass and consists of highly dissected uplands. Local relief varies from 60 m to 120 m. The major drainage traversing the area is the Powder River. Interstate 90 crosses the area in its southern half. An excellent system of secondary roads, many serving scattered, small oil fields, provides access to most locations.

AREA B - PRYOR CONGLOMERATE TONGUE OF THE CLOVERLY FORMATION

The Pryor Conglomerate Tongue of the Cloverly Formation is considered favorable for uranium deposits in Area B (Pl. 1). Area B includes the entire outcrop belt of the Pryor sands and their subsurface extent to a depth of 1500 m. The Pryor Tongue is favorable for both Wyoming roll-type (Subclass 241) and channel-controlled peneconcordant (Subclass 243) types of deposits, because it meets the following criteria:

- It consists of permeable quartz sandstones and chert-pebble conglomerates deposited in fluvial channels.
- It was deposited under alternating oxidizing and reducing conditions of a savannah climate.
- The sandstones are interbedded with and overlain by impermeable tuffaceous sediments thought to be a good source of uranium.
- The sandstones contain abundant carbonaceous material that acted as a reductant for uranium.
- It contains solution banding and limb mineralization.

Area B contains an area of 1560 km^2. The Pryor Conglomerate Tongue averages 6 m in thickness throughout Area B, resulting in a volume of 9.4 km^3 of favorable rock. Area B extends from the outcrop belt of the Pryor to where the Pryor is 1500 m deep. Elsewhere, Area B is bounded by the edges of the Sheridan Quadrangle.

Host Rocks

Stratigraphy of the Cloverly Formation. The rocks of Late Jurassic and Early Cretaceous age in the Bighorn Basin have been assigned by various investigators to Morrison, Cloverly, and other formations. In this report, the divisions proposed by Moberly (1956, 1960) are followed. We found them to be consistent with our field observations.

The Cloverly Formation is underlain by the Upper Jurassic Morrison Formation, which is composed predominately of green and gray nonmarine mudstones and shales. The Morrison averages 60 m (200 ft) thick and has a generally conformable contact with the overlying Cloverly, but in places channel sandstones in the basal Cloverly have scoured down into the Morrison (Moberly, 1956).

The Lower Cretaceous Cloverly Formation averages 85 to 100 m (280 to 300 ft) in thickness. It has been divided by Moberly (1956, 1960) into the Little Sheep Mudstone Member, the Himes Member, and the Pryor Conglomerate Tongue (Fig. 3). The Little Sheep Mudstone Member consists of a thick sequence of variegated, bentonitic, lacustrine, mudstone beds, which have weathered a to distinctive popcorn-textured claystone that does not support vegetation. Colors are dominately shades of red and gray, and the lithology varies from claystone to silty mudstone. The clay is mostly montmorillonite (Moberly, 1956). Veins of chalcedony, thin beds of pure bentonite, silicified white ash beds, chert nodules, and layers of quartzite also occur within the mudstone sequence. Thin lenses of sandstone and chert-pebble conglomerate, similar to those in the Pryor Conglomerate Tongue, are almost always found in the lower part of the Little Sheep. The maximum thickness of the Little Sheep is about 75 m (250 ft) (Moberly, 1956) and in most places ranges from 30 m to 60 m. The popcorn-textured, bentonitic mudstone beds are not recognized south of the Sheridan Quadrangle.

A conglomeratic sandstone facies commonly occurs beneath the Little Sheep, at the base of the Cloverly Formation. This conglomerate has been called the Pryor Conglomerate Tongue of the Cloverly (Moberly, 1956). It is similar in lithology and stratigraphic position to the Pryor Conglomerate in the Pryor Mountains. In Area A, the Pryor Conglomerate Tongue tends to be lenticular and cannot be correlated directly to the type section in the Pryor Mountains (Moberly, 1956). Stratigraphically, the Pryor occurs below the Little Sheep Mudstone Member and typically forms channels that cut into the underlying Morrison Formation. Similar conglomeratic sandstone lenses, isolated from the main body of the Pryor Tongue by bentonitic mudstones, are included within the Little Sheep (Fig. 3 and Moberly, 1956).

> According to Moberly, (1956, p, 31), the lithology of the Pryor Tongue ...consists of several related lithologies, the most conspicuous of which is conglomerate containing rounded black chert pebbles. All size gradations of the chert fragments exist from rare pebbles more than one inch in diameter to sand grains. Angular sand and grit-sized grains of white chert are also abundant. These chert grains are mixed in varying proportions with light-yellowish-brown to white quartz sand grains, resulting in rock types ranging from sandstone to pebble conglomerate.

The chert-pebble conglomerate beds are the most distinctive lithology in the Pryor, but field observations indicate that relatively clean, fine- to

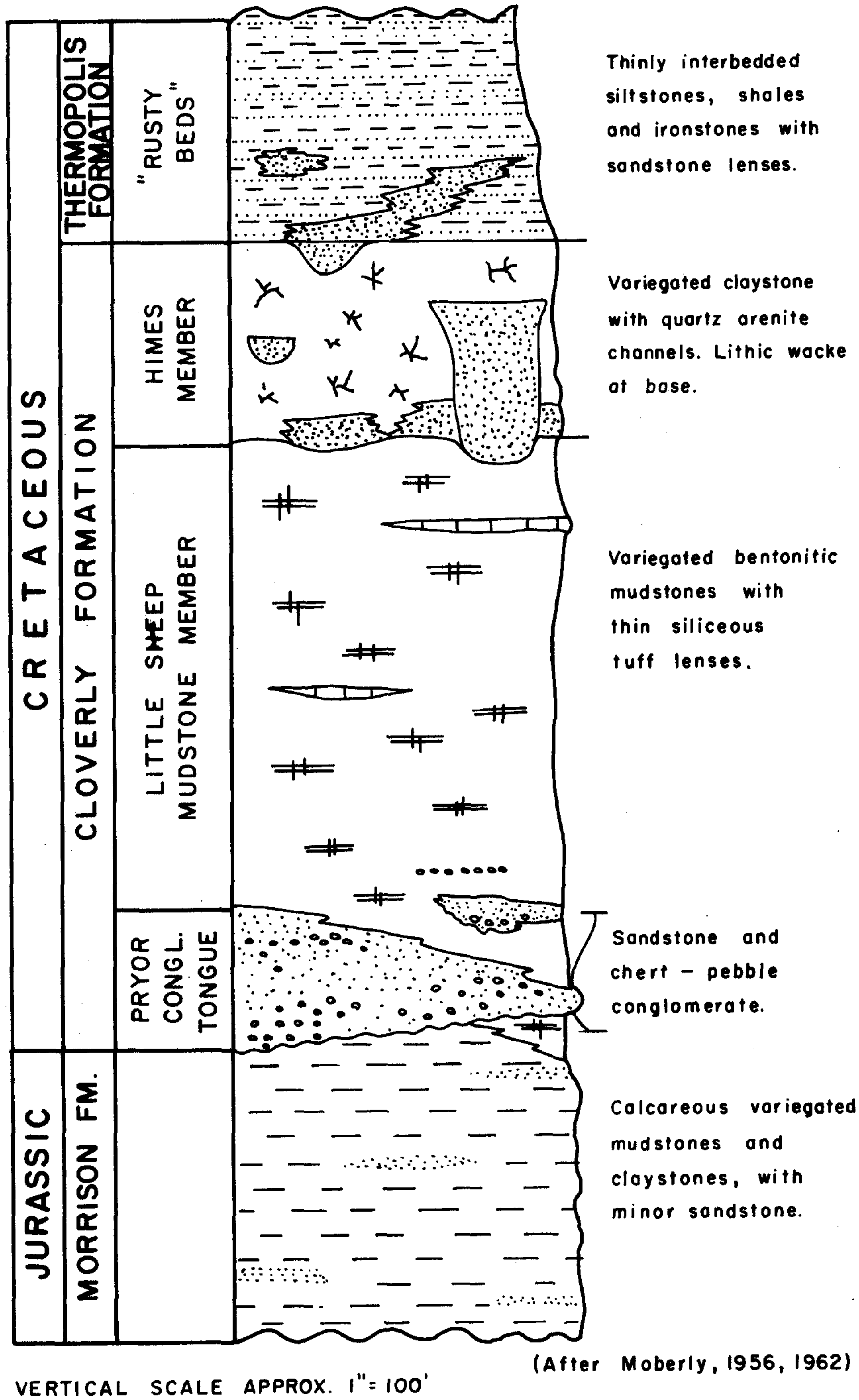

Figure 3. Generalized Stratigraphic Section of Cloverly and Adjacent Formations.

medium-grained quartz sandstone is the dominate lithology. Trough cross-bedding is very common in most all exposures of the Pryor, especially in the coarser-grained beds. Lenses of chert pebbles are often concentrated along the bottom of the cross-bed sets. The chert pebbles in the coarser-grained beds in the Pryor give the rock a distinctive gray color on outcrop; the fine- and medium-grained beds range from yellow-brown to nearly white in color.

Carbonaceous plant remains are interbedded with the sands and conglomerates of the Pryor in many locations. The plant remains are commonly concentrated along bedding planes or as lag deposits at the base of channels.

The Pryor sands are highly permeable. They were deposited by laterally migrating braided streams, and they have relatively good lateral continuity. Therefore, they provide a good medium for the movement of ground water. The sands of the Pryor are generally well sorted within any individual bed, but grain size in adjacent beds may vary from fine sand to pebble conglomerate. The Pryor contains little clay-size matrix to inhibit permeability. Although silica cementation of the sand is common (Moberly, 1956), and calcite cement was observed in a few places (occurrence 21, App. C), field observations suggest that the cementation is not sufficiently extensive to inhibit ground-water flow. The sand bodies are confined by relatively impermeable mudstone beds; thus, the sands are an excellent aquifer for any mineralizing waters, with little chance of dispersion into adjacent beds.

Because of their channel geometry, the sands of the Pryor are quite variable in thickness and in width. Sand thicknesses of up to 30 m of almost uninterrupted clean, fine- to medium-grained quartz sandstone were observed in the field (occurrence 5), and thicknesses of up to 15 m are recorded on subsurface logs (Pl. 11); but most exposures of the Pryor Conglomerate do not exceed 7 m in thickness. Thicknesses may vary widely over short distances. Variations in thickness from 0 m to 7 m or more were observed in distances of a few hundred meters. Examples of the variable sand thickness are described in Uranium Occurrence Reports 15 and 21 (App. C). Due to crosscutting and scouring of one channel by another and lack of exposures of complete channel cross sections, the width of individual channels is difficult to determine. We estimate, however, that most channels are on the order of 10 to 100 m wide.

Overlying the Little Sheep Mudstone (Fig. 3) is the Himes Member of the Cloverly (Moberly, 1956, 1960). The Himes Member consists of about 30 m (100 ft) of claystone, lithic wacke, and thin, lenticular, quartzose channel sandstone. In most places, the base of the Himes consists of olive-gray lithic wacke with a clay matrix, which is overlain by a similar reddish-brown lithic wacke. The upper part of the Himes is mostly claystone, which is laced with thin, shoestring-shaped channel sandstones. Clay in the Himes is predominately kaolinite, in contrast to the montmorillonite in the Little Sheep (Moberly, 1956).

Depositional Environment. The sandstones of the Pryor Conglomerate Tongue were deposited in stream channels in a broad lowland containing many shallow lakes. The streams were probably of the braided type, with velocities of approximately 100 cm/sec (Moberly, 1956). The Pryor sands record periods of uplift in the Sevier orogenic belt hundreds of kilometers to the west in Idaho and Utah, where chert-rich Paleozoic rocks were being eroded (MacKenzie and Ryan, 1962). The sandstones and chert-pebble conglomerates of the Pryor are made up of debris shed eastward during these orogenic pulses. The easterly flow of the streams is supported by paleocurrent measurements of cross-beds in the sands (Moberly, 1956).

The channel sands of the Pryor were being deposited at the same time as the mudstones of the lower part of the Little Sheep Mudstone Member. The mudstones were originally deposited as volcanic ash during periods of intense volcanic activity in the area of present day Idaho (MacKenzie and Ryan, 1962; Mallory, 1972). Large amounts of volcanic ash accumulated rapidly, disrupting the fluvial drainage system and resulting in the development of a vast area of shallow lakes and swamps (Moberly, 1956). Alteration of the ash under the wet conditions of the swamps and lakes resulted in the formation of montmorillonite clay. Volcanic ash is the source of the clays in the lithic wackes and claystones of the Himes Member also. Weathering of the Himes, however, took place under better drainage conditions, and kaolinite was the alteration product of the ash (Moberly, 1956).

A savannah climate prevailed during the time of Cloverly deposition. According to Moberly (1956, p. 88), the savannah climate is "a climate of hot year-round temperatures and moderately high rainfall interrupted annually by a two or three month dry season". The theory that the climate was wet is supported by the large amount of lacustrine mudstones present in the Little Sheep Mudstone and Himes Members. Alternating wet and dry periods is suggested by the variegated colors of the mudstones: the reddish colors are the result of oxidation of the topographically higher muds during dry periods; whereas the gray coloration indicates areas that remained wet and were not oxidized. During periods of uplift to the west, streams cut through these mudstones, depositing the sands of the Pryor Tongue. The main channels probably remained wet year-round and were lined with abundant vegetation. The wet, reducing environment of these trunk streams has preserved much organic material in the Pryor; whereas in the oxidized parts of the mudstones, little or no organic material has been preserved.

Savannah climates are associated with many uranium-bearing rocks in the western United States. A savannah climate is thought to have existed in the Eocene during the time of the formation of the Wyoming roll-type deposits (Bailey and Childers, 1977). Variegated mudstones in the Chinle and Morrison Formations also suggest that a savannah climate existed during the development of uranium deposits on the Colorado Plateau (Trimble and Doelling, 1978).

Structural Development. The tectonic setting of Cloverly deposition was that of a tectonically stable lowland. Slight pulses of uplift in areas marginal to the area of Cloverly deposition resulted in the influx of sand, represented by the Prior Conglomerate Tongue and other sand bodies in the Himes Member. But, overall, the area was tectonically stable during Cloverly deposition. The Cloverly was subsequently buried by thick accumulations of predominately marine sediments deposited during the remainder of Cretaceous time. No significant deformation of the Cloverly took place until the Laramide Orogeny (Fanshawe, 1971). During the Laramide, from Paleocene to early Eocene time, the Bighorn Basin and surrounding mountains were uplifted, and the Cloverly was deformed into a series of folds in the eastern part of the Bighorn Basin. Post-Laramide regional uplift, begun in the Miocene and continuing to the present, initiated a period of erosion that excavated the basin to its present form (Fanshawe, 1971). Plate 7 shows the present-day outcrop pattern of the Cloverly, where it is exposed in a series of folds in the eastern part of the basin.

Uranium Source

Little Sheep Mudstone Member. We consider volcanic ash within the Little Sheep Mudstone Member to be the most likely source for uranium in the Pryor Conglomerate Tongue. The mudstones of the Little Sheep contain some identifiable fragments of tuff and ash (Moberly, 1956); but most of the volcanic material has altered to montmorillonite and is now present in the form of thick bentonitic mudstone. Studies by Waters and Granger (1953) of bentonitic mudstones in the Brushy Basin Member of the Morrison Formation in the Colorado Plateau showed that bentonite was indeed the product of the devitrification of volcanic ash. The bentonite in the Little Sheep is thought to have a similar origin (Moberly, 1956). Several workers have suggested volcanic ash as a possible source of uranium in deposits in Wyoming, Texas, the Colorado Plateau, and elsewhere (Love, 1952; Galloway and others, 1979; Waters and Granger, 1953). Experiments have shown that uranium is easily leached from volcanic glass shards early in diagenesis (Goodell and Trentham, 1980). The late-stage, silicic magmas from which the glass was derived are commonly enriched in uranium (Pilcher, 1978; Henry and Walton, 1978). Uranium contents of 10 to 20 ppm are common for volcanic ash (Goodell and Trentham, 1980). Large amounts of volcanic ash, originally deposited in the Little Sheep, probably contained uranium, even if only in slightly anomalous amounts. Leaching of the ash by ground water would have mobilized significant amounts of uranium during diagenesis (Austin and D'Andrea, 1978). Moberly (1956) has suggested that the ash in the Little Sheep Mudstone Member was altered to clay soon after deposition; this would have freed large amounts of uranium into the ground water, essentially contemporaneous with or slightly later than, the deposition of the Pryor sands. Mobilization of the uranium out of the ash was limited to the time before the ash was completely altered to impermeable montmorillonite. The fact that the source of uranium was effectively sealed off soon after deposition of the ash suggests that any uranium mineralization in the Pryor was initially syngenetic or early diagenetic.

Concentrations of uranium in the Cloverly appear to be spatially related to the areas that contain significant amounts of bentonitic mudstones in the Little Sheep. All uranium occurrences in Area B, along the entire outcrop belt of the Cloverly, are either within or below bentonitic mudstones. Further south, in the Arminto Quadrangle (Damp and Brown, 1980), the lack of uranium occurrences in the Cloverly corresponds closely with the disappearance of the bentonitic mudstones. The close association of uranium mineralization with the mudstones strongly suggests that the mudstones are a likely source of the uranium.

Abundant evidence indicates that the ash of the Little Sheep Mudstone Member has in fact been leached of uranium and other constituents. Silica derived from the devitrified glass has formed numerous veins of chalcedony in the mudstones, and thin sand beds completely silicified into quartzite were observed in several places stratigraphically below the Little Sheep Member (Uranium Occurrence Report 19, App. C). Anomalous radioactivity in carbonaceous zones within the bentonitic mudstones are probably of syngenetic origin and suggest that the source of the uranium was in the ash itself (Uranium Occurrence Report 8, App. C).

White River Formation. An alternate source of the uranium in the Pryor is the ash-rich Oligocene White River Formation that at one time buried most of the Bighorn Basin. The main problem with the White River source is that it was separated from the Cloverly by an unknown, but probably significant, thickness of impermeable sediments of the Wagon Bed Formation. This would have restricted migration of uraniferous waters downward into the Cloverly.

Evidence that Uranium Moved from Source to Host

Mineralization. Abundant evidence indicates that uranium-bearing waters have passed through the Pryor sands, regardless of what the original source of the uranium might have been. The best supporting evidence is the presence of uranium mineralization within and adjacent to the permeable sands and conglomerate beds of the Pryor. Radioactive carbonaceous trash and fossil dinosaur bones are found within the sand beds (similar to mineralization seen in some Colorado Plateau-type deposits), and radioactive zones in shales adjacent to sand beds are common. This pattern of uranium mineralization in shales adjacent to sands is often referred to as "limb mineralization" in roll-type deposits (Bailey and Childers, 1977). Gamma logs of oil wells also indicate possible limb mineralization in the mudstones adjacent to sands (wells 5, 8, 33, 34, 217, and 223, App. D and Pl. 11). Well 22 (Pl. 11; App. D) has a gamma anomaly in a mudstone about one meter above a sand and may indicate a syngenetic concentration of uranium within the mudstone.

Alteration. Solution banding and limonite staining are further evidence that mineralizing fluids have passed through the Pryor sands. Solution banding, consisting of varying shades of yellow, pink, purple, and brown bands crosscutting bedding features, suggests that sands at occurrence 21 are altered. Similar features were also observed at occurrence 9 (App. C). A dark, brick-red staining is often present on the surface of the Pryor sands but coats only the upper meter of the outcrop. Because it does not penetrate the whole rock, the stain appears to be due to surface weathering, unrelated to uranium mineralization. Alteration of the Colorado Plateau type, consisting of reduced zones surrounded by oxidized rock, was not observed in any of the occurrences in the Pryor.

Trace Elements. Elements such as vanadium, molybdenum, selenium, arsenic, and copper, which are closely associated with uranium in other areas, show no correlation with uranium in the Pryor of Area B. Of interest is the anomalous content of several unusual elements found in the samples of dinosaur bone (samples MLK 152 and 166, App. B). In addition to uranium, the bones contained anomalous amounts of lanthanum, strontium, molybdenum, tin, scandium, zirconium, yttrium, niobium, tungsten, and phosphorus. In the case of niobium and scandium, the bones are the only samples in the Cloverly containing these elements in amounts higher than the detection limit of the analysis. High amounts of phosphorus and strontium are perhaps to be expected in bone, but the reason for the high concentration of the other elements is not known. A sample of dinosaur bone from the Morrison Formation from the

Powder River Basin (occurrence 22, sample MLK 44) also showed a similar enrichment in the above elements.

Precipitants

Organic material was probably responsible for the concentration of uranium in the Cloverly Formation. Organic material observed in the field consists of coalified plant remains, humate, carbonaceous shales, and mudstones. Carbonaceous debris, often with identifiable plant remains such as leaves, twigs, and chunks of wood, occurs as lenses within sandstone and shales and in many instances is anomalously radioactive (occurrences 5, 6, 7, 9, 10, 11, 12, 15, 17, 21, App. C). Occurrence 15 contains metatorbernite in carbonaceous trash, which accumulated as a lag deposit in the bottom of a channel incised into mudstone. This is similar to the occurrence of uranium in many of the channel-controlled deposits of the Colorado Plateau (Trimble and Doelling, 1978).

At occurrence 17, anomalous radioactivity is also associated with thin coal seams. Black and dark-brown carbonaceous mudstones and shales are also mineralized in many places, especially where they are adjacent to porous sand beds that may have carried uranium in solution. Examples of anomalous radioactivity in shales adjacent to sands are discussed in occurrences 7, 9, 10, 11, 12, 17, 19, and 21 (App. C). Many of these examples may be limb mineralization, which suggests the possibility of roll fronts down dip.

Anomalous radioactivity also occurs in carbonaceous zones in mudstones and shales isolated from any permeable beds (occurrences 8 and 24). In these cases, the uranium was probably deposited with the mudstone or shale bed and locally reconcentrated by ground water during early diagenesis. Humate, appearing as a resinous brown coating on sand grains, probably acted as a reductant in occurrences 15 and 21. Both of these occurrences also contain abundant mineralized carbonaceous plant remains.

Uranium is concentrated in fossil dinosaur bones at occurrences 9 and 19. The uranium is probably tied up in phosphate minerals (apatite) in the bone, in which uranium substitutes for calcium in the apatite (Jones, 1978). Radioactive carbonaceous trash is also found associated with the fossil bones.

Proposed Model for Uranium Mineralization of the Pryor Conglomerate Tongue

The available evidence seems to indicate that both channel-controlled peneconcordant and roll-front types of uranium mineralization processes have taken place in the Pryor Conglomerate Tongue. We propose the following model for the origin and development of the uranium concentrations.

We propose that the original uranium mineralization in the Pryor Conglomerate Tongue was syngenetic or early diagenetic and was of the channel-controlled peneconcordant type. The source of the uranium was the volcanic ash of the Little Sheep Mudstone Member, which was leached of its uranium during dry periods of the savannah climate. The fact that a savannah climate existed during Cloverly deposition is significant. Bailey and Childers (1977) suggest that the hot, alternating wet and dry conditions of a savannah climate are excellent for the leaching of uranium from source rocks. The leaching of the uranium occurred soon after deposition of the ash and was completed within a geologically brief period of time. After the leaching process, the ash was altered to impermeable mudstone, sealing off the uranium source. The uranium was transported in solution by ground water to low lying areas occupied by braided streams. These areas were perennially wet and contained abundant vegetation. Pockets of decaying vegetation in the channel sands of the streams (Pryor Tongue of the Cloverly) provided excellent sites for the reduction of uranium dissolved in the water.

