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National Uranium Resource Evaluation

DILLON QUADRANGLE MONTANA AND IDAHO

Geoexplorers International, Inc.
Denver, Colorado 80222

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PREPARED FOR THE U.S. DEPARTMENT OF ENERGY
Grand Junction Office, Colorado

This report is a result of work performed by Geoexplorers International, Inc., through a Bendix Field Engineering Corporation subcontract, as part of the National Uranium Resource Evaluation. NURE is a program of the U.S. Department of Energy's Grand Junction, Colorado, Office to acquire and compile geologic and other information with which to assess the magnitude and distribution of uranium resources and to determine areas favorable for the occurrence of uranium in the United States.

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PREPARED FOR THE U.S. DEPARTMENT OF ENERGY
Grand Junction Office
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ABSTRACT

All geologic conditions in the Dillon Quadrangle (Montana and Idaho) have been thoroughly examined, and, using National Uranium Resource Evaluation criteria, environments are favorable for uranium deposits along fractured zones of Precambrian Y metasediments, in the McGowan Creek Formation, and in some Tertiary sedimentary basins.

A 9-m-wide quartz-bearing fractured zone in Precambrian Y quartzites near Gibbonsville contains 175 ppm uranium, probably derived from formerly overlying Challis Volcanics by supergene processes.

The Mississippian McGowan Creek Formation consists of uraniferous, black, siliceous mudstone and chert. In the Melrose district it has been fractured by a low-angle fault, and uranium has been further concentrated by circulating ground water in the 2- to 6-m-thick brecciated zones that in outcrop contain 90 to 170 ppm uranium.

The Wise River, northern Divide Creek, Jefferson River, Salmon River, Horse Prairie, Beaverhead River, and upper Ruby River Basins are considered favorable for uranium deposits in sandstone. Present are suitable uraniferous source rocks such as the Boulder batholith, rhyolitic flow breccia, laharic deposits, or strongly welded tuffs; permeable sediments, including most sandstones and conglomerates, providing they do not contain devitrified glass; suitable reductants such as lignite, pyrite, or low-Eh geothermal water; and uranium occurrences.

INTRODUCTION

PURPOSE AND SCOPE

The Dillon Quadrangle, Montana and Idaho (Fig. 1), was studied to identify geologic environments and delineate areas favorable for uranium deposits, using National Uranium Resource Evaluation (NURE) criteria (Mickle and Mathews, eds., 1978). The study was conducted by Geoexplorers International, Inc., under Subcontract No. 78-111-S to Bendix Field Engineering Corporation (BFEC) for the NURE program, managed by the Grand Junction Office of the U.S. Department of Energy (DOE).

Phase I of the study began April 1, 1978, and ended June 10, 1978. Based on a literature survey, it involved preliminary identification of the geologic environments favorable for uranium deposition, formulation of surface and subsurface study plans, and compilation of an annotated list of references and uranium occurrences. A preliminary geologic map, geologic-map index, uranium-occurrence map, and land-status map were prepared.

Phase II, June 15, 1978, to August 30, 1979, involved 4,756 man-hours of field work documented in six monthly reports submitted to BFEC. These reports summarize field observations and contain preliminary evaluations of geologic environments for uranium favorability.

The identification of environments favorable for uranium deposition involved collection and interpretation of radiometric, geochemical, and geologic data.

Aerial gamma-ray spectrometer anomalies located by Geodata International, Inc. (1979), were ground checked and interpreted geologically. Stream-sediment and stream-water anomalies located by Broxton (1979) were resampled and also interpreted geologically. Stream-sediment, stream-water, and well- and spring-water samples, collected during the present study, were treated statistically to remove some noise from the data and facilitate identification of anomalies.

Detailed investigations of specific geologic environments include

- Checking for uraniferous quartz-pebble conglomerates in pre-Belt gneisses
- Checking for sandstone uranium deposits in Belt Supergroup metasediments, especially the LaHood Formation
- Detailed mapping of the McGowan Creek Formation in the Melrose district and checking for black shale uranium deposits
- Mapping areas of intrusive contacts for contact-metasomatic and other intrusive-related uranium deposits, especially in the Anaconda-Pintlar area and the eastern contact of Pioneer batholith
- Detailed radiometric and geochemical study of the Boulder batholith checking for uraniferous hydrothermal veins
- Detailed mapping of Tertiary volcanic centers south of Dillon and south of Salmon checking for volcanogenic uranium deposits
- Examination of Tertiary basins (which probably are the most promising environment for uranium deposition in the quadrangle) as follows
  a. Granitic intrusives, volcanic flows, and pyroclastics and tuffaceous sediments have been assessed geochemically as source rocks for epigenetic uranium deposits in the basins.
  b. The sediments within the Tertiary basins have been examined as to lithology, permeability, and reductants such as carbonaceous material or pyrite.
  c. Well and spring samples have been analyzed (for a variety of constituents) to locate areas where uranium is being transported and areas where it is likely to be deposited.

The above studies were compiled, and several environments were identified as favorable for uranium deposition.

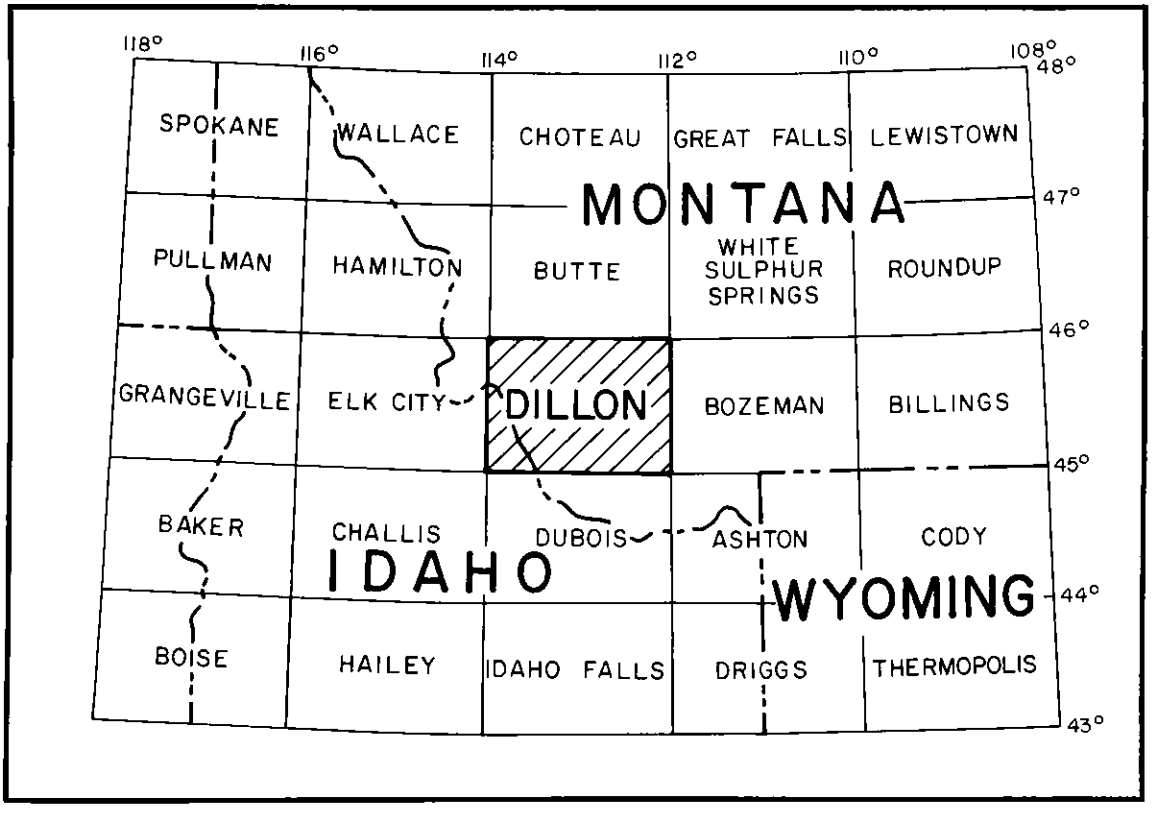


Figure 1. Location map of the Dillon Quadrangle.

ACKNOWLEDGMENTS

During Phase II of the project the authors were greatly assisted in the collection and interpretation of geologic, geochemical, and radiometric data by the following geologists: Robert Birk (Western Washington University), who was involved in the mapping of part of the Anaconda-Pintlar area; Salman Bloch, who collected and analyzed many well and spring samples; J. Slade Dingman, who also collected and analyzed many well and spring samples; Stanton Dodd (Western Washington University), who mapped several intrusive contacts in the Pioneer Mountains and examined the Mooney Claims; Delbert E. Gann, who was involved with the mapping of the Melrose district; Donald Graham, who collected numerous geochemical samples and who found uranium occurrences 3 and 4; Andre Lehre (Western Washington University), who helped in the statistical interpretation of the geochemical results; Kim Marcus (Western Washington University), who helped in mapping part of the Tertiary basins; Brian J. Ruby (Fort Lewis College, Durango, Colorado), who collected numerous geochemical samples and was involved in the mapping of part of the Anaconda-Pintlar area; and Richard B. Wice (Western Washington University), who helped in mapping the volcanic centers south of Dillon and south of Challis. Discussions with them all greatly helped in the evaluation of geologic environments for favorability of uranium deposition. The authors are grateful to Stanton Dodd (BFEC) for permission to use data from his oxygen fugacity–pH diagrams describing vein deposition in the Boulder batholith, and to Scott Monroe (Western Washington University) for permission to use his geologic map and cross section for the Sheep Mountain area.

GEOGRAPHY AND GEOLOGY

Location and Access

The Dillon Quadrangle of the U.S. Geological Survey map series 1:250,000 scale covers 17,249.2 km^2 (6,738 mi^2) in southwest Montana and north-central Idaho. The quadrangle is easily accessible by a system of federal and state highways and county roads (Pl. 13). Air transportation with regular commercial airlines is available from Butte, Montana, the largest city in the quadrangle. Airport facilities are also available at Dillon, Montana, and Salmon, Idaho, municipal airports.

Topography and Geomorphology

The quadrangle, our study area, is in the Northern Rocky Mountain physiographic province, characterized by high mountain ranges and broad intermontane basins.

The altitude of the study area ranges from 1341 m (4,400 ft) to 4000 m (11,154 ft) above sea level. The highest elevation is that of Barb Mountain, within the Pioneer Mountains in the central part of the quadrangle (Pl. 13). Within the same mountain range, numerous peaks occur with elevations above 2743.2 m (9,000 ft), commonly extended longitudinally. Similar elevations occur within the Tobacco Root Mountains (as much as 2227.8 m) and Highland Mountains (as much as 3108.4 m). Also within the quadrangle is the Bitterroot Range, also known as the Beaverhead Mountains, the highest points of which form the Continental Divide (1767.8 to 3237.3 m).

Climatic Conditions

Commonly, in the intermontane basins, the climate is semiarid; in the mountains, semihumid. Summer seasons are short; snow melts about late May or early June and starts falling again by September or October. The distribution of precipitation is very uneven. Usually, in the basins, precipitation is greater during the early summer months and least in the winter (Broxton, 1978).

The climatic conditions, especially rainy days and dry periods, were carefully recorded during our field investigations, and proper corrections for unusual weather are included in our interpretation of the water and stream-sediment geochemical results.

Surface Drainage System

The present physiographic characteristics of the study area and its surface drainage system (mostly Laramide)—the majority reflecting relatively old subsurface structural features—have been developed by glacial, especially fluvioglacial, and fluvial actions. However, glacial sediments, and particularly postglacial lakes, are common and well exposed within mountain ranges, especially in the Beaverhead and Pioneer Mountains.

In these mountain ranges are the headwaters of the Big Hole River, a tributary of the Jefferson River. The confluence of these rivers is in the vicinity of Twin Bridges. In approximately the same area, the confluence of the Jefferson River with the Ruby River and Beaverhead River occurs. These four rivers and a well-developed grid of creeks and streams—mostly intermittent—drain about 85% of the Dillon Quadrangle (Pl. 6). It should also be noted that only major rivers and larger creeks have well-developed valleys (of typical mature or meander phases). Others, especially mountain creeks, are still in a young developmental stage.

The most characteristic of the surface drainage systems is that along the above-mentioned Continental Divide (Pl. 6). On its western slope are the headwaters of the Salmon and Lemhi Rivers. The Salmon River is a tributary of the Snake River, but their confluence is on the western border of Idaho.

Since early Tertiary time, most of the fluvial sediment has been accumulated in large intermontane Tertiary basins. It should be noted that most of the surface water is discharged into these basins; locally, along various structural and contrasting hydraulic boundaries, the ground water is discharged into surface drainage systems.

The hydrographic, hydraulic, and hydrogeologic conditions of each water-sampling site were carefully examined in the field and considered in the interpretation of geochemical data.

Land Use

A generalized land-status map of the Dillon Quadrangle is presented on Plate 12, based principally on information from Bureau of Land Management maps ("National Resource Lands in Montana"). Commonly within the Dillon Quadrangle, all mountain ranges are National Forest areas, and land in the valleys is almost exclusively private. There is also much land administered by the U.S. Bureau of Land Management. Areas withdrawn from exploration and eventual mining operation are limited, and they are mainly confined to the Anaconda-Pintlar Wilderness.

The Dillon Quadrangle is very sparsely populated, and large ranches are more common than small farms. Also within the quadrangle are numerous recently reopened small mines and many mining prospects from previous activities.

Geologic Setting

The area within the Dillon Quadrangle has had a long and complex geologic history. The main elements of the geology are an Archean, high-grade metamorphic complex; a Proterozoic low-grade sequence of fluvial and marine sediments of the Belt Supergroup; a Paleozoic sequence of shelf sediments consisting of carbonates, quartzites, and rarer mudstones; a Mesozoic shallow-marine and terrestrial sediment; Laramide calc-alkaline intrusive and extrusive rocks, with folding, thrusting, and deposition of syntectonic fluvial sediments; Tertiary volcanism, basin and range faulting, and deposition of fluvial and lacustrian sediments in basins; and faulting and hot-spring activity continuing to the present.

The geology of the quadrangle is shown on the map compiled by Fugro (1978). Recent summaries of the geology have been compiled by Geodata International, Inc. (1979), and Broxton (1979), and a brief description is given below.

Archean. Archean metamorphic rocks, commonly referred to as pre-Belt gneisses, mainly occur in the southern Highland Mountains, the Tobacco Root Mountains, and the Ruby Range. The most western known exposure is near Sheep Mountain in the northern Pioneer Mountains.

These rocks have been subdivided into the Cherry Creek Group, Pony Group, and Dillon Granite Gneiss (Tansley and others, 1933; Heinrich, 1960). Gillmeister (1972) also noted the Spuhler Peak formation which is younger than both the Cherry Creek and Pony Groups.

The Cherry Creek Group is an inhomogeneous metasedimentary sequence consisting of amphibolite, pelitic gneiss, quartzofeldspathic gneiss, quartzite, marble, and dolomite. The Pony Group consists predominantly of mafic and quartzofeldspathic gneiss. It also contains iron formation, but material of evident sedimentary origin is less than in the Cherry Creek Group. Tansley and others (1933) considered the Pony Group the older of the two, whereas Reid (1957) concluded that the Pony Group is the younger.

The Dillon Granite Gneiss is a thick quartzofeldspathic gneiss, considered an orthogneiss by Heinrich (1960). Mapping in the central Ruby Range by Gariham (1979) showed that marble and other metasedimentary units are concordant with the granite gneiss, suggesting that the Dillon Granite Gneiss is a quartzofeldspathic metasediment. However, mapping during the present project in Ashbough Canyon, near Whitetail Creek, showed clear intrusive relations between the Dillon Granite Gneiss and the Pony Group. Undoubtedly the Dillon Granite Gneiss is part ortho- and part paragneiss, as suggested by James and Hedge (1980).

The Spuhler Peak formation occurs in the central Tobacco Root Mountains. It consists of amphibolites and rarer quartzofeldspathic gneisses, and, according to Gillmeister (1972), it rests uncomformably upon both the Pony and Cherry Creek Groups. The basal unit of this formation is an extensive green quartzite.

The Archean metamorphic rocks have a complex structure and have been folded at least twice. According to Reid (1963), these rocks have experienced six episodes of folding. They have been metamorphosed to upper-amphibolite and granulite facies (Burger, 1969). They contain orthopyroxene and sillimanite–K-feldspar zone assemblages, and, according to Dahl (1979), various mineral-pair geothermometers suggest temperatures of metamorphism between 745° and 675°C. Recent rubidium-strontium dating by James and Hedge (1980) shows that the age of metamorphism of the Pony Group, Cherry Creek Group, and Dillon Granite Gneiss is 2,762 ±113 m.y., clearly establishing the Archean age of the basement complex. Heinrich (1949b) has noted both metamorphic and postmetamorphic pegmatites within this Archean basement. The postmetamorphic pegmatites could be related to Laramide intrusions such as the Tobacco Root batholith.

Belt Supergroup. Metasedimentary rocks of the Belt Supergroup are found north of latitude 44° 40′ and west of longitude 112° 45′. These approximate lines separate an upland area, the Dillon block, composed of Archean pre-Belt gneisses and a basin into which Belt sediments were deposited. Around the margin of the Dillon block, fluvial sediments were deposited unconformably on pre-Belt gneiss. These grade outward and upward into sediments of varied lithology deposited mainly in a shallow-marine environment.

The stratigraphy, sedimentation, and tectonics of the Belt Supergroup are described by McMannis (1965), Harrison (1972), and Harrison and others (1974). The Belt Supergroup consists of as much as 20,442 m (67,000 ft) of dominantly shallow-marine sediments laid down during the interval 1,450 to 850 m.y. ago. In the Dillon Quadrangle as much as 5486 m (18,000 ft) of Belt sediments are present. From oldest to youngest, the sedimentary units are the Pritchard formation and its equivalent (the LaHood Formation), Ravalli Group, Middle Belt carbonates, and Missoula Group. All except possibly the LaHood are marine in origin. The Pritchard formation is a relatively deep-water, partly redeposited unit that consists mainly of argillite and occurs in the northwest corner of the quadrangle in the Anaconda-Pintlar Wilderness. Possibly calcareous (Newland Limestone) and shaly (Chamberlain Shale) equivalents of the Pritchard occur in the Highland Mountains. The Ravalli Group consists of quartzites and siltites and is also largely restricted to the northwest corner of the quadrangle. North of the Dillon Quadrangle the Ravalli Group includes the copper-rich Revett Quartzite. The Middle Belt carbonates are also restricted to the northwest corner of the quadrangle, where at East Goat Peak they overlie quartzites of the Ravalli Group. The youngest-known sedimentary unit present in the Dillon Quadrangle is the Missoula Group which occurs extensively in the Pioneer Mountains and consists of quartzites, siltites, and argillites. In Idaho and in the Beaverhead Mountains of Montana, post-Archean

metasedimentary rocks consist mainly of quartzites and feldspathic quartzites of the Yellowjacket Formation and the Precambrian Y Lemhi Quartzite (group, in Ruppel, 1975). These units may exceed 10,000 m (32,808 ft) in thickness and are thought to have been tectonically transported as much as 160 km (100 mi) from the west. They are tentatively correlated with the Belt Supergroup.

The dominantly fluvial facies of the Belt Supergroup occurs in the northeast corner of the quadrangle, in the Highland Mountains and at Sheep Mountain in the northern Pioneer Mountains. These rocks have been collectively named the LaHood Formation by McMannis (1965). They were derived from the pre-Belt gneisses of the Dillon block, which at that time had considerable relief. The LaHood Formation consists of arkosic conglomerate and sandstone deposited by torrential streams in the Belt basin. It decreases in grain size up section and is overlain by fine-grained marine sediments. It is correlated with the Chamberlain Shale, Newland Limestone, Greyson Shale, and lower Pritchard formation.

The Belt Supergroup sediments have been metamorphosed to the prehnite-pumpellyite and greenschist facies. They commonly do not contain mineral laminations and are a subschist. Near the contacts with the Idaho batholith they have been transformed into amphibolite-facies schists and gneisses.

Paleozoic and Mesozoic. Paleozoic sedimentary rocks occur in the Pioneer Mountains, the Highland Mountains, the Tobacco Root Mountains, the Ruby Range, and the hills south of Dillon. The Mesozoic sedimentary rocks are mainly confined to the Pioneer Mountains. Commonly, the rocks crop out around the margins of uplifted blocks, the cores of which are Precambrian metamorphic rocks and batholithic intrusions. The Paleozoic rocks consist mainly of carbonate and quartzitic sediments deposited in a shelf environment and rest unconformably on Belt Supergroup and Archean basement.

The stratigraphy and sedimentation of the Paleozoic and Mesozoic has been discussed by numerous authors: McMannis (1965), on a regional scale; Scholten and others (1955) and Klepper and others (1957), from well-exposed sections adjacent to the Dillon Quadrangle; and Shenon (1931), Tansley and others (1933), and Sahinen (1950), within the Dillon Quadrangle. The various formations are briefly described below in order of decreasing age.

The Cambrian is represented by the Flathead and Wolsey Formations, Meagher Limestone, Park Shale, Pilgrim Dolomite, and Red Lion Formation and attains a maximum thickness of about 548.6 m (1,800 ft) (McMannis, 1965). The Flathead Formation rests unconformably on Precambrian basement and is about 30 m (100 ft) thick. It consists of medium- to coarse-grained, well-rounded, well-sorted quartzite with local conglomerate at the base. The Wolsey Formation is as much as 91 m (300 ft) thick and consists of gray to greenish micaceous fissile shale. The Meagher Limestone is as much as 183 m (600 ft) thick and consists mainly of a gray dolomite. The Park Shale is as much as about 46 m (150 ft) thick and consists of greenish and reddish brown shale and sandstone that are locally calcareous, and dolomite. The Pilgrim Dolomite is as much as 183 m (600 ft) thick and consists of a dark-gray dolomite. The youngest Cambrian formation is the Red Lion which consists of shale and laminated limestone and shale.

The Devonian is represented by the Jefferson and Three Forks Formations and attains a maximum thickness of 396.2 m (1,300 ft) (McMannis, 1965). The Jefferson Formation is as much as 213.4 m (700 ft) thick and rests unconformably on Cambrian strata. It consists of pinkish gray to cream dolomite. The Three Forks Formation is as much as 183 m (600 ft) thick and consists of gray to green thin-bedded fissile shale. In the Highland Mountains east of Melrose, it was found during the present project that the Three Forks Formation is overlain by 6 m (20 ft) of light-gray limestone and as much as 46 m (150 ft) of finely laminated dark-gray siliceous mudstone and black chert, which are tentatively correlated with the McGowan Creek Formation in east-central Idaho.

The Mississippian is represented by the McGowan Creek Formation and the Madison Group which is as much as 610 m (2,000 ft) thick (McMannis, 1965) and consists mainly of limestone and rarer dolomite. The Madison is unconformably overlain by the Pennsylvanian Amsden Formation which consists of reddish shale, sandstone, and dolomite, and the Quadrant Formation which is as much as about 610 m (2,000 ft) thick and consists of white to buff quartzite.

The entire Permian is represented by the Phosphoria Formation which varies from less than 30 m (100 ft) in the north to more than 152 m (500 ft) in the south. It is a phosphate-rich, uranium-bearing outer-shelf deposit. The geology and resources of the Phosphoria Formation have been described in

detail by Swanson (1970). The phosphate, hydrocarbon, fluorine, and uranium resources occur within the Meade Peak and Retort Phosphatic Shale Members both of which consist of carbonaceous phosphatic sediments that grade upward into cherty or carbonate-bearing lithologies. The Meade Peak occurs only in the southern part of the quadrangle, but the Retort extends north into the Butte Quadrangle. Both members are oolitic, and the phosphate mineral is fluorapatite. Uranium probably substitutes for the calcium in the apatitic structure.

The Phosphoria Formation is overlain by a Triassic, Jurassic, and Cretaceous sequence with a total maximum thickness of nearly 2438 m (8,000 ft). The Triassic and Jurassic consist mainly of marine calcareous sandstones, siltstones, and mudstones and silty limestones. The Upper Jurassic Morrison Formation is partly terrestrial and contains carbonaceous shale and coal near the top. The Cretaceous is represented by the Kootenai Formation and Aspen Shale, which together are as much as 1524 m (5,000 ft) thick and are in part terrestrial. The Kootenai Formation consists of conglomerate, sandstone, shale, and freshwater limestone. The Aspen Shale is similar but contains bentonitic and volcanic breccia horizons in the upper portion.

Tertiary Sedimentary Rocks. Tertiary sedimentary rocks are in all the basins in the Dillon Quadrangle. They consist of fluvial and lacustrian sediments that range in age from Late Cretaceous-Paleocene to Pliocene and are several thousand feet thick. The geology of the Tertiary basins in Montana has been described by Scholten and others (1955), Kuenzi and Fields (1971), Rasmussen (1973), and Wopat and others (1977). The geology of the Salmon River Basin in Idaho has been described by Anderson (1956, 1957, 1959).

Within Montana, in the Dillon Quadrangle, the Tertiary sedimentary rocks have been divided into Upper Cretaceous-Paleocene Beaverhead Formation and Eocene-Oligocene and Miocene-Pliocene sedimentary rocks that are separated by unconformities.

The Upper Cretaceous-Paleocene Beaverhead Formation consists of conglomerate and minor sandstone and freshwater limestone. The clasts consist essentially of limestone and quartzite boulders of Paleozoic provenance. To the south, in the Dubois Quadrangle (Scholten and others, 1955), the formation is nearly 3048 m (10,000 ft) thick. It is strongly indurated and impermeable. The Beaverhead Formation is a syntectonic deposit that was formed during the later stages of the Laramide orogeny, and was involved in Laramide deformation.

The Eocene-Oligocene sedimentary rocks are present in the Jefferson, Beaverhead, and lower Ruby River Basins where they are 1067 m (3,500 ft), 526 m (1,725 ft), and 732 m (2,400 ft) thick, respectively (Kuenzi and Fields, 1971; Petkewich, 1972). The sediments contain arkosic sands and tuffaceous horizons, between 20% and 30% sandstone, and traces of organic matter (Wopat and others, 1977).

In the upper Ruby River Basin, as much as 2134 m (7,000 ft) of Tertiary sedimentary rocks are present. The Eocene-Oligocene rocks contain tuffaceous horizons but only minor permeable sandstones.

The Miocene-Pliocene sedimentary rocks are present in the Jefferson River, Beaverhead River, Ruby River, Divide Creek, and Medicine Lodge Creek Basins. In the Jefferson River and lower Ruby River Basins the thickness is estimated to be 732 m (2,400 ft) (Kuenzi and Fields, 1971) and 945 m (3,100 ft) (Petkewich, 1972), respectively. The rocks contain about 80% sandstone and conglomerate and traces of organic matter.

In the Divide Creek Basin the Miocene-Pliocene sedimentary rocks are at least 853 m (2,800 ft) thick. The rocks contain feldspathic and tuffaceous sediments and contain about 25% sandstone and conglomerates (Wopat and others, 1977).

In the upper Ruby River Basin, Miocene-Pliocene sedimentary rocks contain tuffaceous material and nearly 40% permeable sandstone and conglomerate (Wopat and others, 1977).

The Big Hole River and Grasshopper Creek Basins contain undifferentiated Tertiary sedimentary rocks. In the Big Hole Valley the thickness is at least 393 m (1,290 ft). The sandstone percentages are high, and tuffaceous and granitic detritus and traces of organic matter are also present (Wopat and others, 1977).

In the Salmon River Basin of Idaho the Tertiary rocks have been divided into the Kriley Formation, Challis Volcanics, and Kenney, Geertson, and Kirtley Formations. The formations are separated by unconformities, and the total thickness is at least 1097 m (3,600 ft). The Tertiary rocks consist of

fluvial conglomerates and sandstones and lacustrian siltstones and sandstones. The sediments are locally tuffaceous, especially near the top of the sequence, and the upper two formations contain carbonaceous materials.

The Kriley Formation lies unconformably on Belt metasediments and is as much as 183 m (600 ft) thick. It is a fluvial sediment consisting mainly of hematite-stained conglomerate with minor cross-bedded tuffaceous sandstones. The conglomerates are of Belt provenance, but they also contain rare granitic clasts. The Kriley Formation may be correlated with the Upper Cretaceous–Paleocene Beaverhead Formation in Montana, which was deposited in the later stages of the Laramide orogeny.

The Challis Volcanics unconformably overlie the Kriley Formation at the north end of the basin and rest unconformably on Belt Supergroup metasediments elsewhere. South of Salmon they are about 762 m (2,500 ft) thick and consist of basalt flows, rhyolite flows, and welded tuffs. Elsewhere in the basin, they consist of about 122 m (400 ft) of tuffs and welded tuffs.

The Kenney Formation lies unconformably on Challis Volcanics, and its maximum thickness is at least 152 m (500 ft). It consists of basement-derived conglomerate with minor rhyolitic and granitic clasts, and sandstones and siltstones that are in part tuffaceous.

The Geertson Formation rests unconformably on the Kriley and Kenney Formations, and its maximum thickness is at least 244 m (800 ft). It consists mainly of basement-derived conglomerate with minor volcanic clasts and rarer interbedded sandstones and siltstones, some of which are tuffaceous and carbonaceous. The conglomerates thin to the south, and shales and sandstone of probably lacustrian origin thicken in this direction. This suggests that the source area for these sediments was to the north and that drainage was to the south.

The Kirtley Formation is the youngest and most widespread of the Tertiary units. It rests unconformably on Challis Volcanics south of Salmon and on the other Tertiary formations elsewhere. Its maximum thickness is at least 396 m (1,300 ft), and it consists of tuffaceous siltstones with minor beds of well-sorted quartz sandstones and lenses of conglomerate. The Kirtley Formation contains carbonaceous sandstones and siltstones and beds of lignites.

Tertiary Volcanic Rocks. Tertiary volcanic rocks occur in the northern Pioneer Mountains, near Salmon, and in the south-central part of the quadrangle.

In the northern part of the quadrangle they consist of andesite, latite, and quartz latite flows and welded tuffs and can probably be correlated with the Lowland Creek volcanics which were erupted about 50 m.y. ago (Smedes and Thomas, 1965).

The volcanics near Salmon consist of rhyolites, welded tuffs, and tuff breccias and underlying basalts which have been mapped by Anderson (1956, 1957, 1959) as Challis Volcanics. Mapping during the present study shows that a rhyolitic volcanic center lies to the south of Salmon, and welded tuffs, probably originating from this center, flowed out into the Salmon and Lemhi River Basins. The Challis Volcanics were erupted 38 to 55 m.y. ago (Armstrong, 1974); Hyndman and others (1977) suggested that they are related to the Lowland Creek volcanics to the northeast.

In the south-central part of the quadrangle, volcanics consist of rhyolites, welded tuffs, and tuff breccias overlain by basalt flows. Mapping during the present project suggests that a rhyolitic volcanic center lies to the south of Dillon. Pyroclastics and laharic deposits originating from this volcanic center probably flowed out into the Horse Prairie, Grasshopper Creek, Jefferson River, and upper Ruby River Tertiary basins.

Plutonic Rocks. Four major Laramide batholiths crop out within the Dillon Quadrangle. They are the Boulder batholith, the Idaho batholith, the Pioneer batholith, and the Tobacco Root batholith. All are dominantly quartz monzonitic composition and hypidiomorphic-granular texture. Minor Tertiary intrusions are present, mainly in Idaho.

The southern part of the Boulder batholith lies within the quadrangle and consists mainly of quartz monzonite, but also contains gabbro, quartz diorite, granodiorite, granite, and the late-stage differentiates, alaskite, aplite, and pegmatite. The batholith dates 78 to 72 m.y., overlapping the age of the Elkhorn Mountain Volcanics (Robinson and others, 1968). The batholith intrudes pre-Belt gneisses, Belt Supergroup metasediments, Paleozoic-Mesozoic sediments, and Elkhorn Mountain Volcanics. Two radically different models have been proposed for the emplacement of the batholith.

Klepper and others (1971) suggested that the batholith has steep intrusive contacts and constitutes a mass that extends to great depths. Hamilton and Myers (1974) contended that it is in effect a thick lava flow mantled by its own ejecta (the Elkhorn Mountain Volcanics). The Boulder batholith consists of two distinct magma series. The main series occupies the entire northern two-thirds of the batholith and includes the Butte Quartz Monzonite; the sodic series, in the southern part of the batholith, includes the Rader Creek, Climax Gulch, Donald, Moose Creek, and Hell Canyon plutons. The two magma series are contemporaneous but geochemically distinct in that the main series has a higher K_2O-to-$K_2O + Na_2O$ ratio and is richer in rubidium, uranium, and thorium (Tilling, 1973).

The Idaho batholith occupies almost the entire northwest corner of the quadrangle and consists mainly of quartz monzonite, but also contains tonalite, granodiorite, and microgranite. It intrudes the Pritchard formation, Ravalli Group, Middle Belt carbonates, the Missoula Group in the north, and Precambrian Y quartzitic metasediments in the south. According to Armstrong and others (1977), it is 80 to 70 m.y. old but has been affected by a 50-m.y. event, which may be related to Challis volcanism (Hyndman and others, 1977). The emplacement of the batholith is related to late Mesozoic subduction (Talbot, 1977). Doming associated with emplacement caused gravitational sliding of Belt and Paleozoic sediments (Talbot, 1977; Scholten and Onasch, 1977) and led to the thick accumulation of Beaverhead Formation.

The Pioneer and Tobacco Root batholiths have been less intensely studied. The Pioneer batholith intrudes the Missoula Group in the west and upper Paleozoic sediments, including Madison Group limestones and the Phosphoria Formation, in the east. The Tobacco Root batholith intrudes Archean gneisses.

The uranium, thorium, and potassium contents of the Boulder batholith, Idaho batholith, and Tertiary intrusives have been studied by Swanberg and Blackwell (1973) and Tilling and Gottfried (1969). The average uranium and thorium contents of the Boulder batholith as a whole are 4.3 and 20.8 ppm, respectively; of the Idaho batholith, 1.9 and 9.1 ppm, respectively; and of the Tertiary intrusives, 11.5 and 31.1 ppm, respectively.

Structure. The Dillon Quadrangle is within an area of extremely complicated structures. In the northern part of the quadrangle there is a boundary between crystalline basement, Archean and Proterozoic, and the southern part of the Boulder batholith, which also intrudes Paleozoic formations. To the west occurs the very irregular boundary of the Idaho batholith and Belt Supergroup. Many small intrusions occur along the periphery of both these major batholiths. Although it is difficult to determine an old structural predisposition and its relationship to younger tectonics, it can be concluded that many satellite plutons were probably emplaced along major fault and fold systems, perhaps already existing during Precambrian time. It should be noted, too, that the east-central part of the quadrangle is within a very large thrust- and fault-belt system of the Rocky Mountains.

Structurally the Archean rocks are most complex. They have been folded several times and, at least locally, have been intruded by Archean granite. Metamorphism of the entire sequence to upper-amphibolite and granulite facies took place about 2.7 b.y. ago (James and Hedge, 1980).

Belt Supergroup sediments are in an elongated basin into which as much as 15,240 m (50,000 ft) of commonly shallow-water sediments were deposited during the interval 1,450 to 850 m.y. ago (Harrison, 1972). The area south of Whitehall and east of Wise River–Grasshopper Creek was a highland consisting of Archean gneiss. The highland area was bounded by faults (Harrison, 1972), and shed sediments into the basin. The Belt Supergroup has been folded and metamorphosed to the greenschist facies.

Dominantly quartzite rocks of Precambrian Y age are in the Beaverhead Mountains and are tentatively correlated with the Belt Supergroup by Ruppel (1975). They are thought to have been tectonically transported east as much as 160 km.

The Paleozoic and most of the Mesozoic was a period of stability characterized by shelf sedimentation, grading southwest into deeper water conditions of the Cordilleran geosyncline (McMannis, 1965). During the Late Cretaceous, sediments were tuffaceous and probably record volcanism associated with the early stages of the Laramide orogeny.

The Laramide orogeny had a most profound effect on the structural features of the quadrangle. Enormous batholiths were emplaced, some, like the Boulder batholith, probably poured out onto the

surface and were capped by their own volcanics, as suggested by Hamilton and Myers (1974). Others, like the Idaho batholith, caused extensive doming and resulted in large-scale gravitational sliding of the uplifted sediments (Talbot, 1977; Scholten and Onasch, 1977), and deposition of syntectonic conglomerates. It was during the Laramide orogeny that the commonly north-trending folding and thrusting took place.

The Tertiary was a period of extensive volcanism, basin and range faulting, and thick accumulation of tuffaceous sediments in fault-angle depressions. The volcanics are 55 to 38 m.y. in age (Armstrong, 1974) and were erupted along a northeast-trending belt on which Challis and Lowland Creek volcanics are found (Hyndman and others, 1977). Clastic sediments from the ranges and tuffs accumulated in thickness to as much as several thousand feet within the downfaulted basins (Wopat and others, 1977). Several of the faults have been active recently.

PROCEDURES AND RESULTS

Identification of environments favorable for uranium deposition was carried out by the following procedure.

- Aerial and ground radiometric measurements
- Geochemical analysis of well-water, spring-water, stream-water, stream-sediment, and selected rock samples
- Field checking and mapping of areas with radiometric and geochemical anomalies, of reported uranium occurrences, and of geologic environments considered potentially favorable for uranium

Radiometric Data

Entire Quadrangle. An aerial radiometric and magnetic survey has been conducted and interpreted by Geodata International, Inc. (1979), and became available to the authors in May 1979. These data have been checked, and locations with anomalous bismuth-214 (equivalent uranium) and anomalous bismuth-214 coincident with anomalous bismuth-214-to-thallium-208 (equivalent uranium-to-equivalent thorium) have been plotted on Plate 3. The Geodata International, Inc. (1979), definition of an anomaly has been adopted; namely, a location is anomalous if there is one three-standard-deviation value and there is a minimum of two adjacent two-standard-deviation values. Most anomalies have been ground checked, and their interpretation is summarized on Plate 3.

Four locations contain coincident bismuth-214 and bismuth-214-to-thallium-208 anomalies, and these could represent epigenetic concentrations of uranium. Ground checking revealed that at one location (south of Salmon) 9 ppm U is present in a carbonaceous and tuffaceous sandstone, but at the other locations no anomalous radioactivity was noted.

About 120 locations contain bismuth-214 anomalies but only four of these are associated with a known uranium occurrence (Comet Mountain) or with thorium-bearing veins (northwest of Salmon). The remaining bismuth-214 anomalies are associated with one or more of the following features.

- Anomalous plutons—most notably the Boulder batholith and associated pegmatites, and part of the Idaho and Pioneer batholiths
- Anomalous rhyolitic lava flows—most notably those associated with volcanic centers south of Dillon and south of Salmon
- Contacts misplaced on the geologic map—most notably volcanic contacts in the Bitterroot Mountains and intrusive contacts in the Pioneer, Highland, and Tobacco Root Mountains
- Exceptionally good outcrops surrounded by poor outcrops in Belt Supergroup rocks in the southwest quarter of the quadrangle
- Phosphoria Formation in the Pioneer Mountains
- Granitic glacial outwash originating from the Tobacco Root batholith
- Mine dumps near the Butte and Argenta mining districts
- Roadbed constructed from uranium-bearing slag—most notably along Interstate 15 southwest of Butte

Ground radiometric data were recorded using Scintrex gamma-ray spectrometers, Model GIS-4, and a geoMetrics gamma-ray scintillometer, Model GR-101A. Because each instrument recorded different levels of radioactivity at the same location, background was standardized at an arbitrarily chosen location (SW½ sec. 20, T. 2 N., R. 7 W.) in Boulder batholith southeast of Butte, and all recorded levels of radioactivity shown on Plate 3 are in multiples of this background. The relationship between ground radiometrics and aerial radiometrics can be seen on Plate 3.

The means and standard deviations of ground radiometric data for various lithologic units in the Dillon Quadrangle are shown in Table 1. Several features are worthy of note in this table.

- The level of radioactivity in rhyolite flows is higher than in rhyolitic tuffs. This supports analytic data that show that tuffaceous rocks contain less uranium than do flow rocks.
- The Boulder and Idaho batholiths are more highly radioactive than other Laramide granitic intrusives.
- The level of radioactivity in Mesozoic-Paleozoic carbonates, quartzites, and sandstones is low; it is 2 to 3 times higher in mudstones and shales (principally the Park Shale and Wolsey and Three Forks Formations); and it is anomalously high in the Phosphoria and McGowan Creek Formations.
- The level of radioactivity in Belt Supergroup metasediments is uniformly low.
- In the Archean gneisses, the level of radioactivity for the Dillon Granite Gneiss is 2 to 3 times as high as that for the Pony and Cherry Creek Groups.

Boulder Batholith. Radiometric readings were recorded at nearly 200 locations in the southern part of the Boulder batholith. This detailed radiometric study was carried out because numerous uranium occurrences are within the Boulder batholith (Becraft, 1956) (one of these, the Mooney Claims, is within the Dillon Quadrangle), and because 16 stream-water geochemical anomalies are associated with the southern part of the batholith.

Radiometric data for the sodic phase, the felsic differentiates (alaskite, pegmatite, aplite) of the sodic phase, the main or potassic phase, and the felsic differentiates of the main phase are compared in Table 2. Outcrops of main-phase rocks along Interstate 90 between Butte and Homestake Creek are tabulated separately because they are more highly radioactive than are other examined parts of the batholith.

These data suggest the following.

- The sodic phase of the Boulder batholith is less radioactive than the main phase. This supports chemical data of Tilling and Gottfried (1969) and Tilling (1973), which suggest that the main phase is indeed richer in uranium and thorium.
- In the main phase the level of radioactivity is highest in the felsic differentiates, whereas in the sodic phase the level of radioactivity is fairly constant without respect to lithology, suggesting that the radioactive elements behaved differently during the crystallization of the two phases of the Boulder batholith.
- The most highly radioactive rocks are in the Butte Quartz Monzonite of the main phase, along Interstate 90 between Butte and Homestake Creek. This part of the Butte Quartz Monzonite is anomalously radioactive.

Geochemical Data

Geochemical data were collected and interpreted for the following types of samples.

- Stream water and stream sediments
- Wells and springs
- Volcanic flow rocks and tuffs
- Granitic intrusions
- Other anomalous rocks

TABLE 1. MEANS AND STANDARD DEVIATIONS OF GROUND RADIOMETRIC DATA FOR VARIOUS LITHOLOGIC UNITS IN THE DILLON QUADRANGLE (MEASURED IN TERMS OF BACKGROUND)

Age	Rock type	No. of locations	Mean	Std. dev.
Tertiary	Rhyolite flows	39	2.5	1.1
	Rhyolitic tuffs	47	1.6	0.9
	Andesite-basalt flows	18	0.9	0.3
	Sediments	125	1.3	0.6
Tertiary-Cretaceous	Boulder batholith	200	1.7	1.7
	Idaho batholith	79	1.5	0.7
	Other batholiths	104	1.0	0.4
Mesozoic-Paleozoic	Carbonates	100	0.4	0.2
	Quartzites and sandstones	48	0.7	0.4
	Shales and mudstones	48	1.5	0.7
	Phosphoria Formation	34	4.5	2.1
	McGowan Creek Formation	37	5.2	5.2
Proterozoic	LaHood Formation	40	1.0	0.3
	Undiff. Belt Supergroup	112	1.2	0.4
Archean	Undiff. gneiss	31	1.3	0.4
	Cherry Creek Group	74	0.7	0.5
	Pony Group	38	0.6	0.3
	Dillon Granite Gneiss	17	1.5	0.5

TABLE 2. LEVEL OF RADIOACTIVITY OF VARIOUS ROCK TYPES IN THE BOULDER BATHOLITH (IN MULTIPLES OF BACKGROUND)

Rock type	No. of readings	Mean	Std. dev.
Sodic phase	27	1.38	0.38
Felsic differentiates of sodic phase	12	1.38	0.42
Main phase	99	1.56	0.42
Felsic differentiates of main phase	18	2.14	0.41
Main phase along I-90 west of Homestake Creek	8	2.36	0.33
Felsic differentiates of main phase along I-90 west of Homestake Creek	7	2.47	0.45

Stream Water and Sediment. A uranium hydrogeochemical and stream-sediment reconnaissance (HSSR) was carried out and interpreted by the Los Alamos Scientific Laboratory (Broxton, 1978, 1979). During the present study most anomalous catchments were examined geologically and radiometrically, and resampled geochemically. Stream-water and sediment samples were collected at about 849 and 416 locations, respectively. Stream waters were analyzed for uranium, and stream sediments for total uranium, for cold extractable uranium (1N HNO_3 leach), and, at selected localities, for thorium. For each sample location, loss on ignition was determined in the sediment, and, for the catchment area above each sample location, the proportion of important rock types was estimated from available geologic maps and field observations. For this purpose the quadrangle was divided into seven rock types: pre-Belt gneisses, Belt Supergroup, Paleozoic-Mesozoic sediments, Boulder batholith, other intrusive rocks, Tertiary volcanics, and Tertiary sediments. Results of geochemical analyses and geology of catchment areas are shown in Appendices B–1 and B–2. Sample locations for stream-water and stream-sediment samples are shown on Plates 5a and 5b, respectively. The geochemical results for stream water, total uranium in sediments, cold extractable uranium in sediments, and total thorium in sediments are shown on Plates 8a, 9a, 9b, and 9c, respectively.

The concentration of uranium in any given stream-water or stream-sediment sample may be influenced by several variables. Probably among the more important are the rock type in the catchment above the sample location (granitic rocks, for example, commonly contain more uranium than do mafic or sedimentary rocks); the proportion of organic matter and/or clay minerals (both can adsorb uranium from the water and concentrate it in the sediment, Doi and others, 1975); and any uranium occurrences that may be within the catchment. In geochemical prospecting the aim is to recognize anomalies caused by uranium occurrences and, hence, it is important to remove the noise due to other causes of uranium variability.

In the present study an attempt has been made to identify anomalous samples by two methods. The first method involves multiple linear regression which has been used by, among others, Rose and others (1970) to identify anomalous stream-sediment values. In multiple linear regression, an equation of the form

$$Y_p = b_o + b_1X_1 + b_2X_2 + \ldots + b_kX_k,$$

where Y_p = predicted value of dependent variable (in this study, uranium concentration),

$X_1, X_2, \ldots X_k$ = independent variables (in this study, proportion of drainage basin underlain by each rock type and loss on ignition),

b_o = intercept, and

$b_1, b_2, \ldots b_k$ = regression coefficients,

is fitted to the observed data using a least-squares procedure (Haan, 1977, p. 197). The uranium concentrations were transformed logarithmically to normalize their log-normal distribution. The predicted concentration calculated in this way can be compared with the measured concentration. The scatter of the observed concentration about the regression is defined by s_m, the standard error of the estimate, which is analogous to the standard deviation in the simpler case of scatter about a mean. The probability that the observed concentration is $2s_m$ by chance is about 2% (Rose and others, 1970).

In the present study the SPSS (Statistical Package for Social Sciences) multiple regression program REGRESSION (Kim and Kohout, 1975; Norusis, 1979) was used for calculation. Observed uranium concentrations greater than $2s_m$ from the predicted value have been considered anomalous and have been indicated in Appendices B–1 and B–2, and on Plate 4a.

The second method for identifying anomalous samples is using cumulative frequency plots. Separate plots have been constructed for uranium in water, total uranium in sediments, cold extractable uranium in sediments, and total thorium in sediments. The uranium analyses have been

plotted separately for samples representing rock types with markedly different uranium contents, namely, Boulder batholith, other intrusive rocks, and nonplutonic rocks. These cumulative frequency plots are constructed on Plates 8a, 9a, 9b, and 9c, and show probable threshold values. Samples with concentrations in excess of the threshold value (>T) are shown in Appendices B-1 and B-2, where it can be seen that, by and large, a good correlation exists with anomalous values identified by the multiple-linear-regression technique.

Stream-sediment and stream-water geochemical data from the HSSR study (Broxton, 1978, 1979) and from the present study are interpreted on Plate 4a. During the present study, 24 stream-water and 10 stream-sediment anomalies were identified. The water anomalies are distributed as follows.

- Sixteen anomalous waters are in or near the Boulder batholith. One of these is downstream from the Mooney Claims uranium occurrence but the remainder are not associated with known occurrences.
- Two anomalous waters occur near the western contact between the Pioneer batholith and a garnetiferous skarn. Both samples are close to the Greenstone Mine, a garnetiferous skarn uranium occurrence.
- Two samples are in the Idaho batholith where it is unconformably overlain by rhyolitic Challis Volcanics.
- One sample is in Belt metasediments, on strike with the Surprise Mine occurrence near Gibbonsville.
- Two samples are downstream from a granodiorite pluton north of Salmon. This pluton was not shown on the preliminary geologic map used for determining geology of catchment areas and so was not taken into account in the multiple-linear-regression analysis interpretation of the geochemical data.
- One sample is in Belt metasediments in the Bitterroot Range north of the Lemhi Pass thorium district, and could be indicative of associated uranium.

Ten stream-sediment anomalies were identified during the present study. These are distributed as follows.

- Six samples are in the Anaconda-Pintlar Wilderness area where the Idaho batholith is anomalously radioactive.
- One sample is in the Idaho batholith close to where it is overlain by rhyolitic Challis Volcanics.
- One sample is near the Comet Mountain uranium occurrence in the Pioneer batholith.
- One sample is near the Bismark fault which displaces the Tobacco Root batholith.
- One sample is close to anomalously radioactive Dillon Granite Gneiss.

The stream-sediment anomalies are related to intrusive rocks other than those of the Boulder batholith. This is in contrast to stream-water anomalies, most of which are related to the Boulder batholith and its satellites.

Wells and Springs. Ground-water samples were collected at 191 localities and were analyzed for uranium, pH, dissolved oxygen, total carbonate, total phosphate, and fluoride. Some uranium-rich samples were also analyzed for potassium and vanadium. The analytic results are shown in Appendix B-3, together with available ratios of reduced to oxidized sulfur species (after Leonard and others, 1978) and calculated Eh. The locations of samples are shown on Plate 5c and the analytic results are shown on Plate 4b together with a cumulative frequency plot on which the threshold value is about 18 ppb. The average and standard deviation for bicarbonate, phosphate, fluoride, and uranium is summarized for each Tertiary basin in Table 3. There is considerable difference among waters of the different basins. The Big Hole River and Grasshopper Creek Basins are low in carbonate and uranium. The average uranium content in the Salmon River Basin is high, but mainly due to one highly anomalous sample. The phosphate content is low in Jefferson River and Salmon River Basins and high in the Wise River Basin, whereas the fluoride content is high in the Jefferson River Basin. The oxygen content of

TABLE 3. AVERAGES AND STANDARD DEVIATIONS FOR HCO_3^{-1}, ΣPO_4^{-3}, F^{-1}, AND U FOR EACH TERTIARY BASIN

Basin	Determinations	Number of samples	Mean value	Standard deviation
Jefferson River	HCO_3^{-1}	17	190	73
	ΣPO_4^{-3}	24	0.27	0.1
	F^{-1}	24	1.21	1.62
	U	24	9.9	14.03
Divide Creek	HCO_3^{-1}	17	190	54
	ΣPO_4^{-3}	20	0.37	0.24
	F^{-1}	20	0.61	0.43
	U	20	7.63	7.47
Salmon River	HCO_3^{-1}	18	214	139
	ΣPO_4^{-3}	30	0.24	0.19
	F^{-1}	30	0.86	1.36
	U	30	20.8	62.3
Big Hole River	HCO_3^{-1}	30	111	123
	ΣPO_4^{-3}	43	0.48	0.20
	F^{-1}	43	0.56	0.23
	U	43	1.0	1.27
Grasshopper Creek	HCO_3^{-1}	14	125	88
	ΣPO_4^{-3}	16	0.43	0.20
	F^{-1}	16	0.52	0.56
	U	11	2.94	4.61
Horse Prairie	HCO_3^{-1}	3	213	—
	ΣPO_4^{-3}	3	0.37	—
	F^{-1}	3	0.68	—
	U	3	7.5	—
Beaverhead River	HCO_3^{-1}	27	166	89
	ΣPO_4^{-3}	32	0.3	0.13
	F^{-1}	32	0.61	0.27
	U	32	7.5	7.7
Wise River	HCO_3^{-1}	3	191	—
	ΣPO_4^{-3}	3	0.7	—
	F^{-1}	3	0.52	—
	U	3	10.0	—
Lower Ruby River	HCO_3^{-1}	7	237	57
	ΣPO_4^{-3}	11	0.25	0.07
	F^{-1}	11	0.74	0.17
	U	11	5.64	2.87
Upper Ruby River	HCO_3^{-1}	7	295	147
	ΣPO_4^{-3}	11	0.3	0.12
	F^{-1}	11	0.87	0.49
	U	11	4.05	1.8
Overall Dillon Quadrangle	HCO_3^{-1}	143	152	—
	ΣPO_4^{-3}	193	0.35	—
	F^{-1}	193	0.73	—
	U	193	6.47	—

most of the ground water is surprisingly high, possibly because of mixing with near-surface waters. Some low-Eh waters are present, however, such as those with reduced sulfur species. There is no apparent correlation between uranium concentration in the waters and their bicarbonate, phosphate, or fluoride contents. There is, however, a clear relation between Eh and uranium concentration; all samples with low oxygen content invariably contain very little uranium.

Thermodynamic calculations have been carried out to determine whether any of the waters are saturated with respect to uraninite, carnotite, autunite, and K-autunite. In Figure 2, thermodynamic data of Langmuir (1978) have been used to show the solubility of uraninite in the presence of phosphate, carbonate, and fluoride. The dominant uranium species in solution under conditions in the ground waters is $UO_2(HPO_4)_2^{-2}$. Most of the ground waters have an Eh greater than 0.0 and are strongly undersaturated with respect to uraninite. However, at least nine ground-water samples contain measurable reduced sulfur species and have an Eh well below 0.0. In these waters, uraninite solubility is several orders of magnitude lower than 10^{-7} M (24 ppb), and, wherever uranium-bearing waters come in contact with such reducing conditions, precipitation of uraninite must take place. Such reducing conditions may be present in some hot springs, where organic matter is present or where sulfate-reducing bacteria are active.

The solubility index, as defined by Mann and Deutscher (1978), of carnotite, autunite, and K-autunite has been calculated at each sampling point where uranium, vanadium, and potassium analytic data were available (commonly uranium-rich waters, see App. B-3). No calcium analyses were carried out, but the autunite solubility index was calculated using the maximum calcium concentration (50 ppm) reported by McMurtrey and Reed (1968) in deep wells in the Jefferson River Basin. The solubility index calculations use thermodynamic data of Langmuir (1978) and follow the procedure of Mann and Deutscher (1978). The calculations show that all the well waters are strongly undersaturated with respect to the minerals under consideration.

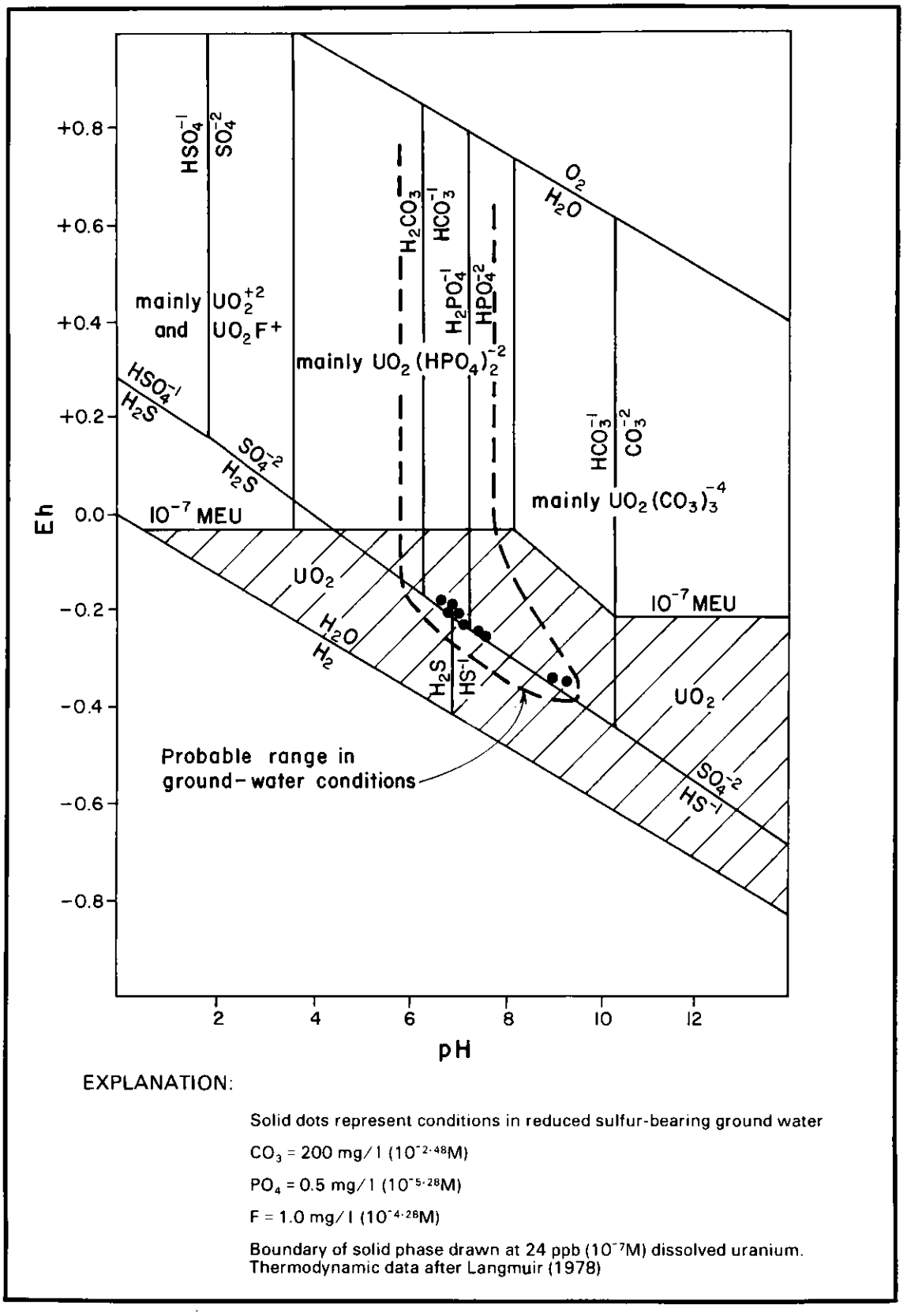
In summary, the ground-water chemical data and the thermodynamic calculations show the following.

- *Most ground waters are strongly undersaturated with respect to uraninite, carnotite, autunite, and K-autunite*. This explains why uranium content of the waters is not related to bicarbonate, phosphate, fluoride, or hydrogen-ion concentration (see Table 3). It means that uranium is actively being dissolved out of the rocks and that the amount of uranium is related to the nature of those rocks rather than water chemistry.
- A few ground waters are highly reducing as shown by the presence of reduced sulfur species. These invariably contain very little uranium.
- *Uranium deposition can be expected where uranium-rich waters come in contact with reduced sulfur-bearing waters*. Areas where such conditions probably exist are outlined on Plate 8b, and include parts of the Jefferson River and Wise River Basins and possibly parts of the Beaverhead River, upper Ruby River, and Horse Prairie Basins.

Volcanic Rocks. Volcanic flow and tuffaceous rocks were collected at 107 locations (see Pl. 5d) and were analyzed for titanium, chromium, thorium, zirconium, lithium, fluorine, and uranium to evaluate the flows and tuffs as source rocks for epigenetic uranium deposits in Tertiary basins. The analytic results are shown in Appendix B-4, which includes results from samples collected in both the Dillon and Dubois Quadrangles. The degree to which each sample has been altered to clays is shown on a 1-to-3 scale. The elements chromium, thorium, zirconium, and titanium are relatively inert in a near-surface environment and have been used to characterize volcanic rocks of different compositions and to correlate these with air-fall tuffs in the Tertiary basins.

The composition of all flow rocks is shown on the ternary thorium-zirconium-chromium composition diagram in Figure 3. The rocks can be divided into three categories.