The development of roll fronts probably did not occur until Laramide time, when the Cloverly and associated formations were folded and uplifted during the formation of the Bighorn Basin. During this time, ground water was again flushed through the uplifted Pryor sands, which had remained relatively undisturbed since deposition and burial. Pre-existing, peneconcordant uranium deposits would have been remobilized and redistributed by oxygenated waters flushing through the rock, resulting in destruction of original tabular ore bodies and creation of roll-type deposits as the oxidizing waters invaded the reduced sands of the Pryor. Tabular deposits that are still deeply buried may not have been affected by this remobilization, and the favorability of the Cloverly for Subclass 243 deposits may be the highest where the rocks are deepest. Tabular deposits may also have been preserved by cementation. This would have rendered the rock impermeable to flushing by oxygenated waters or by faults, which could have isolated the deposits from ground water.

Geography and Land Status

Area B has hilly topography with sparse vegetation. The population is sparse and is dispersed among widely scattered ranches. No major towns exist in the favorable area. Several paved highways and numerous dirt roads provide good access to most of the area.

Land ownership is approximately 80% Bureau of Land Management, 15% State of Wyoming, and 5% private. Most all private land is located along the major drainages. One small U.S. Bureau of Reclamation withdrawal area is located along Nowood Creek between Tensleep and Manderson (Pl. 15).

AREA C - LANCE FORMATION IN PURDY RESERVOIR AREA

Sandstones of the Upper Cretaceous Lance Formation in Area C (Pl. 1) are favorable for Wyoming roll-type deposits (Subclass 241) because they meet the following criteria:

- They are permeable and reduced.
- They are moderately to steeply dipping along the western margin of the Powder River Basin where they were open to ground-water recharge during the Eocene and Oligocene.
- Ground water within them contains anomalous uranium concentrations.
- Lance sandstones immediately south of Area C, in the Arminto Quadrangle, are altered by oxidizing solutions.

Area C encompasses an area of 77 km^2. We approximate 120 m of favorable Lance sandstone, for a volume of 9 km^3. The favorable area has been extended from the Lance outcrop belt to a depth of 600 m. This seems to be the depth limit of mineralization in the Powder River Basin as recorded in the literature. Area C is bound on the south by the edge of the Sheridan Quadrangle. To the north, the boundary between Area C and unevaluated Lance is arbitrary but was drawn to include two anomalous ground-water sample sites within Area C.

Host Rocks

The Upper Cretaceous Lance Formation varies in thickness from 600 m (1,950 ft) to 670 m (2,200 ft) in Area C and is composed of very fine- to medium-grained sandstones interbedded with gray and dark-brown shales (Hose, 1955). Sands vary in thickness from 1 cm to 20 m; they are commonly 5 m thick. The lower 180 m (600 ft) contains dinosaur bones (Hose, 1955).

The Lance Formation was deposited under fluvial conditions by low-energy, eastward-flowing streams. Source rocks were older sedimentary rocks to the west. Childers (1974) suggests that deposition took place under the influence of a tropical and humid climate, as indicated by lack of primary oxidized sediments and by the abundance of carbonaceous material preserved within the sediments. Although Hose (1954) shows a very sandy Lance section in Area C, this could not be confirmed in the field because of a scarcity of outcrops, nor could it be confirmed from electric logs. Similarly, the regional paleodrainage pattern for the Lance has not been described in the literature.

Hose (1955) describes Lance sands as being light gray and grayish yellow, very fine to medium grained, thin to thick bedded, and calcareous in part with shale laminations. Sandstones consist predominately of quartz grains, but also contain minor feldspar, dark-gray to black, translucent to opaque grains, biotite and chlorite. Grains range from subrounded to angular. In the Arminto Quadrangle, Lance sands are very well developed (Damp and Brown, 1980). In T. 45 N., R. 81 W., Sec. 19 for example, 14 km south of Area C, 30-m-thick sand complexes were observed. These sands are fine to medium grained, very clean and porous, and pale to medium yellow-brown with spotty rusty yellow-brown staining.

Beds of the Lance strike northward, along the Bighorn Mountain front, and dip 20° to 25° to the east. The Billy Creek Anticline, which produces oil from the Frontier Formation, is located immediately to the west of Area C. The Lance consistently crops out within 8 km of the steep dip slope marking the eastern escarpment of the Bighorn Mountains.

Uranium Source

The White River Formation appears to be the most likely uranium source for Area C. A reconstruction of Oligocene paleogeography suggests that the Lance subcropped beneath alluvial-fan facies of the Wasatch Formation, similar to that shown in Plate 12 (cross section C-C'). Plate 7 shows that a remnant of the Kingsbury Conglomerate Member of the Wasatch is preserved very near to the northern end of Area C, and most likely overlaid Area C at one time.

Above the Wasatch was the tuffaceous White River Formation. Uranium-bearing ground water from the White River Formation could have moved downward along this basin-margin recharge area, passed through permeable Wasatch sediments, and entered subcropping aquifers of the Lance Formation. By Oligocene time, the Powder River Basin would have been sufficiently compacted, so that meteoric water could move deeply into the basin and could have flushed out the more saline formational waters (Galloway and others, 1979).

Evidence that Uranium Moved from Source to Host

Ground-water and Surface-water Anomalies. Two anomalous artificial-pond water samples and two anomalous ground-water samples were collected in Area C. These are listed in Table 3.

Although the two pond samples (Table 3) were collected where the Fort Union crops out, the ponds are fed by streams that drain areas where Lance subcrops below a thin veneer of terrace gravels. The surrounding country is used for grazing, so contamination of the pond water by phosphates in fertilizer is not suspected.

In an oval-shaped area, which is 6 km to 16 km south of Area C in the Arminto Quadrangle, several water wells that tap ground water in the Lance Formation yielded anomalous samples. These range from 10 ppb to 85 ppb U and are clustered together within an area 8 km long and 1.5 km wide (Damp and Brown, 1980). Since this anomalous area is so close to Area C, it is regarded as supporting evidence for favorability.

Alteration. Altered sandstones were not identified in Area C. However, 16 km south, in the Arminto Quadrangle, fine- to medium-grained Lance sands are altered pink, red, rusty yellow-brown, and maroon and contain solution banding (Damp and Brown, 1980). Additionally, 4 km south of Area C, in T. 46 N., R. 82 W., Sec. 14, a thin zone of red-stained sandstone crops out. This probably-altered sand is in the upper part of the Lance Formation, as mapped by Hose (1954).

Precipitants

The Lance Formation was deposited under reducing conditions and contains carbonaceous trash and pyrite within its sands. Oxidation of indigenous pyrite, due to encroachment of an oxidized tongue of uranium-bearing ground water, would produce HS^-. The hydrogen sulfide would in turn reduce and precipitate uranium along the geochemical interface.

Geography and Land Status

Area C consists of 60% state and 40% private land, all of which is covered by sage and grass. Land use is primarily grazing. In the southern half, topography is fairly gentle, with local relief of about 60 m or less. The northern half mainly consists of the rugged TA Hills, which encompass about 16 km^2 and have local relief of up to 120 m. Access is facilitated on the west by Route 87 and on the east by Interstate 25. The north, middle, and south forks of Crazy Woman Creek drain the region.

TABLE 3. ANOMALOUS WATER SAMPLES COLLECTED IN AREA C

Sample no.		Type	Value (ppb)	Depth
MLK 046		Well	28 (U_3O_8)	45.7 m
LASL*	200974	Well	84.7 (U)	Unknown
LASL	200986	Pond	71.5 (U)	
LASL	200987	Pond	32.3 (U)	

*LASL Samples refer to Morris (1977)

Immediately south of Area C, much of the state and private land is underlain by federally-owned minerals. These minerals have been claimed by mining companies in the areas containing anomalous ground waters and altered sand, as discussed earlier. Closely spaced drilling patterns suggest that mineralization has been found in the subsurface.

AREA D - INTERFINGERING AREA BETWEEN ALLUVIAL-FAN AND PALUDAL FACIES OF WASATCH FORMATION

The Wasatch Formation of Area D (Pl. 1) is favorable for Wyoming roll-type deposits (Subclass 241) and associated uraniferous coal deposits (Class 210) because it meets the following criteria:

- It is the zone in which a permeable alluvial-fan facies intertongues with an impermeable and reduced paludal facies.
- Rocks of Area D were in hydrologic communication with the once-overlying Oligocene White River Formation as well as Precambrian granitic rocks of the Bighorn Mountains. Both of these could have supplied uranium.
- It contains anomalous uranium and other trace-element concentrations.

Area D encompasses an area of 679 km^2 and a thickness of 450 m. The total volume is 306 km^3 of favorable rock. The boundaries of Area D are as accurate as subsurface data will allow. East and west boundaries are drawn to include a generously large zone of interfingering alluvial-fan and paludal sediments. North and south boundaries are drawn to coincide with the central, most highly uplifted part of the Bighorn Mountains block. Further discussion of the northern boundary is supplied later in this section.

Host Rocks

General Statement. Area D is located in the Wasatch Formation along the interfingering contact of a distal facies of alluvial fan deposits and a fine-grained paludal facies that was deposited within the structurally deepest part of the Powder River Basin (Pl. 9). The alluvial-fan system is divided into a lower Kingsbury Conglomerate Member and an upper Moncrief Member; both are in the Wasatch Formation. Basinward, these members lose their lithologic identities as they interfinger with the paludal facies.

Kingsbury Conglomerate Member. The Kingsbury Conglomerate Member consists of 0 m to 240 m (800 ft) of conglomerate, sandstone, and shale (Mapel, 1959). As indicated on Plate 7, it is only recognized immediately adjacent to the Bighorn Mountains. Clasts are subrounded pebbles, cobbles, and boulders derived from Mesozoic and Paleozoic lithologies in the Bighorns, indicating that the Precambrian core of the mountains has not yet been breached. The deposits represent the first significant Laramide uplift of the Bighorn Mountains. During uplift, coarse-grained material was shed and formed a series of alluvial-fan deposits adjacent to the most highly uplifted central segment. Basinward, the Kingsbury grades into the progressively finer sediments of the distal-fan facies. Approximately 13 km eastward from the mountain front, paludal deposits are abruptly encountered.

The Kingsbury Conglomerate is composed mainly of carbonate clasts derived from the Bighorn and Madison Formations. These cobble beds are poorly sorted and interbedded with light gray, medium- to coarse-grained sandstone and greenish-gray siltstone and shale (Whitcomb and others, 1966). Mapel (1959) notes that the conglomerate beds are as much as 6 m (20 ft) thick, and individual boulders are up to 1.2 m (4 ft) in diameter, with most being about 30 cm (1 ft) in diameter. The number and thickness of those beds decrease rapidly eastward. The Kingsbury grades upward into light-gray sandstone and sandy shale. It overlies the Fort Union with a discordance of up to 25° near the mountain front (Mapel, 1959), but this discordance decreases rapidly eastward.

Moncrief Member. The Moncrief Member consists of 0 m to 430 m (1,400 ft) of poorly stratified conglomerate and interbedded lenses of light-gray, coarse-grained sandstone and greenish-gray siltstone (Mapel, 1959). It unconformably overlies the Kingsbury: as much as 60° of discordance have been observed between the two members (Mapel, 1959). It was deposited as a series of alluvial fans immediately adjacent to the central, most highly uplifted segment of the Bighorn Mountains. If the Moncrief once existed elsewhere along the mountain front, it has since been completely removed by erosion.

The Moncrief becomes finer grained down section and eastward. In the upper, coarser part, boulders 3 m to 5 m (10 ft to 15 ft) in diameter are common (Sharp, 1948). Clasts consist of rounded and subrounded pebbles, cobbles, and boulders of crystalline rocks derived from the unroofed Precambrian basement complex. The boulders are granite, gneiss, pegmatite, and diabase. They are commonly 30 cm to 150 cm (1 ft to 5 ft) in diameter, with some exceeding 5 m (15 ft) in diameter (Nelson, 1968). The matrix material is predominately arkosic sandstone and micaceous siltstone, containing small limonitic concretions, stones rich in Fe-Mg minerals, and carbonized woody material. Bedding is absent or crude and irregular (Sharp, 1948). Moncrief crystalline clasts are commonly highly weathered.

Distal-Fan Facies. The area on Plate 7 between the mapped Kingsbury and Moncrief Members and the paludal facies immediately east of Lake De Smet is underlain by the distal facies of the alluvial fans. Some lithologies in the distal facies are fine to coarse grained, but most are medium grained sandstones gradational with the Kingsbury and Moncrief Members. The eastward contact with paludal facies is relatively sharp. Surface outcrops of the distal-fan facies are massive arkosic and micaceous sandstone that correlates with the Moncrief.

Paludal Facies. Plate 12 shows the general stratigraphy of the Wasatch paludal facies. It consists of about 550 m of siltstone, mudstone, coal, and thin sandstone. As reported by Mapel (1959), the thickest coals include the Walters, Healy, and Ucross beds. Above the Ucross, several mappable coal beds exist. Below the Ucross, however, mappable coal beds are scarce. Only one continuous, but unnamed, coal bed was found in well logs below the Ucross (Pl. 12).

Rocks below the Ucross are not exposed in Area D, and very few well logs penetrate the interval. Logs 50 and 51 (App. D) contain very sandy lithologies below the Ucross and indicate a Kingsbury alluvial-fan influence 20 km east of the mountain front. Rocks exposed in Area D include the interval between the Ucross and Walters coals. Most outcrops are clinker-capped hills and very few sandstone bodies are exposed. Shale, coal, and siltstone are the dominant lithologies, as inferred from scattered outcrop data and published lithologic logs (Mapel, 1959).

Coal beds of the Wasatch paludal facies have not been successfully correlated with alluvial-fan lithologies. Mapel (1959) notes, however, that coarse-grained sediments above and laterally equivalent to the Healy coal bed are arkosic. Since the Kingsbury lacks arkosic material, it is logical to place the Kingsbury-Moncrief contact stratigraphically equivalent to the Healy coal.

Tectonic Setting

Nelson (1968) noted that in the Moncrief there is an increase in the percentage of matrix and a thinning in conglomerate beds from the top to the bottom of the member. Sharp (1948) observed an increase in coarseness of gravel upwards, and Mapel (1959) saw that the Moncrief becomes finer grained downward. These observations suggest that the rate of uplift was the most rapid near the culmination of Moncrief deposition, perhaps reaching its climax with over-steepening and thrusting along the Piney Creek and Clear Creek Thrusts (Pl. 12). In the Kingsbury, Mapel (1959) noted that conglomerate graded upward into sand and sandy shale. This suggests that the rate of uplift during Kingsbury deposition was most rapid at its inception. From these observations, it can be deduced that the rates of uplift along the Bighorn front varied through Wasatch time and that, in response to this, coarser grained sediments extended further into the basin during periods of rapid uplift than during periods of relative tectonic quiescence.

An excellent correlation exists between cumulative coal thickness in the paludal facies and the structural axis of the basin (Mapel, 1969; Culbertson, 1975; Culbertson and Klett, 1975a, b; Culbertson and Mapel, 1976; Mapel and Dean, 1976a, b; Mapel, 1976). As indicated on Plate 9, the distribution of mappable coals corresponds very well with the area inside of the 975 m 3,200-ft) contour and indicates a strong structural influence on coal deposition. This trend does not hold in the Lake DeSmet area, however. The coal deposits "climb" up the structural contours, suggesting that at some point during Wasatch deposition the basin axis was even closer to the Bighorns.

Uranium Source

Two possible uranium source rocks are proposed for Area D. These include the Oligocene White River Formation and Archean granites of the Bighorn Mountains. The Moncrief Member is largely composed of deeply weathered, Archean crystalline clasts and may itself be a source.

White River Formation. Following post-Moncrief erosion, a vast blanket of fluviatile sediments was laid down upon the upturned edges of Precambrian, Paleozoic, Mesozoic, and Cenozoic rocks that crop out within and marginal to the Powder River Basin. These fluvial sediments incorporated large amounts of tuffaceous material that originated in the Yellowstone-Absaroka volcanic fields and which was transported eastward by wind and streams. These sediments buried the Bighorn Mountains up to the present day 2750-m (9,000-ft) elevation. Nelson (1968) suggests that Clear Creek, east of Buffalo, was once a major Oligocene drainage. Other deeply incised canyons along the Bighorn Mountains front may have also been excavated in White River time. These include the canyon occupied by Piney Creek and Tongue River Canyon. Several remnants of White River Formation are preserved at the 2750-m (9,000-ft) level in the Bighorn Mountains, as well as at Pumpkin Buttes 80 km to the east. At Pumpkin Buttes, White River sediments occur at the 1830-m (6,000-ft) elevation.

Uranium may have been leached out of tuffaceous material of the White River Formation by meteoric ground water. This ground water could then have entered subcropping recharge areas of the permeable Kingsbury and Moncrief Members.

Archean Crystalline Rocks - in Place, and in the Moncrief Member

Little is known of the uranium content of Precambrian crystalline rocks of the Bighorn Mountains. Reconnaissance sampling in the Edelman Creek Mining District and elsewhere in the Bighorns (occurrences 14 and 20; samples MLK 175, 176, 177, 178, 179, 180, 181; App. A and B1) indicates that anomalous amounts of uranium are incorporated in Th-Si-phosphate minerals and allanite of granite, quartz diorite, quartz monzonite, and granodiorite (App. E).

Arkosic sandstone and conglomerate of the Moncrief Member is typically mafic-rich, which may be important. Minerals such as biotite and hornblende can incorporate significant amounts of uranium within their lattices. Much of this granitic material is also highly weathered, indicating the likelihood that any uranium loosely held along grain boundaries, and possibly within crystal lattices, has been leached and moved by ground water.

Hydrology

The excellent vertical permeability and considerable hydrostatic head within the Moncrief and Kingsbury would allow large volumes of ground water to be pumped down the hydraulic gradient to Area D. The ground-water flow patterns would change with time. If mineralization is Eocene in age, with the Moncrief or Archean granites being the chief source, uranium-bearing ground waters would have entered the Wasatch in recharge areas of the alluvial-fan facies and discharged in the paludal facies, without ever having penetrated the basin very deeply. This is predicted from the hydrologic model for dynamic compacting basins (Galloway and others, 1979). The system would possess good transmissivity and flow rates, but fresh meteoric water would be limited in both vertical and areal extent.

If mineralization is Oligocene or Miocene in age, ground water would have entered in the same basin-margin recharge areas, but would have behaved differently since the basin was then a mature, compacted basin with one hydrologically integrated system (Galloway and others, 1979). Meteoric water would probably have penetrated the basin more deeply than in the Eocene and would have discharged interformationally. This would have allowed for recharge through Fort Union, Lance, and older formations, which subcrop below the alluvial-fan facies.

Evidence that Uranium Moved from Source to Host

Uranium Anomalies. Seven samples with anomalous uranium contents were collected in or very close to Area D (Table 4). In addition, Davidson (1953) reports five uranium anomalies in or adjacent to Area D. These include his samples 27, 30, 33, 34, and 39. Sample 30 is at about the location of MLK 004 and sample 39 is about the location of MLK 048.

Only MLK 209 constitutes a uranium occurrence, but all samples are anomalous when compared with the 3 ppm average uranium content of shale (Krauskopf, 1967). Had the clinkers originally been sand, silt or coal, the average uranium background would have been even lower.

At the locations of the anomalous rock samples, only clinkers crop out; so lithologic relationships could not be compared with the spatial distribution of radiometric anomalies. In most areas, the clinkers have a radiometric background of 15 to 25 UR but range from 1 to 60 UR. MLK 209 gave the highest radioactivity reading of 82 UR. Clinkers are characterized as either hard, brick-red, fused, slatey rock, or black, siliceous, slaggy vesicular material. The black, slaggy material is thought to represent areas of chimney development; here oxygen moved downward to fuel the burning coal. We always found it to be more radioactive than the slatey material.

Trace Elements. The consistently high UR background, particularly in the slaggy clinkers, suggested to us that the process of clinker formation in some way had enriched the baked sediments in radioelements. Similarly, if such a process was operating, perhaps it enriched the clinkers in molybdenum, thorium, arsenic, copper, vanadium, and iron, which are also above background values for shales. In this regard, we sought the advice of James Herring of the Regional Geochemistry Branch, U.S. Geological Survey in Denver, Colorado. Herring informed us that due to their high volatility, arsenic and selenium will be released as a gaseous phase upon the burning of coal. It may possibly be enriched in chimneys by condensation, due to drop in temperature or to entrapment in slaggy material.

Herring further points out that elements such as uranium, copper, molybdenum, vanadium and iron have extremely low volatilities. They should be concentrated in the ashy residue from burned coal and not be mobilized and concentrated in overlying clinkers. However, two possible methods of partially mobilizing refractory elements and concentrating them during coal burning are possible. These include:

- Sorption of refractory elements on particulate matter, which was carried up the chimney where refractories could be trapped by slaggy material or concentrated in soils on the land surface.

TABLE 4. ANOMALOUS ROCK SAMPLES COLLECTED IN OR ADJACENT TO AREA D

Sample no.	Rock type	UR	U_3O_8 (PPM)	Correlative burned coal bed
MLK 003	clinker	59	19	Burgess
MLK 004	clinker	59	12	Healy
MLK 048	clinker	59	16	Walters
MLK 050	clinker	59	9	Walters
MLK 085	clinker	36	14	Walters
MLK 092	clinker	25	7	Healy
MLK 209 (occurrence 4)	clinker	82	77	PK

- Fluxing of refractory elements with alkali elements to lower melting temperature, so that refractories could be mobilized as a fluid.

In the first case, upon burning of the coal bed and carbonaceous material in the overlying strata, refractory elements are released from their organometallic bond as carbon is volatilized. Elements may then become either adsorbed or absorbed on particulate matter and carried upward through the chimney with the smoke. Within the chimney, this particulate matter may become trapped by viscous material undergoing clinker transformation. Herring (personal communication, 1981) notes that, in western North Dakota, uranium is mined by means of burning lignites and thereby concentrating the uranium in the residual ash. He further points out that uranium, molybdenum, and other refractory elements are concentrated in the soil adjacent to the burn operation, probably because of their sorption onto particulate matter.

The second method is undocumented. Herring (personal communication, 1981) notes that iron has been concentrated up to 20 times background in chimney rocks of the Sheridan Coal Field. This may have been accomplished, he notes, by fluxing of iron with alkali elements. The melting temperature of iron may have been lowered sufficiently to allow it to flow. He has observed flow textures in the ironstones that substantiate this hypothesis. One can speculate that uranium, copper, vanadium, and possibly molybdenum, have also been fluxed and mobilized by the same process; though such a process has not been described in the litetature. Both methods, sorption and fluxing, could explain the concentration of refractory elements that we have observed in the black slaggy chimney rocks.

The residual ash of a burned coal will certainly contain concentrated refractory elements, because the amount of refractories in a pre-existing 10-m-thick coal is concentrated in a 1-m-thick residual ash bed after burning. This residual ash zone is difficult to identify in the field because, as the coal burns, overlying rock masses fall into the void. Considerable complicated structural and stratigraphic relationships result. This complexity, plus our inexperience with clinker deposits, leaves open the possibility that some of our anomalous clinker samples may actually contain residual ash that we failed to identify as such.

One rock sample more than any other tends to substantiate the relationship between refractory-element concentration and clinker formation. MLK 112 (Pl. 5a), including both black slaggy and red clinker, contains anomalous uranium, molybdenum, selenium, arsenic, and copper (App. B1). The sample was referred to as supporting evidence of favorability in Area A. Immediately adjacent to the clinkered outcrops of MLK 112, however, is a bulldozed cliff of coal and carbonaceous shales that appears to correlate stratigraphically with the clinker. No interval in the coal and carbonaceous shale contained over 11 UR; whereas the clinker contained 48 UR. This field relationship strongly suggested to us that radioelements were concentrated by burning at this location. Nowhere in Area D, however, can similar field relationships be seen in outcrop.

The above discussion does not conclusively demonstrate that the clinker-forming process has concentrated uranium, copper, molybdenum, thorium, arsenic, and vanadium. We propose that the refractory elements may have been brought into Area D from an extrinsic source and deposited in shales either syngenetically or epigenetically well before clinker formation. Reasons for proposing this include the following:

- This process is fairly simple and has been documented in several Wyoming basins.

- Most of the elements concerned have similar geochemical mobilities in ground waters.

This suite of elements (U, V, Cu, Th, As) is similar to that which is associated with Wyoming roll-front deposits. They may have been leached from a source rock and carried down the hydraulic gradient in oxidizing ground water until reduction and precipitation occurred at depth. Thorium enrichment is problematic: thorium has very low mobility in the near-surface environment. Perhaps the thorium is incorporated in resistate minerals. Selenium, normally included in this suite, has not been enriched; but this may be due to a low-selenium source rock.

Plate 13 shows no correlation between uranium and the other anomalous elements. Perhaps there has been an elemental redistribution due to clinker formation. The original sediment lost its easily volatilized organic carbon during clinker formation (clinkers contain from 0.01 to 0.18% organic carbon); and since the organic fraction would have been most responsible for precipitating (reducing) the element suite, loss of that organic fraction would have made the elements available for local redistribution.

Ground-water Anomalies. Eight anomalous ground-water samples were collected in Area D. These are tabulated in Table 5a. Two anomalous ground-water samples were collected from the Kingsbury or Moncrief Members adjacent to Area D. These are tabulated in Table 5b. These ten samples are considered significant because they exceed the 12 ppb U threshold value established by Texas Instruments Inc. (1980a, b). Anomalous U/CDT x 1000 values (Pl. 4) for several of the above anomalies further substantiate their anomalous character. These ground-water anomalies are considered supporting evidence for favorability.

Anomalous samples MLK 030, 031, and 032 were also collected from surface waters overlying the Kingsbury and Moncrief Members in the Mowry Basin area (Pl. 5b). These samples are suspect because they are from irrigation ditches draining heavily fertilized areas. The Johnson County Extension Agency says that, on the average, 100 lb (45 kg) of fertilizer, high in P_2O_5 and nitrates, are spread per acre (4050 m^2) per year. Phosphate is known to contain trace amounts of uranium, which could be released to ground waters to yield false uranium anomalies.

Precipitants

Assuming that uranium entered Area D via ground waters of the Moncrief and Kingsbury Members, it would be effectively precipitated upon entering strongly reducing rocks of the paludal facies. Uranium could be precipitated either by adsorption on coal beds or by reduction at redox fronts as discussed in Area A. Oxidation of abundant authigenic pyrite in coals would produce hydrogen sulfide, which would in turn reduce and precipitate uranium.

TABLE 5a. ANOMALOUS GROUND-WATER SAMPLES COLLECTED IN AREA D

Sample no.	Type	Value (ppb)	Well depth (m)
MLK 088	Well	17 (U_3O_8)	4.6
MLK 089	Well	22 (U_3O_8)	9.1
MLK 094	Spring	14 (U_3O_8)	--
LASL* 899	Well	16.1 (U)	6
LASL* 390	Spring	29.4 (U)	--
LASL* 889	Well	19.7 (U)	100
MLK 042	Well	12 (U_3O_8)	90
MLK 043	Well	16 ($U_3O_8$0	6.1

*LASL samples refer to Morris (1977)

TABLE 5b. ANOMALOUS GROUND-WATER SAMPLES COLLECTED FROM THE KINGSBURY AND MONCRIEF MEMBERS, ADJACENT TO AREA D

Sample no.	Type	Value (ppb)	Well depth
LASL 391	Well	16.6 (U)	Unknown
MLK 076	Spring	29 (U_3O_8)	- -

Northern Boundary of Area D

The northern limit of Area D is based on the fact that, northward, the alluvial-fan facies are not recognized. They may never have been deposited or may have been eroded in post-Miocene time. The lack of alluvial-fan facies is substantiated by field observations, which indicate that Wasatch lithologies north of Area D are fine grained, silty, and shaly with lenticular sandstone bodies. Although there are uranium rock and ground-water anomalies in the area, none of these can be related to permeable sand systems.

Geography and Land Status

Area D consists of rugged tablelands dissected by deep valleys. Local relief is about 150 m. The area is traversed by Interstate 90 and several all-weather county roads. The land is covered by sage and grass and is used almost exclusively for grazing. Farming is localized along valley flood plains. A major energy company is developing a synfuels project in the Lake DeSmet area. Surface ownership is about 90% private and 10% state. No towns exist.

AREA E - LANCE FORMATION IN THE DAYTON AREA

Sandstones of the Lance Formation near Dayton (Pl. 1) are considered favorable for Wyoming roll-type deposits (Subclass 241) because they meet the following criteria:

- The rocks consist of permeable, fine- to medium-grained lithic arenite.
- The rocks were deposited in a fluvial environment under reducing conditions.
- The permeable sands are confined by impermeable beds.
- The sands occur along the uplifted margin of an intermontane basin, and have a steep hydraulic gradient.
- The sands appear to be altered in outcrop.
- The sands were at one time overlain by tuffaceous sediments, a possible source of uranium.

Area E covers 19.5 km^2 and includes all Lance sandstones to a depth of 600 m. Cumulative sandstone thickness is 40 m, based on an average of 20% sandstone. This translates into a volume of 0.8 km^3 of favorable sandstone contained within Area E.

The boundary, between Area E and areas underlain by unevaluated Lance, was determined by the outcrop of altered sand; north and south of Area E the basal Lance sand does not appear altered. The favorable area was extended downdip to a depth of 600 m. Below this depth, the ground water is most likely stagnant and roll fronts would not be formed.

Host Rocks

The Upper Cretaceous Lance Formation crops out in a narrow band along the west flank of the Powder River Basin. In Area E, it strikes N. 25° W. and dips 35° eastward into the basin. The Lance is composed of sandstones interbedded with carbonaceous shales, siltstones, mudstones, and coals, and conformably overlies the Bearpaw Shale (Fig. 2). The overlying Paleocene Fort Union Formation is lithologically similar to the Lance, but the two formations are not conformable (Dunlap, 1958). The Lance Formation in the Dayton area consists of a 5- to 10-m-thick, fine- to medium-grained, calcareous sandstone at the base, overlying black carbonaceous shale of the Bearpaw Formation. Above the basal sand is a series of interbedded, very fine to fine-grained sandstones, silty sandstones, carbonaceous shales, and siltstones. Electric logs indicate that several 3- to 6-m-thick sandstone beds occur in this sequence, each separated by siltstone, thin sandstone, or shale (wells 111, 112, 134, 140; App. D). The entire formation is reported to be about 200 m (650 ft) thick in the Dayton area(Zakis, 1950).

The basal sandstone is the only Lance sandstone exposed in Area E. It crops out north and south of the Tongue River just east of Dayton (Fig. 4), where it is about 6 m thick. The sandstone is yellow-brown to pink, containing fine- to medium-grained, subangular to subrounded grains of quartz and chert, with minor amounts of plutonic and sedimentary rock fragments. Trough cross-bedding is common. The rock is very calcareous, and in places there are calcite-cemented concretions. In general, however, the rock is porous and not well-cemented.

The Lance Formation records the initial deposition of continental sediments after the withdrawal of the Late Cretaceous Lewis sea (Dunlap, 1958). During Lance deposition in the Powder River Basin, the environment was one "of wide, low, swampy coasts of relative stability through which aggrading streams flowed, depositing sands and silts from the highlands" (Dunlap, 1958, p. 110). The sandstones of the Lance were deposited, under the reducing conditions of a humid, tropical climate (Childers, 1970; Bailey and Childers, 1977), on a broad flood plain by low-gradient, easterly flowing streams.

The source of the Lance sediments was probably sedimentary rocks to the west. The easterly trend of the Lance channel sands, roughly paralleling the present dip of the beds toward the center of the basin, gives the sand beds excellent continuity of permeability in the direction of the present-day hydraulic gradient.

Uranium Source

Tuffaceous fluvial deposits of the Oligocene White River Formation are a potential source of uranium in the Lance. White River channels may have scoured down through the intervening Eocene Wasatch Formation to gain access to the subcropping upturned Lance sands. Such a channel probably existed in Oligocene time along the Tongue River Lineament, a major fault and fracture zone, which cuts northeasterly through the northern Bighorn Mountains and trends directly through Area E (Hoppin and Jennings, 1971). The present course of the Tongue River follows this lineament, presumably because it is a zone of faulted, easily eroded rock. Streams in Oligocene time may have followed the lineament for the same reason.

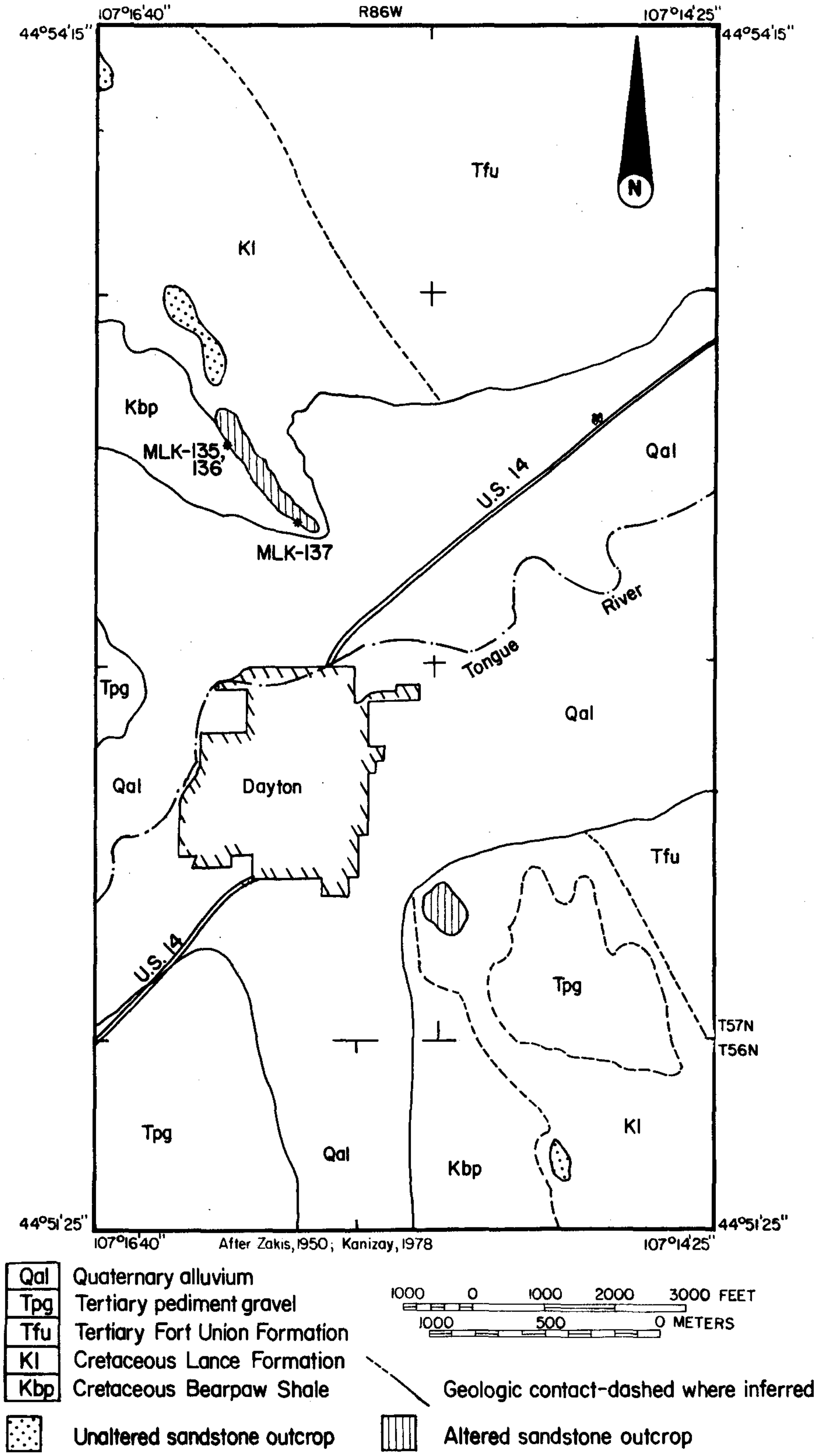

Figure 4. Geologic map of the Dayton area.

Another possibility is that the channels in the White River Formation never eroded all the way through the Wasatch to reach the Lance. Instead, uranium-bearing waters in these channels cut into the Wasatch, infiltrating down to the Lance via permeable sand beds in the Wasatch itself. This process appears reasonable since the Wasatch sediments are often sandy near the front of the Bighorn Mountains.

Evidence that Uranium Moved from Source to Host

Alteration. Alteration features seen in outcrops of sandstone are the most important visible evidence supporting the favorability of the Lance in Area E (Fig. 4). Evidence that ground waters have altered the Lance sands includes solution banding and staining of the originally gray sandstone to pastel shades of pink, red, and purple. The solution bands show a sharp contact between shades of grayish to yellow-brown sandstone on one side (unaltered?) and pink and purplish sandstone on the other (altered?). North and south of Area E, no alteration features were observed in outcrops of Lance sandstone.

The alteration features seen in the Lance at Dayton could be the result of oxygenated waters from the White River channels invading the previously reduced sands of the Lance. The oxygenated waters, oxidizing pyrite to limonite and hematite, produced the alteration colors seen in the outcrops. Migration of the oxidizing waters into the reduced sands may have produced roll fronts downdip.

Trace Elements. Uranium mineralization was not observed in the Lance sandstones in Area E, and samples of altered sandstone did not contain anomalous amounts of uranium or other elements (samples MLK 135, 136, App. B). However, a sample of shale (MLK 137) taken immediately below the altered sand contained 9 ppm U_3O_8, which is two to three times background for shale (Levinson, 1974). Sample MLK 137 also contained 5.46% organic carbon, suggesting that organic material may have adsorbed the uranium. The anomalous amounts of uranium in the shale adjacent to altered sand may be limb mineralization.

Sample MLK 137 also contained 38 ppm selenium, the highest selenium content of any sample taken in the Sheridan Quadrangle, and 28 ppm arsenic, twice background for that element. At occurrence 30 in the Arminto Quadrangle (Damp and Brown, 1980,) high selenium content (68 ppm in sample MJG 136) was associated with uranium mineralization in a Lance sandstone. Selenium was also concentrated with uranium in the Pumpkin Buttes area just outside the southeast corner of the Sheridan Quadrangle (Sharp and others, 1964), and in the Irigaray deposit west of Pumpkin Buttes (Noyes, 1978). Data from Harshman (1974) showed that both selenium and arsenic are associated with roll-front deposits in the Gas Hills and Shirley Basin in Wyoming as well as in Texas and the Black Hills. These data suggest that the anomalous selenium and arsenic content in MLK 137 may be indicative of significant uranium in the Lance Formation in Area E.

Aerial Radiometric Anomalies. The area of altered Lance sand southeast of Dayton (Fig. 4) appears to be the source of an aerial radiometric anomaly (geoMetrics, 1979). This area was closely field checked, however, and no source of anomalous radioactivity was found.

Mineralization Elsewhere in Lance. The possibility that uranium roll fronts may exist in the Lance at Dayton is supported by the existence of uranium in the Lance elsewhere along the margins of the Powder River Basin. The Lance is mineralized in the Pine Ridge area near Midwest, Wyoming (Damp and Brown, 1980). Roll fronts also occur in the Lance on the east flank of the basin in the Moorcroft area. Both of these areas are in structural settings similar to that of Area E.

Precipitants

The Lance Formation was deposited under reducing conditions and contains carbonaceous material and pyrite in the sandstones. Destruction of pyrite by the invasion of oxygenated ground water would release HS^-, which is an excellent reductant for any uranium contained in the water (Granger and Warren, 1978).

Geography and Land Status

The land in Area E is immediately adjacent to the town of Dayton (pop. 400) and contains numerous houses and ranches. The Tongue River flows through the center of the area. All of the land is privately owned.

ENVIRONMENTS UNFAVORABLE FOR URANIUM DEPOSITS

In the Sheridan Quadrangle, unfavorable environments include all Precambrian, Cambrian, Ordovician, Permian, Triassic, and Middle Jurassic rocks; the Thermopolis, Mowry, Cody, Meeteetse, and Bearpaw Formations; the Sundance, Morrison, Frontier, Mesaverde, Lance, Fort Union, and Willwood Formations of the Bighorn Basin; the Wasatch Formation, excluding Areas A and D; and all Oligocene and Miocene rocks.

PRECAMBRIAN ROCKS

The Precambrian rocks of the Sheridan Quadrangle are considered unfavorable for uranium deposits for the following reasons:

- They have low $^{87}Sr/^{86}Sr$ ratios, indicating only slight, if any, contamination of mantle material by crustal rocks.
- They are peraluminous and calc-alkalic.
- They may not be igneous but rather the product of pervasive potash metasomatism. If this is the case, then uranium enrichment was not found to be associated with the metasomatism.

- The only uranium anomalies found were associated with discrete grains of allanite, thorium-silicon-phosphate minerals, monazite, or as primary uranium silicates in pegmatites. There is no evidence to indicate anything more than localized uranium enrichment.

Rock Types

The Archean crystalline rocks of the Sheridan Quadrangle crop out over an area of about 2900 km^2 along the axial crest of the Bighorn Mountains. The major rock types include quartzofeldspathic gneiss; granitic rocks including granite, quartz monzonite, quartz diorite, tonalite, trondhjemite, and granodiorite; amphibolites and diabase dikes; agmatite; and pegmatite dikes.

The granitic rocks predominate in the northern half of the Precambrian complex while gneisses are most abundant in the southern half. Agmatites are mostly concentrated between the two zones (Heimlich, 1969). The remaining rock types are scattered throughout.

Gneiss. Gneisses are quartzofeldspathic, gray, fine to coarse grained, equigranular, and compositionally layered. They have been dated at 3 b.y. (Arth and others, 1980). Osterwald (1959) reports they average 20% biotite plus hornblende and 80% feldspar and quartz. These rocks have been metamorphosed to the almandine-amphibolite facies, staurolite-quartz subfacies (Heimlich, 1969). Locally, augen gneiss is found containing microcline and plagioclase porphyroblasts. Associated with the quartzofeldspathic gneiss are amphibolite, hornblende-biotite schist, muscovite schist (Heimlich, 1969), and, in the extreme south, marble, calc-silicates and iron formation (Palmquist, 1967; Sargent, 1960).

Osterwald (1959), noting the fragmental texture of the gneiss and comparing chemical analyses, suggests the gneisses were originally pyroclastics. Heimlich (1971) includes felsic, plutonic igneous rocks, their volcanic equivalents, or graywackes as likey parent rocks. Trondhjemite gneisses of the Lake Helen 7 1/2' quadrangle are considered to be intrusive in origin, based upon the overall homogeneity of major elements (Barker and others, 1979). They were intruded synkinematically and metamorphosed to the upper amphibolite facies. The gneiss contains plagioclase, quartz, biotite, microcline, hornblende, and iron-titanium oxides and muscovite as accessory minerals. Within the trondhjemite gneiss are quartz-microcline-albite pegmatite bodies interpreted by Arth and others (1980) as having been formed by partial melting of the trondhjemite gneiss. The trondhjemite gneiss has an initial $^{87}Sr/^{86}Sr$ of 0.7001 ± 0.0001. This suggests that it originated from a mafic source, the magmas of which had no significant crustal history (Arth and others, 1980).

Heimlich (1969) summarized that gneisses of the southern terrane average about 54.6% plagioclase, 2.8% microcline, 32.8% quartz, 8.0% biotite, 0.1% hornblende, 0.5% opaque accessories and 1.2% nonopaque accessories. Accessories include apatite, epidote, allanite, zircon, sphene, magnetite, pyrite, and muscovite.

Granitic Rocks. Granitic rocks predominate in the northern terrane and vary greatly in composition and grain size. Barker and others (1979) describe intrusive rocks in the Lake Helen area as being younger than the trondhjemitic gneiss, synkinematic, calc-alkalic and peraluminous, with an initial $^{87}Sr/^{86}Sr$ of 0.7015. These rocks may have been derived from the mantle or by remelting of older gneisses. They are dated at 2.8 b.y. These intrusive rocks in the Lake Helen area include hornblende-biotite quartz diorite, biotite tonalite, biotite granodiorite, trondhjemite, and biotite granite (Arth and others, 1980). They are well foliated.

Heimlich (1971) has mapped quartz diorites and quartz monzonites in the northern half of the Precambrian terrane. These rocks are medium to coarse grained, locally very coarse grained, equigranular, and massive, but locally well foliated. They are peraluminous, differing chiefly in their relative amounts of microcline (Heimlich, 1969). Both rock types contain plagioclase, quartz, microcline, and biotite; accessory minerals include magnetite, ilmenite, apatite, allanite, zircon, sphene, epidote, hornblende, monazite, myrmekite, calcite, and chlorite. Both types contain two generations of plagioclase: an older, altered andesine and a younger, fresh oligoclase. Fresh microcline occurs as interstitial grains and granular aggregates (Heimlich, 1969). Heimlich (1969, 1971) interprets these granitic rocks as having been formed by potash metasomatism of original quartzofeldspathic gneiss, akin to the gneiss described for the southern terrane. Osterwald (1955) first proposed this origin. He cited textural relationships as indicators that potassium feldspar replaced plagioclase and quartz replaced both plagioclase and potassium feldspar. Perthitic and myrmekitic intergrowths support this replacement process. Osterwald (1955) summarized that metasomatic changes involved addition of K_2O, Na_2O, and SiO_2, the loss of FeO, MgO, and MnO, with CaO and Al_2O_3 remaining constant. He also noted that oxidation of Fe^{+2} to Fe^{+3} was an associated process. Heimlich (1969) states that sericitization, chloritization, and the formation of leucoxene suggest that potash-bearing fluids moved through the rocks.

Agmatite. Agmatite consists of angular blocks of gneissic rock enclosed within gray granitic or pegmatitic matrix. The enclosed blocks constitute 10% to 70% of the agmatite and individually range from 5 cm (2 in.) to 2 m (6 ft) in diameter (Heimlich, 1969). Heimlich (1969) notes that both rock types contain plagioclase, quartz, hornblende, biotite and minor magnetite, apatite, zircon, epidote, calcite, chlorite, and microcline. Reconnaissance mapping by Heimlich (1971) shows three large agmatite bodies in the center of the Precambrian terrane intermediate between the northern granitic terrane and the southern gneissic terrane.

Heimlich (1969) interprets the agmatite as an intermediate zone in the progression northward from gneiss to agmatite to quartz diorite to quartz monzonite. This sequence is thought to result from progressively greater degrees of metasomatism northward.

Pegmatite and Aplite Dikes. Pegmatite dikes, usually constituting a volumetrically minor rock type, are a dominant type in the Geneva Pass area, as well as on the west side of Bomber Mountain. As described by Kiilsgaard and others (1972, p. C13):

Pegmatite and aplite dikes intrude both gneissic and granitic rocks in the Bighorn Range. Tabular to lenticular bodies of pegmatite are concordant to gneissic layering at some localities; elsewhere, they cut the layering and the foliation. The pegmatites range in thickness from less than an inch to several feet. Strike length of the dikes varies widely, but normally it is less than 100 feet. In some places, as on the west side of Bomber Mountain, pegmatite dikes are clustered in a swarm large crystal of beryl but no beryl was seen in place. White fine-grained aplite dikes ramify gneissic and granitic rocks and cut pegmatites.

Quartz-microcline-albite pegmatites within the 3-b.y.-old trondhjemite gneiss of the Lake Helen area are interpreted by Barker and others (1979) as being the product of partial melting of the gneiss. They both transect, are conformable with banding, and make up 5% to 10% of the total rock volume.