A—rhyolites very rich in thorium and originating in the volcanic center south of Dillon
B—rhyolites moderately rich in thorium and originating from those Challis Volcanics in the vicinity of Salmon
C—intermediate to basaltic rocks poor in thorium and rich in zirconium or chromium



EXPLANATION:

Solid dots represent conditions in reduced sulfur-bearing ground water

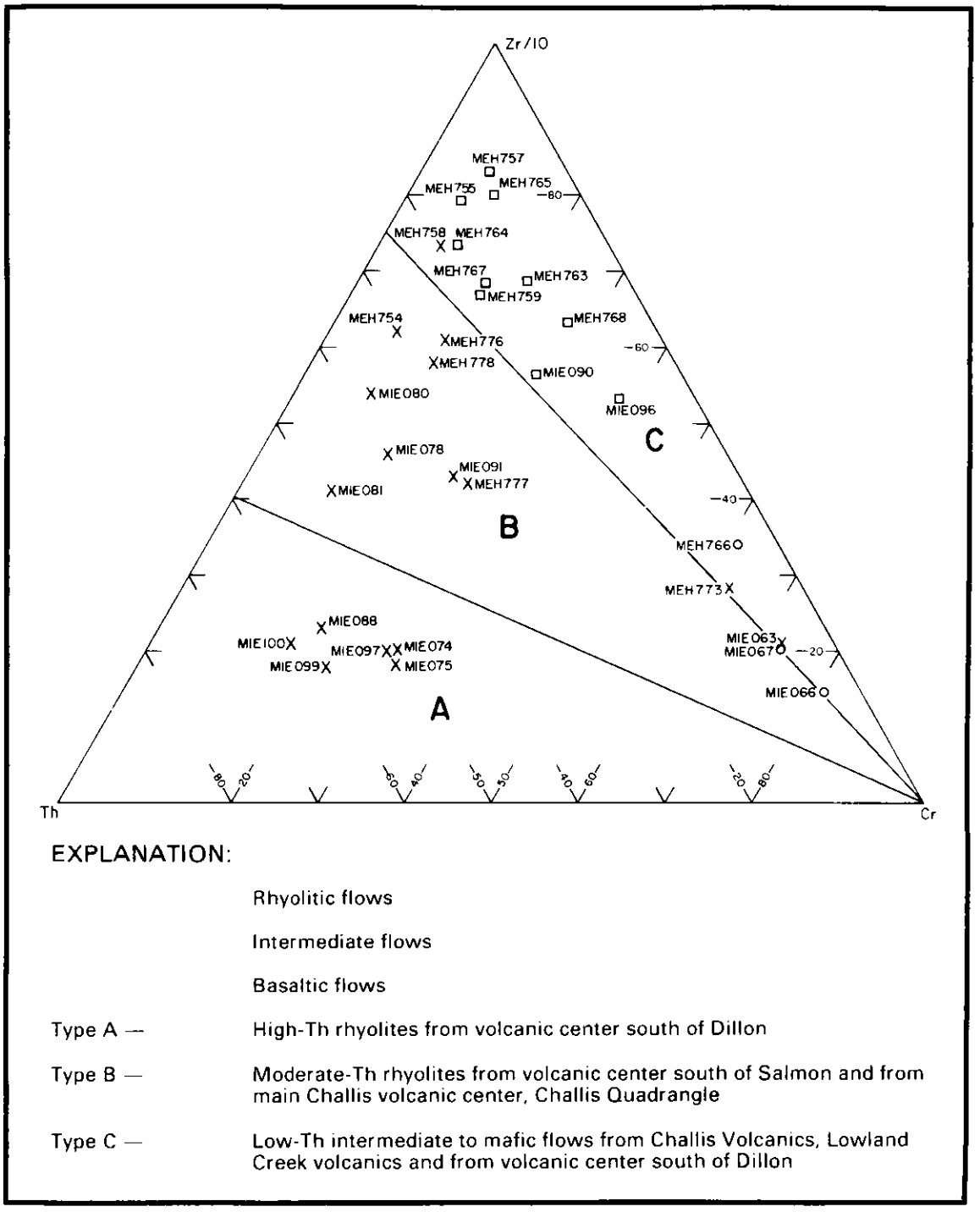
CO_3 = 200 mg/l ($10^{-2.48}$M)

PO_4 = 0.5 mg/l ($10^{-5.28}$M)

F = 1.0 mg/l ($10^{-4.28}$M)

Boundary of solid phase drawn at 24 ppb (10^{-7}M) dissolved uranium. Thermodynamic data after Langmuir (1978)

Figure 2. Partial aqueous equilibrium diagram of system $U-O_2-CO_2-P-F-H_2O$, showing probable range of ground-water conditions.



EXPLANATION:

Rhyolitic flows

Intermediate flows

Basaltic flows

Type A — High-Th rhyolites from volcanic center south of Dillon

Type B — Moderate-Th rhyolites from volcanic center south of Salmon and from main Challis volcanic center, Challis Quadrangle

Type C — Low-Th intermediate to mafic flows from Challis Volcanics, Lowland Creek volcanics and from volcanic center south of Dillon

Figure 3. A ternary Zr-Th-Cr discrimination diagram for flow rocks from Dillon and Dubois Quadrangles.

Similar diagrams have been constructed for air-fall tuffs collected from Tertiary basins (Fig. 4 and 5). All the tuffs fall into either category B or C. The uranium, lithium, and fluorine contents of flow rocks and of tuffs are compared in Table 4. The uranium and lithium contents decrease from category A to B and C and from rhyolitic to intermediate and basaltic rocks.

The concentration of uranium in tuffs is lower than that in flow rocks of comparable composition; however, the uranium concentration does not change with increasing intensity of alteration of the tuffs.

The concentration of lithium also appears to be slightly lower in tuffs than in rhyolites, but, in contrast to uranium, its concentration in tuffs increases with increasing alteration of glass to clays.

The fluorine distribution does not show any definite pattern except that it is most abundant in the high-thorium rhyolites.

The above analytic results suggest that both uranium and lithium have been lost from the tuffs either before or during the volcanic eruption. After the tuffs have been deposited in the sedimentary basins, however, uranium has remained immobile, whereas some lithium has been added to the tuffs and has probably been incorporated into clay-mineral structures. This apparent immobility of uranium during alteration of volcanic glasses is confirmed by Rosholt and others (1971), who found that the uranium content of glasses does not change as a function of the degree of their hydration. It appears, therefore, that *the tuffaceous rocks within the Tertiary sedimentary basins have not been particularly potent sources of uranium for epigenetic deposits in the basins, a conclusion supported by recent findings of Noble and others (1980).*

The rhyolite flows themselves and fragmental rocks derived from them may, however, be good sources of uranium. This is suggested by the following.

- The high uranium contents of rhyolites south of Dillon and south of Salmon (Dillon Quadrangle)
- The presence of uranium occurrences in and below rhyolitic laharic deposits in upper Ruby River Basin (Dillon Quadrangle) and in Ennis Gulch (Dubois Quadrangle)
- The presence of a uranium occurrence (Moida Claims, Dubois Quadrangle) in a tuffaceous sandstone beneath a strongly welded tuff
- The high uranium concentration in ground water (as much as 200 ppb) in brecciated rhyolite flows south of Salmon

Granitic Intrusions. It has been suggested by several authors, including Stuckless and others (1977), that granitic rocks can be good sources of uranium for nearby sedimentary basins provided that the granite is unmetamorphosed, is rapidly exposed to erosion, and is deposited rapidly in the basins. Numerous stream-water and sediment samples have been collected during the present study from areas of granitic outcrop to evaluate the granitic rocks in the Dillon Quadrangle as sources of uranium for deposits in the Tertiary sedimentary basins. The results are shown on Plates 8a, 9a, 9b, and 9c. Boulder batholith stream-water data, both from HSSR and from the present study, are summarized in Figure 6.

Examination of the analytic results shows that the granitic rocks are far from uniform with respect to the uranium contents of stream sediment and waters draining them. Most anomalous stream waters drain Boulder batholith and a small granodiorite intrusion north of Salmon. In the Boulder batholith, four drainage areas, shown as A, B, C, and D in Figure 6, contain stream waters that carry an average of more than 10 ppb uranium. These anomalous areas are present in both the main and sodic phases of the batholith, and one of them (C) appears to cut across a contact between the phases. Based on these analyses it is possible to calculate the amount of uranium transported into the Jefferson River Tertiary basin from areas C and D. If it is assumed that the mean annual precipitation is 25 cm, that the anomalous areas cover 200 km^2 (77.3 mi^2), and that the average uranium concentration of the waters is 10 ppb, then it is possible to calculate that 500,000 tons of uranium will be transported into the Jefferson River Basin in 1 million years. Evidently *the Boulder batholith is a potent source of epigenetic uranium.* Waters draining the other intrusive rocks contain about a tenth or less of the uranium, and are less likely to be ore-forming solutions.

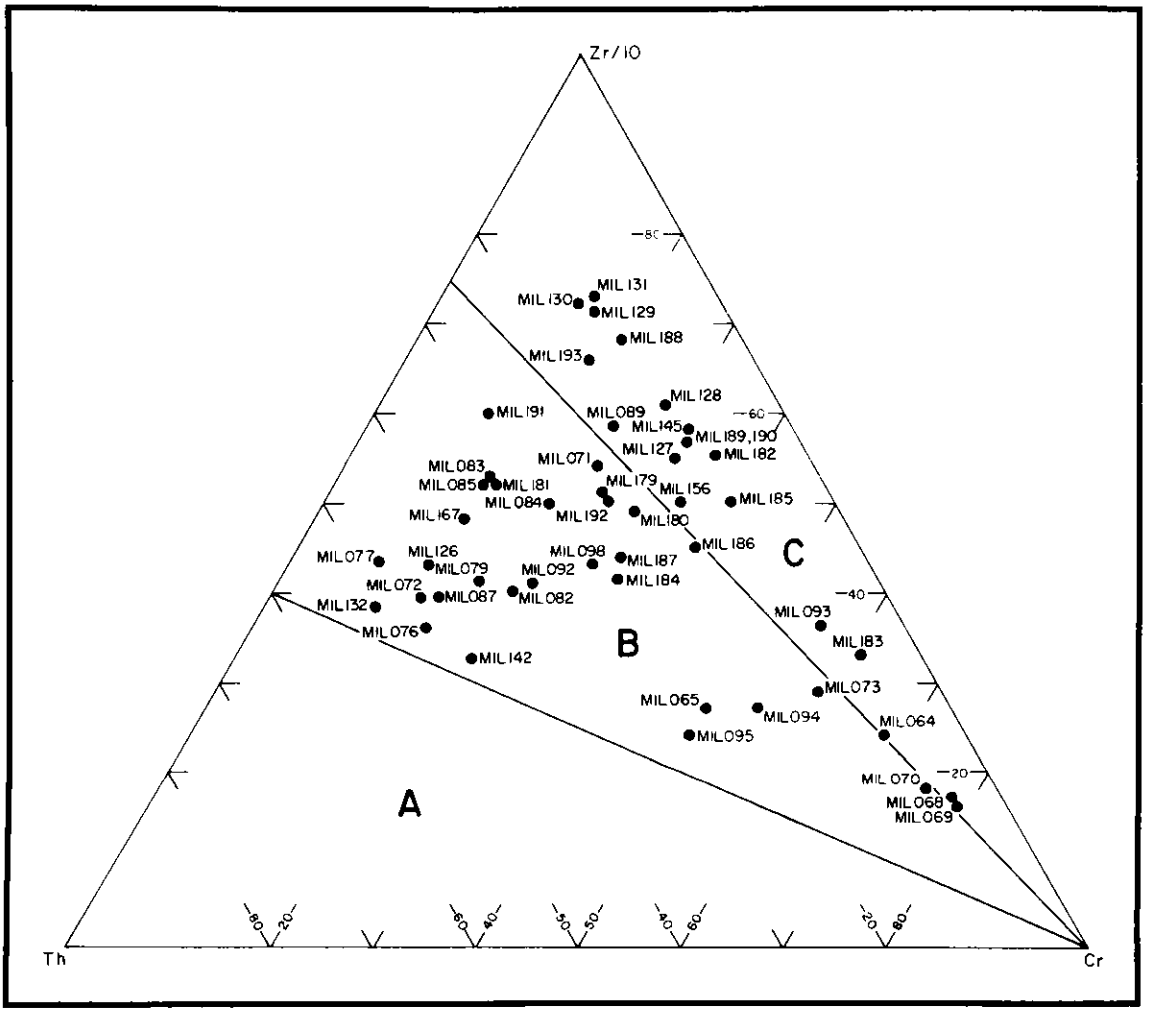


Figure 4. A ternary Zr-Th-Cr discrimination diagram for tuffs from Dillon Quadrangle. Areas A, B, and C drawn from discrimination diagram for flow rocks.

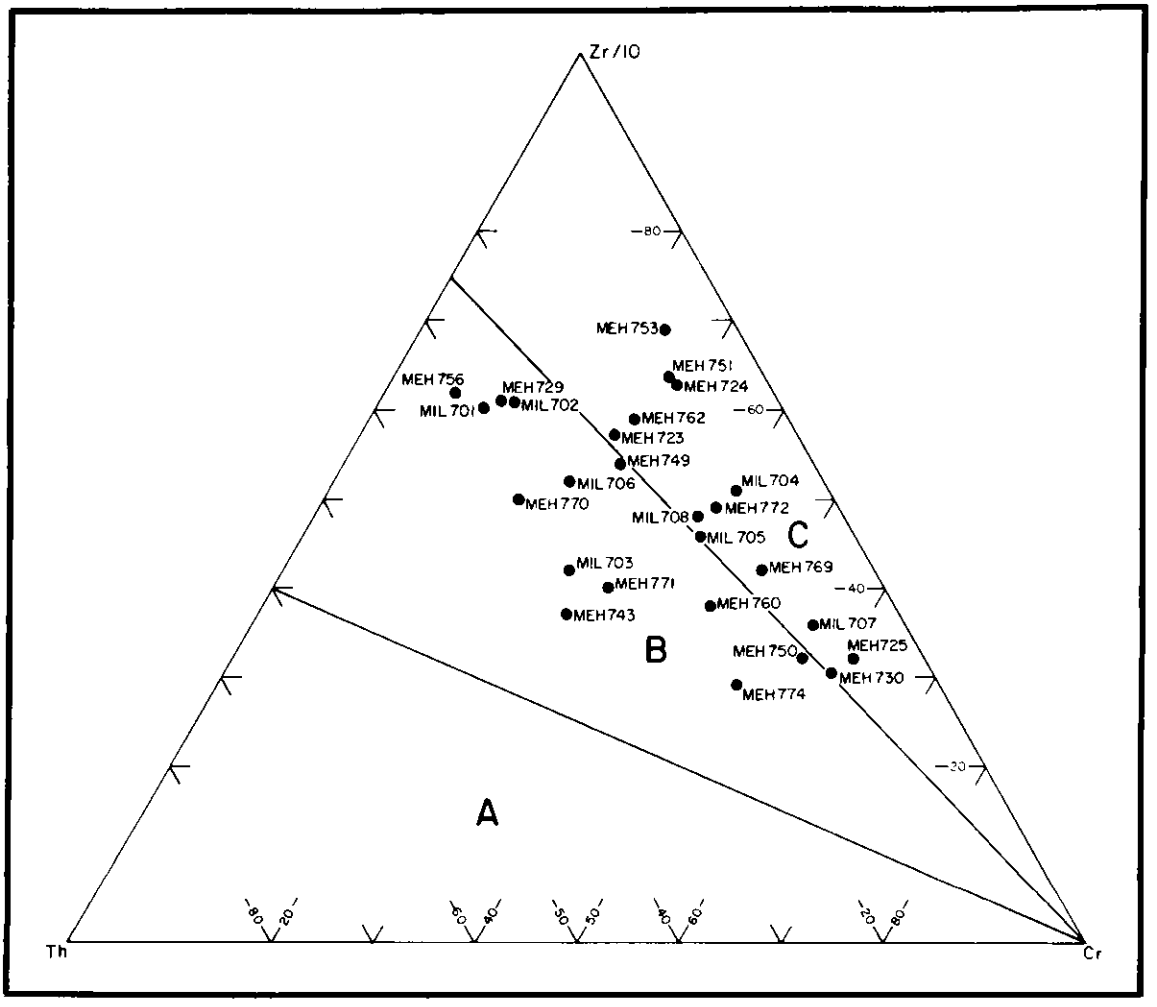


Figure 5. **A ternary Zr-Th-Cr discrimination diagram for tuffs from Dubois Quadrangle. Areas A, B, and C drawn from discrimination diagram for flow rocks.**

TABLE 4. COMPARISON OF URANIUM, LITHIUM, AND FLUORINE COMPOSITIONS OF HIGH-THORIUM, MODERATE-THORIUM, AND LOW-THORIUM FLOWS AND TUFFS

ALTERATION:

Unaltered tuffs	(1) glass mainly unaltered
Moderately altered tuffs	(2) glass partly altered to clays
Completely altered tuffs	(3) glass completely altered to clays

	Type A High-Th rhyolitic rocks			Type B Moderate-Th rhyolitic rocks			Type C Low-Th intermediate rocks			Type C Low-Th basaltic rocks			Alteration, flows/ tuffs
	U	Li	F	U	Li	F	U	Li	F	U	Li	F	
n	6	6	6	8	8	8	7	7	7	10	10	10	All flows
$\bar{x}$	4.7	207	850	4.3	48	338	3.0	34	379	1.4	24	541	
s	0.8	30	460	1.3	10	263	0.8	21	88	0.5	13	214	
n	—	—	—	39	39	39	32	32	32	—	—	—	All tuffs
$\bar{x}$	—	—	—	2.8	33	432	2.4	34	410	—	—	—	
s	—	—	—	2.2	17	238	1.3	20	181	—	—	—	
n	—	—	—	7	7	7	5	5	5	—	—	—	(1)
$\bar{x}$	—	—	—	3.0	24	424	2.2	20	552	—	—	—	
s	—	—	—	3.5	11	221	0.5	10	120	—	—	—	
n	—	—	—	16	16	16	12	12	12	—	—	—	(2)
$\bar{x}$	—	—	—	2.7	33	420	2.4	32	383	—	—	—	
s	—	—	—	1.9	16	288	1.4	20	164	—	—	—	
n	—	—	—	13	13	13	6	6	6	—	—	—	(3)
$\bar{x}$	—	—	—	2.7	37	503	2.6	37	440	—	—	—	
s	—	—	—	2.1	20	164	0.8	27	125	—	—	—	

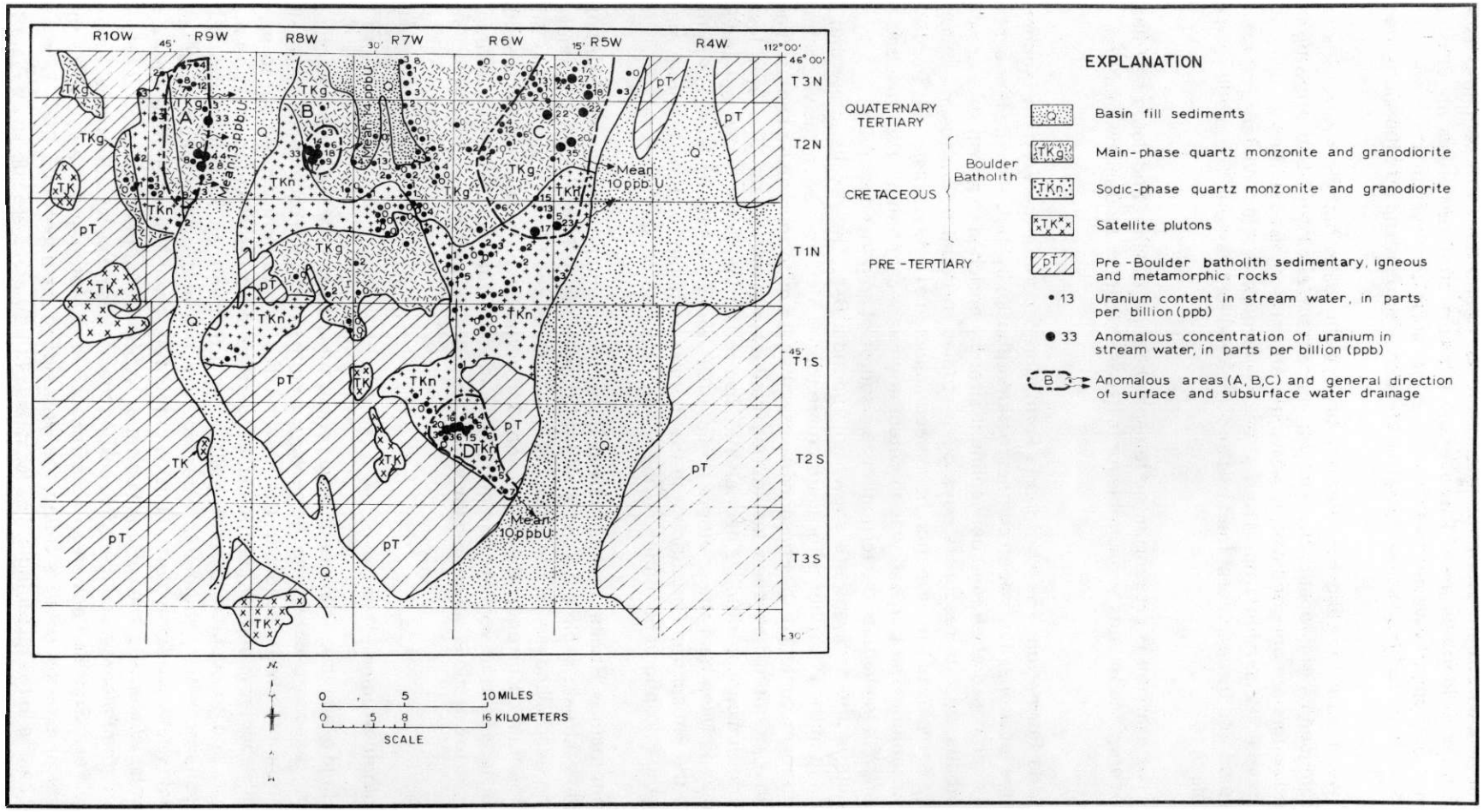


Figure 6. **Sketch map of southern part of Boulder batholith showing sodic and main phases of quartz monzonite and granodiorite relationship of geochemical results in water including areas of anomalous amounts of uranium in stream waters.**

Most anomalous stream-sediment results are for Idaho batholith samples, especially in the Anaconda-Pintlar Wilderness area. The average uranium content here is about 50 ppm and the highest is over 200 ppm; however, this uranium is not soluble in the surface waters. In order to test whether this uranium can be dissolved by ground water, the following investigations were carried out.

- Well waters from the Big Hole Tertiary basin near Idaho batholith were analyzed for uranium (see Pl. 4b). Most of the well waters contain less than 1 ppb, showing that the ground waters are not effectively dissolving uranium from the sediments.
- An anomalous sample from Trout Creek, Anaconda-Pintlar Wilderness area, was separated into three mineral fractions and analyzed for uranium. The results are shown in Table 5.

Most of the uranium is present in the feldspar-bearing fraction and could be released into the ground water only if conditions are suitable for feldspar alteration, an unlikely situation in the Tertiary basins.

Phosphoria Formation. The Phosphoria Formation occurs in the western Pioneer Mountains, where, in some locations, it has been contact metamorphosed by the Laramide Pioneer batholith. The Phosphoria is composed of an unusual sediment strongly enriched in phosphate, uranium, fluorine, and hydrocarbons, and its resources have been studied in detail by Swanson (1970). During the present study, samples of the formation have been collected at various distances from intrusives and analyzed for uranium. The purpose was to detect any chemical changes that resulted from contact metamorphism and to evaluate the formation as a source of epigenetic uranium.

The results of the analyses are shown in Appendix B-5. The results show that the average uranium content of the Phosphoria Formation more than 0.5 mi from an intrusive contact is 80 ppm, whereas the uranium content of the Phosphoria closer than 0.5 mi to an intrusive contact is about 50 ppm, suggesting that uranium has been lost during contact metamorphism. The only location where anomalous uranium concentration is near an intrusive contact, and near the Phosphoria Formation, is in the Greenstone Mine near the southern end of the Pioneer Mountains. Here, garnetiferous skarn lies between the Phosphoria Formation and the Pioneer batholith, and the uranium may have been derived from the Phosphoria Formation during contact metamorphism.

Other Anomalous Rocks. In Appendix B-5 are geochemical analyses of assorted anomalous samples, from a stream sediment separated into three mineral fractions, the Mooney Claims, the Surprise Mine near Gibbonsville, the Phosphoria Formation, the Melrose district, the Bismark Mine, the Comet Mountain occurrence, the Greenstone Mine, the Seven Mile Creek occurrence, the upper Ruby River Basin, a thorium vein near Salmon, and a thorium-rare-earth vein near Shoup. The results are discussed in the sections describing favorable, unfavorable, and unevaluated environments in this report.

Detailed Geologic Studies

Detailed field examination has been carried out in selected parts of the quadrangle for one or more of the following reasons: to determine the geologic setting of uranium occurrences, to evaluate certain geologic environments with respect to their favorability for uranium deposition, to examine areas where several radiometric and/or geochemical anomalies are present and to interpret them in terms of the geology, and to evaluate certain geologic environments as source regions for epigenetic uranium deposits in Tertiary sedimentary basins. With this in mind the following areas have been examined geologically in some detail: the Senate Mine area; the LaMarche Creek area of the Anaconda-Pintlar Wilderness; the LaHood Formation at Sheep Mountain, at Camp Creek, and near the Jefferson River; the Paleozoic sedimentary rocks in the Melrose district; a Precambrian unconformity in the Spuhler Peak-Sunrise Peak area in the Tobacco Root Mountains; the volcanic center south of Salmon; the volcanic center south of Dillon; the west side of the upper Ruby River Tertiary basin; and other Tertiary basins in the quadrangle. The locations of these areas are shown on Plate 11.

TABLE 5. URANIUM CONTENT OF DIFFERENT MINERAL FRACTIONS IN ANOMALOUS STREAM-SEDIMENT RESULTS FROM TROUT CREEK, ANACONDA-PINTLAR WILDERNESS AREA

Sample no.	Mineral fraction	Wgt. %	U (ppm)	% U
MIE 146	quartz & feldspar	97	3	82
MIE 147	biotite & muscovite	2.5	16	11
MIE 148	heavier, including zircon, monazite, apatite	0.5	48	7

Senate Mine Area. The Senate Mine area lies on the northern boundary of the Anaconda-Pintlar Wilderness (Pl. 11) and contains Belt Supergroup metasedimentary rocks intruded by the Idaho batholith. The area was investigated because stratiform copper concentration is within a quartzitic unit and could be associated with uranium concentration.

The geology of the area is shown in Figure 7. The sediments exposed near Senate Mine constitute a regressive sequence. The oldest unit exposed is a massive quartzite and quartzofeldspathic sandstone which is overlain by graded sandstones and mudstones of probably deep-water origin. These are overlain by an impure carbonate that consists of well-sorted and rounded quartz, microcline, plagioclase, muscovite, and traces of tourmaline, cemented with a carbonate that weathers rusty brown and is probably ferroan dolomite or ankerite. The calcareous rocks are overlain by a copper-bearing quartzite that consists of interlocking quartz grains and minor microcline, orthoclase, and plagioclase (<15%). Minor pyrite and chalcocite are interstitial to the clastic grains. An abandoned mine (the Senate Mine) is located in this unit, and the dump material has a level of radioactivity as much as 3.5 times background. The quartzite is overlain by bedded sandstone and mudstone with locally developed cross-bedding. The youngest unit exposed is a cross-bedded, ripple-marked quartzofeldspathic sandstone, the cross-bedding indicating sediment transport from the south. The sandstone consists of poorly sorted and rounded quartz, polycrystalline quartz, and lesser amounts of microcline, plagioclase, and orthoclase (~10%) in a sericitic, hematite-bearing matrix. This unit is similar to the Flathead Formation (Cambrian), but appears to rest conformably on the underlying sediments. The entire sequence has been folded into a syncline which plunges 30° N. The lower part of the sequence is intruded by the Idaho batholith, but the contact was not observed.

The sediments represent a regressive sequence of variable redox potential, contain permeable, immature sediments of granitic provenance, and could be a favorable environment for uranium concentration.

LaMarche Creek Area. Part of the Anaconda-Pintlar Wilderness (Pl. 11) has been mapped because nine uranium stream-sediment anomalies are within the West Fork LaMarche Creek and Trout Creek catchments. The area contains metasedimentary rocks of the Belt Supergroup intruded by at least two phases of the Idaho batholith (see Fig. 8).

The Belt Supergroup metasediments crop out along an east-west striking zone. In the northern part of this zone, quartzites, possibly of the Ravalli Group, predominate. The southern part consists of interbedded phyllites and quartzites and, at East Goat Peak, minor laminated limestone, and may constitute part of the Pritchard formation.

The metasedimentary rocks are intruded by two distinct plutonic rock types. To the north of the Belt outcrop is a homogeneous, coarse-grained quartz monzonite, which consists of biotite, oligoclase, perthitic orthoclase, microcline, and accessory sphene. The microcline is locally large (as much as 2 cm) porphyroblasts. The microcline grew at the expense of plagioclase, which has a myrmekitic texture near its margins. Pegmatites, alaskites, and aplites occur in minor proportions (<1%), mainly near intrusive contacts and as dikes in the country rocks.

To the south of the Belt metasediments, heterogeneous granitic rocks intrude the phyllites and quartzites. The intrusives consist of alaskites, leucocratic granites, and pegmatites that contain microcline, albite, quartz, muscovite, and minor (<1%) biotite. They have a weak foliation oriented subparallel to intrusive contacts. Pelitic rocks in the lower reaches of West Fork LaMarche Creek and Trout Creek have been contact metamorphosed to chiastolite-, sillimanite-, plagioclase-, biotite-, muscovite-, and graphite-bearing schists and hornfels. Thus, in this area are hydrous, two-mica granites that intrude graphite-bearing metasediments, an environment that may have been conducive to uranium concentration.

Uranium Mineralization in the Boulder Batholith. Numerous uranium occurrences are within the Boulder batholith, especially near the towns of Boulder and Clancy (Butte Quadrangle). Uraninite is commonly associated with chalcedony and minor iron, base metal, and silver sulfides (Becraft, 1956; Wright and Shulhof, 1957; Bieler and Wright, 1960). The concentration occurs along fissures, some of which are cut by Lowland Creek volcanic dikes.

In the Dillon Quadrangle, uranium-bearing chalcedony veins are in the Boulder batholith at the Mooney Claims. Chalcedony occurs along fractures together with sericite, pyrite, and minor stibnite.