Osterwald (1955) thinks that the pegmatites were formed by replacement, due to lateral diffusion of material into places of lower mechanical pressure. He notes that some pegmatites are narrow border phases of aplites or form local lenses within aplites. Although both types crosscut each other, most commonly pegmatites cut and offset aplites. Osterwald (1955) observed that pegmatite and aplite dikes are most abundant near the margin of the northern granite mass. We found this to be true from limited field reconnaissance in the Geneva Pass area. Osterwald (1955) further points out that many dikes are subhorizontal and probably formed along subhorizontal fractures related to late-stage cooling of the granite.

Reasons for Unfavorability

Only data of a reconnaissance nature are available for the Archean rocks of the Bighorn Mountains, and conclusions reached by different workers are in conflict. Regional studies by Heimlich (1969, 1971) and Osterwald (1955) suggest that the gneissic terrane was formed by metamorphism of pre-existing sedimentary, volcanic, or igneous rocks and that some of these gneisses were altered to granitic rocks by potash metasomatism. Detailed work in a relatively small area, however, indicates that granitic rocks as well as gneisses are intrusive in origin (Arth and others, 1980; Barker and others, 1979).

If the intrusive origin is accepted and applied to the entire Archean terrane, uranium unfavorability of the granites and gneisses is proposed on the following grounds:

- They are calc-alkalic and peraluminous.
- They have very low initial $^{87}Sr/^{86}Sr$, indicating only a small amount of remelting or contamination by crustal rocks.

If the metasomatic origin is accepted, uranium unfavorability is likewise proposed. No evidence was found to show that the gneisses were uraniferous or that uranium was introduced or mobilized with potassium during metasomatism. Our very limited field work shows that localized uranium enrichments are associated with either resistate minerals in rocks ranging from diorite to granite or with pegmatites (Uranium Occurrence Reports 14 and 20, App. C). No evidence indicates that the resistate minerals were crystallized during metasomatism. Heimlich and Banks (1968), in fact, used zircon morphology to show that quartz monzonite of the northern Precambrian terrane was nonmagmatic. At the extreme southern end of the Archean terrane, in the Horn area, allanite deposits are found in calc-silicate rocks. These were probably formed in situ by regional metamorphism of impure argillaceous dolomite (Sargent, 1960).

GROS VENTRE FORMATION, GALLATIN LIMESTONE, AND BIGHORN DOLOMITE

Shale and carbonate units of the Gros Ventre, Gallatin, and Bighorn Formations are unfavorable for uranium deposits because they lack permeability. Conglomerate beds in the Cambrian units are cemented with calcite. Uranium occurrences are not known in these formations in the Sheridan Quadrangle. Additionally, Kiilsgaard and others (1972) and Segerstrom and others (1976) studied these units in and adjacent to the Cloud Peak Primitive area (Pl. 15) and failed to find evidence of uranium potential.

FLATHEAD SANDSTONE

The Flathead Sandstone is unfavorable because it lacks permeability and reductants. It is composed of 5 m to 15 m of sand and conglomerate deposited in beach, tidal flat, and fluvial environments. Sands are well lithified, highly silica cemented, highly hematite and limonite stained, and lack carbonaceous material. The abundance of purple and red banding in the Flathead suggests deposition under oxidizing conditions or pervasive oxidation.

Thorium-bearing sandstones of the basal Flathead are widespread, and two such sandstones occur in the Sheridan Quadrangle. These include a thorium occurrence at MLK 47 (Pl. 5a; App. B), as well as the Bald Mountain monazite deposit in T. 56 N., R. 91 W. The latter contains ilmenite, monazite, magnetite, and zircon concentrated as a 1- to 3-m- (2.5- to 10-ft-) thick placer resting unconformably on Precambrian rocks (Wilson, 1960). Occurrence X3 (Pl. 2) was not found, but is reported to contain pitchblende mineralization.

PHOSPHORIA, GOOSE EGG, CHUGWATER, AND GYPSUM SPRING FORMATIONS

The Permian Phosphoria and Goose Egg are time-equivalent formations. The Phosphoria, consisting of limestones, red shales, and siltstones, was deposited under shallow-marine to marginal-marine conditions; it is present in the extreme western part of the Sheridan Quadrangle. The Phosphoria grades eastward into the Goose Egg, which consists of red shales, siltstones, and evaporites deposited at or slightly below sea level. Similar redbeds and evaporites were deposited in Triassic and Jurassic time in the Chugwater and Gypsum Spring Formations. All of the above formations are considered unfavorable for uranium deposits for two reasons. First, these formations contain large amounts of relatively impermeable shale and lack suitable host sandstones. Secondly, the rocks were deposited under dominately oxidizing conditions and do not contain reductants required for the precipitation of uranium.

The Phosphoria Formation is known to contain uranium in phosphatic shale beds far to the west in Idaho and Utah. These phosphatic shales are not present in the Sheridan Quadrangle. Because of this, the Phosphoria is not considered favorable for phosphorite uranium deposits (Class 140, Jones, 1978) in the Sheridan Quadrangle.

SUNDANCE AND MORRISON FORMATIONS IN THE BIGHORN BASIN

The Jurassic Sundance and Morrison Formations are considered unfavorable for sandstone-type uranium deposits (Class 240) because they lack adequate sand development and are isolated from a uranium source. The Sundance, which was deposited under shallow-marine conditions, consists of greenish-gray shales, limestones, and glauconitic sandstones. The sandstones, which mostly occur in the upper part of the formation, are often silty and calcite cemented and do not have the permeability necesssary to transmit the large amounts of ground water required for the formation of a uranium deposit. The overlying Morrison Formation was deposited under continental flood-plain, fluvial, and lacustrine conditions. Lithologies in the Morrison are predominately greenish-gray shale and claystone, with minor sandstones, carbonaceous shales, and limestones. The sandstones of the Morrison are calcareous and contain fine-grained matrix material that may inhibit permeability. The sands are lenticular and isolated from one another by impermeable shale beds.

Possible uranium sources for the Sundance and Morrison include the Oligocene White River Formation and the Little Sheep Mudstone Member of the Cretaceous Cloverly Formation. The White River may be ruled out because it was isolated from the Sundance and Morrison by impermeable sediments of the once-overlying Eocene Wagon Bed Formation. Uranium from the Little Sheep Mudstone Member probably did not penetrate the shale beds of the Morrison to reach host rocks in the upper Sundance. However, evidence at occurrence 7 (App. C) indicates that, at least locally, uranium mineralization occurs in upper Morrison sandstones. Because most of the Morrison sands are isolated from the uranium source of the Little Sheep Mudstone by impermeable beds, they are considered unfavorable for sandstone-type uranium deposits.

THERMOPOLIS, MOWRY, CODY, MEETEETSE, AND BEARPAW FORMATIONS

The Cretaceous Thermopolis, Mowry, Cody, and Bearpaw Formations are marine shale units containing few sandstones. The Meeteetse Formation is the nonmarine equivalent of the Bearpaw Formation. It consists of shale, shaly coals, and sandstone. All of the above formations are considered unfavorable for Class 240 uranium deposits, primarily due to the lack of permeability of the shales and the isolated nature of most of the sandstones. In the Bighorn Basin, the lack of a source of uranium is also an unfavorable factor. Details of the lithologies and unfavorable characteristics of these formations are described below.

The Thermopolis shale consists primarily of soft, black shale, with numerous thin bentonite beds. The Muddy Sandstone Member, which occurs in the lower third of the Thermopolis, is a whitish, fine- to medium-grained, marine sandstone that is 3 m to 30 m thick. This sand is surrounded by thick sequences of impermeable shale and is an unlikely host for sandstone-type uranium deposits.

The Mowry is hard, siliceous shale that weathers to a distinctive silvery-gray color. It also contains numerous bentonite beds. One sample of bentonite from the Mowry contained 24 ppm U_3O_8 (MLK 156), but the lack of sandstone and the impermeability of the shales and bentonites make the Mowry unfavorable for Class 240 uranium deposits.

The Cody consists of gray to black, soft, fissile shale, shaly sandstones, and a few thin bentonites. The sandstones, which occur mostly in the upper half of the formation, are fine grained but highly permeable. The Sussex and Shannon sandstones are significant oil producers in the Powder River Basin. They are surrounded by impermeable shales, however, and do not have hydrologic communication with a recharge area.

The Bearpaw is a dark-green to gray marine shale with thin beds of sandstone in the upper part. It does not contain sufficient amounts of sandstone to be favorable for Class 240 deposits. Westward, the Bearpaw grades into the Meeteetse, a non-marine sequence of gray to brown shales, sandstones, sandy clays, shaly coals and a few bentonites (Downs, 1952). The sandstones of the Meeteetse are isolated from each other by intervening shale beds and do not have the lateral continuity of permeability required for favorability. Since the Meeteetse is present only in the Bighorn Basin, it is also unfavorable because it is isolated from a uranium source.

The most likely source of uranium in these formations is the White River Formation, a tuffaceous unit of Oligocene age that once blanketed both the Bighorn and Powder River Basins. In the Powder River Basin, the White River was in hydrologic communication with Cretaceous rocks, via lower Eocene sandstones, only along the margin of the basin; here, the older rocks had been uplifted and bevelled by erosion. In the Bighorn Basin, the White River was underlain by impermeable sediments of the Wagon Bed Formation, preventing uranium from reaching host rocks below.

FRONTIER, MESAVERDE, LANCE, FORT UNION, AND WILLWOOD FORMATIONS IN THE BIGHORN BASIN

The Cretaceous Frontier, Mesaverde, and Lance, and the Paleocene Fort Union Formations all contain significant amounts of permeable sandstones that could be suitable hosts for sandstone-type uranium deposits. The Willwood contains little sandstone.

The Frontier is a marine unit consisting of thick carbonaceous shales and bentonites with intervening sandstones, some of which may be tens of meters thick. These sands are permeable, have good lateral continuity, and are reduced, providing a favorable environment for the formation of sandstone uranium deposits. The Mesaverde contains both marine and nonmarine strata and consists of sandstone, siltstone, shale, carbonaceous shale, and coal. These sandstones are also permeable and reduced, and may reach thicknesses of several tens of meters. The Lance and Fort Union Formations are of continental origin and contain sandstone, siltstone, shale, and coal deposited in fluvial, flood-plain, and swamp environments. Both formations contain significant amounts of permeable sand. The sands are reduced and contain rarbonaceous debris. The Willwood Formation is a basin-fill deposit consisting almost entirely of variegated mudstones and siltstones and containing no significant amounts of sandstone in the Sheridan Quadrangle.

The sandstones in the above formations, though favorable lithologically, are considered unfavorable for Class 240 uranium deposits for two reasons. First, the sandstones did not have access to a source of uranium. The only reasonable source for uranium is the Oligocene White River Formation, which contains large amounts of volcanic debris. However, impermeable beds in the once-overlying Wagon Bed Formation prevented uranium leached from the White River from reaching sandstone host rocks in Paleocene and older formations. Secondly, basin excavation in post-Miocene time has removed all the Oligocene, and much of the Eocene, strata and has deeply eroded Paleocene and older rocks, reducing the probability that uranium deposits would be preserved.

WASATCH FORMATION, EXCLUDING AREAS A AND D

The Wasatch Formation in the Powder River Basin is not considered favorable for sandstone-type (Class 240) uranium deposits outside of Areas A and D. Because the Wasatch Formation is known to contain significant uranium deposits in the Powder River Basin south of the Sheridan Quadrangle, much time was spent investigating it, both in the field and in literature research. Results of these studies indicated that only Areas A and D contained the proper sandstone systems necessary for the development of roll-type uranium deposits. A brief discussion follows that outlines the unfavorable aspects of the Wasatch outside of these areas.

Lithology and Environment of Deposition

The Wasatch Formation outside of Areas A and D is similar to that within the favorable areas, except that the percentage of sandstone channels is significantly less. Field investigations indicate that the predominant rock types are siltstone, carbonaceous shale, coal, and very fine-grained sandstone. Large-scale channel sandstones are conspicuously absent. Outcrops of the Wasatch north and east of Areas A and D have an evenly banded appearance typical of deposition under low energy conditions. The rocks do not show the channel scours and crosscutting channel relationships seen further to the south. Investigation of oil test logs (App. D), as well as dozens of U.S. Geological Survey coal investigation logs (U.S. Geological Survey and Montana Bureau of Mines and Geology, 1973, 1976a, b, 1977; Correia, 1980), also indicate poor sand development outside of Areas A and D. The lithology and sedimentary features suggest that paludal and flood-plain environments dominated Wasatch deposition outside of the favorable areas. These are merely lower energy facies of the same depositional system that formed the favorable sand complexes in Areas A and D.

Reductants and Source of Uranium

Possible reductants and sources of uranium are the same as those discussed for favorable Areas A and D.

Uranium Anomalies

Uranium anomalies were found in ground-water, coal, and clinker samples in the Wasatch outside of the favorable areas. Anomalous amounts of uranium were found in clinker in samples MLK 207 and 209 (App. B1) and in coal in samples MLK 002, 016, and 060 (App. B1). One coal sample (MLK 002) and one clinker (MLK 209) contained sufficient uranium to be considered uranium occurrences (occurrences 1 and 4, App. C). Occurrence 1, which is in a coal, also is associated with an aerial radiometric anomaly located slightly to the south (Pl. 3). Field checking of this anomaly revealed that the source is anomalously radioactive clinker (sample MLK 207). The anomalous uranium in all the above samples appears to be syngenetic; nowhere is it adjacent to permeable sand beds. Clusters of ground-water anomalies near the city of Sheridan, in the northeast corner of the quadrangle (Pl. 4), also indicate local concentrations of uranium. One water anomaly (LASL 201041, Morris, 1977) comes from a sand 60 m (200 ft) deep. Twenty-four hundred meters to the northeast, a gamma-ray anomaly occurs adjacent to a 3-m-thick sand in this same horizon (Hole US-76135, U.S. Geological Survey and Montana Bureau of Mines and Geology, 1977). Another significant gamma-ray anomaly was reported in a U.S. Geological Survey coal exploration hole in sec. 14, T. 56 N., R. 77 W. (Robert Hobbs, personal communication, 1980); however, it was in a shale adjacent to a coal and was not associated with any sand beds.

Discussion and Conclusions

Despite the existence of uranium anomalies and two uranium occurrences, the Wasatch, exclusive of Areas A and D, is not considered favorable for Class 240 uranium deposits. None of the anomalies can be related to permeable sand complexes, which are of primary importance in the formation of sandstone-type deposits. Also, the favorable characteristics of the adjacent Areas A and D cannot be traced into the portions of the Wasatch designated as unfavorable. Favorable Area A cannot be enlarged because of the lack of sandstone channel development further north and east. The interfingering zone between the coarse-grained mountainward facies and the flood-plain and swamp facies of the Wasatch, the favorable environment of Area D, cannot be extended northward, because it has either been removed by erosion or never existed.

WHITE RIVER FORMATION AND UNDIFFERENTIATED MIOCENE ROCKS

The Oligocene White River Formation and undifferentiated Miocene rocks, both of which at one time covered large areas of the Sheridan Quadrangle, have been almost totally removed by erosion. The White River and Miocene rocks are now preserved only as isolated remnants high in the Bighorn Mountains. These remnants are too small to have potential for the minimum size and grade uranium deposit required for the NURE program. Additionally, they were all deposited under oxidizing conditions and lack reducing agents necessary to precipitate uranium.

UNEVALUATED ENVIRONMENTS

MADISON LIMESTONE, TENSLEEP SANDSTONE, AND AMSDEN FORMATION

The Mississippian Madison Limestone is mineralized in the Pryor-Little Mountain Mining District, which lies immediately west of the northwest corner of the Sheridan Quadrangle. We decided the best possibility of favorable environments in the Madison was, therefore, in this northwestern corner. We devoted three weeks attempting to evaluate that area and time limitations did not permit us to look elsewhere.

The Madison, Amsden and Tensleep Formations form a group of marine, near-shore, and fluvial deposits up to 480 m thick in the Sheridan Quadrangle (Fig. 2). The Madison Limestone consists almost entirely of limestone and dolomite, varying in thickness in the Sheridan Quadrangle from 60 m to 300 m. Carbonates were deposited on the continental shelf adjacent to the Cordilleran Geosyncline. Thin evaporites in upper Madison carbonates probably represent emergent conditions. Epeirogenic uplift of the Cordilleran foreland initiated post-Madison erosion. Evaporitic beds were leached from the upper part of the Madison and an extensive karst topography developed. Subsidence allowed the advance of the Amsden sea, resulting in the deposition of the Darwin Sandstone Member of the Amsden Formation over the irregular Madison surface. These sands represent beach, offshore-bar, and fluvial deposits. Overlying the Darwin Member are cyclic sequences of siltstones, shales, and carbonates deposited during eastward transgression of the miogeosynclinal sea onto the Cordilleran platform. In total, the Amsden Formation attains thicknesses of 60 m in the Sheridan Quadrangle. The Pennsylvanian Tensleep Sandstone conformably overlies the Amsden Formation. It was also deposited on the Cordilleran platform and varies from fine- to medium-grained, cross-bedded sandstone to carbonates in the eastern half of the Sheridan Quadrangle. The Tensleep varies from 30 m to 120 m thick.

Laramide uplift of the Bighorn Mountains formed large-amplitude drape folds adjacent to the uplift. Folds of lesser amplitude are common out in the Bighorn Basin. Many of these fold systems have been tensionally jointed, or faulted, as in the Pryor Mountains. Laramide uplift also lowered the ground-water table so that the karst system in the Madison was re-excavated, particularly along the joint and fault systems discussed above. The result of this re-solution of the Madison was the development of an excellent ground-water system with through-going permeability.

From Eocene to Miocene time, the Bighorn Basin was filled, first by sediments shed off the adjacent mountain uplifts and later by stream and wind-borne tuffaceous sediments derived from volcanic centers in the Yellowstone-Absaroka region of northwestern Wyoming. Pre-Eocene topography was buried up to an elevation of at least 2700 m (9,000 ft) (McKenna and Love, 1972), but Hart (1958) feels that the highest parts of Big Pryor and East Pryor Mountains (elevation of 2400 m) remained slightly above the highest level of the aggraded fill deposits. Tuffaceous sediments, which may have contained anomalous uranium concentrations, directly overlay pre-Eocene rocks and may have contributed significant volumes of ground water to fault- and joint-associated permeability trends of the Madison Limestone.

Small-amplitude anticlines of the Little Mountain District are associated with uranium mineralization (McEldowney and others, 1977). Similarly, the Cottonwood Creek Anticline nearby has been prospected intensively for uranium. These fold systems merge and trend into the Sheridan Quadrangle just south of Little Mountain. This area, where the folds trend into the Sheridan Quadrangle, should be a likely place to find uranium mineralization.

To this end, we field checked prospects in the area of interest and succeeded in finding uranium mineralization at two such prospects, identified as occurrences 2 and 3 (App. A). Field reconnaissance of Madison outcrops elsewhere in the northwest corner of the quadrangle yielded no anomalies. Terrain is extremely rugged, and a thorough search was impossible under the circumstances. Much of the Madison did contain karst zones, however. The problem was in identifying the extent, if any, of Laramide reopening of pre-Amsden karst features. Neither extensive cavern systems, as seen at the Little Mountain District, nor brecciated fault zones typical of the Pryor District, are known in the northwest corner of the Sheridan Quadrangle.

Occurrences 2 and 3 proved to be very interesting. Although both are in the Tensleep Sandstone, they lie directly "on-trend" with structures of the Little Mountain District and occur along the drape fold that marks the western extent of the Bighorn uplift. Occurrence 3 is of special interest; the uranium is associated with quartzite formed by replacement of limestone by cryptocrystalline silica. The silica was most likely derived from once-overlying tuffaceous sediments. Secondly, occurrence 3 is 2417 m above sea level. In the Pryor Mountain District, massive silica-replacement of limestone is encountered at an elevation of 2377 m at the Old Glory Mine. It seems highly significant that silicification and uranium mineralization occur at similar elevations at occurrences that are located 50 km apart. McKenna and Love (1972) indicate diagrammatically that in this particular area, the Eocene (Wagon Bed Formation?)-Oligocene (White River Formation) contact may be placed at about 2400 m above sea level. Perhaps impermeable Wagon Bed sediments forced ground waters of the overlying White River Formation to move laterally into subcropping permeable conduits of the Madison Limestone. Mineralization at lower elevations would have to depend on more complex ground-water flow patterns, perhaps involving Oligocene channeling or basin-axis recharge.

The Madison, Tensleep, and Amsden are unevaluated in the Sheridan Quadrangle; although, the Little Mountain structural trend extends into Sheridan, where two uranium occurrences in the Tensleep are found. Cavernous plumbing systems, as seen throughout the Pryor-Little Mountain area, are yet to be found in Sheridan. McEldowney (1971) demonstrated the usefulness of electromagnetics for delineating these underground systems, but no such surveys were available. Geophysical data and helicopter support are necessary to properly evaluate this geologic environment.

SUNDANCE, MORRISON, CLOVERLY, FRONTIER, MESAVERDE, AND LANCE FORMATIONS OF THE POWDER RIVER BASIN EXCLUDING AREAS C AND E

The Sundance, Morrison, Cloverly, Frontier, Mesaverde, and Lance Formations all contain permeable sandstones that crop out on the western flank of the Powder River basin. Sundance, Frontier, and Mesaverde sandstones are predominately near-shore marine in origin; Morrison, Cloverly, and Lance sands are mostly fluvial, with some Morrison sands being eolian.

In the Buffalo-Lake DeSmet area (Pl. 16), the Sundance Formation is 85 m (280 ft) thick (Mapel, 1959). It contains a basal sandy zone that is about 10 m thick. The Morrison Formation is about 55 m (180 ft) thick and includes only lenticular beds of fine-grained sandstone (Mapel, 1959). The Cloverly is about 50 m (155 ft) thick in the same area and contains 10 m (30 ft) of thick, basal, fine- to coarse-grained sandstone (Mapel, 1959). Near Buffalo, the Frontier is about 150 m (500 ft) thick and contains several deltaic sandstone beds (Mapel, 1959). These sandstones are thin, fine-grained, and interbedded with shale almost everywhere. The Mesaverde contains the 220-m-thick (720-ft-thick) Parkman Sandstone Member, most of which is composed of fine-grained sandstone (Mapel, 1959). The Lance varies from 200 m thick near Sheridan to 600 m thick south of Buffalo. It contains several fluvial sandstone units, particularly in the basal part (Mapel, 1959).

These sandstones once subcropped below either mountainward facies of the Wasatch Formation or directly beneath the White River Formation along the basin margin. They all are reduced, at least in part. On these grounds, they might be favorable for uranium deposits. Time did not allow us to investigate any of these units, however, and they are therefore left unevaluated.

FORT UNION FORMATION IN THE POWDER RIVER BASIN

The Fort Union Formation consists of interbedded siltstone, sandstone, shale, and coal deposited under fluvial and paludal conditions. It underlies all of the Powder River Basin but is poorly exposed. In most places, the Fort Union is buried beneath up to 500 m of Wasatch Formation. Exposures of the Fort Union are confined to the area from Sheridan west to the Bighorn Mountains, in badlands adjacent to the Powder River in the extreme northeast corner of the quadrangle, and in a narrow band of steeply dipping outcrops parallelling the east flank of the Bighorns. The only information available outside of these areas of outcrop is from well logs.

Because of time limitations and few exposures, outcrops of the Fort Union were examined in only a few places. Exposures along the Powder River in the northeast corner of the quadrangle, and in the vicinity of Goose Creek and the Tongue River north of Sheridan, show good channel-sand development in several places. These sands are interbedded with siltstones, carbonaceous shales, and coal. Most of the Fort Union along the Bighorn Mountain front was not investigated due to time restraints; moreover, much of it has been buried by debris from the Piney Creek and Clear Creek Thrusts. Fort Union exposed along the mountain front near Area C was commonly shaley and did not contain significant amounts of sandstone.

Subsurface data indicate that significant thicknesses of permeable sandstones exist in both the Tongue River and Tullock Members of the Fort Union. In many places, however, the Tullock and Tongue River sandstones lie at depths of over 500 m, and roll-front deposits are not known to occur at such depths elsewhere in the Powder River Basin. Scattered gamma-ray anomalies in the logs suggest that there is a possibility of roll-fronts at such depths, but the available data is not sufficient to place the deeply buried Fort Union sandstones in either the favorable or unfavorable category.

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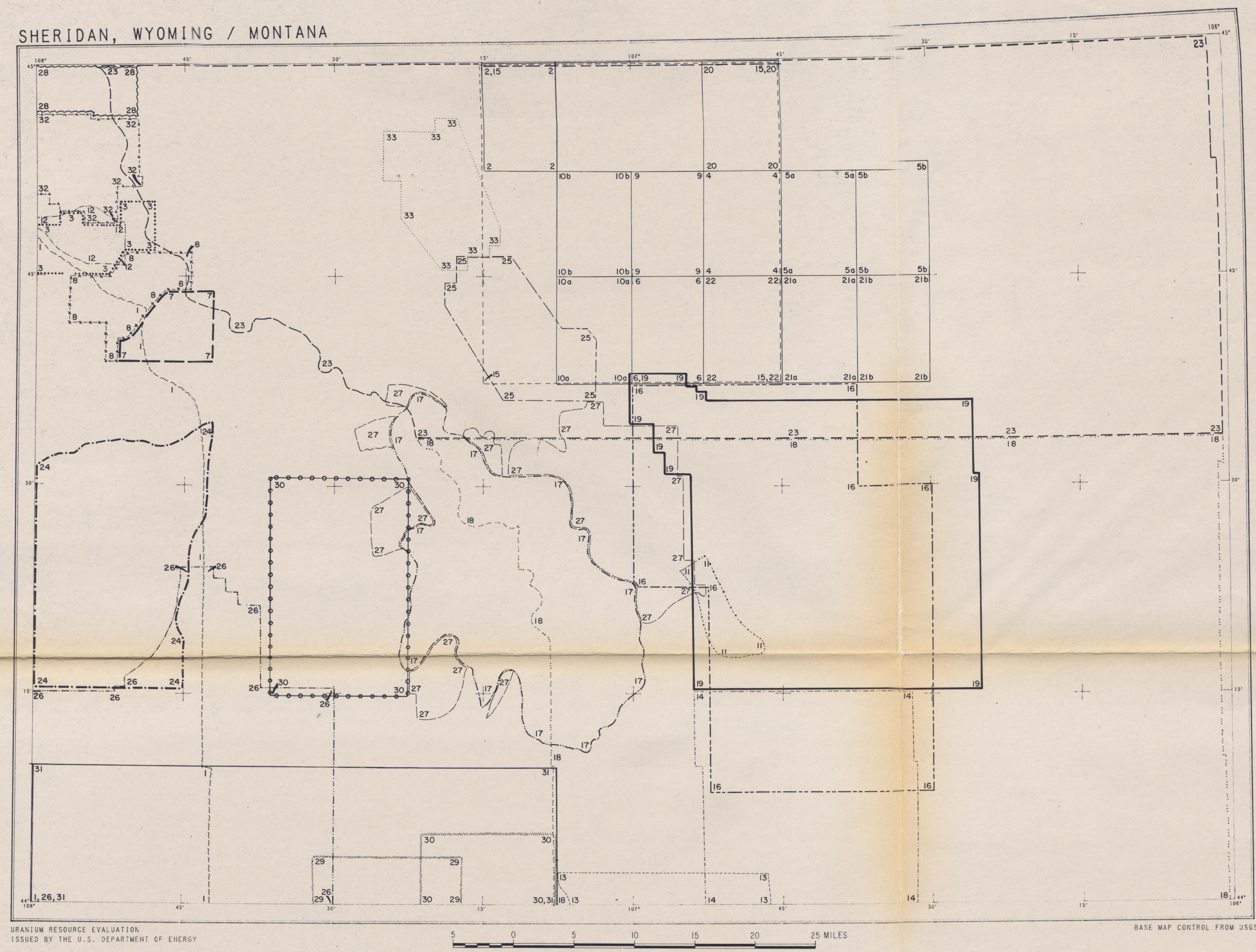

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19. Mapel, 1959, scale 1:48,000.
20. Mapel, 1976, scale 1:24,000.
21a,b. Mapel and Dean, 1976, scale 1:24,000.
22. Mapel and Malahy, 1976, scale 1:24,000.
23. Morgan, 1937, scale 1:126,720.
24. Pierce, 1948, scale 1:48,000.
25. Ramsay, 1955, scale 1:24,000.
26. Rogers, Richards, Conant, Vine and Notley, 1948, scale 1:48,000.
27. Segerstrom and Weisner, 1976, scale 1:63,360.
28. Taucher, 1953, scale 1:21,120.
29. Trotter, 1953, scale 1:21,120.
30. Vietti, 1977, scale 1:48,000.
31. Weitz and Love, 1952, scale 1:187,500.
32. Willis, 1953, scale 1:20,000.
33. Zakis, 1950, scale 1:31,680.

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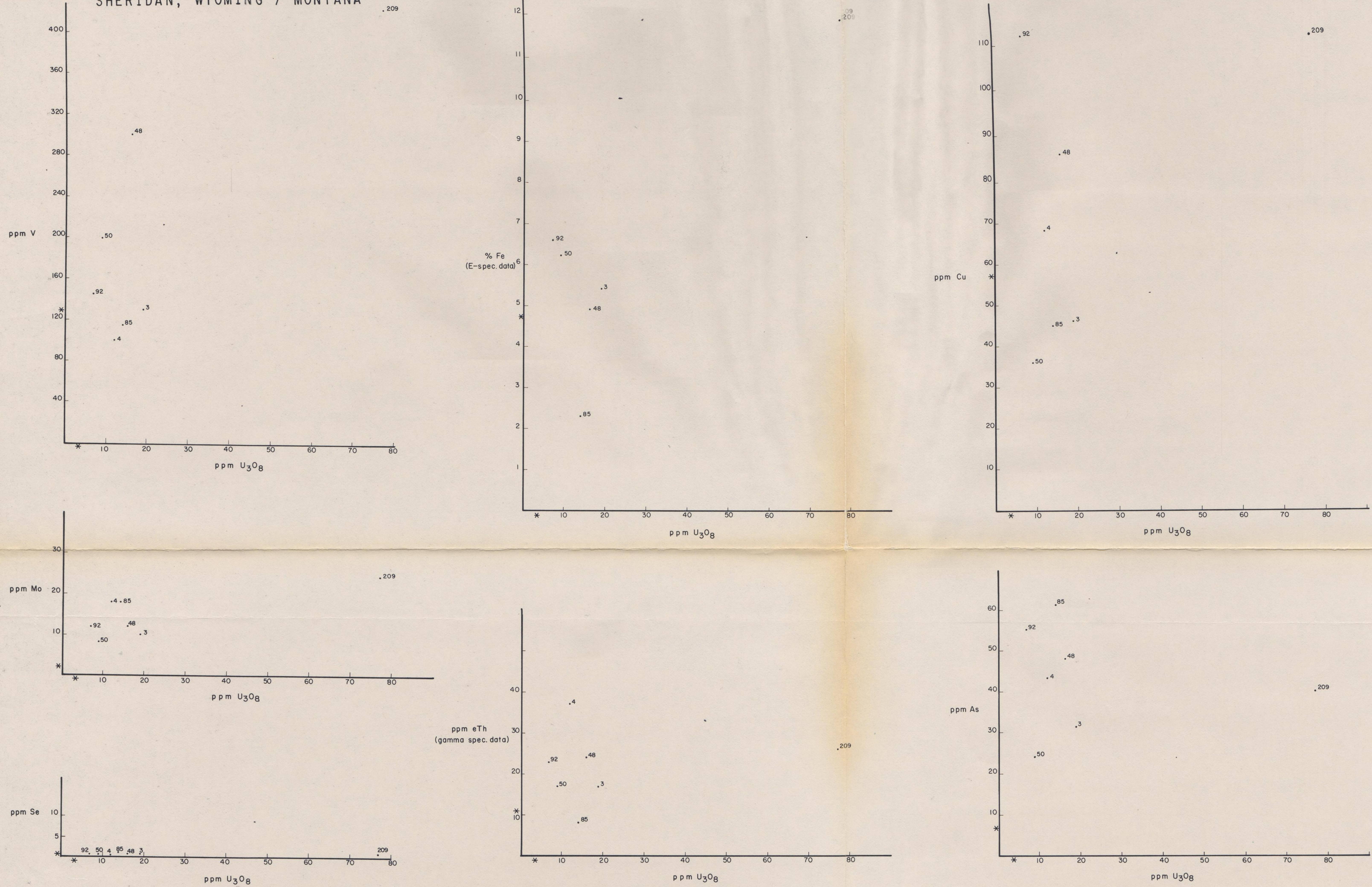


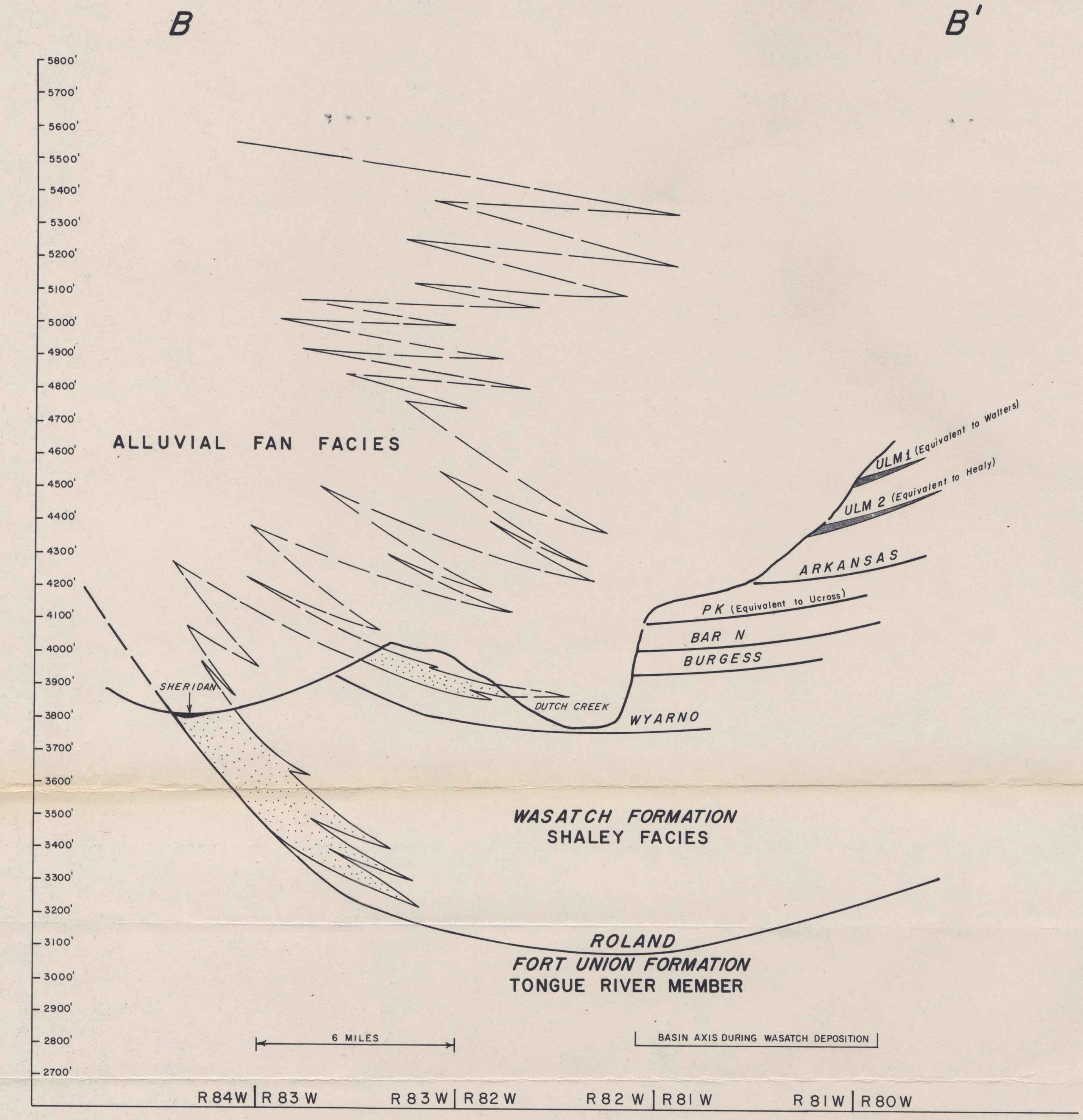
Asterisks Along Axes Indicate the "Average" Concentration of the Particular Element in Shales, as Reported by Krauskopf. (1967)

Sample Numbers Have MLK Prefix.

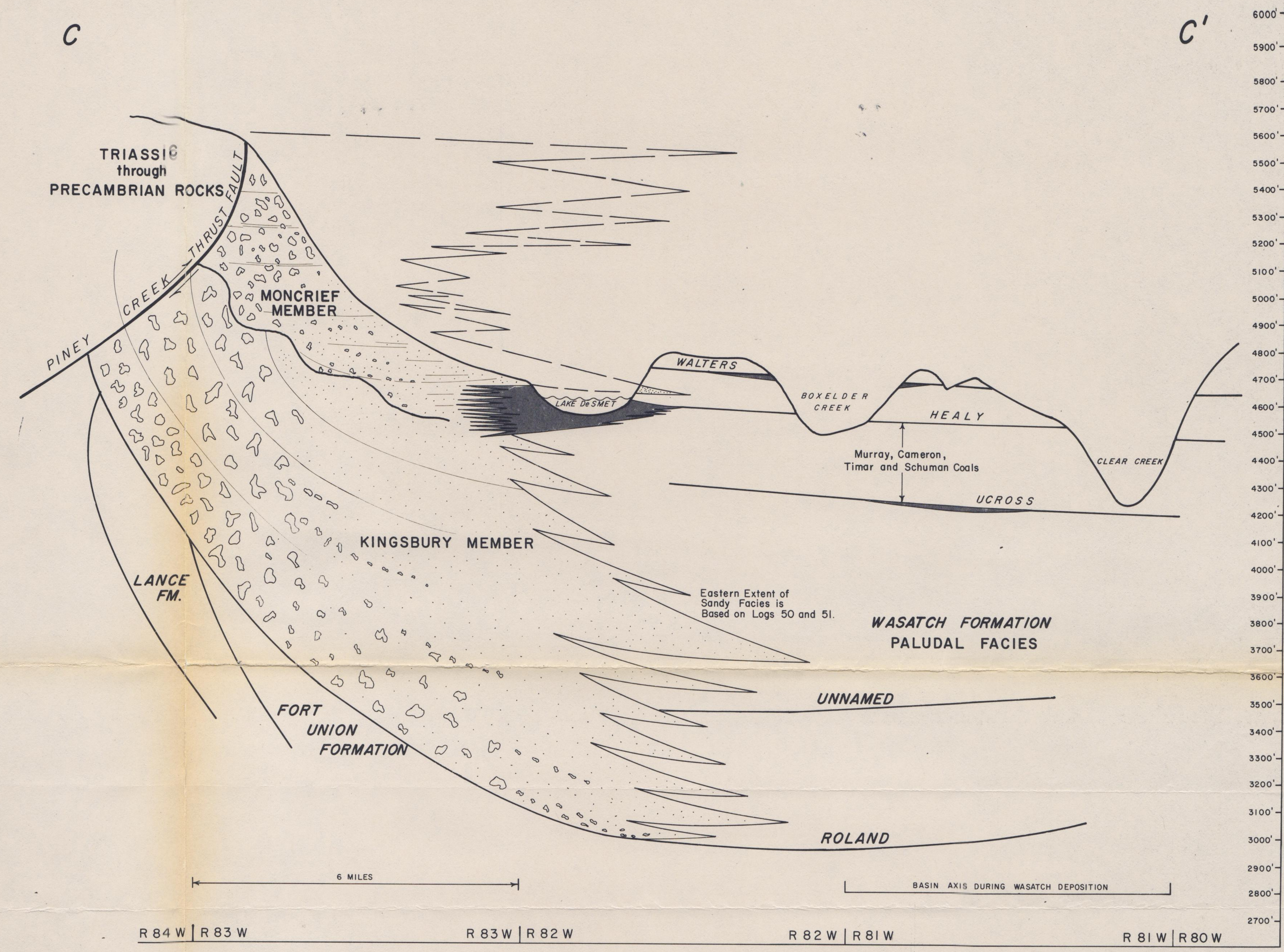
Plate 13. RELATIONSHIPS BETWEEN URANIUM AND VANADIUM, MOLYBDENUM, SELENIUM, IRON, THORIUM, COPPER AND ARSENIC IN ROCK SAMPLES OF CLINKERS COLLECTED FROM AREA "D"

Plate 13.

SHERIDAN, WYOMING / MONTANA



A. CROSS SECTION THROUGH THE SHERIDAN AREA SHOWING STRATIGRAPHY OF WASATCH FORMATION AND HYPOTHETICAL RELATIONSHIP OF ALLUVIAL FAN FACIES.