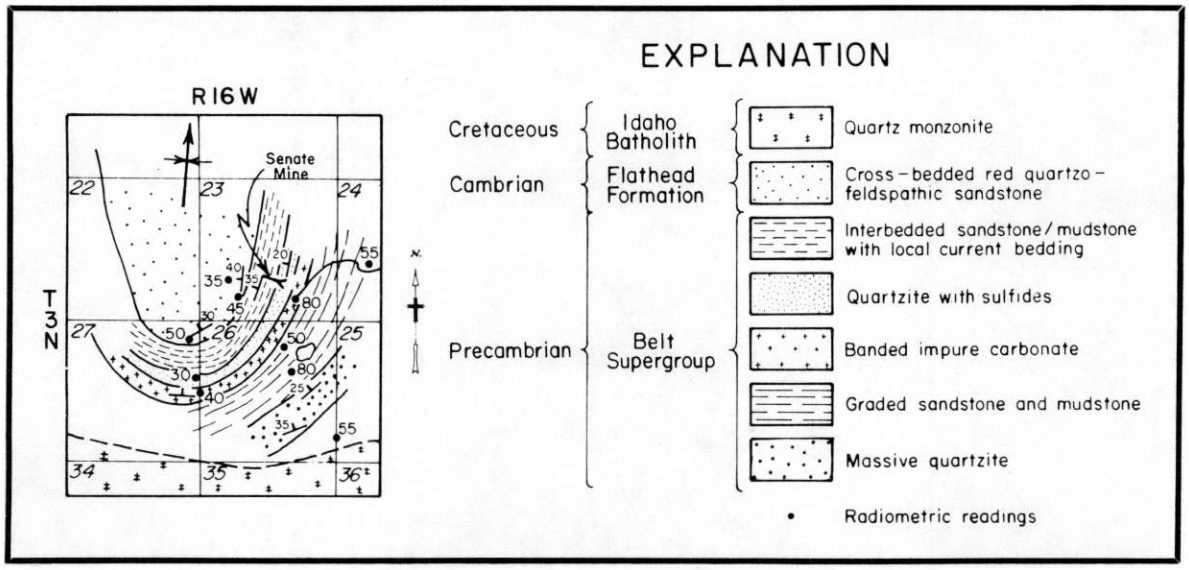


Figure 7. Geologic map of Senate Mine area.

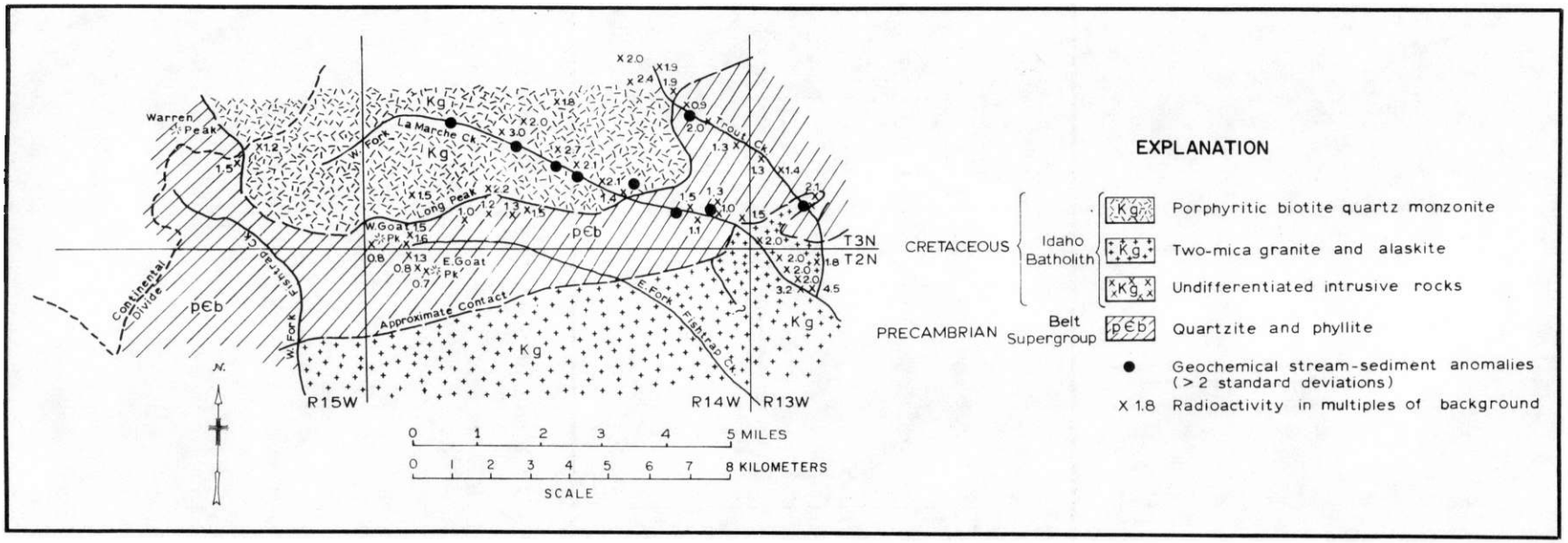


Figure 8. Geologic map and geochemical and radiometric sample locations, LaMarche Creek area, Anaconda-Pintlar Wilderness.

As much as 63 ppm uranium is present in these veins. Quartz monzonite adjacent to the veins is hydrothermally altered. Biotite and hornblende are replaced by nearly colorless chlorite and pyrite, plagioclase is replaced by sericite, and chalcedony and K-feldspar remain unaltered.

A log fO_2-pH diagram (Fig. 9) has been constructed at 10°C showing conditions under which pyrite, sericite, and uraninite, in equilibrium with various complex uranium ions, are stable. The conditions chosen, temperature = 100°C, $\Sigma S = 10^{-3.1}$ M, $\Sigma CO_2 = 10^{-2.55}$ M, $\Sigma K^+ = 10^{-4.0}$ M, approximate those in present-day hot springs in southwest Montana, specifically Boulder Hot Springs (Leonard and others, 1978). It can be seen from this diagram that conditions under which uranium can be transported in solution are far more oxidizing than conditions under which sulfides are stable, and this applies equally at temperatures as low as 25°C and as high as 200°C. The most likely explanation for the occurrence of uranium with sulfides is through mixing of two different waters: one containing reduced sulfide species and probably originating at depth, and the other more oxidizing solution carrying uranium in solution and originating under near-surface conditions. This model not only explains the coexisting uranium and sulfides but also the ubiquitous chalcedony, which probably formed as a result of rapid quenching of the hot hydrothermal fluid by mixing cold descending water.

The important consequences of this interpretation are as follows.

- The vertical extent of uranium mineralization must be limited to the zone of mixing of the two waters.
- Assuming that the uranium was derived by leaching, the amount of uranium deposited cannot be great, because the volume of rock from which the uranium would have been leached is restricted to the rocks above the zone of mixing.

LaHood Formation. The LaHood Formation was studied at Sheep Mountain, at Camp Creek, and near the Jefferson River in the northeast quarter of the quadrangle (Pl. 11). The formation consists mainly of conglomerates and sandstones and might be a potential host rock for sandstone-type uranium deposits. Its lithology and distribution in southwest Montana have been described by McMannis (1965).

At Sheep Mountain (see Fig. 10) the LaHood Formation consists of 213 m (700 ft) of quartz-rich conglomerates and sandstones with as much as 25% plagioclase and K-feldspar in a sericite and locally hematite-bearing matrix. It is overlain by 24 m (80 ft) of a black carbonaceous mudstone, which at the contact with the LaHood is light green and contains gold, pyrite, and as much as 10% chlorite. The mudstone is overlain by an impure carbonate that weathers rusty brown and is probably ankerite or ferroan dolomite. It is very similar to the carbonate occurring near the Senate Mine described earlier.

In the Highland Mountains near Camp Creek (see Fig. 11) the LaHood Formation sandstones and conglomerates unconformably overlie and are in fault contact with quartzofeldspathic pre-Belt gneiss. The formation is more than 152 m (500 ft) thick and consists of granite and quartz pebbles, grains of quartz, microcline, plagioclase, minor biotite and muscovite, and traces of apatite, monazite, zircon, and iron oxides. The matrix consists of sericite and chlorite and locally is stained red. At one locality minor chalcopyrite and pyrite are disseminated in the LaHood. Here feldspar has been replaced by sericite and biotite by chlorite. The LaHood Formation becomes finer grained upwards and grades into siltstones and mudstones, some of which are carbonaceous. In the eastern part of the mapped area the LaHood Formation is intruded by a satellite pluton of the Boulder batholith and has been metamorphosed to biotite hornfels.

In the northeast corner of the quadrangle (Fig. 12) the LaHood Formation has lithology similar to that in the Camp Creek area but is better sorted. The basalt contact with pre-Belt gneisses is not exposed but the sediments also have a granitic (probably Dillon Granite Gneiss) provenance. In the north the LaHood grades upward into fine sandstone and finely laminated mudstone. In the other areas it is unconformably overlain by Paleozoic sediments or is in fault contact with Elkhorn Mountain Volcanics. The LaHood Formation is intruded by porphyritic epizonal granites that contain minor disseminated pyrite. Base-metal and gold mineralization is especially associated with these intrusives and occurs along east-west striking silicified breccia zones. One such silicified zone occurs in post-LaHood laminated mudstone and is currently being mined for gold. It is in this area (sec. 19, 20, and

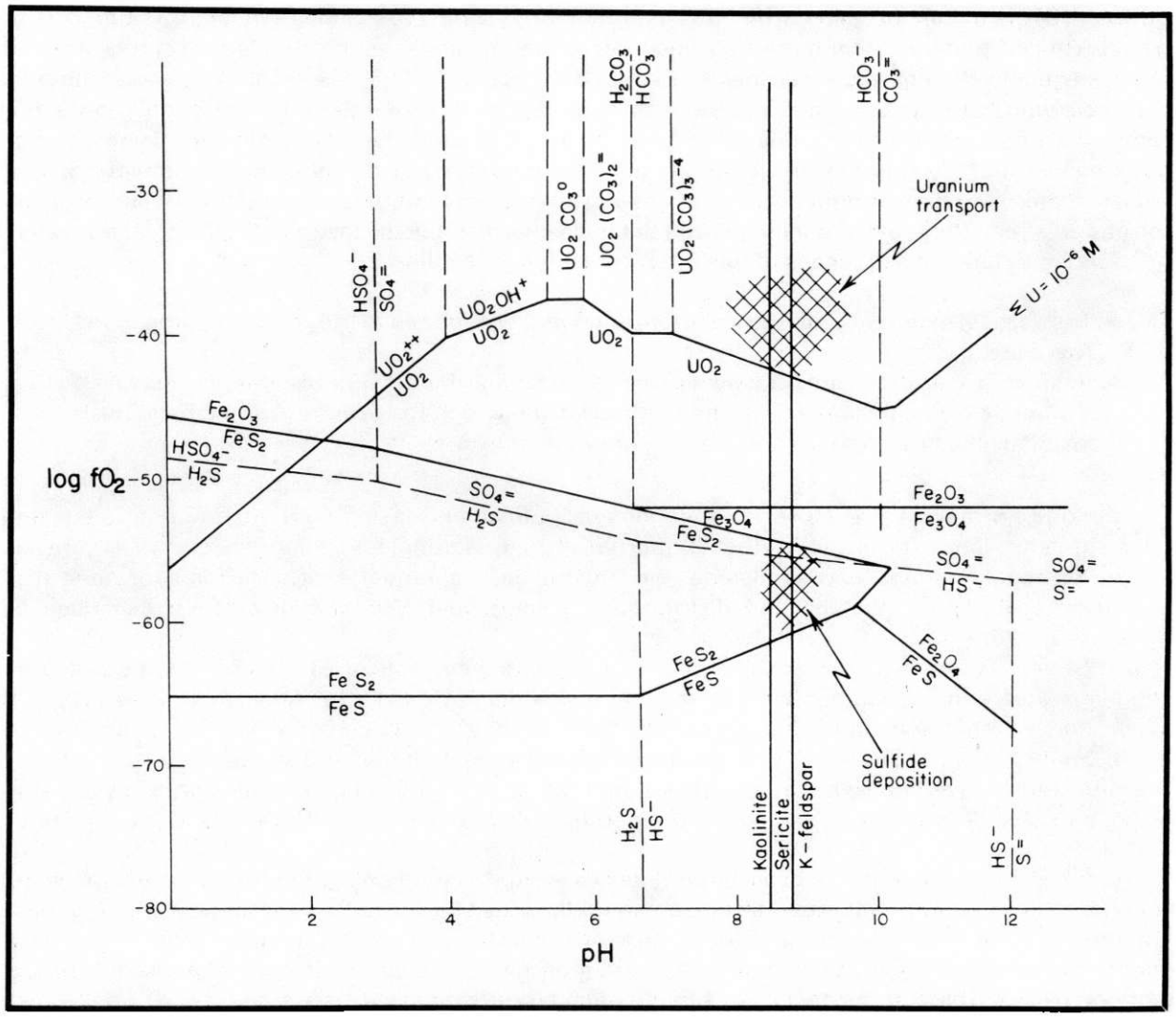


Figure 9. Log fO_2-pH diagram showing stability fields of iron, sulfide, carbonate, silicate, and uranium species. Activity of total uranium in solution ~10^{-6} M. Assumed conditions are: T = 100°C; $\Sigma CO_2 = 10^{-2.55}$ M; $\Sigma S = 10^{-3.1}$ M; $\Sigma K^+ = 10^{-4.0}$ M. Thermodynamic data used after Helgeson (1969) and Langmuir (1978). Diagram modified after S. Dodd (pers. comm.).

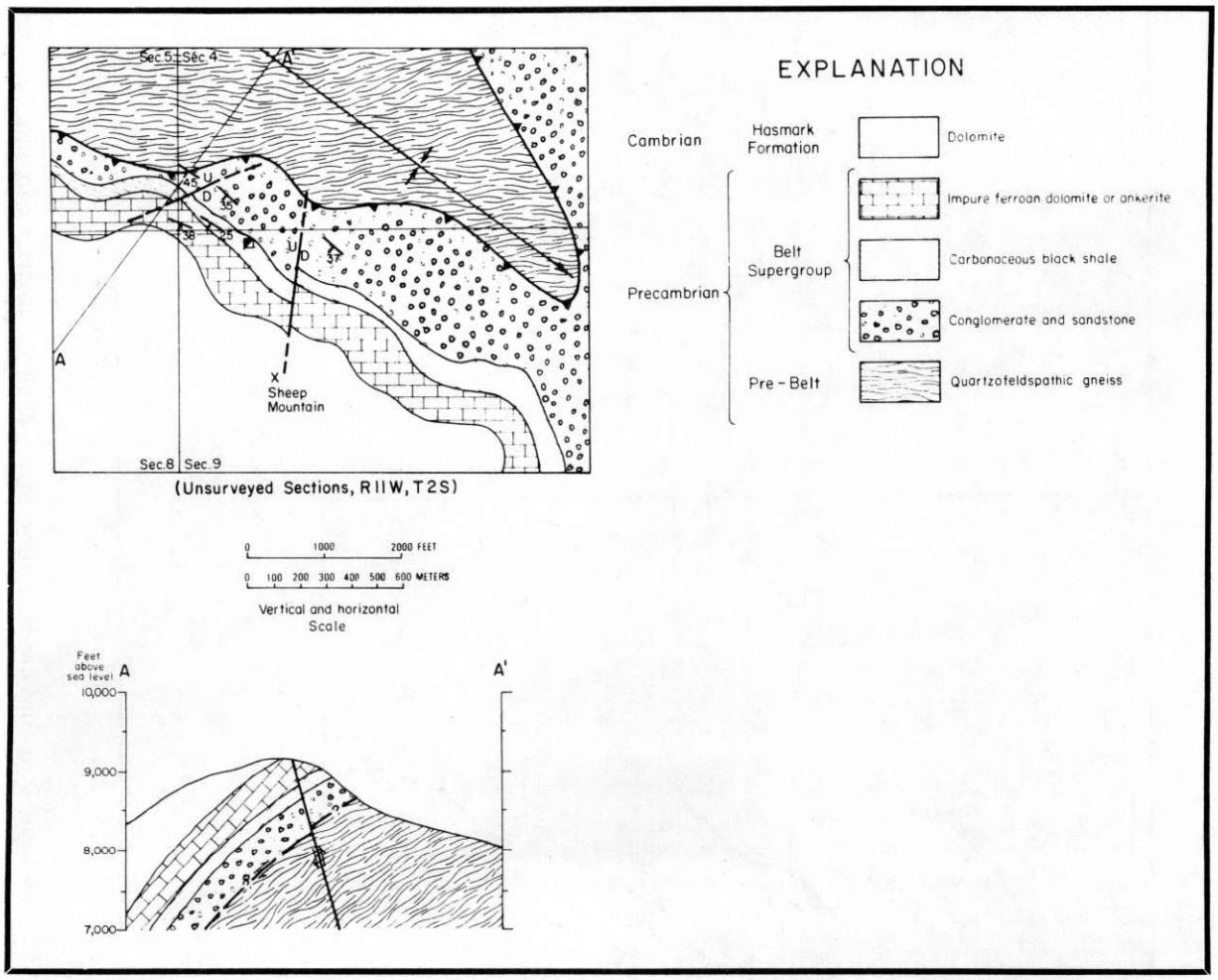


Figure 10. Geologic map and cross section of Sheep Mountain.

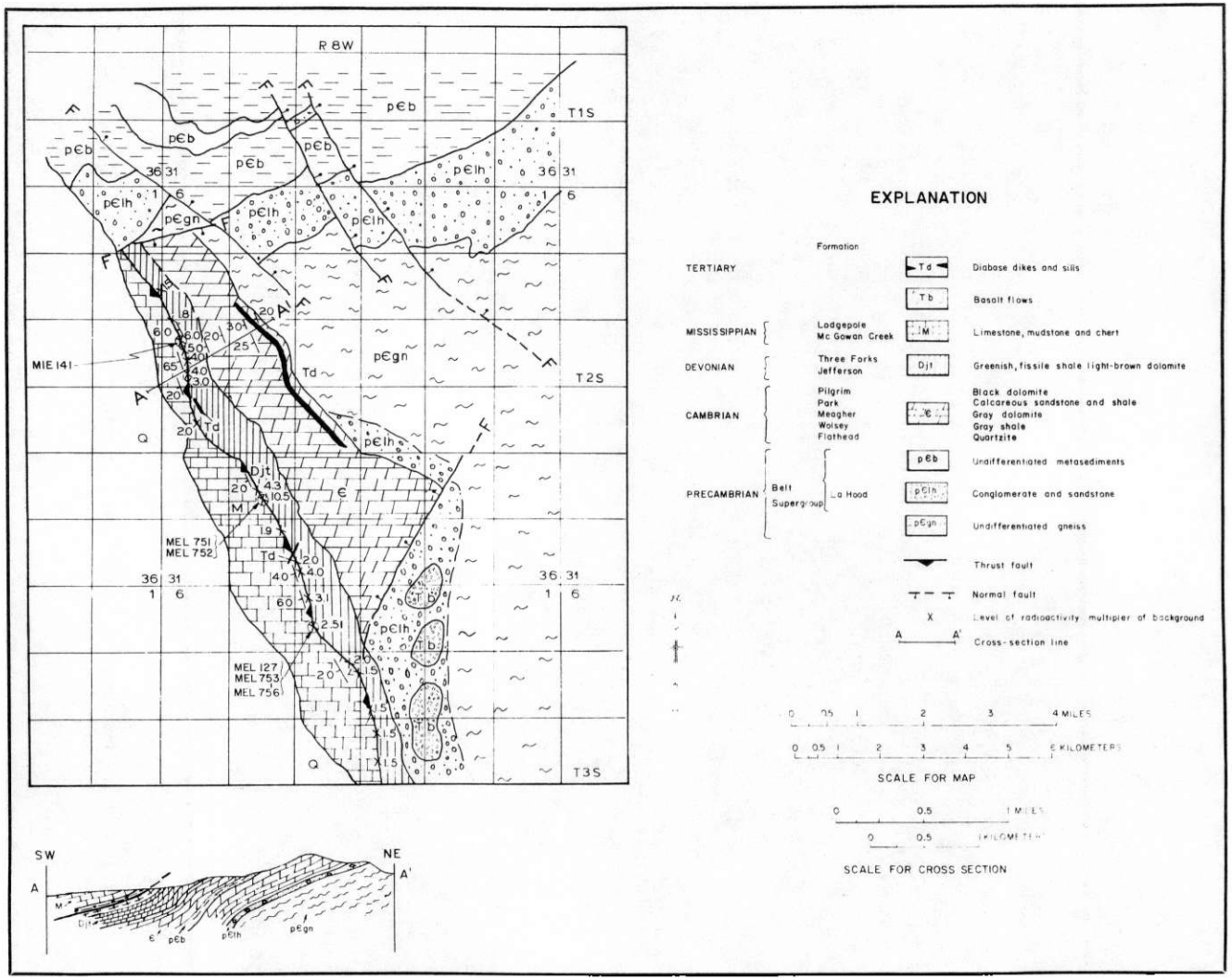


Figure 11. Geologic map and cross section of the Melrose district and adjoining areas.

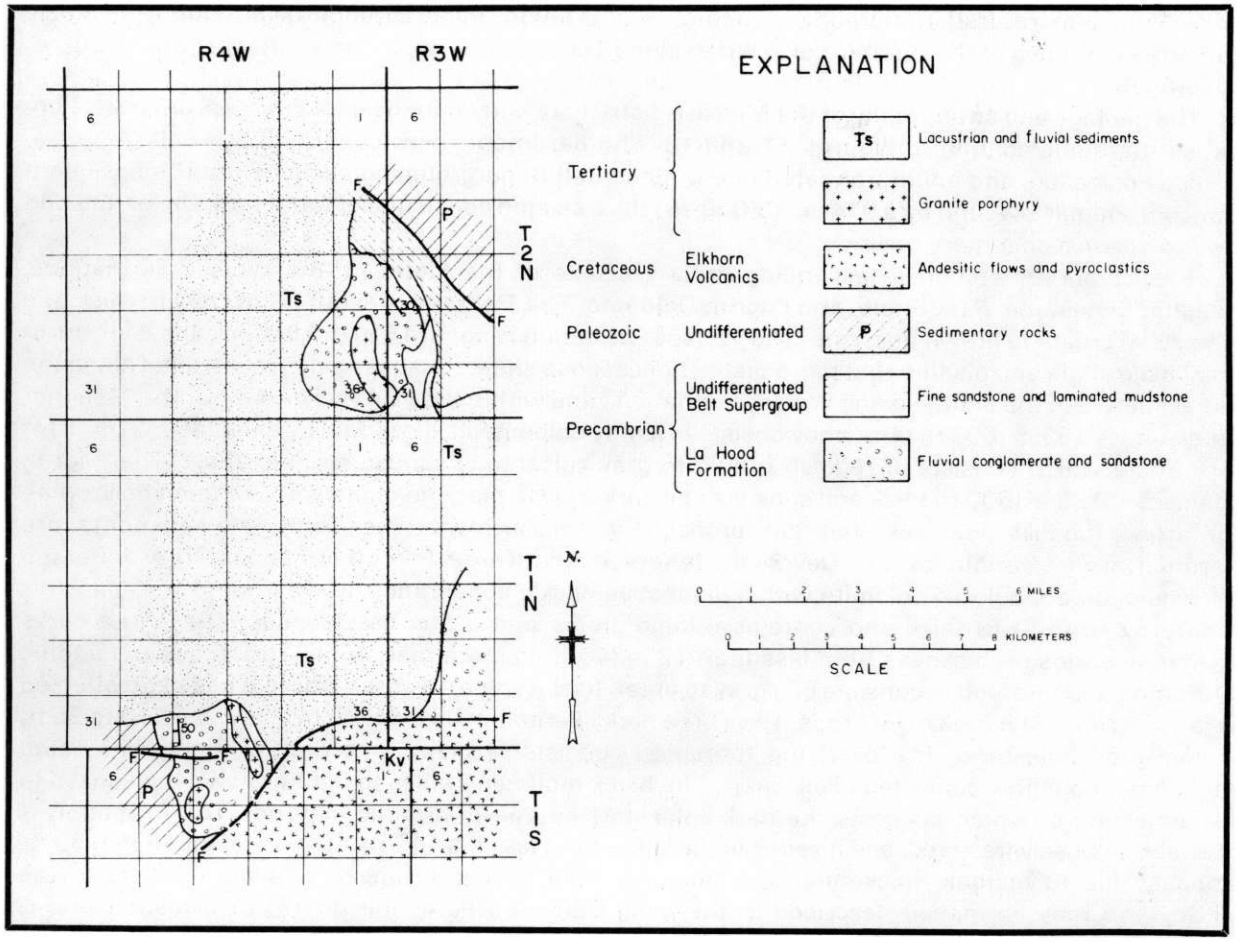


Figure 12. Distribution of LaHood Formation in the northeast corner of the Dillon Quadrangle.

30, T. 2 N., R. 3 W.) that Elevatorski (1977) reported three uranium occurrences. Careful searching during the present study revealed a maximum level of radioactivity of 2.5 times background in the silicified mudstone.

In summary, the LaHood Formation is permeable, is of granitic or granite gneiss provenance, and represents an oxidizing environment. It is overlain by finer grained, locally carbonaceous mudstones, and, on geologic and geochemical grounds, the contact zone between these two lithologies could be a favorable location for uranium deposition.

Melrose District. The area lies in the foothills of the Highland Mountains east of Melrose (Pl. 11). It has been mapped in some detail because it contains at least three uranium occurrences, and the stratigraphic horizon within which the occurrences are present can be traced about 13 km (8 mi) along strike. Furthermore, the stratigraphy, structure, and uranium mineralization bear some remarkable similarities to those of the Birch Creek district, some 160 km (100 mi) to the southwest of the Dubois Quadrangle.

The geology and stratigraphy of the Melrose district are shown in the geologic map, cross section, and stratigraphic column in Figures 11 and 13. The basement rocks consist of pre-Belt gneisses, LaHood Formation, and undifferentiated fine-grained Belt Supergroup metasediments. The basement is unconformably overlain by a 914-m- (3,000-ft-) thick section consisting of Cambrian, Devonian, and Mississippian sedimentary rocks.

The Cambrian section in ascending order consists of the Flathead and Wolsey Formations, Meagher Limestone, Park Shale, and Pilgrim Dolomite. The Flathead is about 30 m (100 ft) thick and consists of cream to brown quartzite. The Wolsey Formation is about 15 m (50 ft) thick and consists of gray fissile shale and phyllite that has a distinct micaceous sheen. Diabase sills are intruded along the contact between the Flathead and Wolsey Formations and within the Wolsey Formation. The Meagher Limestone is 183 m (600 ft) thick and consists of a gray dolomite. It is overlain by about 46 m (150 ft) of Park Shale which consists of reddish brown to gray calcareous sandstone, and shale. The Pilgrim Dolomite is 183 m (600 ft) thick and consists of a dark-gray to black dolomite with common horizontal, light-gray, tubelike features that are probably worm burrows. The Cambrian sediments are disconformably overlain by the Devonian Jefferson and Three Forks Formations. The Jefferson consists of cream-colored dolomite with a distinctive hackly appearance on weathered surfaces. It is about 152 m (500 ft) thick and contains crinoid stems and a few brachiopods. The Three Forks Formation varies in thickness from less than 12 m (40 ft) to more than 46 m (150 ft) due to tectonic thickening and thinning. It consists of a gray to green fissile shale. In areas where it has been affected by fault movement it breaks into rods. The Three Forks Formation is overlain by 3 to 7.6 m (10 to 25 ft) of light-gray limestone. The overlying formation consists of black to dark-gray, finely laminated mudstone and highly contorted black chert. The black mudstone fades to light gray when exposed to the atmosphere, which suggests the dark color may be due to organic material. The formation is invariably intensely fractured, and it varies in thickness from less than 12 m (40 ft) to about 46 m (150 ft), probably due to tectonic thickening and thinning. This formation appears to be identical to the McGowan Creek Formation described in the Long Canyon area in the Birch Creek district and is tentatively correlated with it. The youngest Paleozoic formation present is the Lodgepole Limestone which consists of gray limestone that contains crinoid stems, rugose corals, and brachiopods. The Devonian and Mississippian sediments are intruded by dikes and sills of diabase, probably Tertiary. A few hills in the southeast part of the mapped area are capped by olivine basalt flows.

The Paleozoic rocks have a 20° to 70° dip to the west-southwest. In the north and southwest they are in fault contact with Precambrian rocks, and elsewhere the contact is an angular unconformity. The McGowan Creek and, to a lesser extent, the Three Forks Formation have undergone brecciation, small-scale folding, and lateral changes in thickness. These are due to a fault that, over most of its length, is parallel to the bedding. Vergence directions of small folds in the McGowan Creek Formation suggest transport of the upper block from east to west, that is, downdip. The fault may be a bedding-plane gravity fault.

Where it is intensely brecciated the McGowan Creek Formation is cemented by opaline silica, iron oxides, and fluorite and is anomalous in uranium and molybdenum. Uranium concentration probably took place in two stages, first, an initial concentration during McGowan Creek sedimentation, and

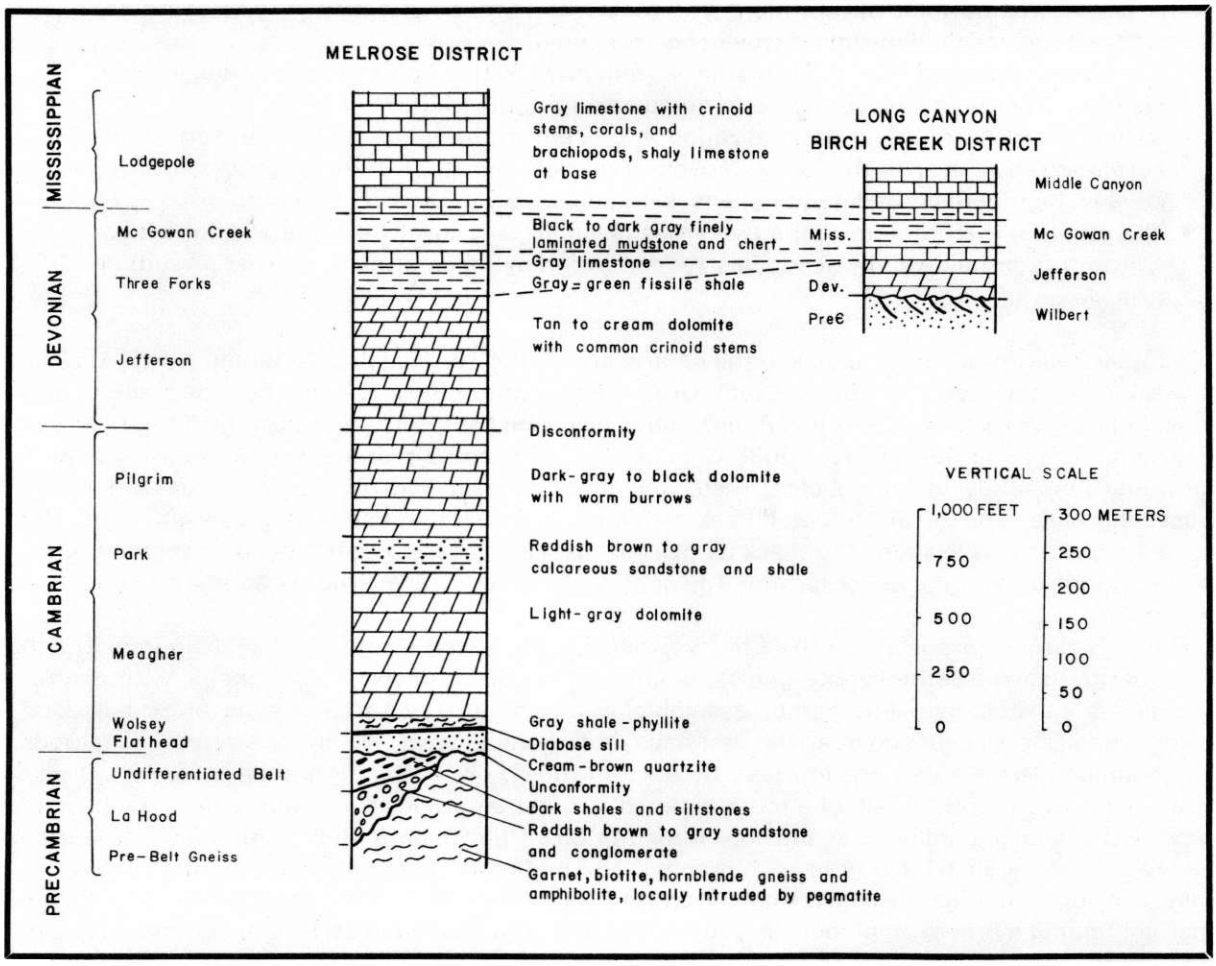


Figure 13. Stratigraphic column in the Melrose district with possible correlation in the Birch Creek district.

second, during the faulting episode. There does not appear to be any relation between the uranium occurrences and diabase intrusions.

The stratigraphy, structure, and uranium mineralization in the Melrose district is strikingly similar to that in the Birch Creek district, 160 km (100 mi) to the south in the Dubois Quadrangle.

- The two areas have similar stratigraphy in the Devonian to Mississippian part of the section, except for the apparent absence of the Three Forks Formation from the Long Canyon area (see Fig. 13). R. Scholten, who has been mapping in the Birch Creek district, has informed us, however, that in most places the Three Forks Formation is present between the McGowan Creek and Jefferson Formations.
- A bedding-plane fault occurs along the McGowan Creek Formation in both districts, where it has resulted in similar types of deformation.
- Brecciated McGowan Creek Formation is cemented with silica and iron oxides in both districts. Fluorite, however, has been noted only from the Melrose district.
- In both districts, uranium mineralization is present in the brecciated McGowan Creek Formation. It is only in the Long Canyon area, however, that uranium occurs in low-density, high-porosity sedimentary lenses in the McGowan Creek Formation.
- The origin of the uranium in the two areas is similar and involves primary sedimentary concentration followed by secondary redistribution by fluids probably during a faulting episode.

Sunrise Peak Area. The area lies in the central part of the Tobacco Root Mountains (Pl. 11) close to the contacts between the Cherry Creek Group, Pony Group, and Spuhler Peak formation. The contact between the Cherry Creek and Pony Groups has been considered an unconformity by Tansley and others (1933) and Reid (1958, 1963). Gillmeister (1972) noted that the Spuhler Peak formation (consisting dominantly of amphibolite) rests unconformably on both the Cherry Creek and Pony Groups, the basal unit of the Spuhler Peak formation being a characteristic green quartzite. The Sunrise Peak area was examined to check for possible uranium-bearing quartz-pebble conglomerates, especially along or near the unconformity. The geology is summarized on the schematic cross section in Figure 14.

The oldest rocks exposed are the Cherry Creek Group, which in the vicinity of Spuhler Gulch consist of quartzofeldspathic biotite gneiss, pelitic biotite-garnet gneiss, mafic gneiss with biotite-plagioclase-amphibole-pyroxene-garnet assemblages, ultramafic rocks containing amphibole and pyroxene, and calc-silicate and quartzite that have undergone at least two and possibly three periods of deformation. These rocks are intruded by a 15-m (50-ft) sill of biotite granite which in turn is intruded by a 152-m (500-ft) sill of a more mafic intrusion that grades from gabbro near the base to quartz diorite and granodiorite at the top. Near the base, the gabbro shows cumulate structures showing both mineralogic and grain-size grading. The mafic intrusion has mobilized the underlying granite, and pegmatites intrude both the gabbro and the granite. Above the mafic sill, about 91 m (300 ft) of gneiss containing a brown amphibole (anthophyllite) and large (as much as 10 cm) porphyroblasts of garnet are present.

The above sequence is overlain by a green (fuchsite-bearing) quartzite and a succession of alternating amphibolite and quartzofeldspathic gneisses. The ratio of mafic to felsic gneiss is about 1:5. Each rock type is homogeneous except near contacts, where there is interlayering. This sequence and the underlying gabbro and granite intrusives are structurally simpler than is the Cherry Creek Group. They are interpreted as metamorphosed rhyolitic and basaltic flows and tuffs, possibly comagmatic with the underlying mafic and granitic intrusives.

No angular unconformity was seen between the Cherry Creek Group and the overlying green quartzite and the quartzofeldspathic and amphibolite gneisses. However, the abrupt change in lithology and the simpler structural history of the rocks above the green quartzite suggest that a major break does occur at this horizon. No anomalous radioactivity was noted at or near this contact; in fact, the level of radioactivity in the entire sequence studied varies only from 0.3 to 1.1 times background.

Volcanic Center South of Salmon. Challis Volcanics are well exposed in the southwest corner of the quadrangle and lie south of the Salmon River Basin (Pl. 11). The area was studied in detail because

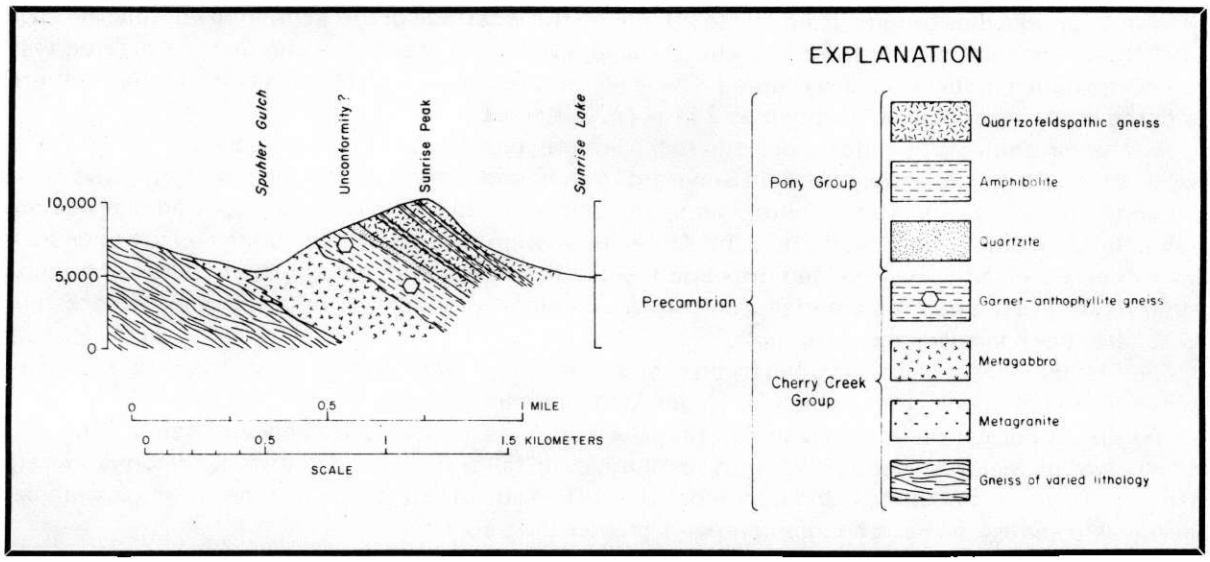


Figure 14. A schematic north-south geologic cross section through Sunrise Peak, Tobacco Root Mountains.

uranium occurrences are within the rhyolitic volcanics that also constitute a good source of uranium for epigenetic deposits in the nearby Salmon River Tertiary basin.

The geology of the area is shown on the geologic map and geologic cross section in Figure 15. The basement consists of Precambrian Belt Supergroup metasediments which in this area consist mainly of quartzites. At the onset of Challis volcanism, considerable relief was present in the basement rocks, and the Lemhi Range, Bitterroot Range, and Salmon depression already existed. The Challis Volcanics in this area contain the following lithologic units: basalt flows, a dacitic shallow intrusive, rhyolite flows, rhyolitic welded tuffs and unwelded tuff breccias, and fine air-fall deposits. These rocks are overlain by the Kirtley Formation.

The basalt flows and basaltic breccia are the oldest Challis unit present. They lie unconformably on Belt metasediments and, north of Williams Lake, are at least 183 m (600 ft) thick. The basalt is dark gray and commonly aphyric, but some flows contain olivine and pyroxene phenocrysts.

The basalt is overlain by rhyolite flows and pyroclastics. The rhyolite flows are pink to cream, commonly flow banded, and contain phenocrysts of feldspar, smoky quartz, biotite, and, rarely, hornblende. Boundaries of flows are commonly brecciated. The rhyolites unconformably rest on and possibly intrude Belt rocks in Perreau Creek, and unconformably rest on basalt flows at the ridge between Williams Creek and Henry Creek. Elsewhere they rest on rhyolite welded tuffs. The rhyolite flows have variable dips ranging from 10° to 20° NE on the west side of the Salmon River and from 10° to 50° NE on the east side of the river. The variable and locally steep dips suggest the magma was viscous and hence probably locally erupted. The rhyolites are variable in thickness and, in the northern half of the study area, may be as much as 244 m (800 ft) thick.

Two major units of rhyolitic pyroclastic rocks are present. The lower unit is about 213 m (700 ft) thick and rests unconformably on Belt Supergroup metasediments and on the basaltic flows. It is overlain unconformably by the rhyolite. The upper unit is about 152 m (500 ft) thick and overlies the rhyolite. It is unconformably overlain by the Kirtley Formation. The pyroclastic units consist of welded tuffs, tuff breccias, and finer, bedded tuffs and rhyolite flows. The welded tuffs have flattened pumice fragments, form bold outcrops, and, locally, show columnar jointing. The other pyroclastic rocks are less coherent and locally show bedding.

The Challis Volcanics are intruded by an oval-shaped plug near Williams Lake. The rock is a dacite and contains phenocrysts of hornblende, plagioclase, and minor quartz.

The Kirtley Formation (formerly the Carmen Formation) rests unconformably on Challis Volcanics. It consists of bedded tuffaceous siltstones, bentonitic air-fall tuffs, minor Belt-derived conglomerate lenses, well-sorted sandstones, and lignite horizons. The ratio of tuffaceous sediments (impermeable) to permeable sandstones and conglomerates is greater than 10:1.

Volcanic Center South of Dillon. Volcanic rocks are well exposed in the hills south of Dillon where they lie adjacent to the Beaverhead River Tertiary basin (Pl. 11). The area was studied in detail because uranium-rich rhyolites are in the area and may constitute a good source of uranium for epigenetic deposits in the nearby Tertiary basins.

The geology of the area is shown on the geologic map and cross section in Figure 16, and the stratigraphy is shown on Plate 10, columns 24 and 25. Basement rocks consist of Paleozoic quartzite and limestone, Cretaceous limestone, and Paleocene Beaverhead Formation. The Tertiary volcanics rest unconformably on the basement which at the time of their deposition had considerable relief. The Tertiary volcanics consist of welded tuffs, rhyolite flows, tuffaceous sediments, and basaltic to andesitic flows.

The oldest volcanic rocks exposed crop out in Grasshopper Creek (sec. 26, T. 8 S., R. 10 W.) and consist of three weakly welded tuff-flow units at least 37 m (120 ft) thick (Pl. 10, column 25). The flow units contain basement and pumice fragments, and from oldest to youngest they become progressively poorer in mafic minerals and richer in quartz. The upper welded-tuff unit is overlain by cross-bedded tuffaceous sandstone derived from the underlying welded tuff by stream action.

The rhyolite flows are in domelike structures as much as 914 m (3,000 ft) thick near Rattlesnake Cliffs and to the south capping a hill at sec. 31, T. 8 S., R. 9 W. The rhyolites are anomalously radioactive (as much as 5.0 times background) and contain smoky quartz and feldspar phenocrysts. They are red to red brown and locally show flow banding that is contorted and commonly steep. In some areas the rock has vugs and fractures filled with chalcedony.

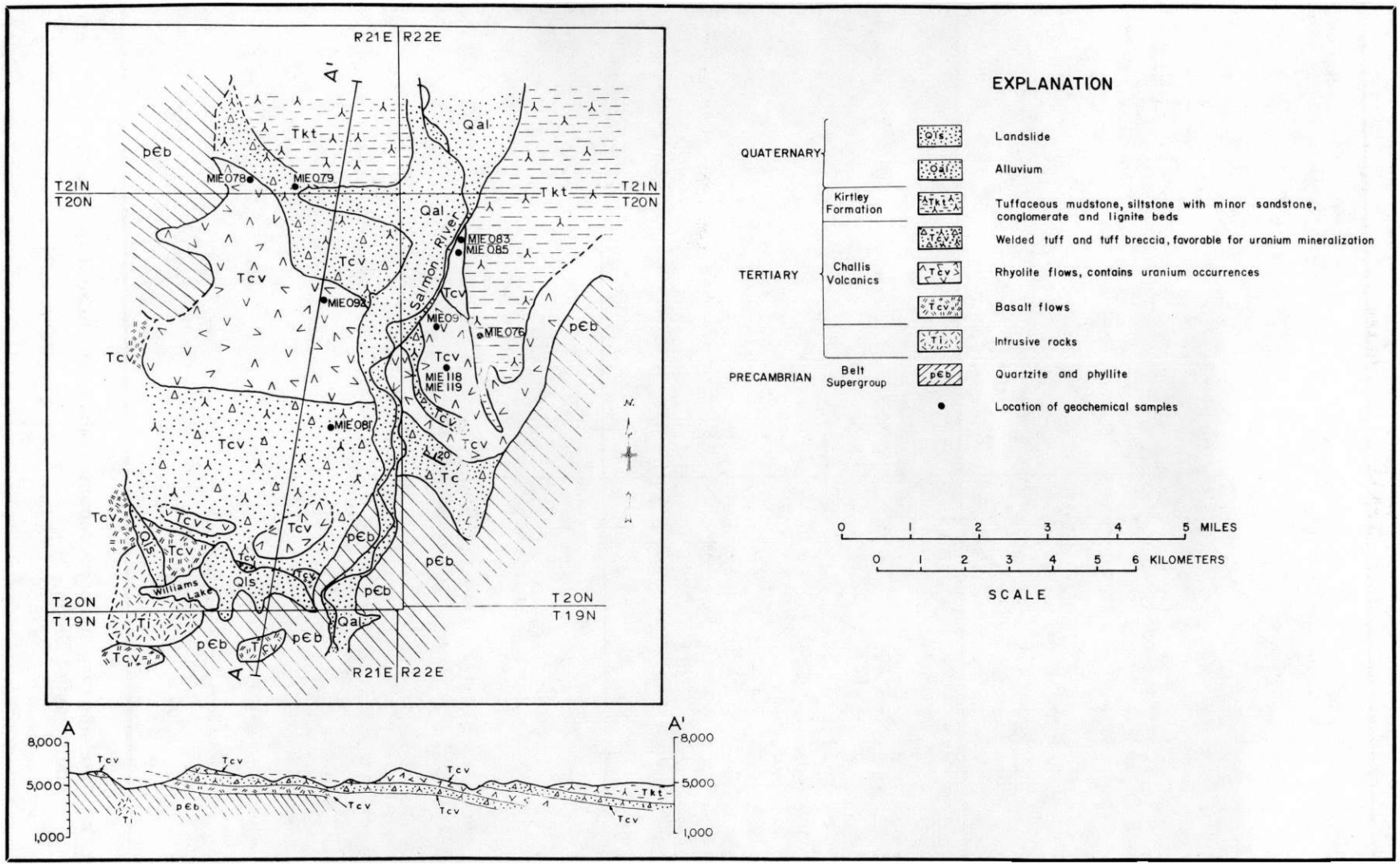


Figure 15. Geologic map and cross section of upper Salmon River Gorge, south of Salmon.

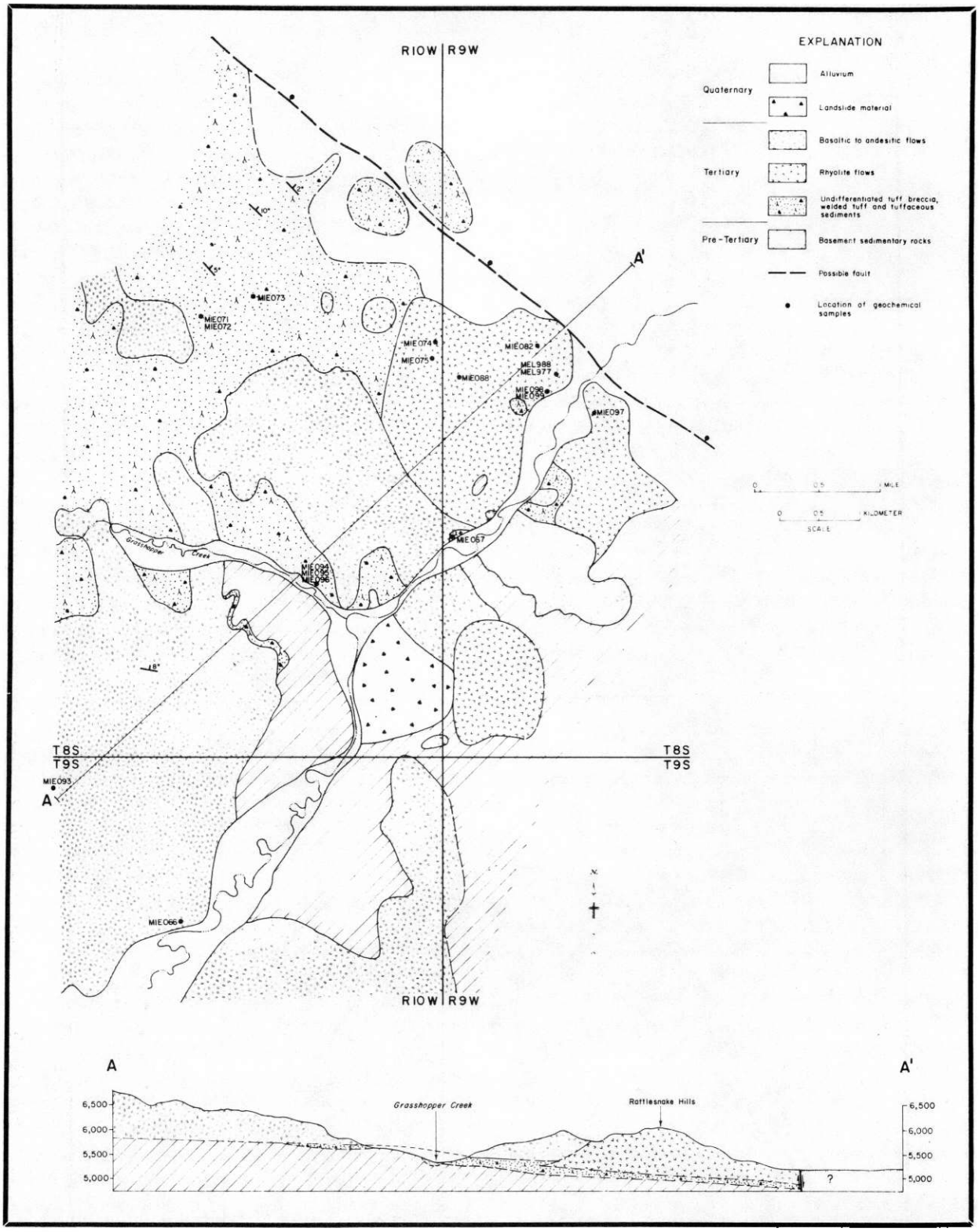


Figure 16. Geologic map and cross section of the Beaverhead River-Grasshopper Creek area, southwest of Dillon.

The welded tuff and rhyolite eruptions were followed by a prolonged period of erosion and deposition of volcaniclastic sediments. These sediments must have been in part derived from the apron of fragmental and tuffaceous debris associated with the rhyolite eruptions and thus contained anomalous amounts of uranium. The volcaniclastic sediments were deposited in local valleys and in the nearby Beaverhead River Tertiary basin (Pl. 10, column 24) where they could constitute source rocks for epigenetic uranium deposits. During this interval as much as 305 m (1,000 ft) of relief developed.

During the final stage of volcanism, voluminous intermediate to basaltic flows were erupted. They filled valleys and locally (at the airway beacon, sec. 10, T. 9 S., R. 10 W.) accumulated to at least 335 m (1,100 ft) thick. Most of the flows are aphyric, but some basaltic flows contain pyroxene and olivine phenocrysts and some intermediate flows contain plagioclase phenocrysts and minor quartz.

Western Side of the Upper Ruby River Basin. The area is in the southeast part of the quadrangle (Pl. 11). It has been studied in detail because exposures are good and the two uranium occurrences here can be studied in relation to the geologic setting. The geology of the area is shown on the map and geologic cross section in Figure 17.

The basement consists of pre-Belt gneiss. The oldest Tertiary unit is about 37 m (120 ft) thick and consists of about 13 tuff-breccia flow units. These units average about 3 m (10 ft) thick, are crudely graded with coarser material at the bottom and fine tuff at the top, and contain rhyolitic and minor basement clasts and also pieces of the underlying flow unit. No welding is evident, and the flow units probably represent lahar deposits or unwelded nuée ardente deposits. These deposits are overlain by about 244 m (800 ft) of tuffaceous siltstone, with two 6-m (20-ft) tuffaceous sandstone layers in the upper half of the section.

In the gorge of Sweetwater Creek the tuff-breccia flow units are intensely hydrothermally altered, resulting in alteration of feldspars to clay and intense silicification of the matrix. Two hills near the north end of the silicified area are capped with an angular breccia composed of silicified tuff fragments cemented with fine-grained silica and interpreted as hydrothermal explosion breccia. The intense alteration of the basal Tertiary units probably reflects their high initial permeability.

Uranium occurrence 11 is along a steep fractured zone within the hydrothermally altered tuff breccia. It was probably deposited after the hydrothermal silicification. Uranium occurrence 12 is within four of the basal tuff-breccia flow units just beyond the zone of hydrothermal silicification. The outcrops are weathered and the smell of oxidizing sulfides can be detected. The level of radioactivity is as much as 14 times background and is the highest recorded in the Tertiary sedimentary rocks in the Dillon Quadrangle. This occurrence is within beds of high initial permeability that contain rhyolite clasts—a likely source for dissolved uranium. The occurrence lies near the outer periphery of the hydrothermally altered zone, and the precipitation of uranium most likely took place near the interface of uranium-bearing ground waters and reducing hydrothermal fluids. Similar conditions may exist in other Tertiary basins such as the Jefferson River Basin where uranium-rich oxygenated ground water comes in contact with reduced sulfur-bearing hot-spring waters.

Tertiary Basins. The Tertiary sedimentary basins cover approximately a third of the Dillon Quadrangle and represent a geologic environment that at least locally may be favorable for uranium deposition. Plate 10 shows the location of the basins, the recently active faults along their boundaries, and the approximate boundary between Eocene–lower Miocene and lower Miocene–Pliocene sediments after Anderson (1956, 1957, 1959), Kuenzi and Richard (1969), Rasmussen (1973), and Wopat and others (1977). Geologic factors most important in evaluating the favorability of the basins for uranium deposition are probably an adequate source rock for the uranium, both permeable and impermeable strata, and reducing conditions. With this in mind, 24 sections have been measured in the Tertiary basins, and the stratigraphic columns are shown on Plate 10.

Some generalizations regarding the rock types in the basins are as follows.

- A large proportion of the sediments in all the Tertiary basins is tuffaceous.
- Most tuffaceous rocks are siltstones and sandstones of air-fall, fluvial, or lacustrian origin. At the southern ends of the Salmon River and Beaverhead River Basins,

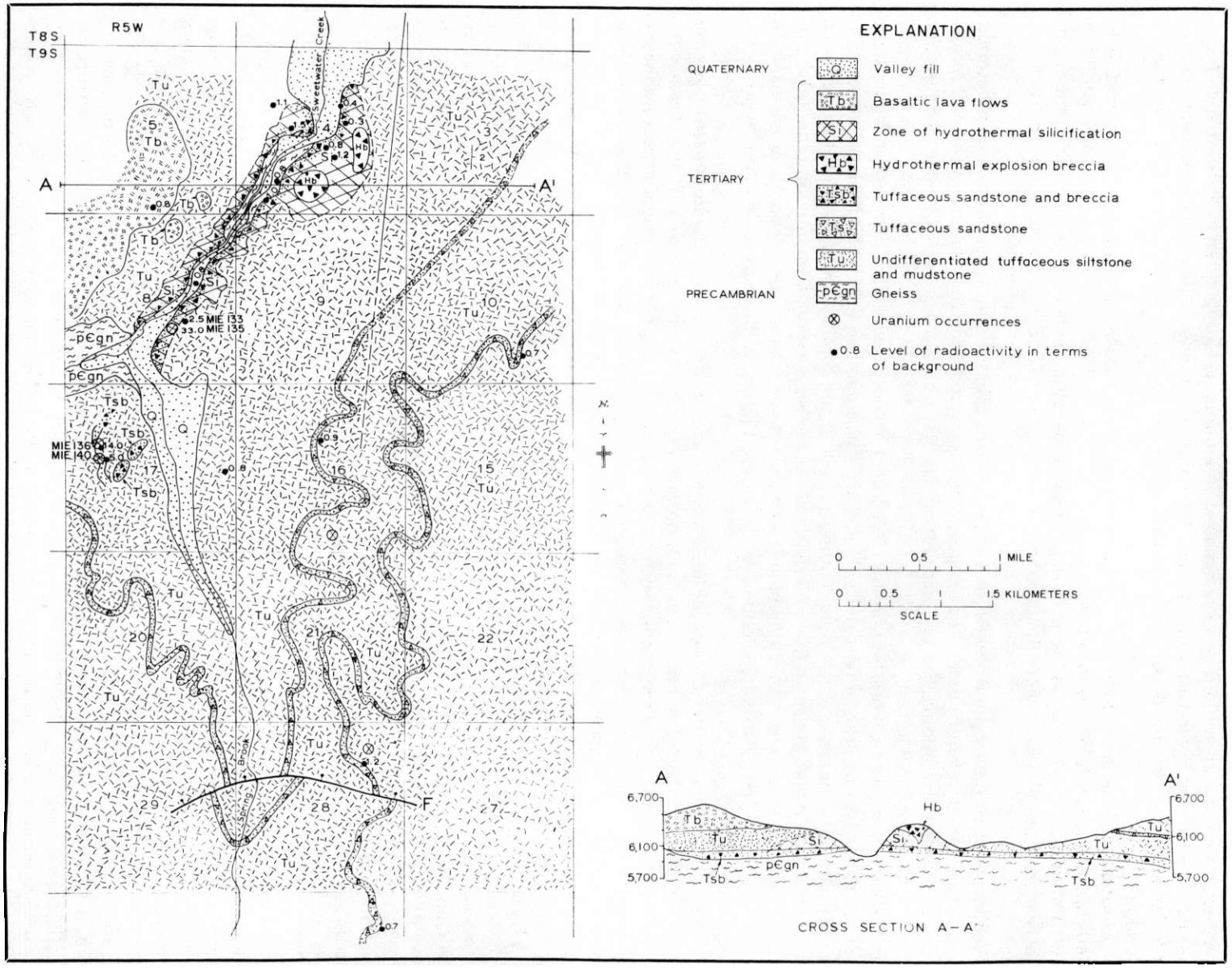


Figure 17. Geologic map and cross section of Sweetwater Creek-Spring Brook area.

brecciated rhyolites are present. These were derived from the nearby rhyolitic volcanic centers. Minor tuff breccia of possible laharic origin occurs in the Big Hole River, Wise River, and upper Ruby River Basins.

- The Jefferson River and Divide Creek Basins contain sediments derived from the Boulder batholith. The remaining Tertiary basins contain variable but minor proportions of sediments derived from other Laramide intrusions.
- All basins contain both permeable and impermeable strata. Commonly, tuffaceous siltstones, tuffaceous sandstones, and most tuff breccias are highly impermeable due to alteration of glass to clays. Rhyolite breccias and some laharic deposits are permeable. In the Big Hole River, Wise River, Divide Creek, Jefferson River, and Beaverhead River Basins the proportion of permeable strata is less than 25%, and in the Salmon River Basin it is about 40%. In the upper Ruby River Basin, volcanic glass is less altered so that some of the tuffaceous sandstones and air-fall tuffs are permeable. The thick breccia units are mudflow-type deposits and are commonly impermeable, whereas the tuff breccias of probable laharic origin are relatively permeable. It is estimated that approximately 35% of the rocks in the upper Ruby River Basin are permeable.
- Carbonaceous sediments and lignites were observed within the Salmon River Basin. Wopat and others (1977) reported minor carbonaceous matter in the Big Hole River, Wise River, Horse Prairie, and upper Ruby River Basins. In the upper Ruby River Basin, hydrothermal pyrite is within basal laharic breccia near uranium occurrences 11 and 12.