B. CROSS SECTION THROUGH THE LAKE DeSMET AREA SHOWING STRATIGRAPHY OF WASATCH FORMATION IN AREA D.

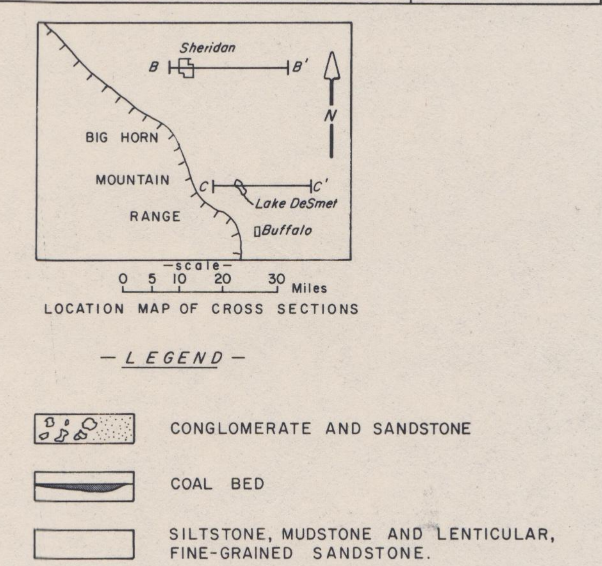


Plate 12. IDEALIZED EAST-WEST CROSS SECTIONS SHOWING WASATCH STRATIGRAPHY ALONG WESTERN MARGIN OF POWDER RIVER BASIN

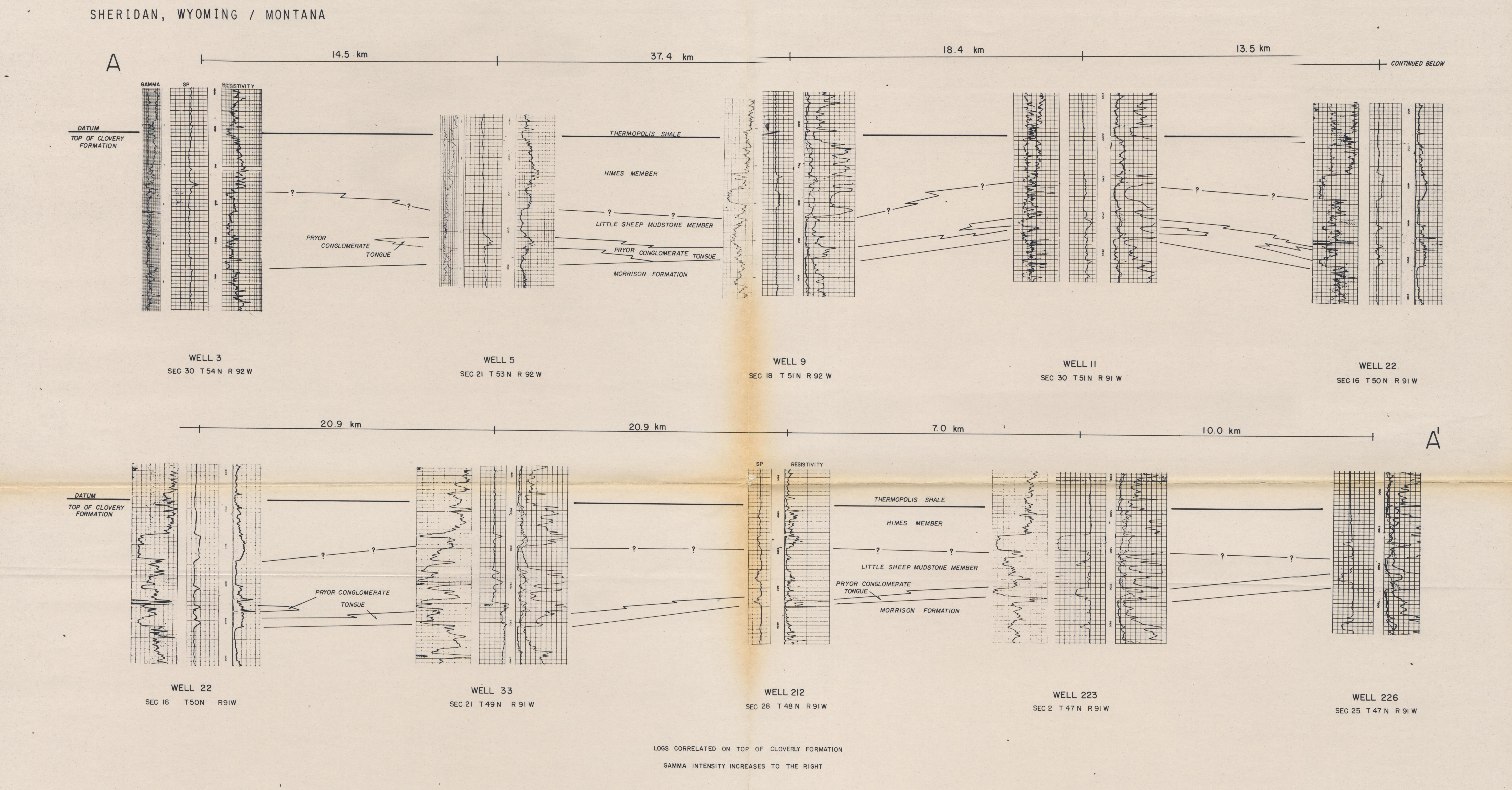
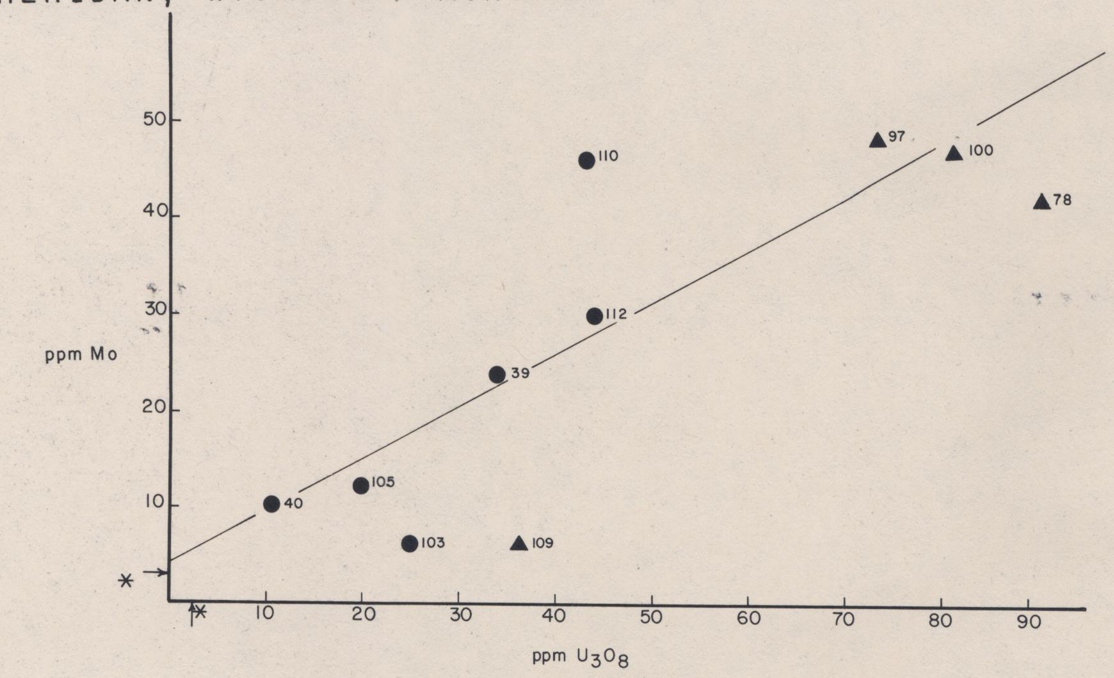
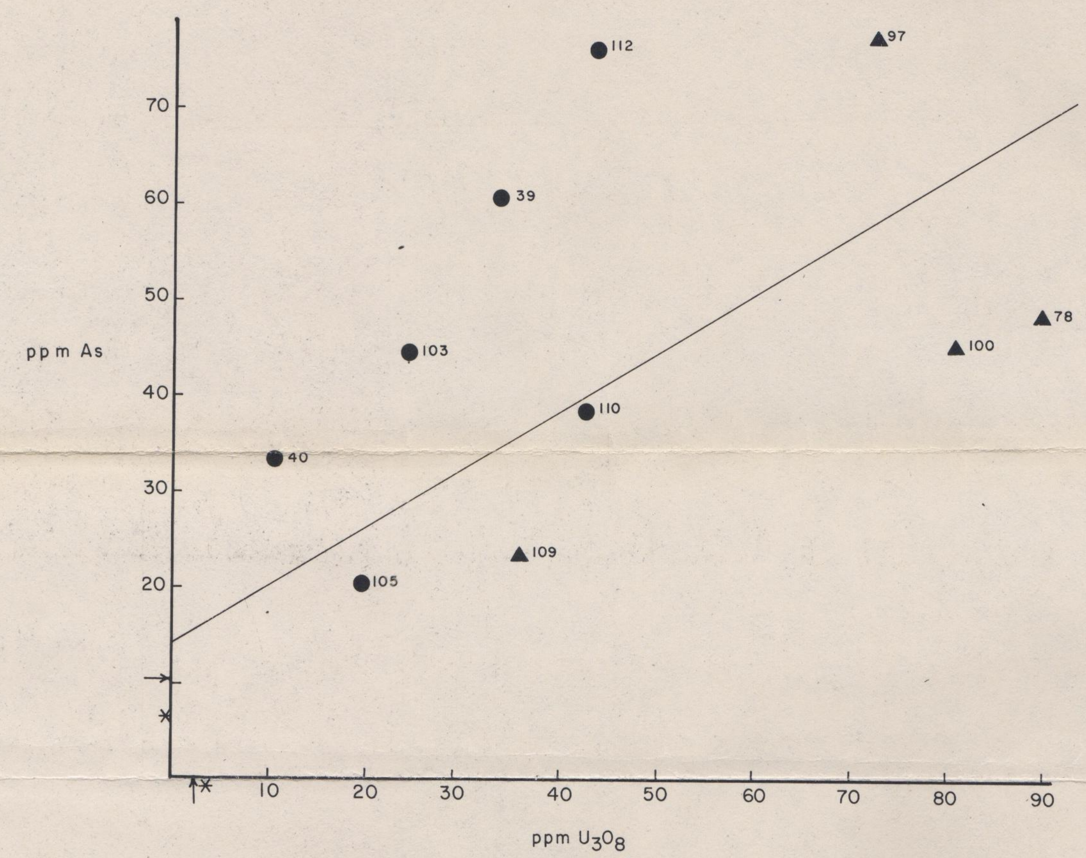
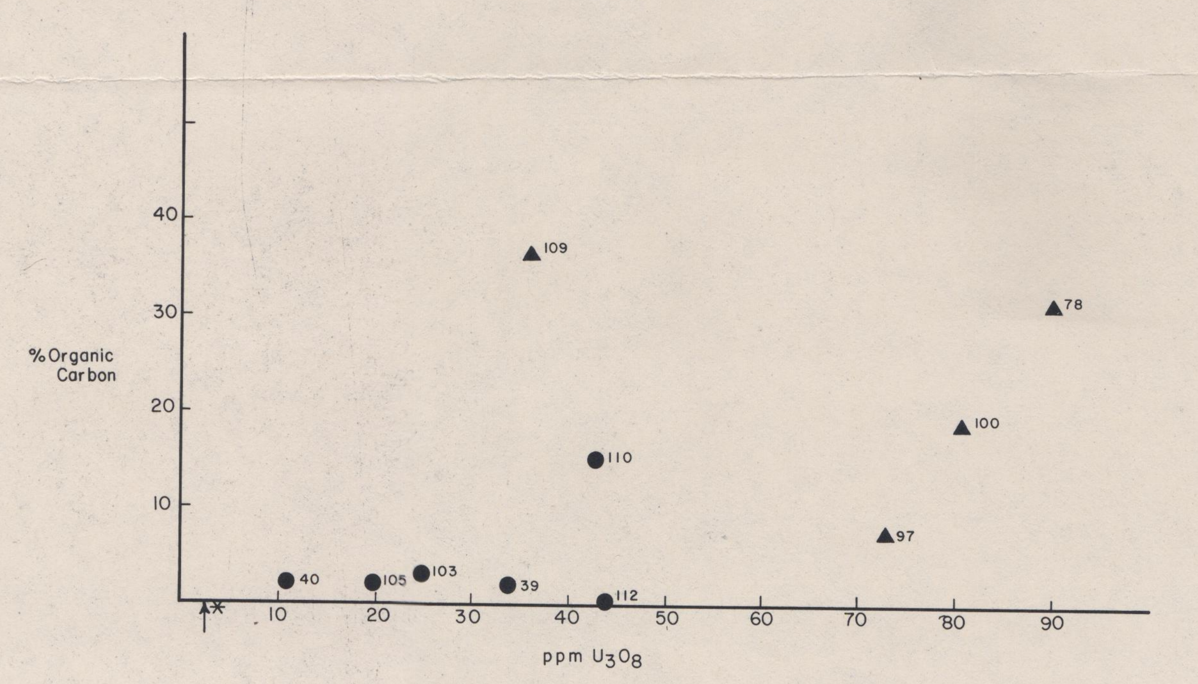


Plate 11. CROSS SECTION OF CLOVERLY FORMATION IN BIGHORN BASIN SHOWING RADIOMETRIC ANOMALIES





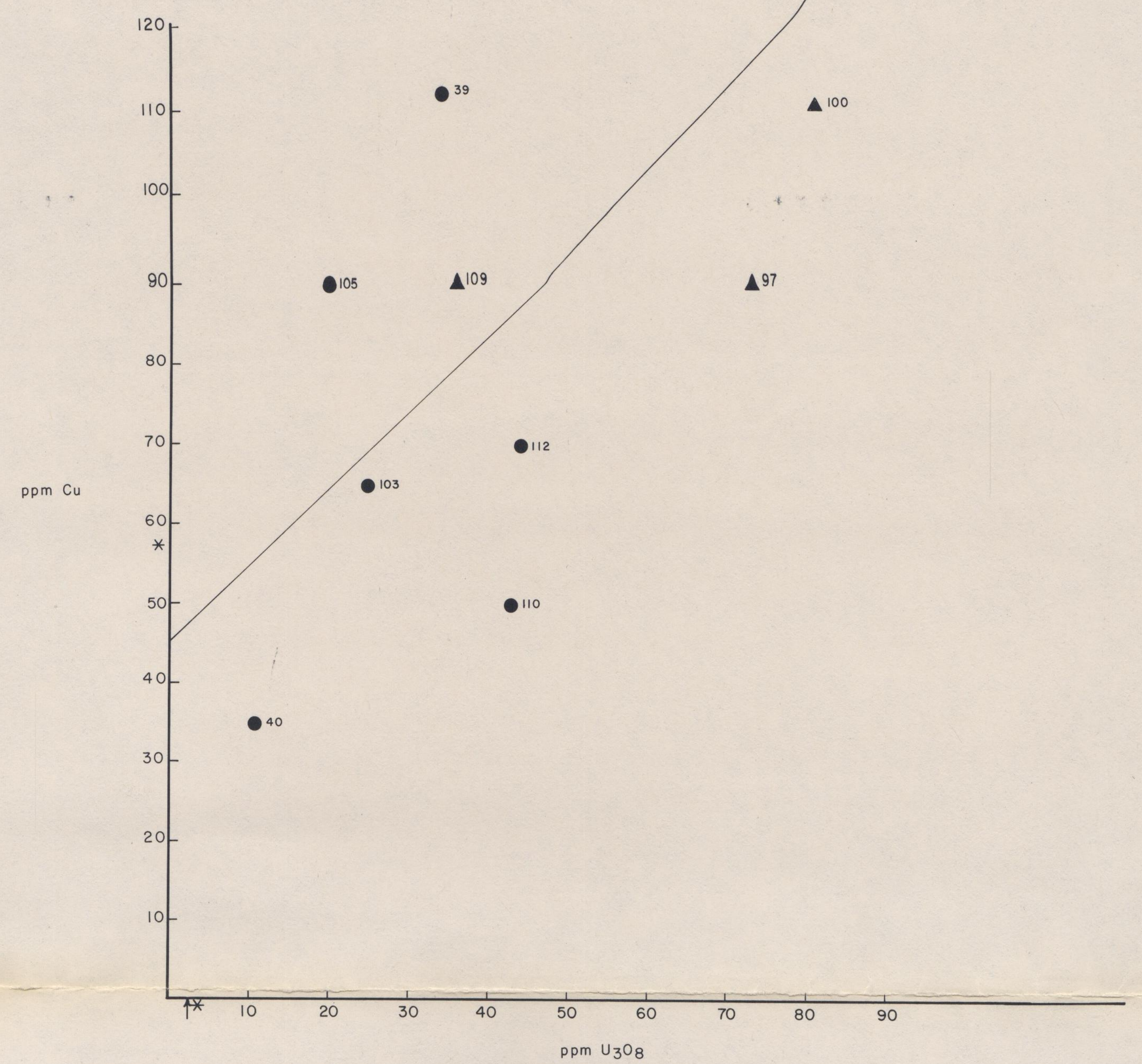


● "Syngenetic" Uranium Concentrations.
▲ "Epigenetic" Uranium Concentrations.

Arrows Along Axes Indicate the Average Concentration of the Particular Element in Northern Powder River Basin Coals, as Reported by Culbertson (1975); Culbertson and Klett (1975); Mapel (1976); Mapel and Dean (1976 a,b).

Asterisks Along Axes Indicate the Average Concentration of the Particular Element in Shales, as Reported by Krauskopf (1967)

Solid Line is Suggested "Trend" of Correlation.



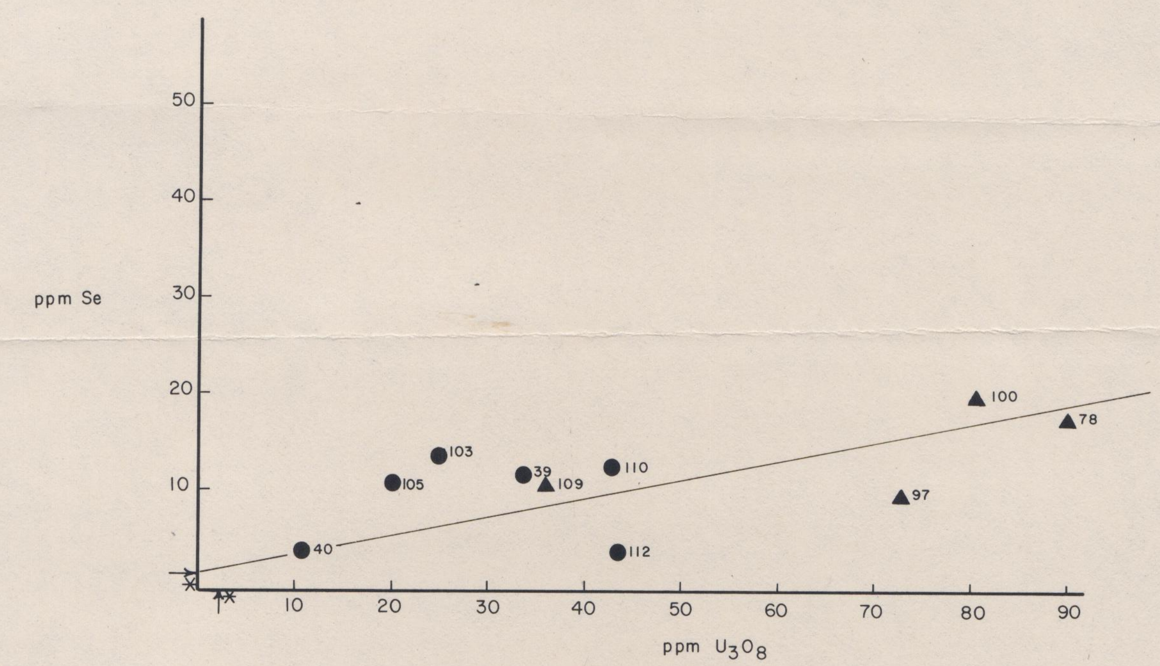
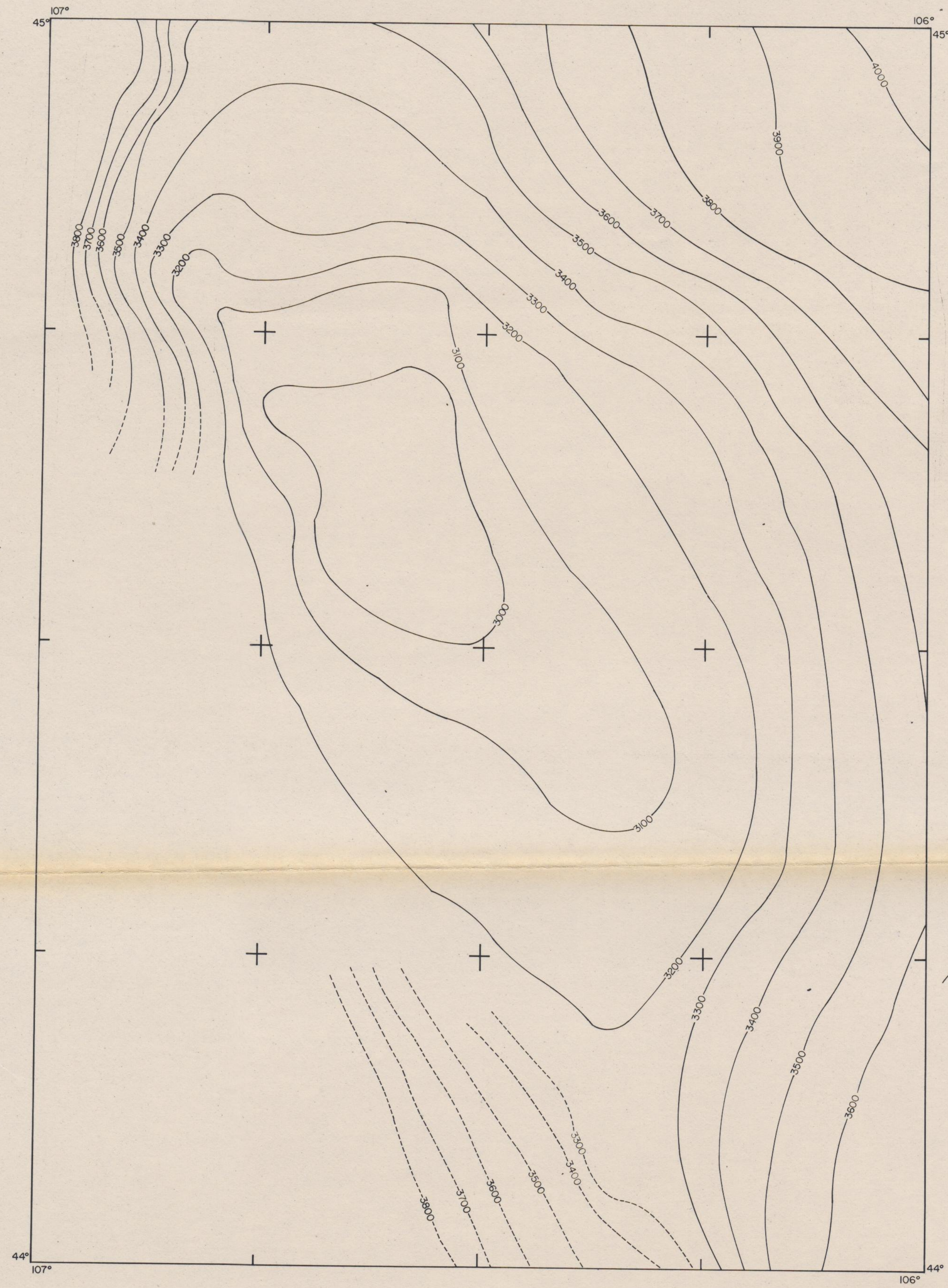
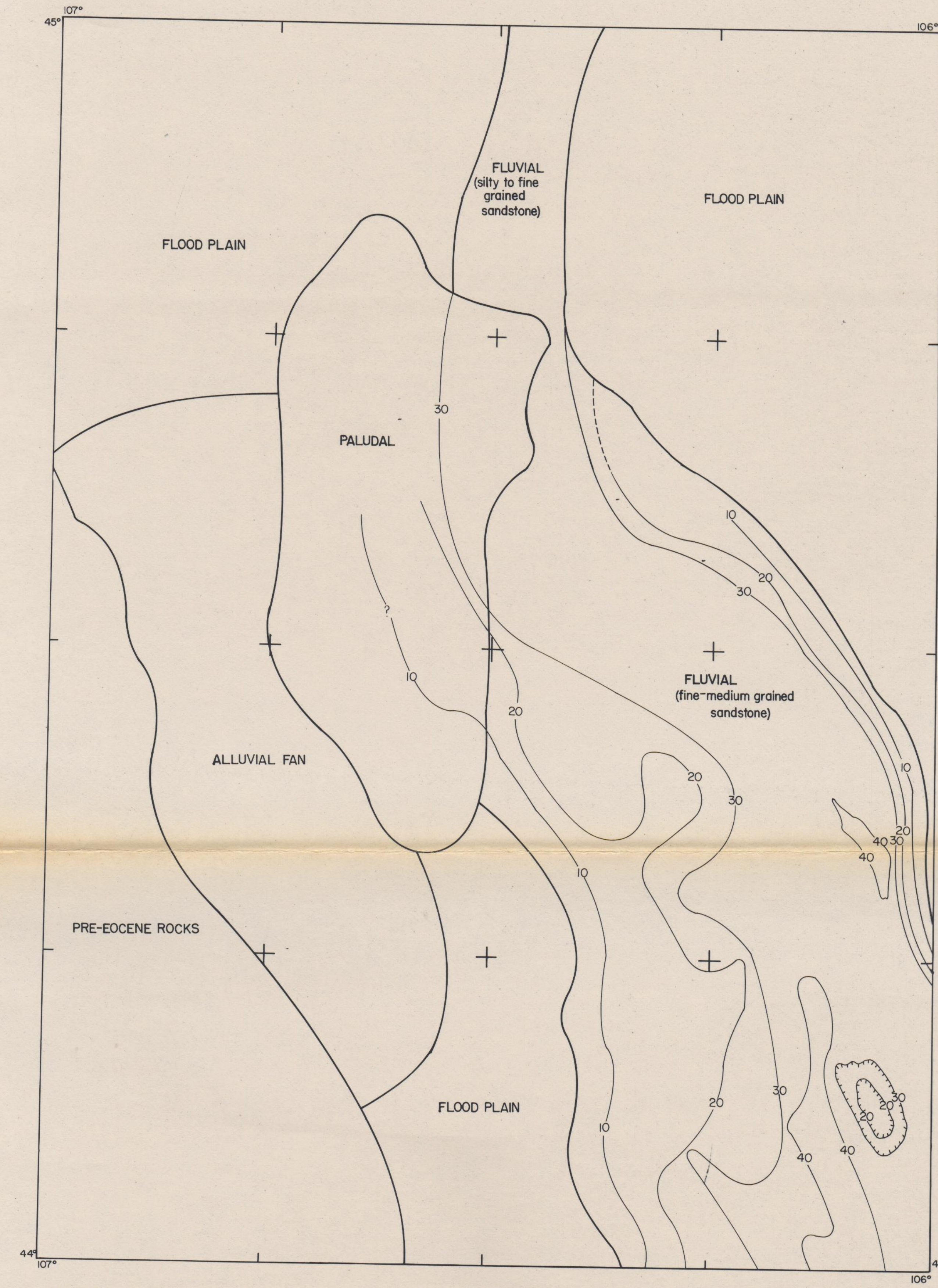


Plate 10. RELATIONSHIPS BETWEEN URANIUM AND MOLYBDENUM, ARSENIC, COPPER, SELENIUM AND ORGANIC CARBON IN ROCK SAMPLES COLLECTED FROM AREA "A".



3100 Elevation (in feet above sea level) of Wasatch-Fort Union contact. Dashed were inferred.

In northern half of map, data is partially based on published stratigraphic correlations of Culbertson, 1975; Culbertson and Klett, 1975a, b; Mapel, 1976; Mapel and Dean, 1976 a,b; Mapel and Malahy, 1976; and/or published geologic maps of Kanizay, 1978; and Love, Christiansen, and Earle, 1978.



20 20% Sandstone in Wasatch Fluvial Facies

Distribution of Paludal Facies is based on published coal thickness and reserve estimates of Culbertson and Mapel, 1976 and Mapel, 1959.