Oil and Gas Exploration Logs. Within the Dillon Quadrangle some of the formations, particularly lower Paleozoic, and the Permian Phosphoria Formation can be considered good source rocks for hydrocarbons. In the same Paleozoic sequence there are numerous sandstone, limestone, and dolomitic strata that appear favorable as hydrocarbon host rocks. Although these and other relevant geologic features have been recognized and some oil companies have explored this area for oil and natural gas, no oil or gas of commercial value has yet been discovered. Nevertheless, exploration activity within the Dillon Quadrangle is again being conducted.

During our study of uranium favorability we have also thoroughly investigated and examined all available geophysical and lithologic logs. We have selected two geophysical logs and one lithologic log worthy of special comment.

Unfortunately, only one well penetrated the entire thickness of Tertiary sediments. The following remarks concern an unpublished lithologic log for the oil well registered as Margaret Hagenbarth No. 1 [May Petroleum, Inc., in sec. 12, T. 5 S., R. 5 W.; elevation 1507 m (4,945 ft) above sea level]. The top of the Kootenai Formation (Cretaceous) was found at depth 355 m (1,166 ft). The stratigraphic assignment is not identified for strata lying above the Kootenai Formation, although they are lithologically similar to strata within it. Nevertheless, in the vicinity of the Margaret Hagenbarth No. 1 well, the Kootenai Formation occurs already at the surface, and in this area it cannot be thicker than about 400 m (1,300 ft). There is also considerable disagreement with the stratigraphic sequence as identified in the nearby well. This one, registered as Rebish 29–1 (American Quasar Petroleum Co.), is in the upper-central part of the Jefferson River Basin [sec. 29, T. 5 S., R. 7 W.; elevation 1478 m (4,849 ft) above sea level], only 3.5 mi from the Margaret Hagenbarth No. 1 well. In spite of the close proximity of these wells, their geophysical logs are different; correlation can be approximated using resistivity logs, but the stratigraphic subdivisions for these two wells are in total disagreement. The greatest differences between these wells are gamma-ray characteristics. Apparently significant gamma anomalies that occur in the Margaret Hagenbarth well at depth 408.4 m (1,340 ft) to 413.3 m (1,356 ft) and then at depths 417.6 m (1,370 ft), 429.8 m (1,410 ft), 481.6 m (1,580 ft), 499.9 m (1,640 ft), 667.5 m (2,190 ft), 673.6 to 481.6 m (2,210 to 2,220 ft), 1029.6 to 1042.6 m (3,378 to 3,420 ft), and 1077.2 to 1079.0 m (3,534 to 3,540 ft) do not appear in the Rebish 29–1 well. Instead, in this latter well, a strong gamma-ray anomaly occurs only at depth 1271.0 to 1489.4 m (4,170 to 4,280 ft). The gamma-ray log for this depth interval for the Margaret Hagenbarth well is not available. It is noteworthy, too, that at least some of these gamma-ray anomalies occur within irregularly high resistivity and about 15% porosity intervals. In these cases it seems very likely that high gamma-ray anomalies are caused by an

anomalous concentration of uranium perhaps within the McGowan Creek Formation or its equivalent (here identified only as the Three Forks Formation), which correlates with the Melrose area unit (see Fig. 13).

Uranium Occurrences. Twelve uranium occurrences have been examined in the Dillon Quadrangle, and their locations are shown on Plate 2. Each occurrence is described in detail in the uranium-occurrence reports in Appendix C and in Appendix A. The geologic setting of the occurrences has been described in earlier sections of this report. A brief description of the uranium occurrences is given below.

Uranium occurrences 5, 6, and 7 have been previously described by Trites and Tooker (1953). They occur in the Mississippian McGowan Creek Formation which consists of finely laminated siliceous mudstone and chert. The formation in this area varies in thickness from 12 to 46 m (40 to 150 ft) because of tectonic thickening and thinning, and contains, on the average, about 20 to 40 ppm uranium. According to the classification of Jones (1978) the class of these deposits is marine black shale (Class 130).

All three occurrences also contain uranium along shears and fractures, accompanied by iron oxide, silica, and fluorite. At occurrence 5 the shear zone is 1.8 m (6 ft) thick and contains 90 ppm uranium. At occurrence 6 the sheared zone is 6.1 m (20 ft) thick and contains 170 ppm uranium. The shearing is related to a bedding-plane fault within the McGowan Creek Formation. The uranium was probably concentrated by ground water during or after fault movement. According to the classification of Mathews (1978b) the class of these deposits is vein-type in sedimentary rocks (Class 730).

Uranium occurrence 12 has been noted by Broxton (1978). It is within a series of permeable rhyolite-bearing laharic deposits near the base of Tertiary sediments. The occurrence contains pyrite and is on the margin of an intensely hydrothermally silicified area within the same laharic deposits. The uranium was probably deposited in an area where reducing geothermal water mixed with uranium-bearing oxygenated ground water. The radioactive laharic deposits are 4.6 m (15 ft) thick and, on the average, contain 25 ppm uranium. According to the classification of Austin and D'Andrea (1978) the class of this deposit is non-channel-controlled peneconcordant (Subclass 244).

Uranium occurrence 11 has not been described previously. It is along a steep fracture within hydrothermally silicified, rhyolite-bearing, laharic deposits near the base of Tertiary sediments. The deposit occurs close to what is interpreted as a hydrothermal explosion vent, and the fracturing may be related to the hydrothermal event. The fractured zone is 1.2 m (4 ft) wide and contains 160 ppm uranium. According to the classification of Mathews (1978b) the class of this deposit is vein-type in sedimentary rocks.

Uranium occurrence 2 has previously been described by Trites and Tooker (1953), Weis and others (1958), and Anderson (1958). It is in a sheared, steep, quartz vein in the sheared Proterozoic sandstone and quartzite wall rocks. The shears are associated with clay minerals and are saturated with water. Nearby hilltops are covered with remnants of once more-extensive flows and pyroclastics of the Challis Volcanics. The origin of the deposit is uncertain, but the uranium may have been transported from the overlying volcanics by ground water and then deposited along shears within Proterozoic metasediments. The precipitation of the uranium may have been facilitated by the former presence of sulfides in the hydrothermal quartz vein. The width of the sheared zone averages 9.1 m (30 ft) and the average uranium content is 175 ppm uranium. According to the classification of Mathews (1978b) the class of this deposit is vein-type in sedimentary rocks.

Uranium occurrence 10 has been noted by Elevatorski (1977). It is within the footwall of an alaskite dike that intrudes pre-Belt gneisses. The dike is about 61 m (200 ft) thick, dips 40° W, and can be traced for 1.6 km (1 mi) along the strike. It is not foliated, unlike the surrounding gneisses, and is probably Laramide or Tertiary. The basal 3 m (10 ft) of the dike are anomalously radioactive. This 3-m (10-ft) basal zone contains 46 ppm uranium and 29 ppm thorium. According to the classification of Mathews (1978a) the class of this deposit is pegmatitic (Class 320).

Uranium occurrence 1 has previously been noted by Elevatorski (1977). It is along silicified shears within the Boulder batholith. The shears contain chalcedony, uraninite, pyrite, and stibnite, and the surrounding quartz monzonite has been sericitized. The coeval precipitation of uraninite and sulfides in chalcedony is not likely to have taken place from one hydrothermal solution (see section on uranium

mineralization in Boulder batholith), and the most likely explanation is that the uranium was precipitated in a zone where oxygenated near-surface waters mingled with reducing, upwelling hydrothermal water. Two silicified shear zones are in the area. The first is between 3 and 3.6 m (10 and 15 ft) wide, can be traced for 46 m (150 ft), and contains between 30 and 60 ppm uranium. The second is between 3 and 3.6 m (10 and 15 ft) wide, can be traced for 55 m (180 ft), and contains 55 ppm uranium. According to Mathews (1978a) the veins in Boulder batholith are in the magmatic-hydrothermal (Class 330) class, but present work suggests a better classification would be authigenic (Class 360).

Uranium occurrence 3 has not been described previously. The uranium occurs in a vein cutting quartz monzonite of the Pioneer batholith. The vein contains fine-grained quartz or chalcedony together with minor pyrite and possibly gold. Again, the most likely explanation is that the uranium was precipitated in a zone where oxygenated, near-surface, uranium-bearing waters intermingled with reducing, upwelling, sulfur-bearing hydrothermal water. Anomalous radioactivity is present at four levels in the mine. The average width of the vein is 0.8 m (2.5 ft), and the average uranium content is 30 ppm. According to the classification of Mathews (1978a) the class of the deposit is authigenic.

Uranium occurrence 4 has not been described previously. The uranium occurs in a garnetiferous skarn developed in Madison Group limestone in the Greenstone Mine near the contact with the Pioneer batholith. The anomalously radioactive skarn is developed within a 6-m (20-ft) zone that contains 50 ppm uranium. According to the classification of Mathews (1978a) the class of the deposit is contact-metasomatic.

Uranium occurrences 8 and 9 have been described by Anderson (1956, 1958) and in an unpublished report by Shockey and Oref (1958). The deposits are in rhyolite flows that are both overlain and underlain by welded tuffs. Occurrence 8 is along two steep shears within rhyolite. The shears are 1 and 1.2 m (3 and 4 ft) wide, are silicified, are stained with iron oxides, and contain 120 and 96 ppm uranium, respectively. The shears pinch out 3 to 4.6 m (10 to 15 ft) above the base of the outcrop.

Occurrence 9 is also within a rhyolite flow, but does not appear to be associated with shearing. At two localities this rhyolite is highly radioactive. At the southern locality a 3-m (10-ft) horizon within the rhyolite that can be traced laterally for about 20 m (65 ft) contains 57 ppm uranium. At the northern locality a 3-m (10-ft) horizon within the same flow can also be traced laterally for about 20 m (65 ft) and contains 150 ppm uranium. According to Shockey and Oref (1958) the entire rhyolite flow within which the occurrences are present is somewhat uranium anomalous, suggesting that some concentration may have taken place during the magmatic stage. However, the occurrence of uranium along shears and within sporadic hot spots within the rhyolite suggests that the uranium has been redistributed during postmagmatic processes. According to the classification of Pilcher (1978) the class is probably hydroauthigenic (Class 530).

ENVIRONMENTS FAVORABLE FOR URANIUM DEPOSITS

The locations of favorable environments are shown on Plate 1. The environments are uraniferous veins in Precambrian Y metasediments (Area C), the McGowan Creek Formation in the Melrose district (Area A), and some of the Tertiary sedimentary basins (Areas B_1 through B_7). The environments are considered favorable because of the presence of uranium occurrences and of geologic and geochemical characteristics that favor transport and concentration of uranium. Generalized land status in the Dillon Quadrangle is shown on Plate 12.

URANIFEROUS VEINS IN PROTEROZOIC METASEDIMENTS

This favorable area (Area C) is at the Surprise Mine, Gibbonsville (occurrence 2). The uranium occurs in a sheared, steep quartz vein and in sheared Precambrian Y sandstone and quartzite wall rocks. The sheared zone can be traced underground for about 230 m (750 ft) along the strike, is about 9 m (30 ft) wide, and has an average 175 ppm uranium. Locally, the concentration is as high as 2,100 ppm uranium. The only uranium mineral seen is green and micaceous and is probably torbernite or metatorbernite. It is not known to what depth the uranium concentration persists.

The form of the deposit suggests vein-type in sedimentary rocks (730) but its origin is uncertain. As discussed in the section on uranium occurrences, the uranium was probably transported from formerly overlying Challis Volcanics by ground water and then deposited along shears within the quartz vein and metasedimentary wall rocks. The precipitation of the uranium may have been facilitated by sulfides (reductants) in the hydrothermal quartz vein and wall rocks. If this interpretation is correct then mineralization is not likely to persist deeper than river level, about 250 m (800 ft), and the volume of the environment is about 0.5 X 10^6 m^3 (18 X 10^6 ft^3).

McGOWAN CREEK FORMATION

This favorable area (Area A) is near Melrose. Uranium occurs within the Mississippian McGowan Creek Formation which consists of dark-gray, laminated siliceous mudstones and interbedded chert. The formation varies between 12 m (40 ft) and 45 m (150 ft) in thickness, the variation being due to tectonic thickening and thinning. The formation is cut by a low-angle, bedding-plane fault that locally fractures the formation intensely.

The average uranium content of the McGowan Creek is 20 to 40 ppm, and the primary uranium concentration is of the class marine black shale (130). Where the McGowan Creek has been sheared by faulting it is enriched in uranium associated with iron oxides, opaline silica, and fluorite. These deposits are classified as vein-type in sedimentary rock (730) because of their association with silica, fluorite, and iron oxides along brecciated fault zones, which, at least locally, crosscut bedding. The uranium was probably concentrated by ground water during or after fault movement.

The width of the fractured zones along which the uranium is concentrated varies from 2 m (6 ft) to 6 m (20 ft). The uranium content varies from 65 to 480 ppm and averages probably between 100 and 150 ppm. The McGowan Creek Formation underlies an area of about 60 km^2 (23 mi^2). It crops out (though poorly) along a strike length of about 10 km (6 mi), but it is anomalously radioactive for only about 3 km (1.8 mi), 30% of the outcrop. In the anomalous areas, uranium is concentrated in fractured rocks about 3 m (10 ft) thick. Extrapolating these data to the entire 60-km^2 area, the volume of rock in which uranium deposits may occur is 54 X 10^6 m^3 (1,900 X 10^6 ft^3).

TERTIARY BASINS

The Tertiary basins are the largest and most favorable environment for uranium deposits. The basins are also an environment difficult to evaluate, mainly because most of the sediments cannot be examined directly. In order to evaluate each basin, the following types of observations have been made.

- The presence of favorable uranium source rocks in or adjacent to each basin has been determined. Various source rocks have been evaluated in the section on geochemical data. It was found that rhyolite flows, fragmented rhyolitic rocks such as laharic deposits, and waters draining from the Boulder batholith are the most potent sources of uranium.
- The proportion of permeable to impermeable rocks has been estimated using present data and data of Wopat and others (1977). Following Wopat and others, 30% to 80% permeable sediments is regarded as favorable.
- An attempt has been made to identify basins and portions of basins where reducing conditions are present. Indicators of such conditions can be carbonaceous material, pyrite, or chemical evidence from well and spring samples.
- A large number of well and spring waters have been analyzed for uranium and other constituents. Obviously, waters that are rich in uranium are more likely to give rise to uranium ore deposits.
- Any uranium occurrences present were noted and examined. Much of the geologic and geochemical data that are used in the evaluation of the basins is shown on Plates 8b and 10.

The Tertiary basins have been classified as either favorable or unevaluated; favorable basins are discussed in this section.

Wise River Basin

The Wise River Basin (see Area B_1) contains an unknown thickness of undifferentiated Tertiary sediments. Rhyolitic tuff breccia, probably related to the Lowland Creek volcanics, is present in the basin and may constitute a suitable source of uranium. About 30% of the strata are permeable, and minor carbonaceous matter is present. One well water has a highly anomalous concentration of uranium, and two well waters contain reduced sulfur species in solution.

The oxidizing, uranium-rich waters may have come in contact with the low-Eh water along a zone that could be 2500 m (8,000 ft) long. If it is assumed that the thickness of an aquifer within which mixing takes place is 10 m (33 ft)—a reasonable assumption based on the available measured sections (see Pl. 10)—and that the width of the zone in which uranium is precipitated is 20 m (66 ft), then the volume of rock in which uranium deposits may occur is 0.5×10^6 m^3 (18×10^6 ft^3). According to the classification of Austin and D'Andrea (1978), the deposit so formed would be in the Wyoming roll-front (241) subclass.

Divide Creek Basin

The sediments in Divide Creek Basin (see Area B_2) are Miocene-Pliocene, are at least 900 m (3,000 ft) thick, and contain 20% to 25% permeable strata. No organic matter has been reported from the basin, but some of the permeable conglomerates are altered and stained with ferric oxides. Two highly anomalous wells are present in the north where the basin is surrounded by the Boulder batholith. Streams averaging 13 ppb uranium drain into the northern part of the basin from a 10-km by 2-km area overlying Boulder batholith. If one assumes a mean annual precipitation of 0.25 m (10 in.), then 6.5×10^4 tons of uranium are transported into the basin every million years.

The highly anomalous waters enter the basin along a 10-km (6-mi) front. If it is assumed that conditions become reducing due to oxidation of organic matter or ferrous iron, that the thickness of the aquifer into which the uranium-rich water enters is 5 m (16 ft)—a reasonable assumption based on the available measured section (see Pl. 10)—and that the width of the zone in which the uranium is precipitated is 20 m (66 ft), then the volume of rock in which uranium deposits may occur is 1×10^6 m^3 (35×10^6 ft^3). According to the classification of Austin and D'Andrea (1978), the deposit so formed would be of the Wyoming roll-front (241) subclass.

Jefferson River Basin

The Jefferson River Basin (see Area B_3) contains as much as 1100 m (3,500 ft) of Eocene-Oligocene sediments and as much as 750 m (2,400 ft) of Miocene-Pliocene sediments. The Eocene-Oligocene sediments contain 20% to 30% permeable strata and traces of organic matter, and the Miocene-Pliocene sediments contain about 80% permeable strata and also contain traces of organic material. Six highly anomalous wells are in the north where the basin is bounded on its western side by the Boulder batholith, and there are two locations in the basin where hot-spring waters containing reduced sulfur species enter the sediments. Streams averaging 10 ppb uranium drain into the northern part of the basin from a 200-km^2 (80-mi^2) area. Assuming a mean annual precipitation of 0.25 m (10 in.), 5×10^5 tons of uranium are transported into the basin from this area every million years.

The highly uranium-rich stream waters are fed into the basin along a front about 12 km (7 mi) long. If it is assumed that the aquifer into which the uranium-rich waters enter is 5 m (17 ft) thick, that conditions become progressively more reducing downdip as a result of water interactions with reductants in the sediments, and that the width of the zone in which precipitation takes place in 20 m (66 ft), then the volume of rock in which uranium deposits may occur is 1.2×10^6 m^3 (42×10^6 ft^3). The probability of uranium deposits is enhanced by two hot springs that discharge water into the Tertiary sediments. These hot springs contain reduced sulfur species and are also likely to act as reductants for uranium carried in the ground water. According to the classification of Austin and D'Andrea (1978), the deposits expected in the Jefferson River Basin would be of the Wyoming roll-front (241) subclass, the uranium being along roll fronts or along zones of mixing between uranium-bearing ground water and reduced sulfur species–bearing hot-spring water.

Salmon River Basin

The sediments in the Salmon River Basin (see Area B_7) are from Paleocene to Pliocene in age and are at least 1100 m (3,600 ft) thick. Overall the sediments contain about 40% permeable strata, but the Kirtley Formation, at the top of the sequence, contains only about 10% permeable strata, whereas the underlying Kriley, Kenney, and Geertson Formations contain about 60% permeable strata. Challis Volcanics rhyolite flows and welded tuffs rest upon Kriley Formation or basement and are unconformably overlain by Kirtley Formation in the southern part of the basin and by the other Tertiary formations elsewhere. Two uranium occurrences (8 and 9) are in the Challis Volcanics just south of the basin. The Geertson and Kirtley Formations, the upper part of the sequence, contain carbonaceous sandstones and siltstones and beds of lignite. Four well waters within the basin are highly anomalous with respect to uranium; one of the wells probably penetrates rhyolite breccia, and the water contains 200 ppb uranium.

The most potent source of uranium is the fragmented rhyolite flows and welded tuffs originating in the rhyolitic volcanic center south of the Salmon River Basin. Uranium-rich ground waters (with as much as 200 ppb uranium) are fed into the basin along a front about 8 km (5 mi) wide. If it is assumed that the aquifer along which uranium-rich waters flow is 10 m (33 ft) thick (the brecciated upper surface of the rhyolite flows), that conditions become progressively more reducing downdip (north) as a result of water interaction with overlying carbonaceous material, and that the width of the zone in which precipitation of uranium may take place is 20 m (66 ft), then the volume of rock in which uranium deposits may occur is 1.6×10^6 m^3 (56×10^6 ft^3). According to the classification of Pilcher (1978), the deposit so formed would be of the hydroallogenic (540) class.

Horse Prairie Basin

The Horse Prairie Basin (see Area B_6) is between 1300 m (4,300 ft) and 2100 m (7,000 ft) deep, and contains between 10% and 60% permeable strata and also carbonaceous shales (Wopat and others, 1977). Anomalous concentration of uranium is present in one water well close to another well in which conditions are relatively reducing. In the Dubois Quadrangle, 3 km (2 mi) to the south, permeable carbonaceous fluvial sandstones are overlain by uranium-rich, strongly welded tuffs (containing as much as 30 ppm uranium). The sandstone fills channels in basement rock and is the host of a uranium occurrence (Wodzicki and Krason, 1980, in press). If it is assumed that fluvial channels underlie 1% of the area (a reasonable stream-channel density), that the welded tuff underlies 10% of the area, and that the thickness of uranium deposits in the fluvial sands beneath the welded tuff is 10 m (33 ft), then the volume of rock in which uranium deposits may occur is 2.5×10^6 m^3 (88×10^6 ft^3). According to the classification of Austin and D'Andrea (1978), the deposit would be of the channel-controlled peneconcordant (243) subclass.

Beaverhead River Basin

The Beaverhead River Basin (see Area B_4) contains as much as 500 m (1,700 ft) of Eocene-Oligocene sediments and 750 m (2,400 ft) of Miocene-Pliocene sediments containing traces of organic matter and 20% to 30% and 80% permeable strata, respectively (Wopat and others, 1977). The present study shows that in the southern part of the basin somewhat less than 25% of the beds are permeable. Five wells in the southern and eastern parts of the basin contain highly anomalous concentrations of uranium, and reducing conditions are present in one hot spring and possibly in three wells. A rhyolitic Tertiary volcanic center borders on the southern part of the basin. Brecciated rhyolite lavas, and other fragmental debris, dip north into the basin and are probably an excellent source of uranium.

Ground waters, rich in uranium, probably enter the basin from the volcanic center and its surrounding apron of fragmental debris along a front estimated to be 5 km (3 mi) long. If it is assumed that the aquifer along which the uranium-rich waters flow is 5 m (17 ft) thick, that conditions become progressively more reducing downdip (north) as a result of water interactions with reductants, and that the width of the zone in which precipitation of uranium may take place is 20 m (66 ft), then the volume of rock in which uranium deposits may occur is 0.5×10^6 m^3 (18×10^6 ft^3). The probability of uranium deposits is enhanced by a hot spring that discharges water into the Tertiary sediments. This hot-spring

water contains reduced sulfur species that are also likely to act as a reductant for uranium carried in the ground water. According to the classification of Austin and D'Andrea (1978), the deposits expected in the Beaverhead River Basin would be of the Wyoming roll-front (241) subclass, the uranium being along roll fronts and along zones of mixing between uranium-bearing ground water and reduced sulfur species–bearing hot-spring water.

Upper Ruby River Basin

The upper Ruby River Basin (see Area B_5) contains as much as 2100 m (7,000 ft) of Eocene-Oligocene and Miocene-Pliocene sediments. Wopat and others (1977) estimated that 20% to 30% of the lower Tertiary strata and about 80% of the upper Tertiary strata are permeable. The present study suggests that, overall, approximately 25% of the Tertiary sediments in the basin are permeable. The basal unit in the southwest part of the basin is a laharic deposit that contains angular rhyolite fragments and is probably a good source of uranium. Possible reductants in the basin include minor carbonaceous matter reported by Wopat and others (1977), hydrothermal pyrite associated with a fossil geothermal field in Sweetwater Creek, and low Eh in a hot spring. No highly anomalous well waters are known in the basin, but two uranium occurrences (11 and 12) are associated with the fossil geothermal field. At uranium occurrence 12 the uranium was probably precipitated near the interface between oxygenated ground water and reducing hot-spring water within the permeable, basal laharic deposit.

The basal rhyolite-bearing laharic deposits are probably good sources of uranium. If it is assumed that the strike length of the unit is 10 km (6 mi), that the thickness of the aquifer is 15 m (50 ft) (the thickness at occurrence 12), that conditions become progressively more reducing downdip as a result of water interaction with reductants in the sediments, and that the width of the zone in which precipitation of uranium takes place is 20 m (66 ft), then the volume of rock in which uranium deposits may occur is 3×10^6 m^3 (106×10^6 ft^3). The probability of uranium deposits is enhanced by a hot spring that discharges water into the Tertiary sediments and by a fossil geothermal field near occurrences 11 and 12. Both of the above are likely to act as reductants to uranium carried along an aquifer by ground water, the hot spring because it contains reduced sulfur species, and the fossil geothermal field because associated hydrothermally altered rocks contain pyrite. According to the classification of Austin and D'Andrea (1978), the deposits expected in the upper Ruby River Basin would be of the Wyoming roll-front (241) subclass, the uranium being present along roll fronts, along the periphery of pyrite-bearing hydrothermally altered aquifers, and along zones of mixing between uranium-bearing ground water and reduced sulfur species–bearing hot-spring waters.

ENVIRONMENTS UNFAVORABLE FOR URANIUM DEPOSITS

The remaining environments that have been studied are classified as unfavorable, because either they lack evidence for uranium concentration, or available evidence shows that grade and/or tonnage is too low for the environment to be classed as favorable. The environments are discussed in order of decreasing age of host rock.

ARCHEAN

The Archean gneisses have been examined in the Tobacco Root and Ruby Mountains. No aerial gamma-ray spectrometer anomalies are related to the gneisses (Pl. 3), and ground radiometric data, summarized in Table 1, show that the level of radioactivity in the gneisses is low to moderate and has a narrow spread of values. Only one geochemical anomaly is associated with the Archean rocks (Pl. 4a) and this is probably related to the nearby Dillon Granite Gneiss which registers only 2 to 4 times background. The classes of deposits specifically searched for in the Archean rocks are quartz-pebble conglomerates and anatectic pegmatites.

Quartz-Pebble Conglomerates

Uraniferous quartz-pebble conglomerates most commonly occur in rocks that are older than about 2.2 b.y. (a time when the earth's atmosphere was not so oxidizing), and consist of quartz-rich conglomerates (Working Group 3, 1970; Jones, 1978). The Cherry Creek Group and the Spuhler Peak formation could conceivably contain such deposits. No anomalous radioactivity or conglomeratic metasediments were seen within the Cherry Creek Group, although, because of its extensive outcrop area in a mountainous terrain, it was not possible to examine the group in detail. The basal part of the Spuhler Peak formation was examined. It overlies the Cherry Creek Group, possibly unconformably, and the basal unit consists of quartzite. This quartzite may have been a quartzitic conglomerate prior to folding and high-grade metamorphism; however, absolutely no anomalous radioactivity is associated with it, and it is concluded that this environment is not favorable for uranium deposits.

Anatectic Occurrences

Uranium can be depleted from rocks during granulite facies metamorphism (Kalsbeek, 1974) and may possibly be concentrated in felsic alaskites and pegmatites (Mathews, 1978a) such as occur at the well-known Rössing deposit (von Backstrom, 1970; Berning and others, 1976). Pegmatites are in the Archean rocks in both the Ruby and Tobacco Root Ranges (Heinrich, 1949b), but no anomalous values greater than 4.0 times background were noted. It is concluded that this environment is not favorable for uranium, possibly because the uranium concentration in the metasedimentary rocks themselves was too low.

PROTEROZOIC

Proterozoic metasediments of the Belt Supergroup and the Lemhi Quartzite have been examined in the Beaverhead, Pioneer, Highland, and Tobacco Root Mountains. Several aerial gamma-ray spectrometer anomalies occur in or near these rocks (Pl. 3). Most have been ground checked and are due to errors on the geologic map such as misplaced contacts, or to the presence of exceptionally good outcrops. One anomaly north of Salmon is due to a thorium-bearing vein. Ground radiometric data (Table 1) show that the level of radioactivity is low and has a narrow spread.

Eight geochemical anomalies have been identified for Proterozoic rocks (Pl. 4a). Of the three stream-water anomalies, one occurs close to a Challis Volcanics-capped mountain, one is on strike with the deposit at Surprise Mine (occurrence 2), and one is just north of the Lemhi Pass thorium district. The five stream-sediment anomalies occur close to contacts with the Idaho batholith and are discussed in a later section.

The classes of deposits specifically searched for in the Proterozoic metasediments are sandstone uranium deposits, unconformity-related deposits, and vein-type deposits in sedimentary rocks. (Vein-type deposits in sedimentary rocks are discussed in the favorable-environments section.)

Sandstone

Permeable sediments are sometimes good host rocks for commonly stratiform, epigenetic uranium deposits. This is particularly so if there is a suitable source rock such as granite, the sediments are interlayered with impermeable strata, and suitable reductants are present (Austin and D'Andrea, 1978). These conditions could be present in the LaHood Formation and in a possible extension of the Revett Quartzite near the Senate Mine in the northwest part of the quadrangle.

The LaHood Formation consists of conglomerates and sandstones, locally containing hematite, which are overlain and interbedded with black shales. The formation has an Archean basement provenance, contains much granitic debris, and could be host to ancient stratiform sandstone-type deposits. The LaHood Formation has been very carefully checked both radiometrically and geochemically during this project, with totally negative results. It is uniformly poor in uranium.

The Revett (?) Quartzite, near the Senate Mine, is a feldspathic quartzite that contains minor pyrite and chalcocite. It is both overlain and underlain by rocks of granite provenance, some of which are impermeable. The maximum level of radioactivity, however, is only 3.5 times background on the mine dump, and the environment is not considered favorable for uranium deposits.

Unconformity-Related Deposits

Unconformity-related deposits have only recently been recognized, mainly in Australia and Canada. The deposits occur near a paleosurface and are commonly Proterozoic (Robertson and others, 1978). The LaHood Formation rests unconformably on Archean gneisses in the Highland Mountains and could be the site of such a deposit. Very careful mapping and radiometric and geochemical observations show that this environment is uniformly poor in uranium.

PALEOZOIC AND MESOZOIC

Paleozoic and Mesozoic sediments have been examined, mainly in the Pioneer Mountains and in the Highland Mountains. Four aerial gamma-ray spectrometer anomalies are associated with the Phosphoria Formation, and one anomaly with Cretaceous sediments (Pl. 3). Ground checking of the former, however, failed to locate the anomaly. Ground radiometric data are summarized in Table 1 where the highly anomalous and variable level of radioactivity in the McGowan Creek and Phosphoria Formations can be seen. One stream-water geochemical anomaly (Pl. 4a) is associated with a skarn contact of Paleozoic sediments with the Pioneer batholith and will be discussed in a later section.

The classes of deposits specifically searched for in the Paleozoic and Mesozoic sediments are uraniferous phosphorite, marine black shale, and veins in sedimentary rocks. (Uraniferous veins occur in the McGowan Creek Formation and are described in the favorable-environments section.)