5 0 5 10 15 20 25 MILES

5 0 5 10 15 20 25 KILOMETERS

Plate 9. STRUCTURAL CONTOUR AND FACIES MAPS OF THE WASATCH FORMATION, EASTERN HALF OF THE SHERIDAN QUADRANGLE

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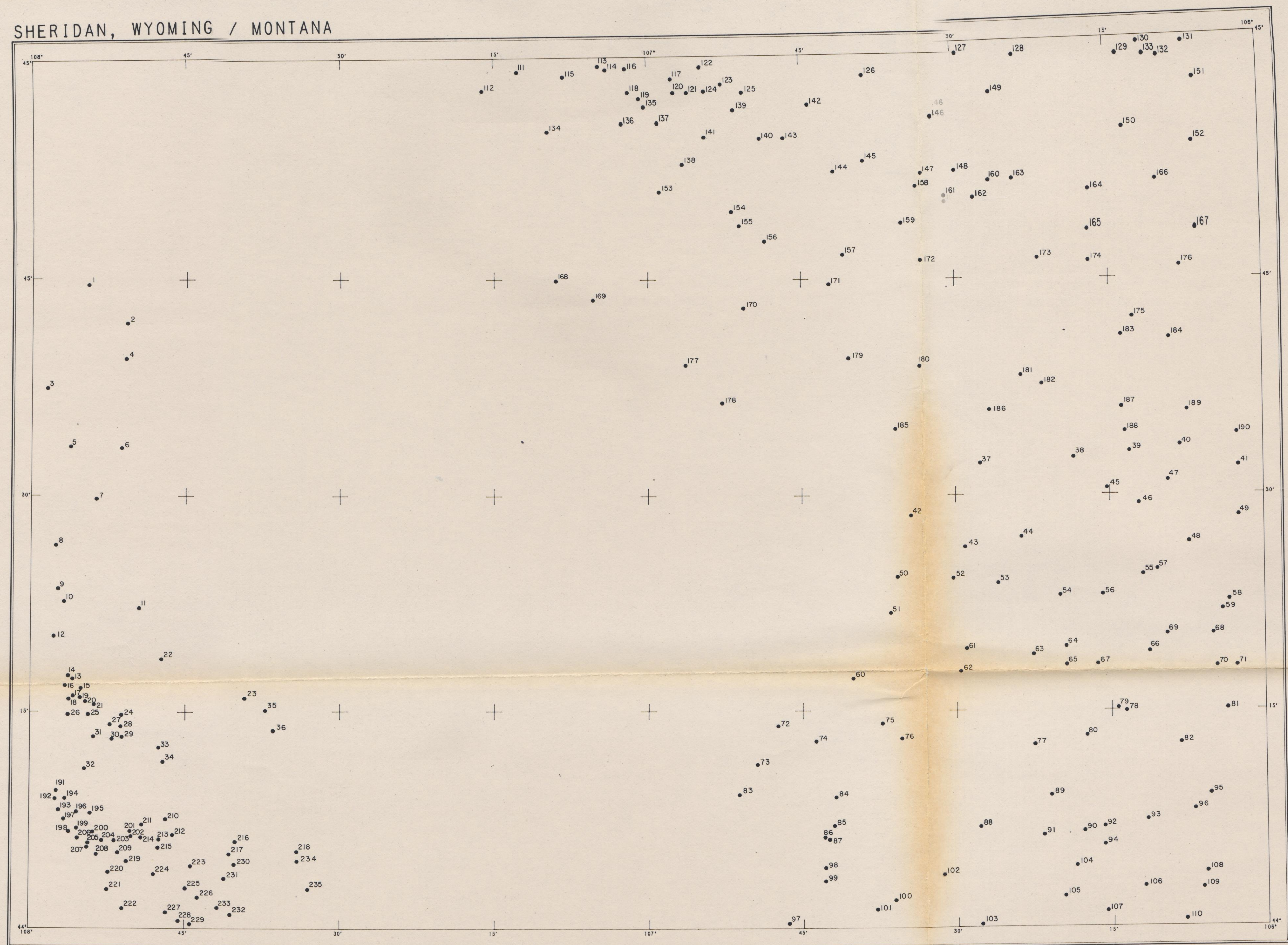


URANIUM RESOURCE EVALUATION
ISSUED BY THE U.S. DEPARTMENT OF ENERGY

BASE MAP CONTROL FROM USGS

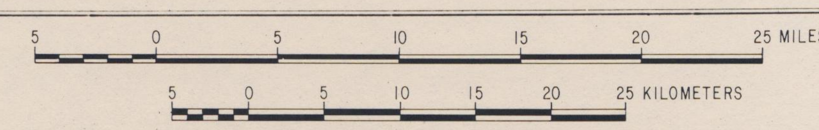


Plate 8. WELL-LOG LOCATION MAP

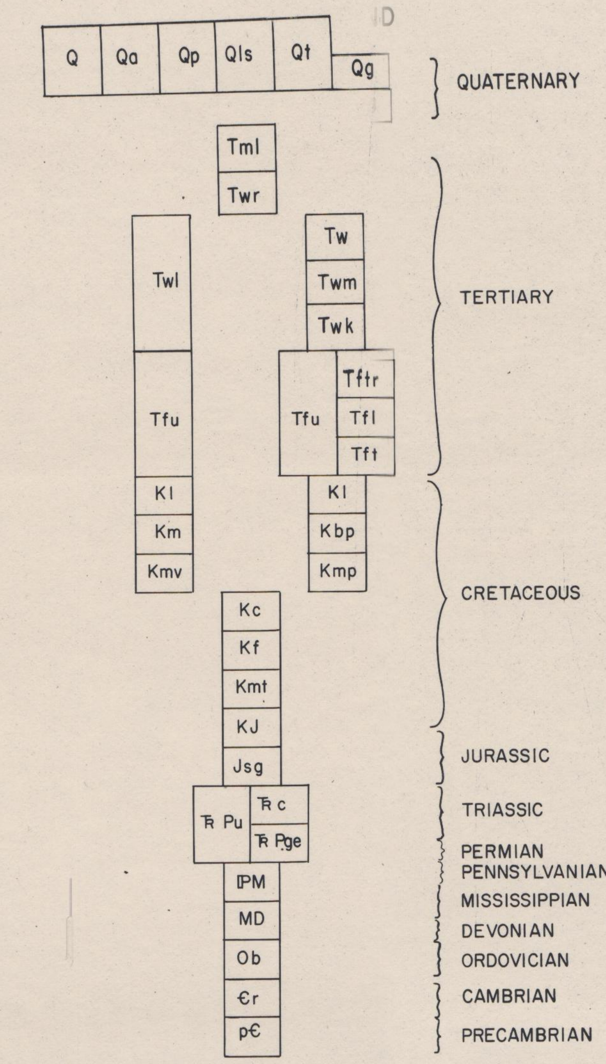
SHERIDAN, WYOMING / MONTANA

URANIUM RESOURCE EVALUATION
ISSUED BY THE U.S. DEPARTMENT OF ENERGY

Modified after Love, Christiansen and Earle, 1978

Plate 7 GEOLOGIC MAP

LEGEND



LIST OF MAP UNITS

QUATERNARY DEPOSITS

- Q — Undivided
- Qa — Alluvium and colluvium
- Qp — Pediment deposits
- Qls — Landslide deposits
- Qt — Terrace deposits
- Qg — Glacial deposits

TERTIARY ROCKS

- Tml — Lower Miocene rocks
- Twr — Oligocene White River Formation
- Twl — Lower Eocene Willwood Formation
- Tw — Lower Eocene Wasatch Formation
- Twm — Moncrief Member
- Twk — Kingsbury Conglomerate Member
- Tfu — Paleocene Fort Union Formation
- Tftr — Tongue River Member
- Tfl — Lebo Member
- Tft — Tullock Member

UPPER CRETACEOUS ROCKS

- Kl — Lance Formation
- Km — Meeteetse Formation
- Kbp — Bearpaw Shale
- Kmv — Mesaverde Formation
- Kmp — Parkman Sandstone Member
- Kc — Cody Shale
- Kf — Frontier Formation

LOWER CRETACEOUS ROCKS

- Kmt — Mowry and Thermopolis Shales

LOWER CRETACEOUS AND UPPER JURASSIC ROCKS

- KJ — Cloverly and Morrison Formations

UPPER AND MIDDLE JURASSIC ROCKS

- Jsg — Sundance and Gypsum Spring Formations

TRIASSIC ROCKS

- Ꞧc — Chugwater Formation

TRIASSIC AND PERMIAN ROCKS

- ꞦPge — Goose Egg Formation
- ꞦPu — Chugwater and Goose Egg Formations

PENNSYLVANIAN AND UPPER MISSISSIPPIAN ROCKS

- IPM — Tensleep Sandstone and Amsden Formation

MISSISSIPPIAN AND DEVONIAN ROCKS

- MD — Mainly Madison Limestone

UPPER ORDOVICIAN ROCKS

- Ob — Bighorn Dolomite

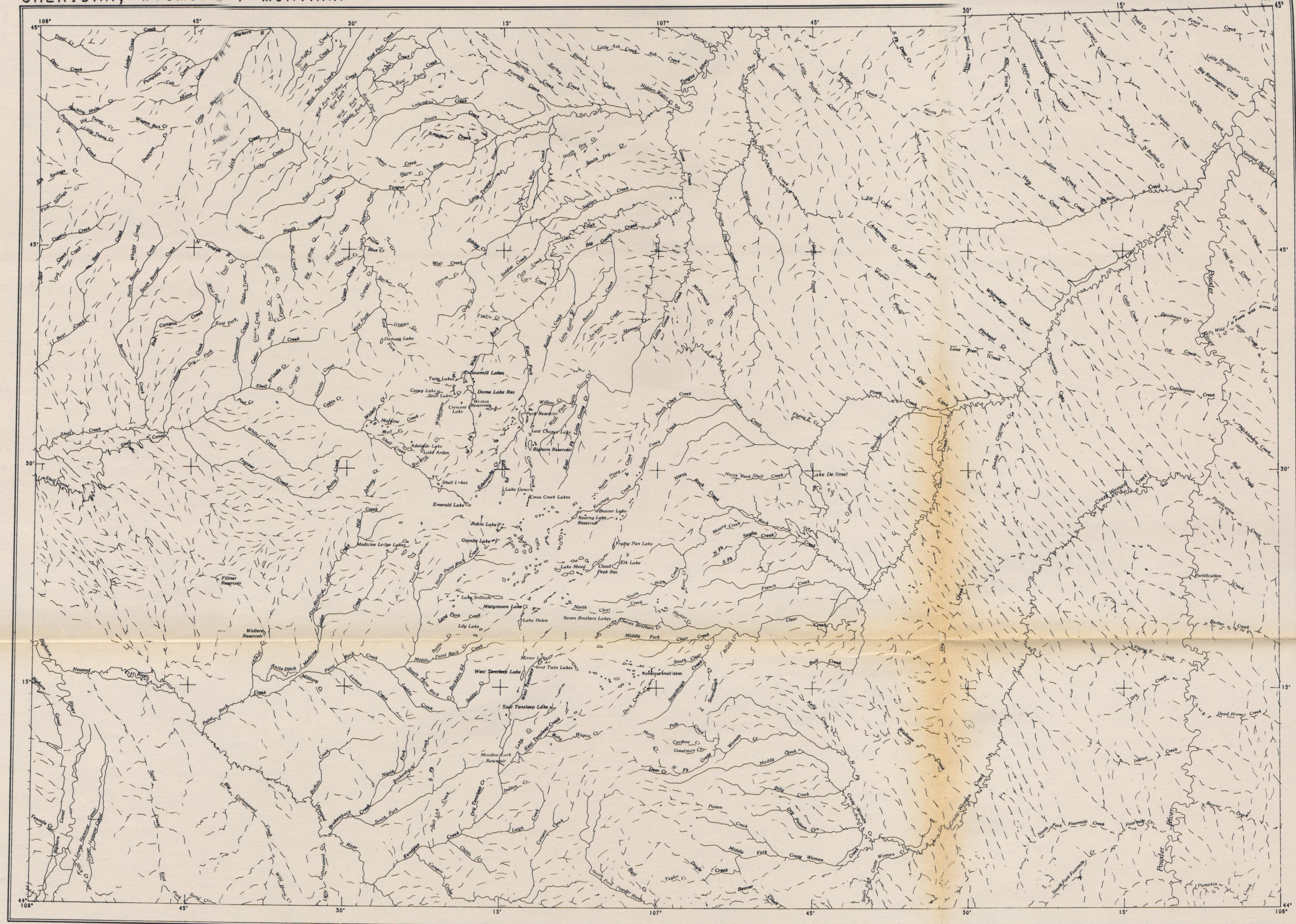
UPPER AND MIDDLE CAMBRIAN ROCKS

- Єr — Gallatin Limestone, Gros Ventre Formation, Flathead Sandstone

PRECAMBRIAN ROCKS

- pЄ — PRECAMBRIAN ROCKS

SHERIDAN, WYOMING / MONTANA



URANIUM RESOURCE EVALUATION
ISSUED BY THE U.S. DEPARTMENT OF ENERGY

5 0 5 10 15 20 25 MILES

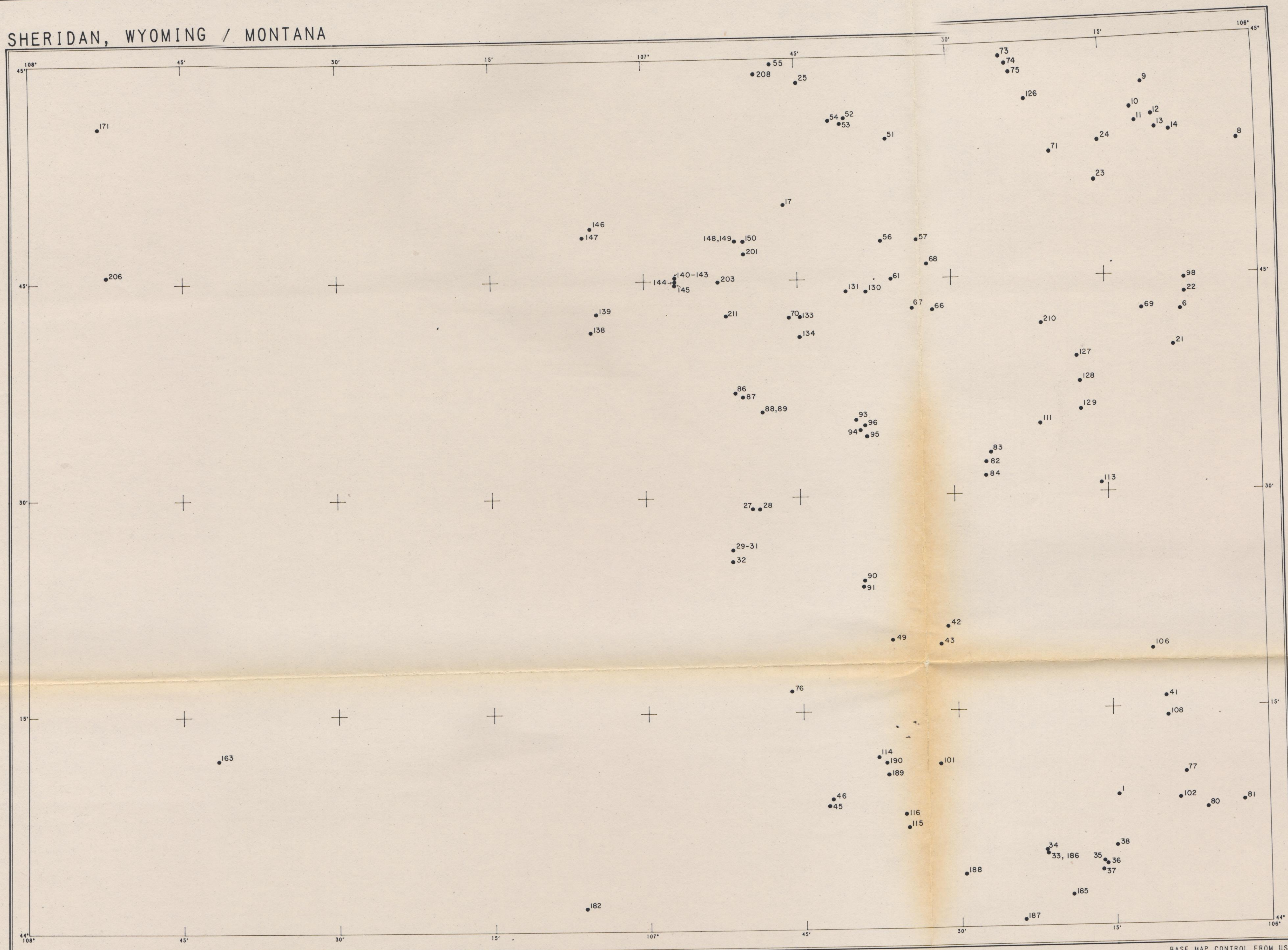
5 0 5 10 15 20 25 KILOMETERS

BASE MAP CONTROL FROM USGS

Plate 6. DRAINAGE

Plate 6.

SHERIDAN, WYOMING / MONTANA



URANIUM RESOURCE EVALUATION
ISSUED BY THE U.S. DEPARTMENT OF ENERGY

5 0 5 10 15 20 25 MILES

5 0 5 10 15 20 25 KILOMETERS

BASE MAP CONTROL FROM USGS

Plate 5b. LOCATION MAP OF WATER SAMPLES

EXPLANATION

•5 B.F.E.C. Sample MLK 5; Water

Plate 5b.

EXPLANATION

•48 BFEC Sample MLK 48; Roc
o104 BFEC Sample MLK 104; Seck.
(Samples MLK 72,104 and 2iment.
only sediment samples.) 202 are the

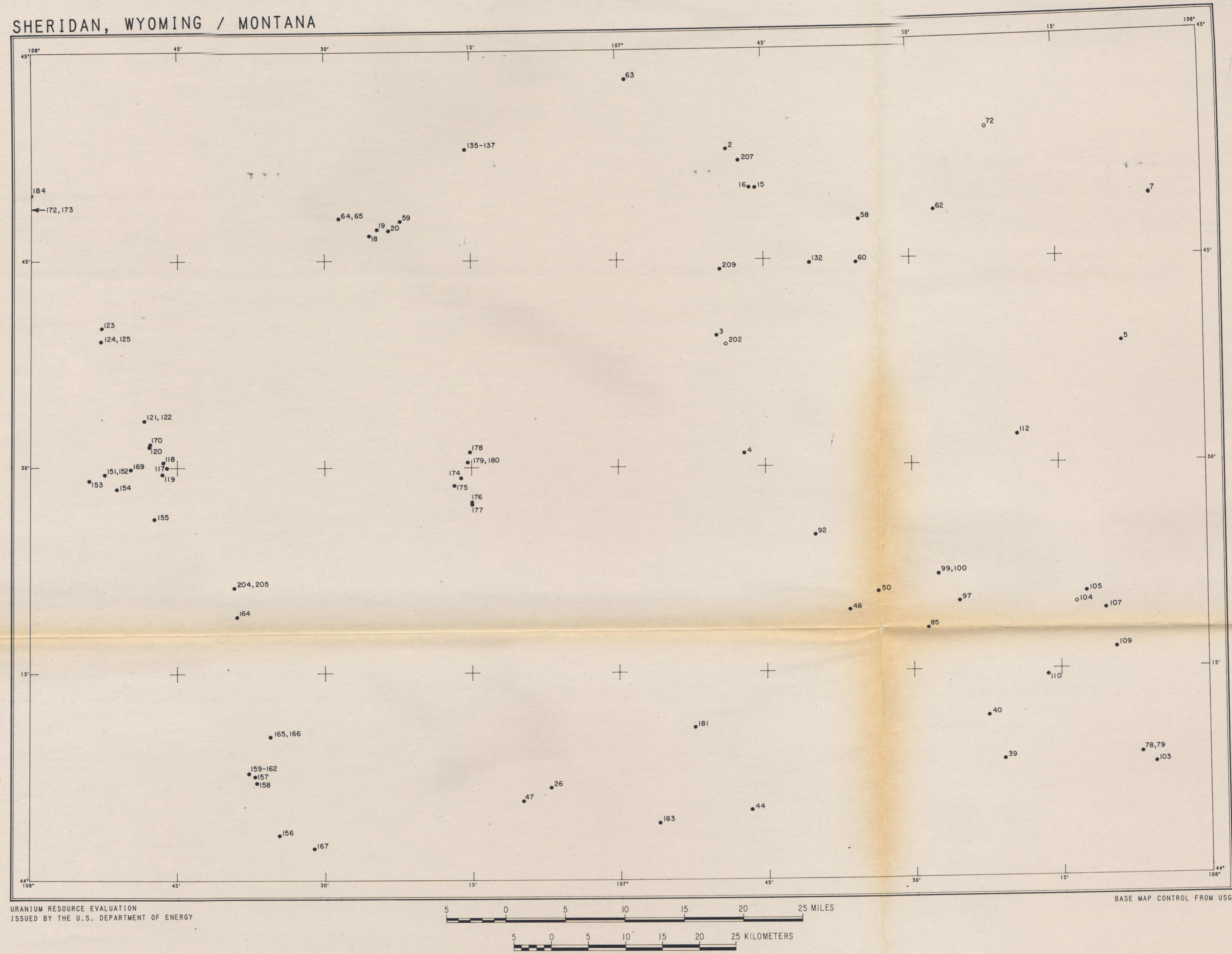


Plate 5a. LOCATION MAP OF ROCK AND SEDIMENT SAMPLES

Plate 5a.

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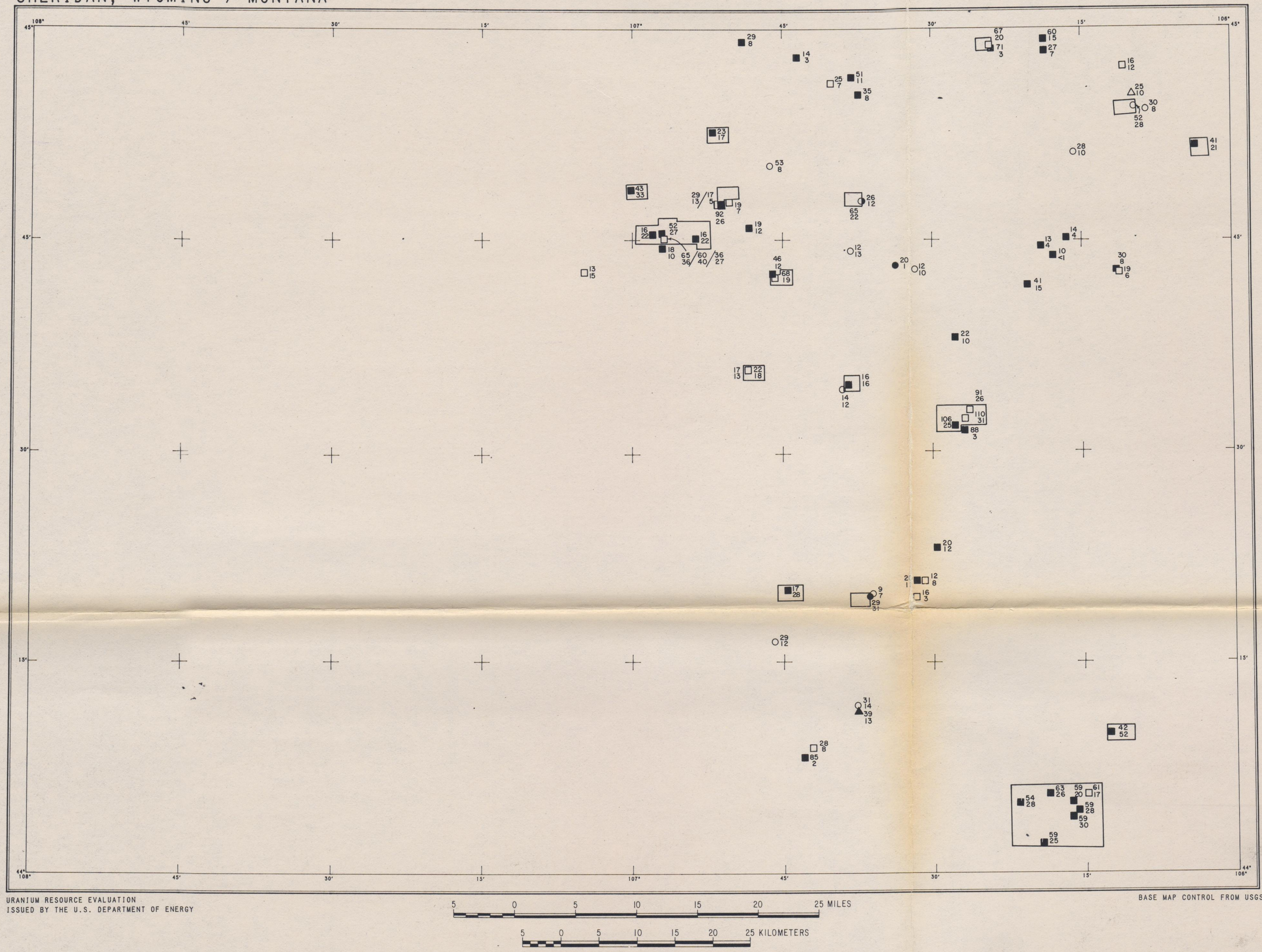

URANIUM RESOURCE EVALUATION
ISSUED BY THE U.S. DEPARTMENT OF ENERGY

BASE MAP CONTROL FROM USGS

EXPLANATION

△ Stream Water Anomaly in ppb U_3O_8; Collected by B.F.E.C.