Uraniferous Phosphorite

The Phosphoria Formation contains two members (the Retort and the Meade Peak) that are phosphatic and contain fluorapatite, hydrocarbons, and anomalous concentrations of uranium. The geology and resources of the Phosphoria Formation in southwest Montana have been described in detail by Swanson (1970). In the Dillon Quadrangle there are two principal phosphate districts: the Melrose district where only the Retort Phosphatic Shale Member is present, and the Dillon district where both the Retort Phosphatic Shale and Meade Peak Phosphatic Shale Members are present. The uranium resources of both districts are summarized in Table 6 which is based on Table 15 in Swanson (1970).

In addition to phosphate and uranium, the Phosphoria Formation contains anomalous concentrations of fluorine, hydrocarbons, chromium, vanadium, and nickel (Swanson, 1970). The fluorine content approximates 0.1 of the phosphate content. Hydrocarbons are most abundant in the poorly phosphatic mudstones immediately above the phosphatic members and have been reported from the Dillon district. In the Lima district to the south of the Dillon Quadrangle, 40 to 80 liters per ton (10 to 20 gal/ton) are present over thicknesses of 5 to 8 m (18 to 27 ft). The chromium, vanadium, and nickel contents of the phosphatic members vary from 0.01% to 1.0%, 0.01% to 1.0%, and 0.001% to 1.0%, respectively.

The Phosphoria Formation is classified as unfavorable because, on the average, it contains only about 50 ppm uranium. However, it should be emphasized that extraction of uranium, possibly together with the other trace elements, and of hydrocarbons from overlying shales may become economic as a "byproduct" of phosphate mining and fertilizer production. The technology of uranium extraction from phosphatic rocks is known (Habashi, 1970); the recovery of chromium, vanadium, and nickel has been demonstrated (Banning and Rasmussen, 1951); and it is possible to extract fluorine in useful forms (Waggaman and Ruhlman, 1960). Thus, in spite of the low grade of the uranium, the Phosphoria Formation may become an important uranium source in the future.

Marine Black Shale

Uraniferous black shales are large but very low-grade (generally less than 100 ppm) uranium deposits (Jones, 1978). Maximum uranium concentrations reported in the Wolsey, Three Forks, and Amsden Formations in southwest Montana by Mapel (1956) are 10 ppm, 50 ppm, and 30 ppm, respectively. The maximum of 50 ppm reported from the Three Forks Formation could have actually been from the McGowan Creek Formation which overlies the Three Forks in the Highland Mountains.

TABLE 6. URANIUM RESERVES IN THE PHOSPHORIA FORMATION IN MELROSE AND DILLON DISTRICTS (AFTER SWANSON, 1970)

District	Uranium in rock containing >31% P_2O_5		Uranium in rock containing >24% P_2O_5		Uranium in rock containing >18% P_2O_5	
	grade (ppm)	tons uranium	grade (ppm)	tons uranium	grade (ppm)	tons uranium
Melrose, Retort member	50	15,800	50	54,300	50	118,000
Dillon, Retort member	—	—	50	23,000	50	198,000
Dillon, Meade Peak member	—	—	70	350	70	400
Total tonnage		15,800		77,650		316,400

The level of radioactivity in Paleozoic shales (excluding the McGowan Creek and Phosphoria Formations) determined during the present study is only 1.5 times background. The marine black shales, excluding the McGowan Creek Formation, are considered unfavorable environments. The McGowan Creek Formation is discussed in the section on favorable environments.

LARAMIDE INTRUSIVES

All major Laramide intrusives have been investigated during this project. Numerous gamma-ray spectrometer anomalies are associated with the intrusives, especially with the Boulder batholith and its felsic differentiates (see Pl. 3). Most of these anomalies have been ground checked. One group of anomalies is associated with the Comet Mountain occurrence (3). The remaining aerial anomalies are a result of unusually good outcrops, misplaced geologic contacts, or anomalous plutons or portions of plutons such as pegmatites. Ground radiometric data are summarized in Table 1 and show that the level of radioactivity in the Boulder batholith is higher and more variable than that for the other intrusives.

Seventeen stream-water and eight stream-sediment anomalies are associated with batholiths or their contacts (Pl. 4a). All of these stream-water anomalies are associated with the Boulder batholith. Only one is probably associated with an occurrence (1), and the rest reflect the leachable nature of the uranium in Boulder batholith. Two of the stream-sediment anomalies are associated with known uranium-bearing deposits along faults, namely the Comet Mountain occurrence (3) and the Bismark Mine in the Tobacco Root Mountains. The remaining stream-sediment anomalies are found near intrusive contacts between the Idaho batholith and Belt Supergroup metasediments.

The classes of deposits specifically searched for in association with the Laramide intrusions are pegmatitic, authigenic veins in the batholiths, and contact-metasomatic.

Pegmatitic

As an incompatible element, uranium is concentrated in pegmatites. All intrusives studied contain pegmatites, but they are most common in the main phase of the Boulder batholith and in two-mica granites in the Idaho batholith. The highest level of radioactivity encountered in the pegmatites is 5.6 times background, but more commonly it is 2.0 to 2.5 times background. The level of radioactivity is too low for the pegmatites to be considered a favorable environment.

Authigenic

Vein uranium deposits in the Boulder batholith (occurrence 1) and in the Pioneer batholith (occurrence 3) are considered authigenic class. The uranium was deposited in a zone of mixing between cold, oxygenated ground water and upwelling, reducing hot water. The reasons for this were given in the sections on uranium mineralization in Boulder batholith and on uranium occurrences. Two important consequences of this interpretation are that the vertical extent of uranium deposition must be limited to the zone of mixing and that the amount of uranium is limited because the volume of rock from which the uranium has been leached is restricted to the rocks above the zone of mixing. In both occurrences the grade does not exceed 60 ppm and the width does not exceed 4 m (12 ft). It is concluded that this environment is not favorable for economic deposits in this quadrangle.

Contact-Metasomatic

Contact-metasomatic deposits form as a result of magmatic-hydrothermal solutions replacing calcareous or mafic country rocks (Mathews, 1978a). In this report, this definition has been broadened to include all country rocks near an intrusive contact. The areas where this environment has been investigated in detail during this project are in the Anaconda-Pintlar Wilderness and on the eastern margin of the Pioneer batholith.

In the Anaconda-Pintlar area, hydrous, two-mica granites and pegmatites intrude a graphite-bearing schist of the Pritchard formation (see section on geology of LaMarche Creek area). The maximum level of radioactivity found in the metasediments is only 4.0 times background.

On the east side of the Pioneer Mountains, the Pioneer batholith intrudes Madison Group carbonates and the Phosphoria Formation. The uranium concentration in the Phosphoria Formation decreases during contact metamorphism (see section on geochemical data, Phosphoria Formation). The skarns developed along the contact have extremely low levels of radioactivity except at the Greenstone Mine (occurrence 4) where a 6-m (20-ft) zone in a garnet-bearing skarn contains 50 ppm uranium. The source of the uranium could have been the granite or the nearby Phosphoria Formation. The isolated nature of this occurrence and the low uranium concentration suggest this environment is not favorable for uranium deposits.

TERTIARY VOLCANICS

Tertiary volcanics have been examined throughout the quadrangle, in detail near the rhyolitic volcanic centers south of Dillon and south of Salmon. Seventeen aerial gamma-ray spectrometer anomalies coincide with rhyolitic volcanics south of Dillon, south of Salmon, and along the western border of the quadrangle (see Pl. 3). The anomalies are associated with rhyolite flows and strongly welded tuffs that in the above areas register about 3.0 times background. Two stream-water anomalies and one stream-sediment anomaly are associated with Challis flows capping the Idaho batholith in the northwest corner of the quadrangle (see Pl. 4a). One highly anomalous well water (200 ppb) south of Salmon (see Pl. 8b) comes from a well that probably penetrates brecciated rhyolite flow rock.

Volcanogenic uranium deposits are most commonly associated with felsic volcanic centers (particularly with related calderas), and with felsic welded tuffs that originate in these volcanic centers (Pilcher, 1978). With this in mind, the rhyolitic volcanic centers south of Salmon and south of Dillon have been mapped (see section on detailed geologic studies), and the welded tuffs, probably erupted from them, have also been examined. The classes of uranium deposits searched for are initial magmatic, pneumatolitic, and hydroauthigenic.

Initial Magmatic

The level of radioactivity and uranium content of tuffs is considerably lower than that of flow rocks of comparable composition (see Tables 1 and 4). This may be due to loss of uranium from the tuffs during the eruption. The rhyolite flows from both volcanic centers are more highly radioactive. The level of radioactivity in the Salmon volcanic center ranges from 2.0 to 4.0 times background and in the Dillon volcanic center from 2.0 to 3.5 times background. The range in uranium concentration in the flows is from 2 to 6 ppm (not taking occurrences into consideration). This range is probably due to the magmatic origin. The concentrations are small, however, and the rocks are not considered favorable for initial magmatic deposits.

Pneumatolitic and Hydroauthigenic

Pneumatolitic and hydroauthigenic uranium deposits form as a result of uranium transportation and deposition by postmagmatic fluids and thus tend to occur along permeable zones in volcanics. Examples of such permeable zones are certain welded tuffs and fractured zones associated with horst and graben faults, caldera-collapse structures, and other faults. No evidence of posteruptive hydrothermal uranium transport has been seen in any of the welded tuffs. In the two mapped rhyolitic volcanic centers no evidence of horst and graben or caldera-collapse faulting has been seen (see section on detailed geologic studies). In the volcanic center south of Dillon there is no evidence of hydrothermal transport of uranium. In the volcanic center south of Salmon uranium occurrences 8 and 9 are within rhyolites. Occurrence 8 is along two steep silicified shears which are more than 1 m (3 ft) wide and contain 120 and 96 ppm uranium. Occurrence 9 is in two local but diffuse hot spots within a rhyolite flow. The hot spots are about 3 m by 20 m in area and contain between 50 and 150 ppm

uranium. The rocks are not evaluated as favorable for pneumatolitic and hydroauthigenic deposits because there is very little evidence for hydrothermal transport of uranium, and the two occurrences are very localized and low grade.

TERTIARY SEDIMENTARY ROCKS

Tertiary sedimentary rocks are potential hosts for sandstone-type uranium deposits. They are discussed in the section on favorable environments.

UNEVALUATED ENVIRONMENTS

Unevaluated environments are in the Big Hole River, southern Divide Creek, Grasshopper Creek, and lower Ruby River Tertiary basins. The near-surface data from these basins suggest a lack of favorability, but because the deeper portions of the basins are inaccessible, the basins are classed as unevaluated.

BIG HOLE RIVER BASIN

The Big Hole River Basin contains undifferentiated Tertiary sediments, at least 400 m (1,300 ft) thick and with a high proportion of permeable strata and traces of organic matter. The granitic debris from the Idaho and Pioneer batholiths and tuffs in the sediments are not considered good sources of uranium. Furthermore, the absence of anomalous concentrations of uranium in well waters suggests the near-surface part of the basin is unfavorable for uranium deposit. The deeper parts cannot be evaluated.

SOUTHERN PART OF DIVIDE CREEK BASIN

The geology of the southern part of Divide Creek Basin is similar to that of the northern part already described under favorable environments. However, the southern part of the basin is not near Boulder batholith and does not contain wells with anomalous uranium concentrations. The near-surface part of this area is considered unfavorable, but the deeper parts cannot be evaluated.

GRASSHOPPER CREEK BASIN

The geology of Grasshopper Creek Basin is probably similar to that of the Horse Prairie Basin already described under favorable environments. However, there are no known good sources for uranium, no wells with anomalous uranium concentrations, and no nearby uranium occurrences. The near-surface part of this basin is considered unfavorable, but the deeper parts cannot be evaluated.

LOWER RUBY RIVER BASIN

The lower Ruby River Basin contains 750 m (2,400 ft) of Eocene-Oligocene sediments with 20% to 30% permeable beds and 750 m (2,400 ft) of Miocene-Pliocene sediments with about 80% permeable beds. Traces of organic matter are in both lower and upper Tertiary beds. There are, however, no good sources for uranium, no highly anomalous wells, and no uranium occurrences nearby; the near-surface part of this basin is considered unfavorable for uranium deposits. The deeper parts of the basin cannot be evaluated.

RECOMMENDATIONS

Additional work is recommended in the Melrose district and in several Tertiary sedimentary basins.

MELROSE DISTRICT

Surface indications of uranium concentration over a strike length of about 7 km (4.5 mi) warrant further investigation. Surface mapping and sampling have already been carried out, and it is recommended to drill at least three exploration holes to the west and downdip from the three uranium occurrences in the Melrose district. The holes should be at NW¼SW¼ sec. 4, T. 3 S., R. 8 W.; SW¼SW¼ sec. 29, T. 2 S., R. 4 W.; SW¼ sec. 18, T. 2 S., R. 4 W. The purpose of the holes is to investigate thickness and grade of the uranium deposits below the level of weathering.

TERTIARY BASINS

Additional work is recommended in the Divide Creek, Jefferson River, Salmon River, Beaverhead River, and upper Ruby River Tertiary sedimentary basins. However, Tertiary basins are deeply buried (as much as several thousand feet), and commonly they are covered with Quaternary sediments; direct geologic observations and exploration with the most commonly used techniques (i.e., geochemistry and radiometric surveys) are limited almost exclusively to the ground surface and the top thin layers in the subsurface. Consideration of the structural setting and lithologic features favorable for uranium deposits in numerous Tertiary basins in north-central Idaho and southwest Montana and the results of geochemical analyses of ground water reveal the necessity for more sophisticated exploration techniques. It is our opinion that one such technique to examine these deeply buried, perhaps uranium-bearing strata is a helium survey. This technique is not yet commonly used in exploration for uranium deposits, and in any case it cannot substitute for a good understanding of the geology of the area. It can, however, determine more precisely the deeply buried targets, and it can save a substantial amount of money required for exploratory drilling (Pogorski and Quirt, 1980).

Drilling is needed in all favorable basins in spite of the helium-survey recommendation because targets are subsurface and cannot be investigated further by surface techniques. Geologic, resistivity, and gamma-ray logs would be needed for all the holes. In addition, all aquifers should be sampled separately and the pH, Eh, total carbonate, total phosphate, and uranium concentrations should be determined wherever possible. The aim of the drilling is to determine stratigraphy of the basins and to identify permeable strata, location of reductants, location of uranium-rich aquifers, and location of aquifers in which Eh is low. All the proposed holes are in areas that, based on geologic and geochemical evidence, are highly favorable for uranium deposits, and all should be drilled to intersect basement.

Divide Creek Basin

The northern part of Divide Creek Basin is surrounded by the Boulder batholith from which uranium-rich waters enter the sediments. It contains permeable horizons and anomalous ground water. An exploration hole should be located at sec. 14, T. 2 N., R. 9 W.

Jefferson River Basin

The northern part of Jefferson River Basin is bounded on the west by the Boulder batholith from which uranium-rich waters enter the sediments. The basin contains permeable horizons, several highly anomalous waters, and two hot springs which are highly reducing. A hole is recommended at sec. 30, T. 1 N., R. 4 W., an area close to both uranium-rich well waters and highly reducing spring waters.

Salmon River Basin

The southern part of Salmon River Basin is near a rhyolitic volcanic center that contains two volcanogenic uranium occurrences. Fragmented rhyolitic flows and breccias dip northward into the basin and are overlain by locally carbonaceous, relatively impermeable sediments. An aquifer within the permeable volcanics contains 200 ppb uranium. A hole is recommended at sec. 20, T. 21 N., R. 22 E.

Beaverhead River Basin

The southern part of Beaverhead River Basin is near a rhyolitic volcanic center. Fragmented rhyolite flows and debris dip into the basin and are overlain by sediments, some of which are impermeable. Several highly anomalous well waters are present in the area. A hole is recommended at sec. 4, T. 8 N., R. 9 W.

Upper Ruby River Basin

In the southwest part of upper Ruby River Basin, a rhyolitic laharic deposit has been hydrothermally altered and contains minor pyrite. Two uranium occurrences are on the southwest margin of the altered rocks. The uranium was probably deposited at the interface of reducing hydrothermal water and oxygenated ground water. A hole is recommended at sec. 2, T. 9 S., R. 5 W. to intersect the eastern margin of the hydrothermal alteration in the laharic deposit.

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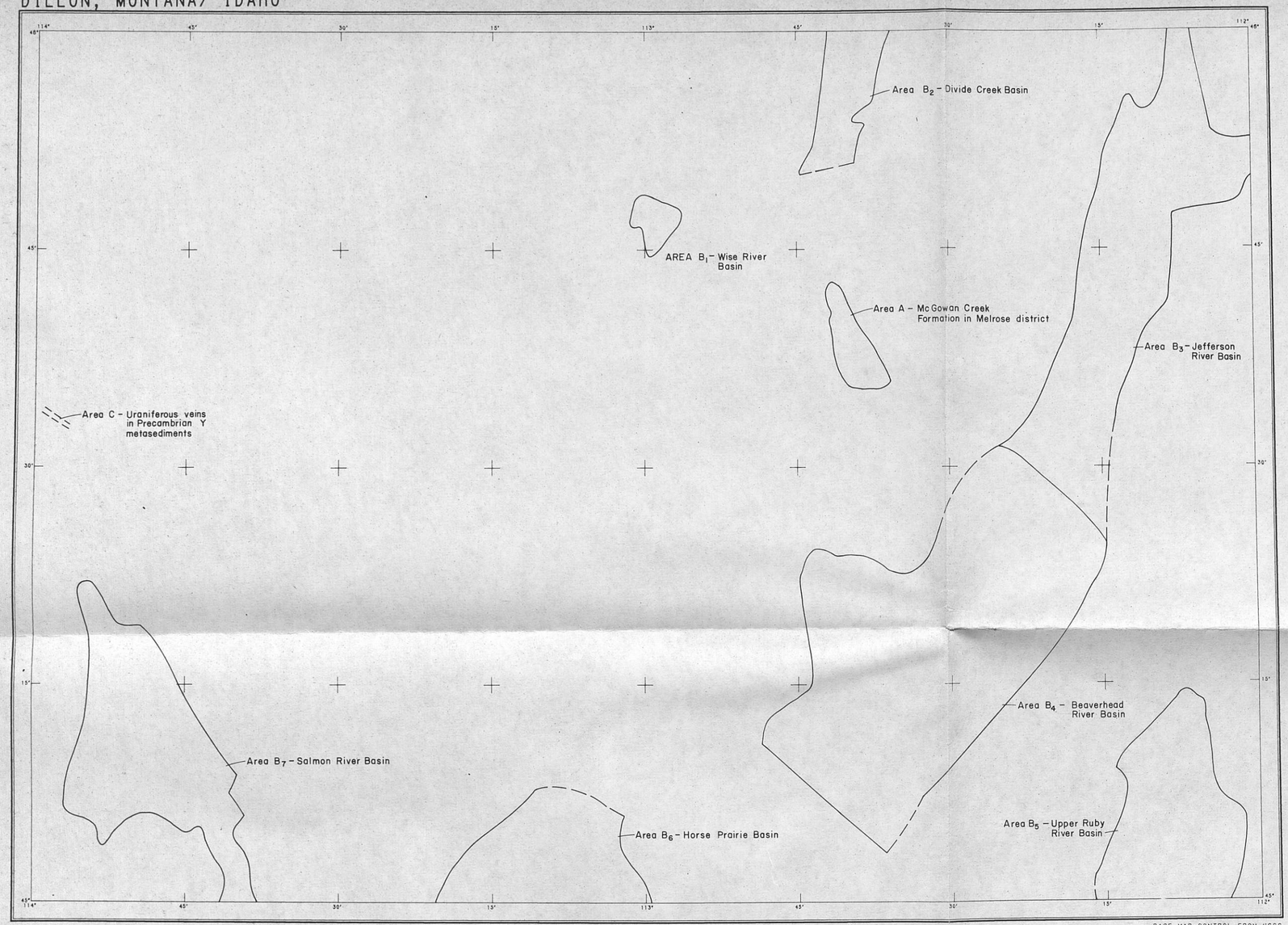
APPENDIX A. URANIUM OCCURRENCES IN THE DILLON QUADRANGLE

Occurrence no.	Name	Location					Host rock	Deposit class or subclass (no.)	Production	Reference
		Sec.	Twp.	Rng.	Lat. (N)	Long. (W)				
1	Mooney Claims	32	3N	9W	45 58 10	112 45 23	Boulder batholith Quartz monzonite	Authigenic (360)*	a##	Elevatorski, 1977
2	Surprise Mine	27 (unsurveyed)	26N	21E	45 33 26	113 57 58	Precambrian Y Quartzite	Vein-type in sedimentary rocks (730)‡	a	Trites and Tooker, 1953; Weis and others, 1958; Anderson, 1958
3	Unnamed	26	4S	12W	45 27 37	113 03 03	Pioneer batholith Quartz monzonite	Authigenic (360)	a	This report
4	Greenstone Mine	11	5S	10W	45 24 14	112 48 12	Madison Group Garnet skarn	Contact metasomatic (340)*	a	This report
5	Carnotite Claims	18	2S	8W	45 39 14	112 38 24	McGowan Creek Formation Mudstone	Marine black shale (130)# Vein-type in sedimentary rock (730)	a	Trites and Tooker, 1953
6	R and M Claims	29	2S	8W	45 37 58	112 37 08	McGowan Creek Formation Mudstone	Marine black shale (130) Vein-type in sedimentary rock (730)	a	Trites and Tooker, 1953
7	Uranium Claims	4	3S	8W	45 36 13	112 36 13	McGowan Creek Formation Mudstone	Marine black shale (130) Vein-type in sedimentary rock (730)	a	Trites and Tooker, 1953
8	Donna Lou Group	6	20N	22E	45 05 30	113 54 30	Challis volcanics Rhyolite	Hydroauthigenic (530)**	a	Anderson, 1956, 1958; Shockey and Oref, 1958
9	Donna Lou Group	18	20N	22E	45 05 24	113 53 48	Challis volcanics Rhyolite	Hydroauthigenic (530)	a	Anderson, 1956, 1958; Shockey and Oref, 1958
10	Branzell & Eby Prospect	35	7S	4W	45 11 10	112 03 49	Pegmatite	Pegmatitic (320)*	a	Elevatorski, 1977
11	Unnamed	8	9S	5W	45 03 46	112 14 17	Tertiary sediments Laharic breccia	Vein-type in sedimentary rocks (730)	a	This report
12	Unnamed	17	9S	5W	45 03 17	112 14 46	Tertiary sediments Laharic breccia	Non-channel-controlled peneconcordant (244)‡	a	Jarrard and Van Alstine, 1954

* Mathews, 1978a
‡ Mathews, 1978b
\# Jones, 1978
** Pilcher, 1978
‡ Austin and D'Andrea, 1978
Production categories: a. 0 to 20,000 lb U_3O_8 (no uranium production reported from these occurrences)

DILLON, MONTANA/ IDAHO

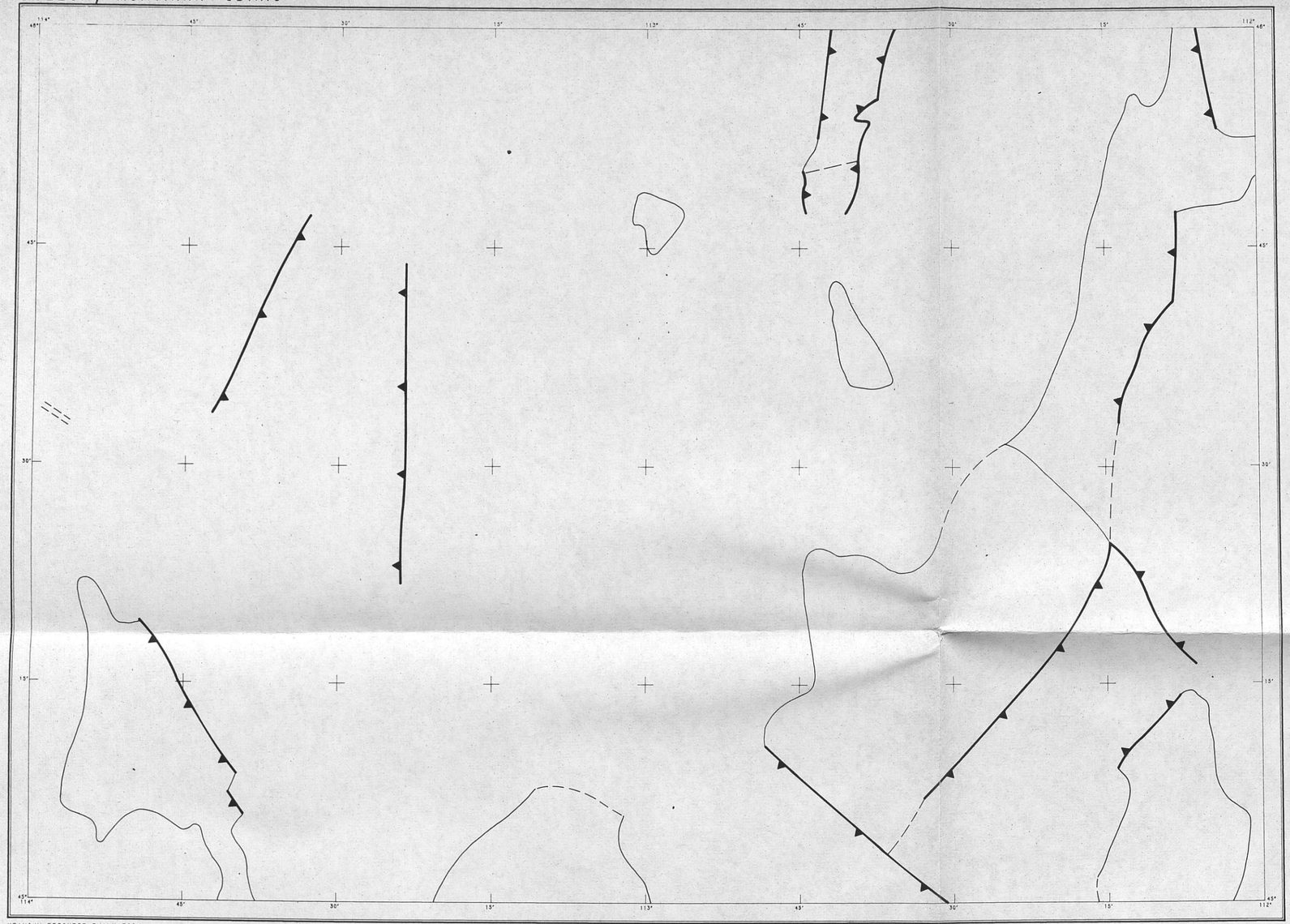


URANIUM RESOURCE EVALUATION
ISSUED BY THE U.S. DEPARTMENT OF ENERGY

BASE MAP CONTROL FROM USGS

Plate Ia. AREAS FAVORABLE FOR URANIUM DEPOSITS

DILLON, MONTANA/ IDAHO



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

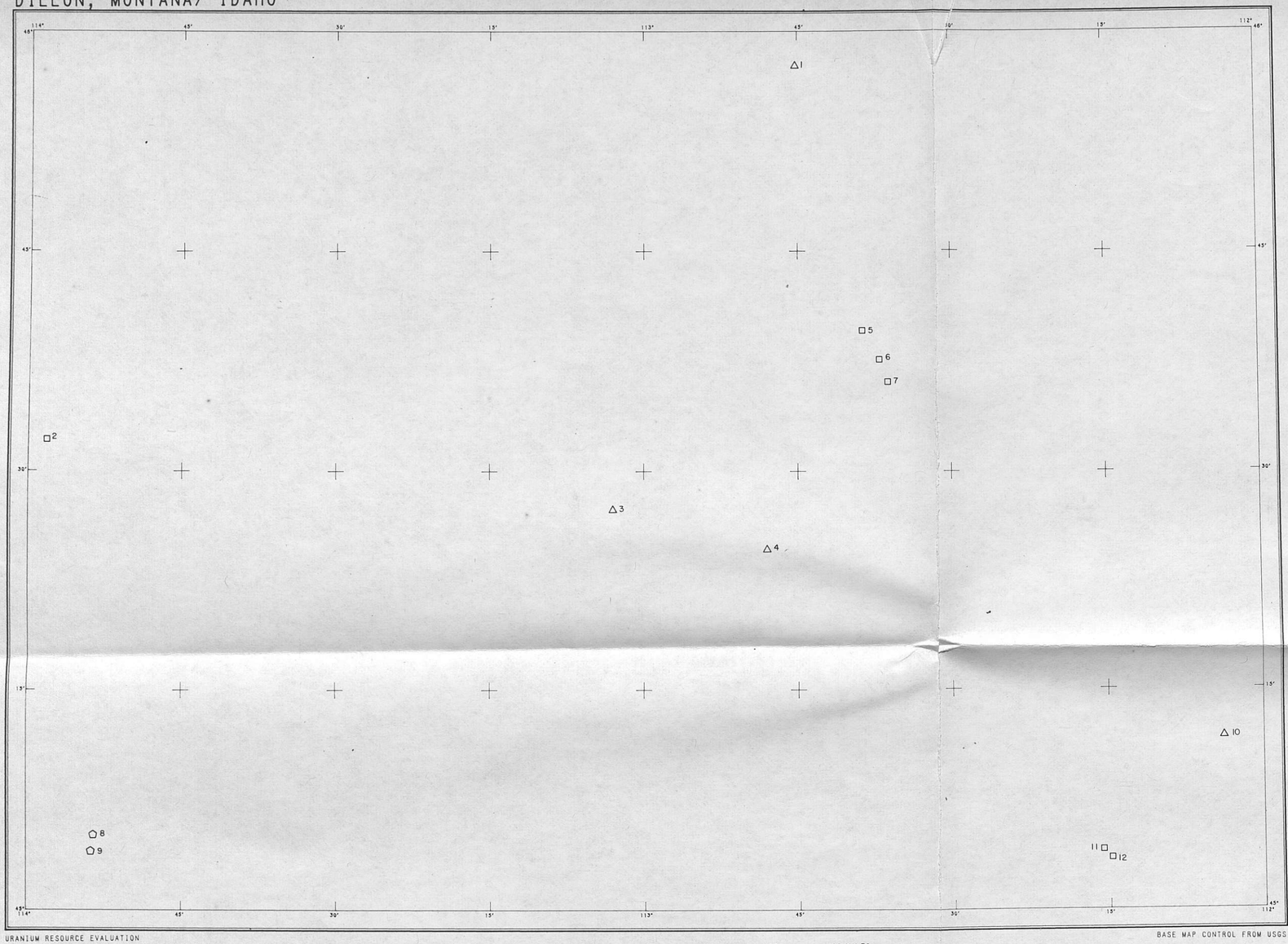
5 0 5 10 15 20 25 MILES

5 0 5 10 15 20 25 KILOMETERS

BASE MAP CONTROL FROM USGS

Plate Ib. AREAS FAVORABLE FOR URANIUM DEPOSITS WITH BOUNDARY FAULTS

DILLON, MONTANA/ IDAHO



EXPLANATION

URANIUM OCCURRENCES

	CLASSIFICATION			
	Sedimentary	Plutonic	Volcanic	Other
Minor prospect or mineral occurrence	□	△	⬠	☼
Significant prospect or mine reporting minor production	◪	▲	◔	✹
Mine having production over 200,000 pounds U_3O_8	■	▲	⬟	✹
Mining District	⬭			