○ Spring Water Anomaly in ppb U_3O_8; Collected by B.F.E.C.

□ Well Water Anomaly in ppb U_3O_8; Collected by B.F.E.C.

▲ Stream Water Anomaly in ppb U; Collected by L.A.S.L. (Morris, 1977).

● Spring Water Anomaly in ppb U; Collected by L.A.S.L.

■ Well Water Anomaly in ppb U; Collected by L.A.S.L.

▲ 31 31= ppb U
11 11= ppb U / μ mhos per cm X 1000

△ 8 8= ppb U_3O_8
1 1= ppb U_3O_8/μ mhos per cm X 1000

[u mhos per cm is reported units of groundwater conductivity (CDT)]

□ Indicates samples or groups of samples with U/CDT X 1000 values greater than 15

Plate 4. INTERPRETATION OF DATA FROM HYDROGEOCHEMICAL AND STREAM-SEDIMENT RECONNAISSANCE

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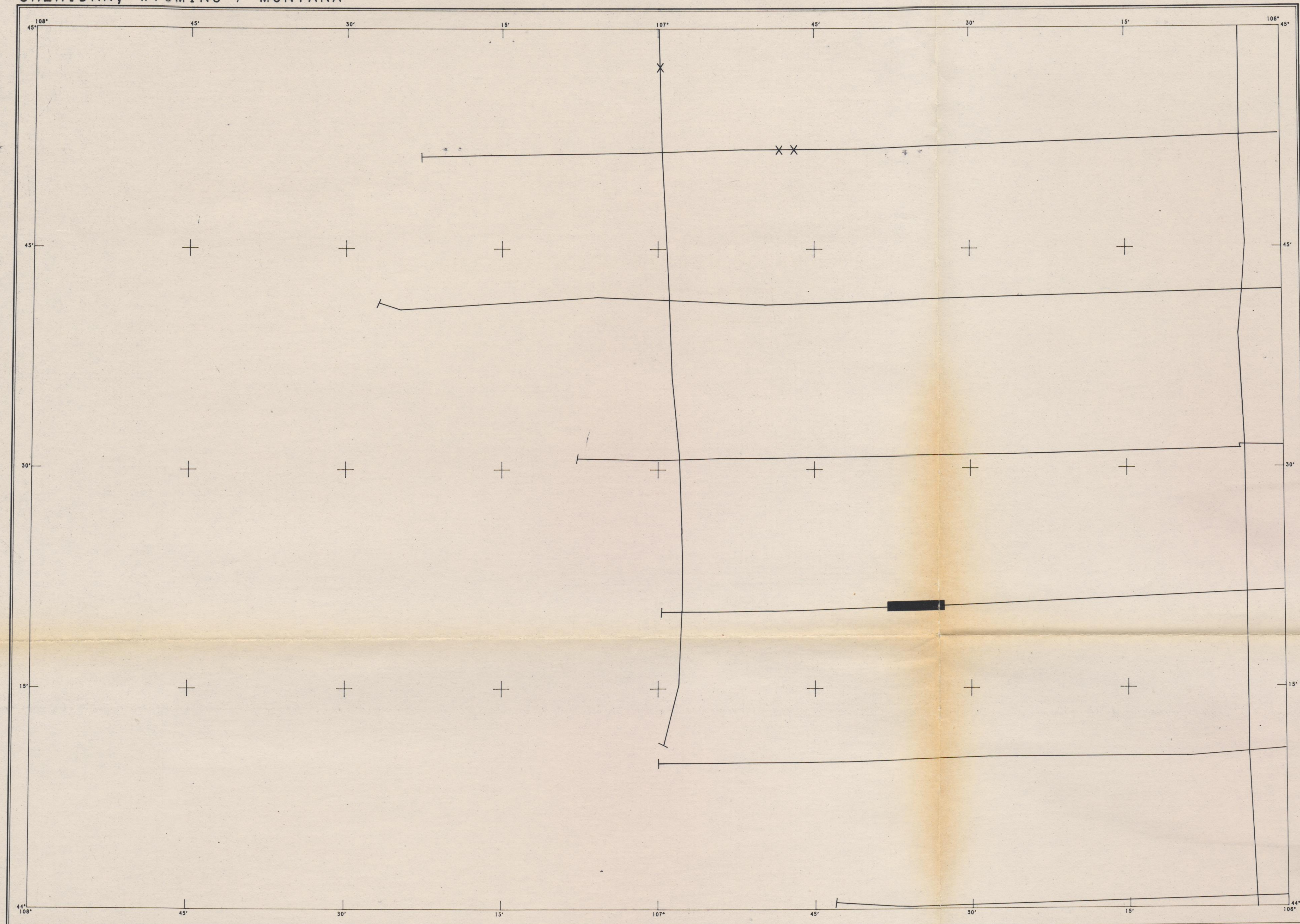
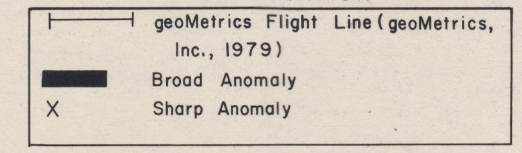


EXPLANATION



URANIUM RESOURCE EVALUATION
ISSUED BY THE U.S. DEPARTMENT OF ENERGY

BASE MAP CONTROL FROM USGS

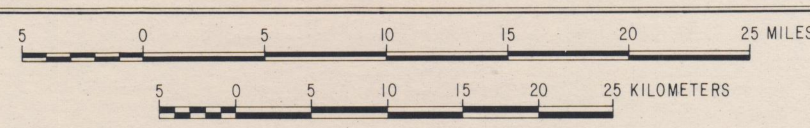


Plate 3. INTERPRETATION OF AERIAL RADIOMETRIC DATA

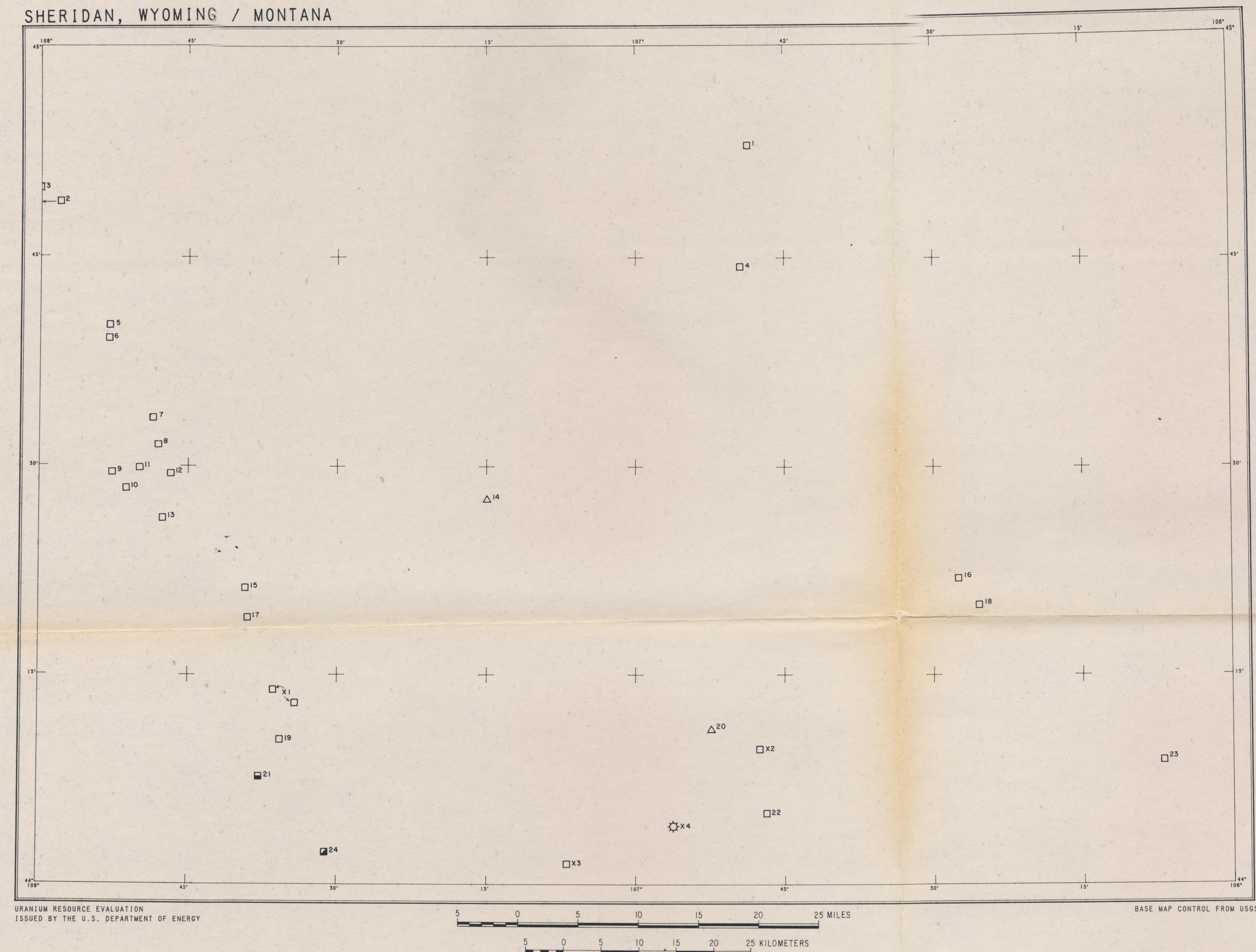


Plate 2. URANIUM OCCURRENCES

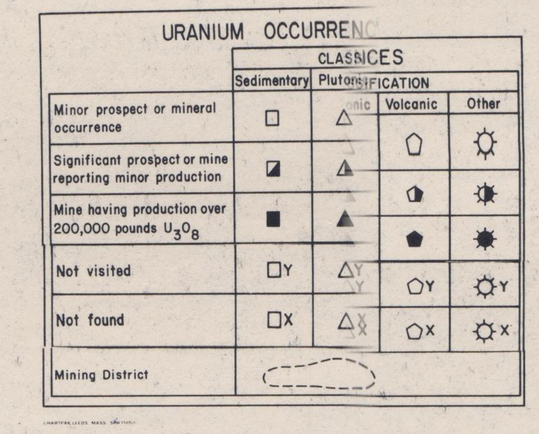


Plate 2.

SHERIDAN, WYOMING / MONTANA

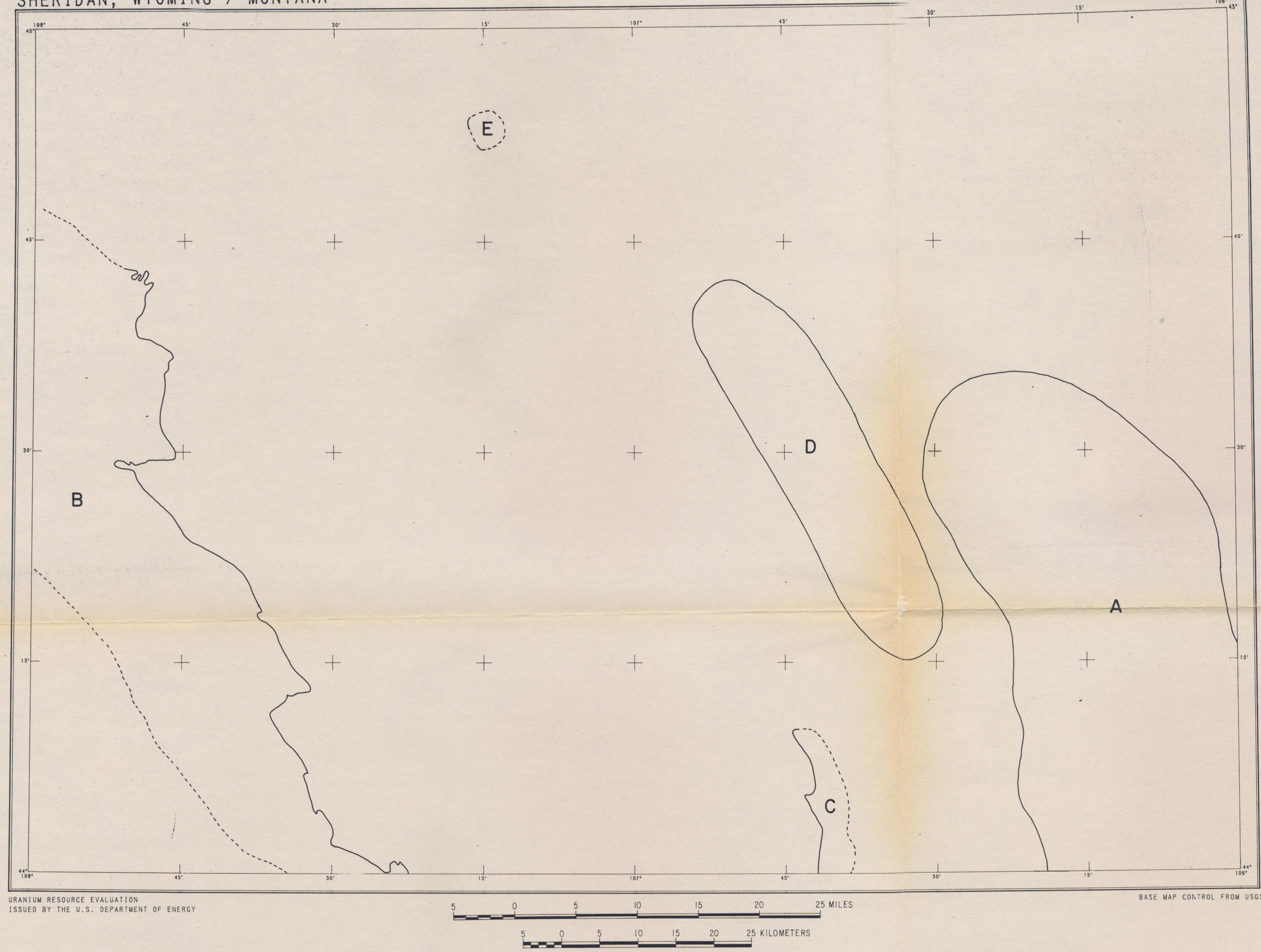


Plate I. AREAS FAVORABLE FOR URANIUM DEPOSITS

EXPLANATI TION

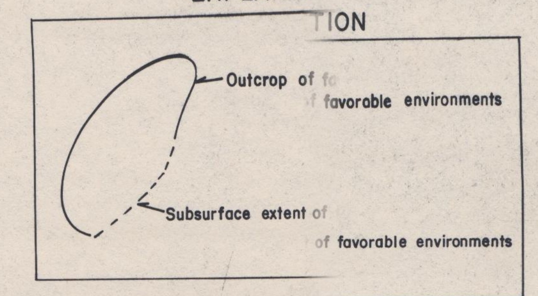


Plate I.

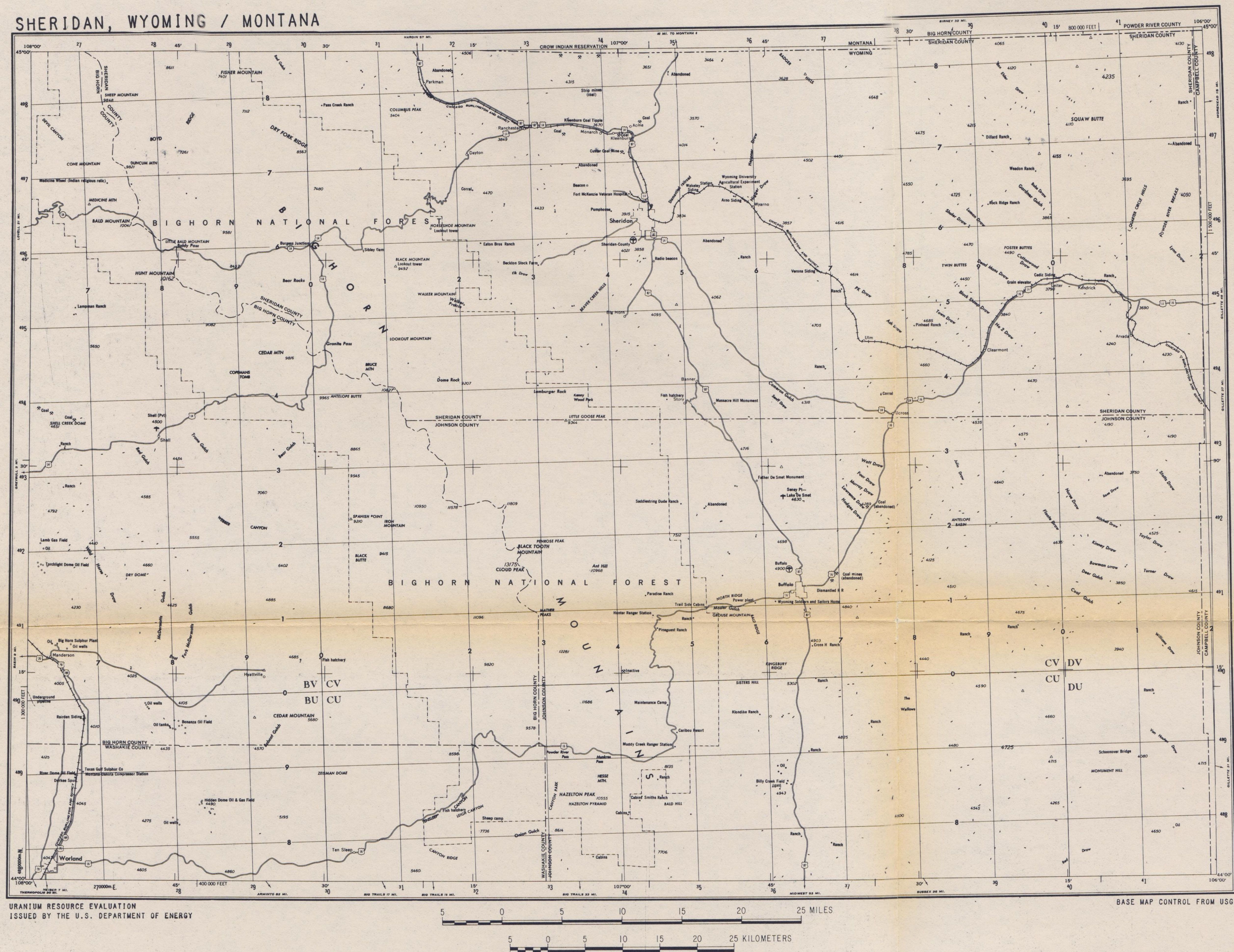
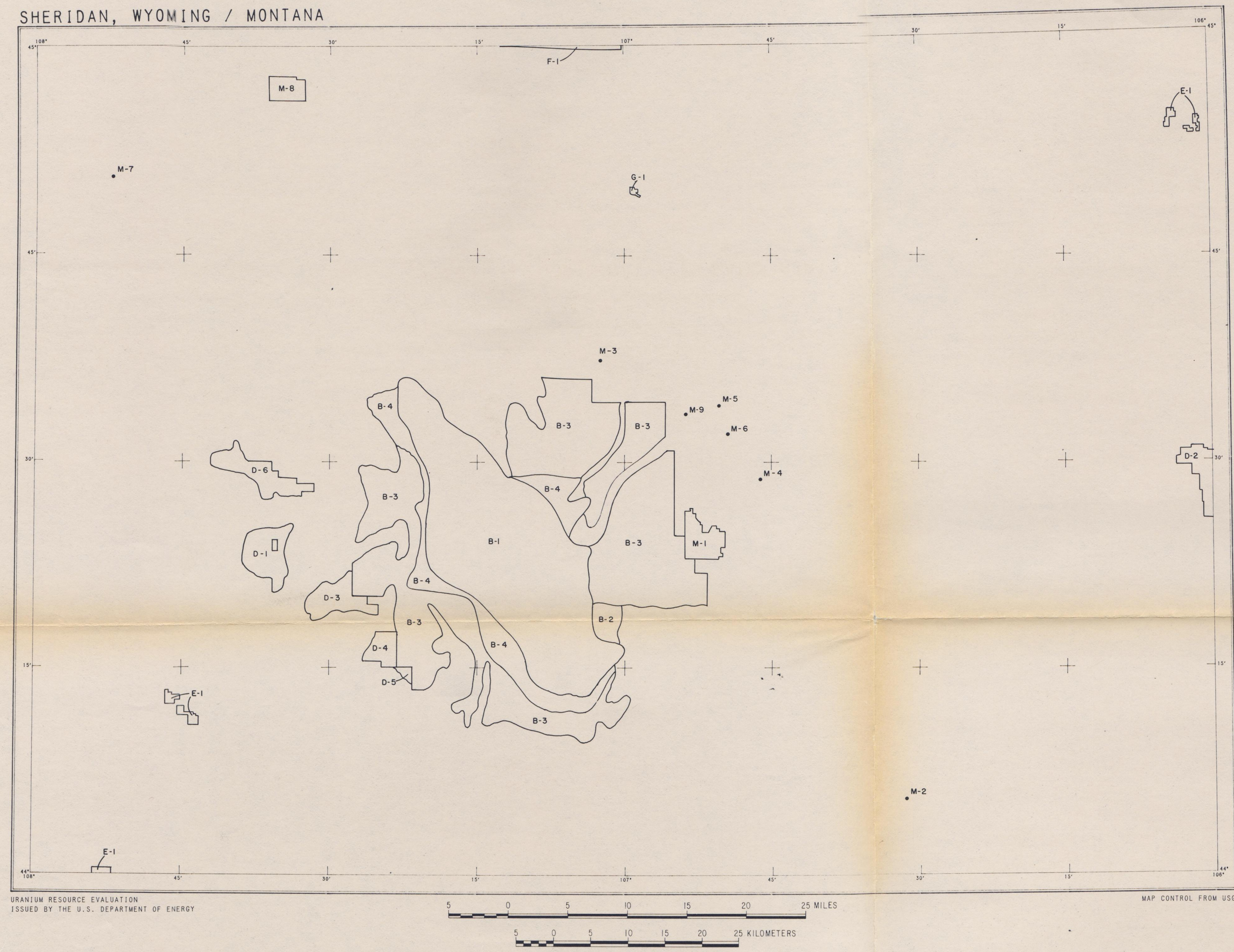


Plate 16. CULTURE



URANIUM RESOURCE EVALUATION
ISSUED BY THE U.S. DEPARTMENT OF ENERGY

MAP CONTROL FROM USGS

Plate 15. GENERALIZED LAND STATUS

INDEX

B. Forest Service Wilderness Areas, Wilderness Study Areas and Primitive Areas
- B-1 Cloud Peak Primitive Area
- B-2 Proposed Wilderness Areas
- B-3 Wilderness Planning Areas
- B-4 Administratively Endorsed Wilderness Areas

D. Bureau of Land Management Wilderness Study Areas
- D-1 Alkali Creek Wilderness Study Area
- D-2 Fortification Creek Wilderness Study Area
- D-3 Medicine Lodge Wilderness Study Area
- D-4 Point Rock Wilderness Study Area
- D-5 South Point Rock Wilderness Study Area
- D-6 Trapper Creek Wilderness Study Area

E. Bureau of Reclamation Withdrawal Areas
- E-1 Bureau of Reclamation Withdrawal Areas

F. Indian Lands
- F-1 Crow Indian Reservation

G. Government Installations
- G-1 Fort MacKenzie Veterans Hospital

M. State Land Withdrawals
- M-1 Bud Love Big Game Winter Range
- M-2 Crazy Woman Battle Historical Site
- M-3 Crook's Camp Historical Site
- M-4 Father DeSmet Monument
- M-5 Fetterman Monument
- M-6 Fort Phil Kearny Historical Site
- M-7 Medicine Wheel Archeological Site
- M-8 Sheridan County Winter Elk Pasture
- M-9 Wagon Box Battle Site