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

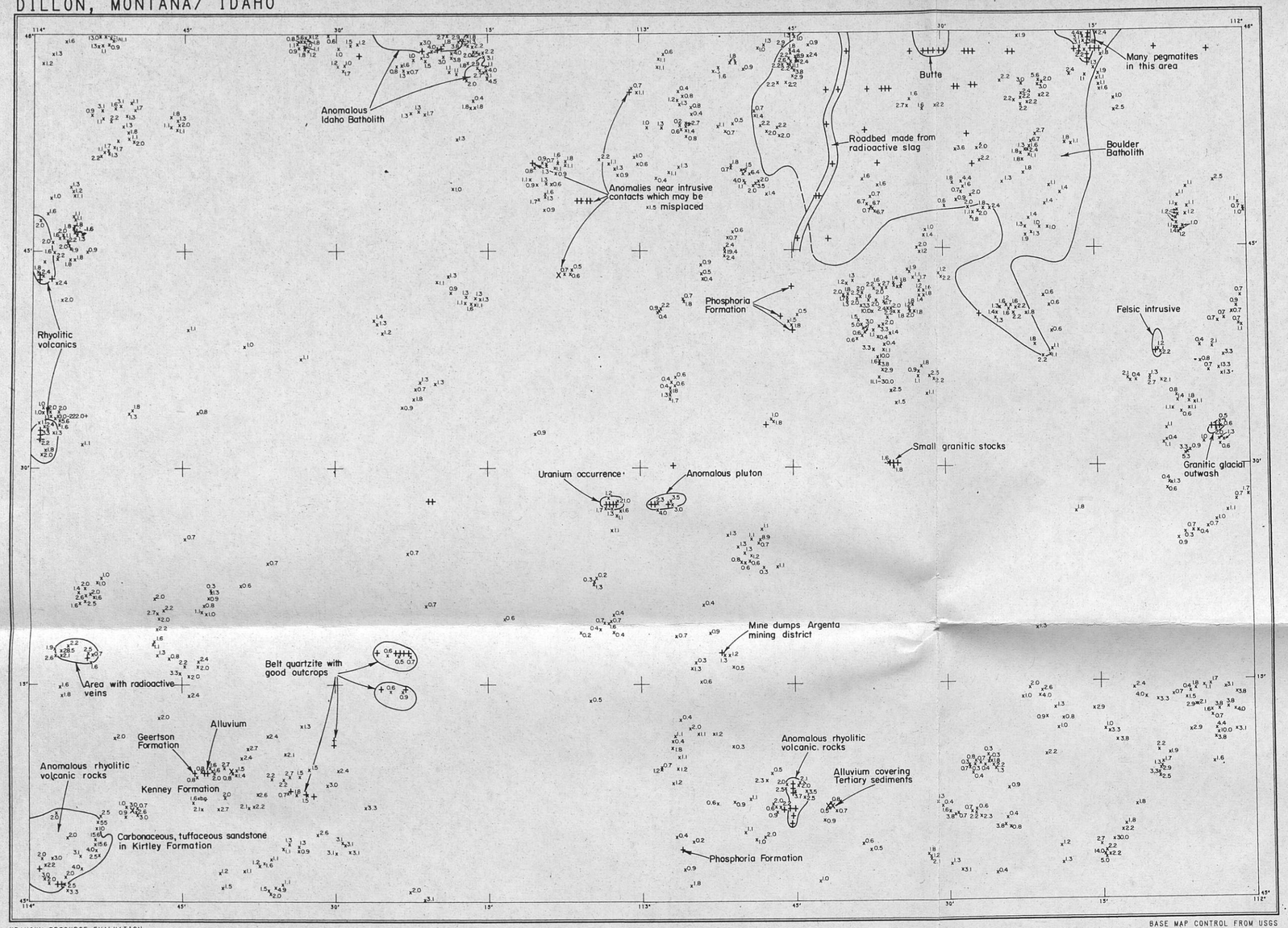
BASE MAP CONTROL FROM USGS

5 0 5 10 15 20 25 MILES

5 0 5 10 15 20 25 KILOMETERS

Plate 2. URANIUM OCCURRENCES

DILLON, MONTANA/ IDAHO



EXPLANATION

- x2.2 — Ground radiometric data point radioactivity as multiple of background
- \+ — Aerial radiometric ^{214}Bi anomaly
- X — Aerial radiometric ^{214}Bi and ^{214}Bi/^{208}Tl anomaly
- Anomalous area

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

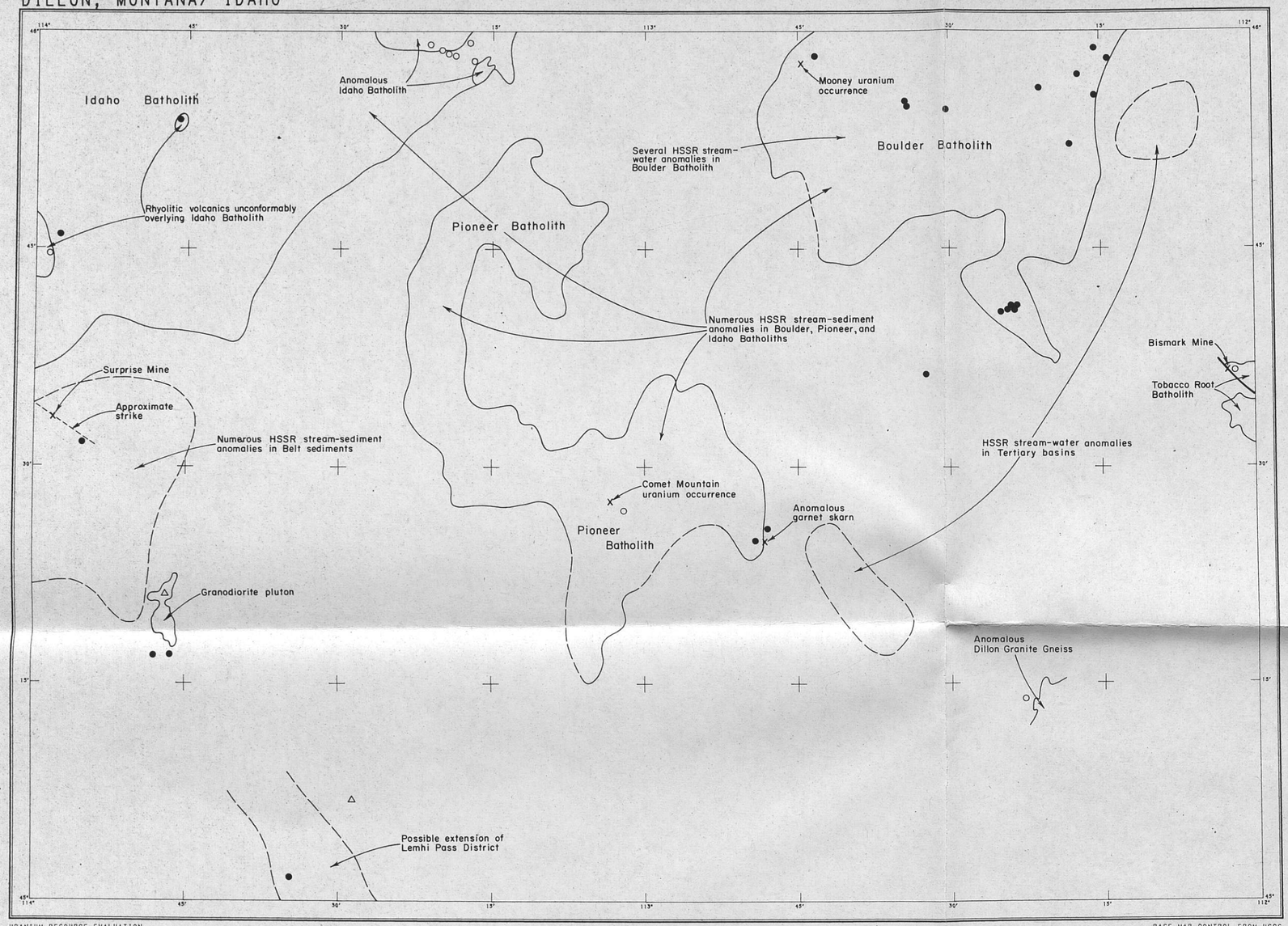
BASE MAP CONTROL FROM USGS

5 0 5 10 15 20 25 MILES

5 0 5 10 15 20 25 KILOMETERS

Plate 3. GROUND RADIOMETRIC DATA AND INTERPRETATION OF AERIAL RADIOMETRIC SURVEY

DILLON, MONTANA/ IDAHO



EXPLANATION

- ● Stream-water uranium anomalies (>2 standard errors)
- ○ Stream-sediment uranium anomalies (>2 standard errors)
- △ Stream-sediment thorium anomalies (above threshold value)

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

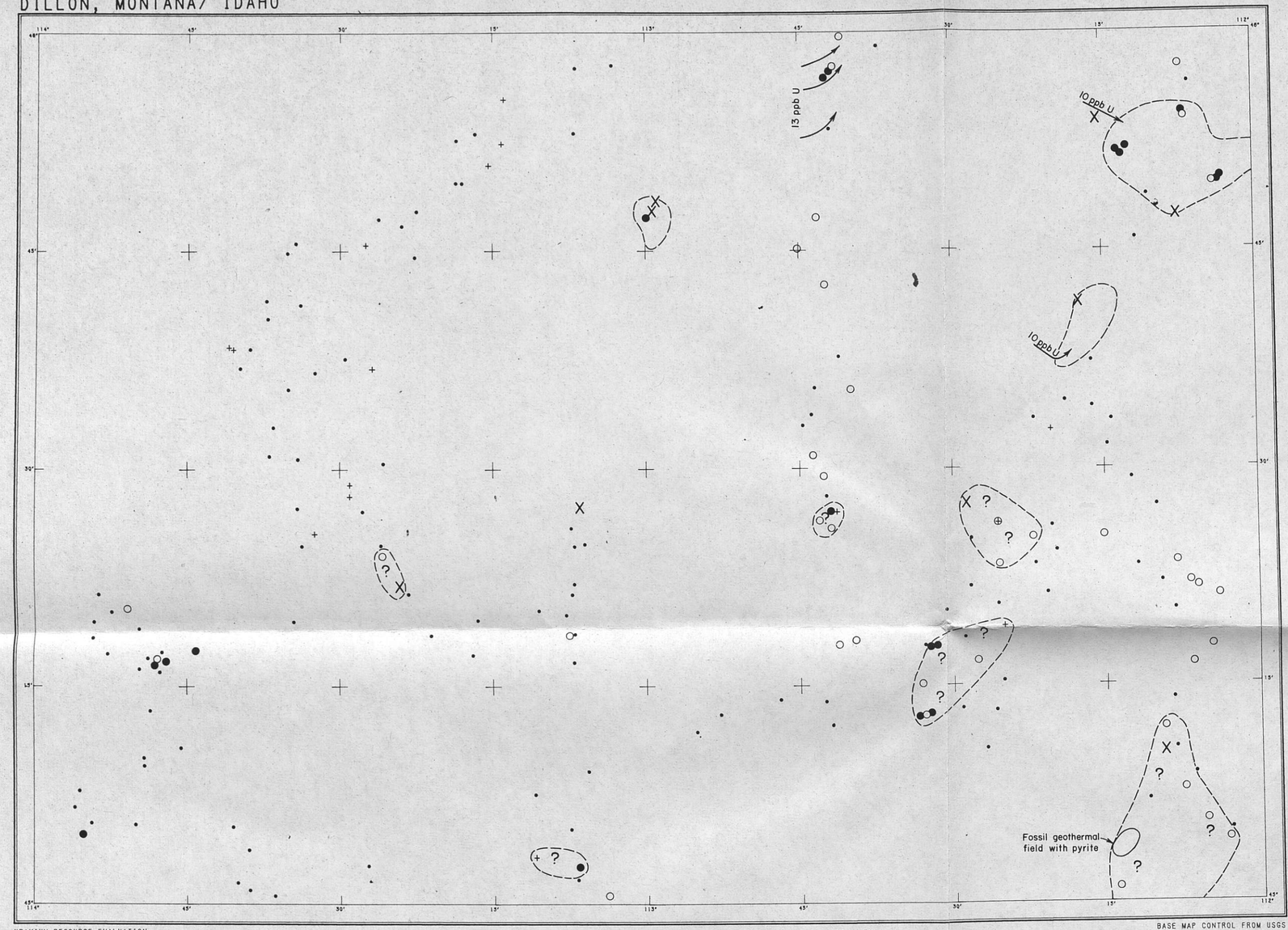
BASE MAP CONTROL FROM USGS

5 0 5 10 15 20 25 MILES

5 0 5 10 15 20 25 KILOMETERS

Plate 4a. INTERPRETATION OF GEOCHEMICAL DATA

DILLON, MONTANA/ IDAHO



EXPLANATION

- Waters with <5 ppb U
- Waters with 5-15 ppb U
- Waters with >15 ppb U
- \+ Waters with no measurable O_2
- X Waters with measurable H_2S
- 10 ppb U → Anomalous surface drainage seeping into basins
- Areas where waters with moderate to high uranium concentration are in close proximity to low Eh waters

5 0 5 10 15 20 25 MILES

5 0 5 10 15 20 25 KILOMETERS

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

BASE MAP CONTROL FROM USGS

Plate 4b. INTERPRETATION OF WATER-WELL AND SPRING GEOCHEMICAL DATA

DILLON, MONTANA/ IDAHO

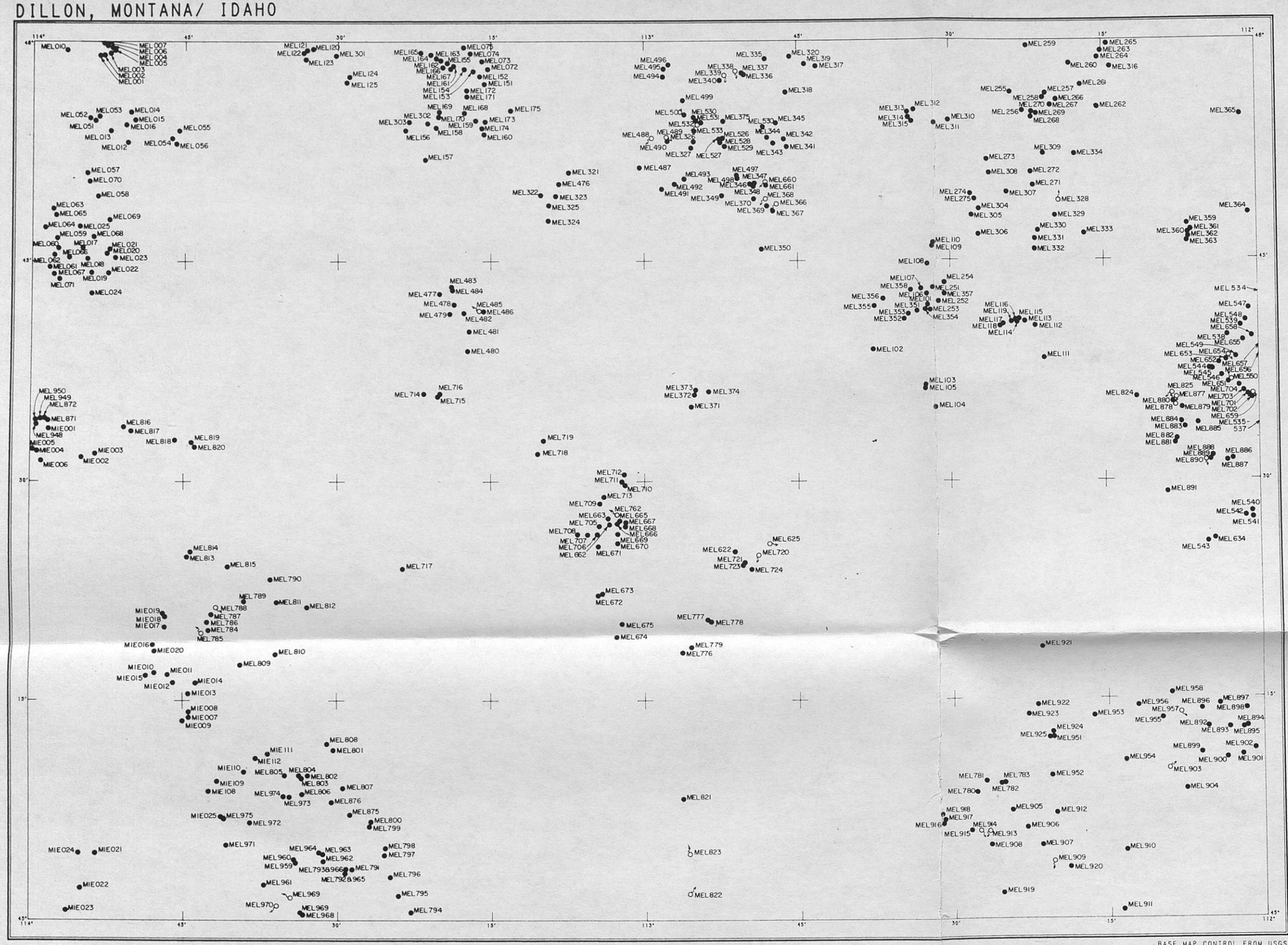
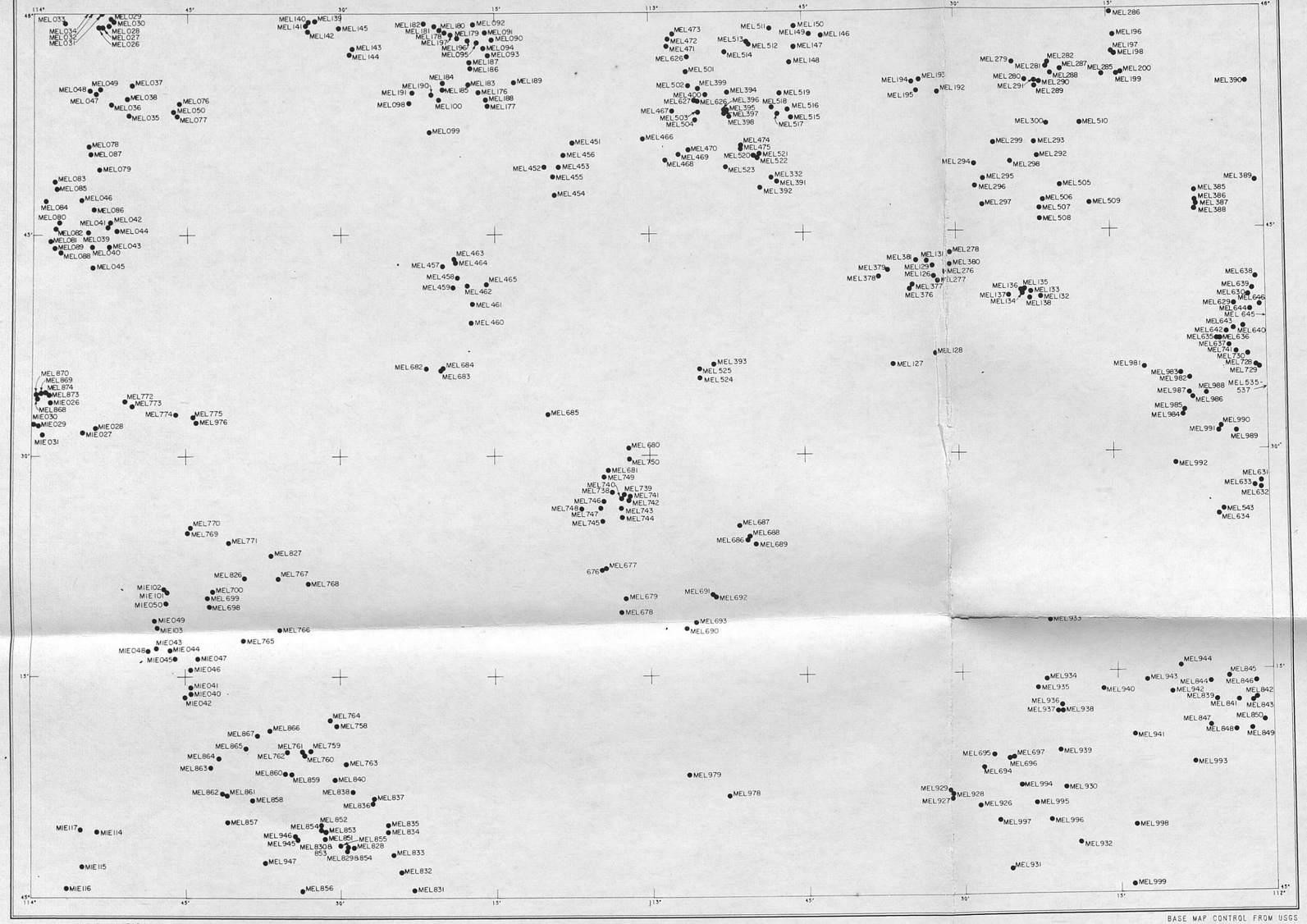


Plate 5a. LOCATION MAP OF STREAM- AND SPRING-WATER GEOCHEMICAL SAMPLES

DILLON, MONTANA/ IDAHO



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

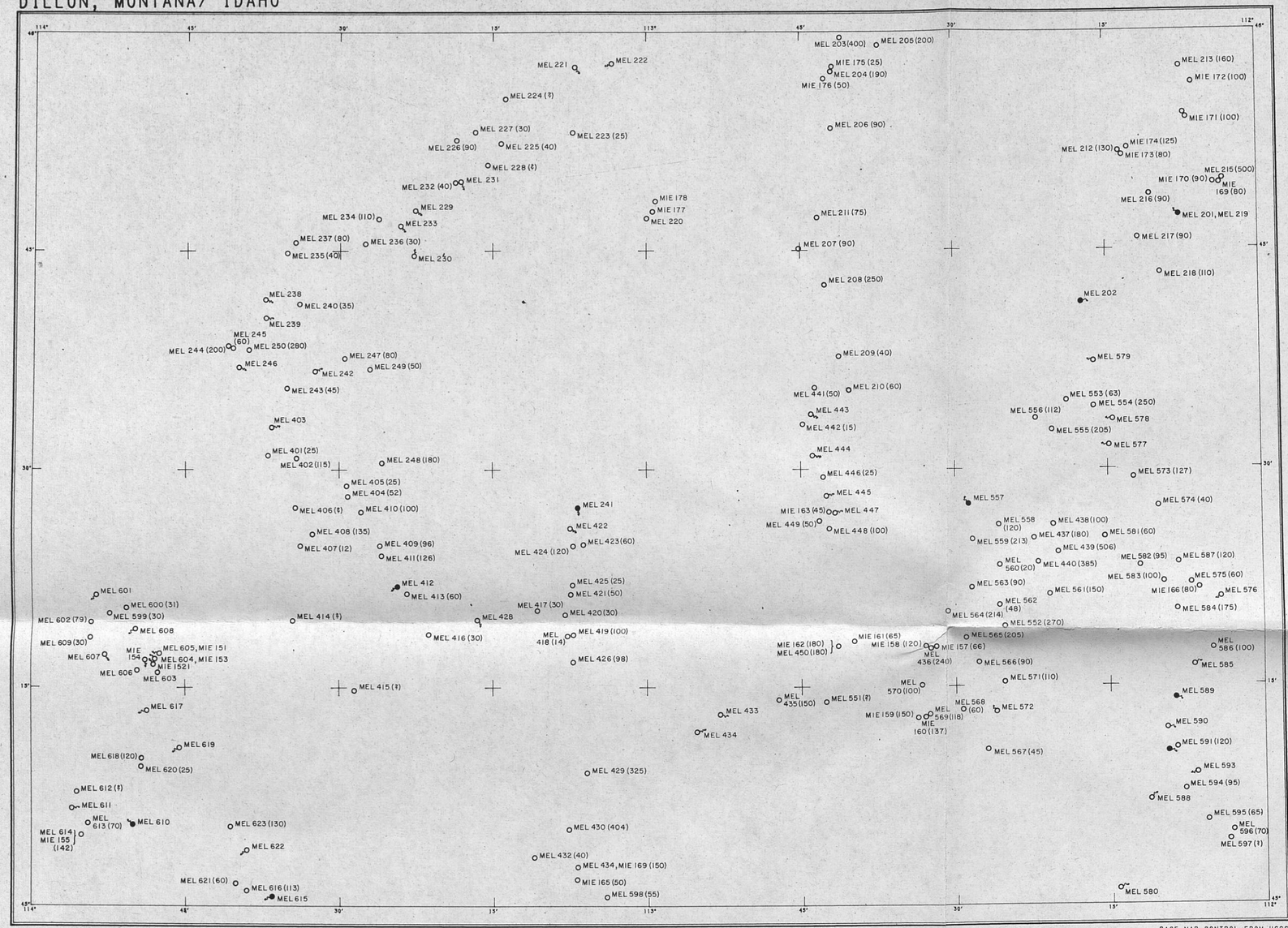
BASE MAP CONTROL FROM USGS

5 0 5 10 15 20 25 MILES

5 0 5 10 15 20 25 KILOMETERS

Plate 5b. LOCATION MAP OF STREAM-SEDIMENT GEOCHEMICAL SAMPLES

DILLON, MONTANA/ IDAHO



EXPLANATION

MEL 558 (60)	Well-sample location (depth in feet)
MEL 572	Spring-sample location
MEL 241	Hot-spring sample location

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

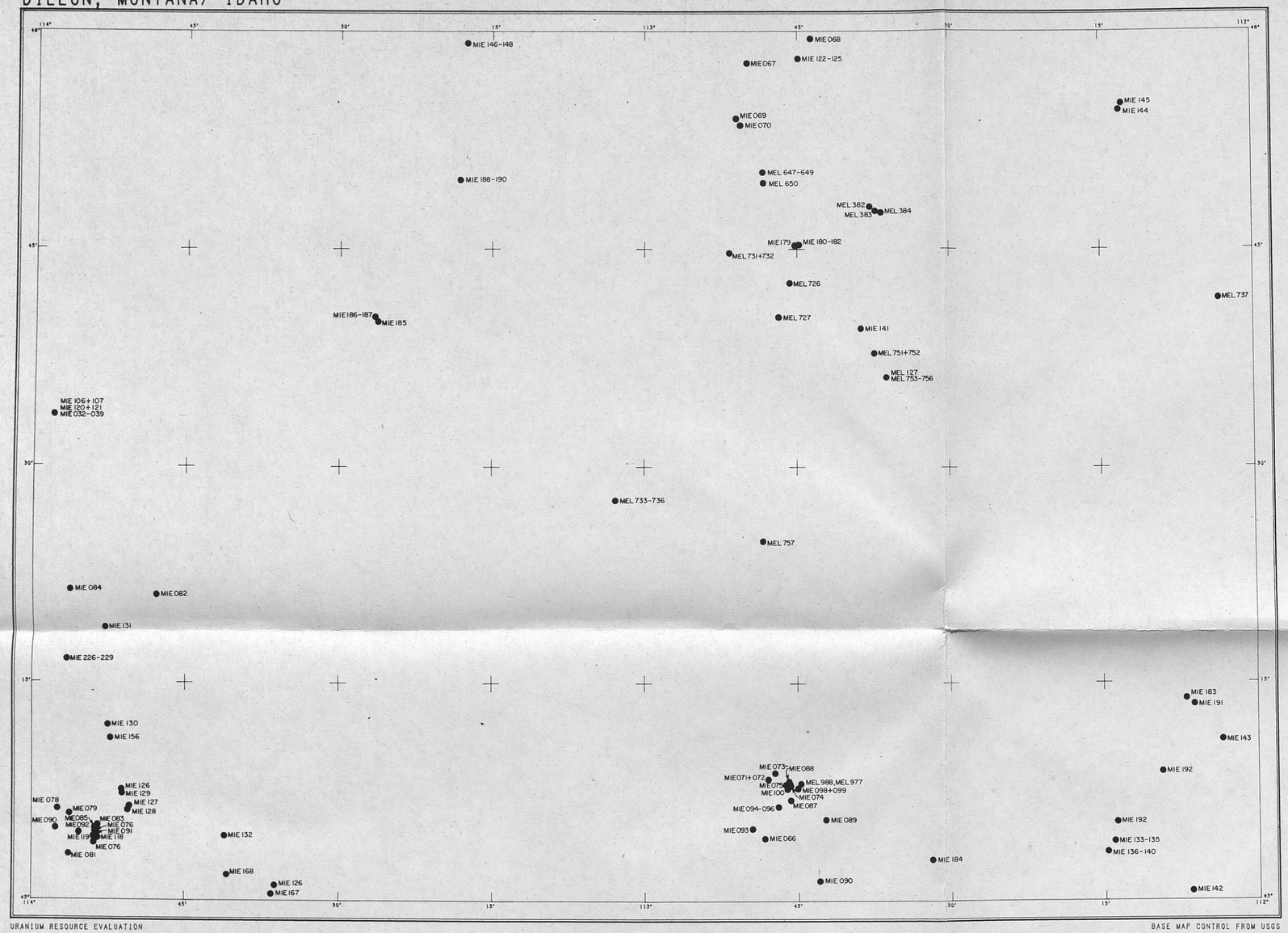
BASE MAP CONTROL FROM USGS

5 0 5 10 15 20 25 MILES

5 0 5 10 15 20 25 KILOMETERS

Plate 5c. LOCATION MAP OF WATER-WELL AND SPRING GEOCHEMICAL SAMPLES

DILLON, MONTANA/ IDAHO



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

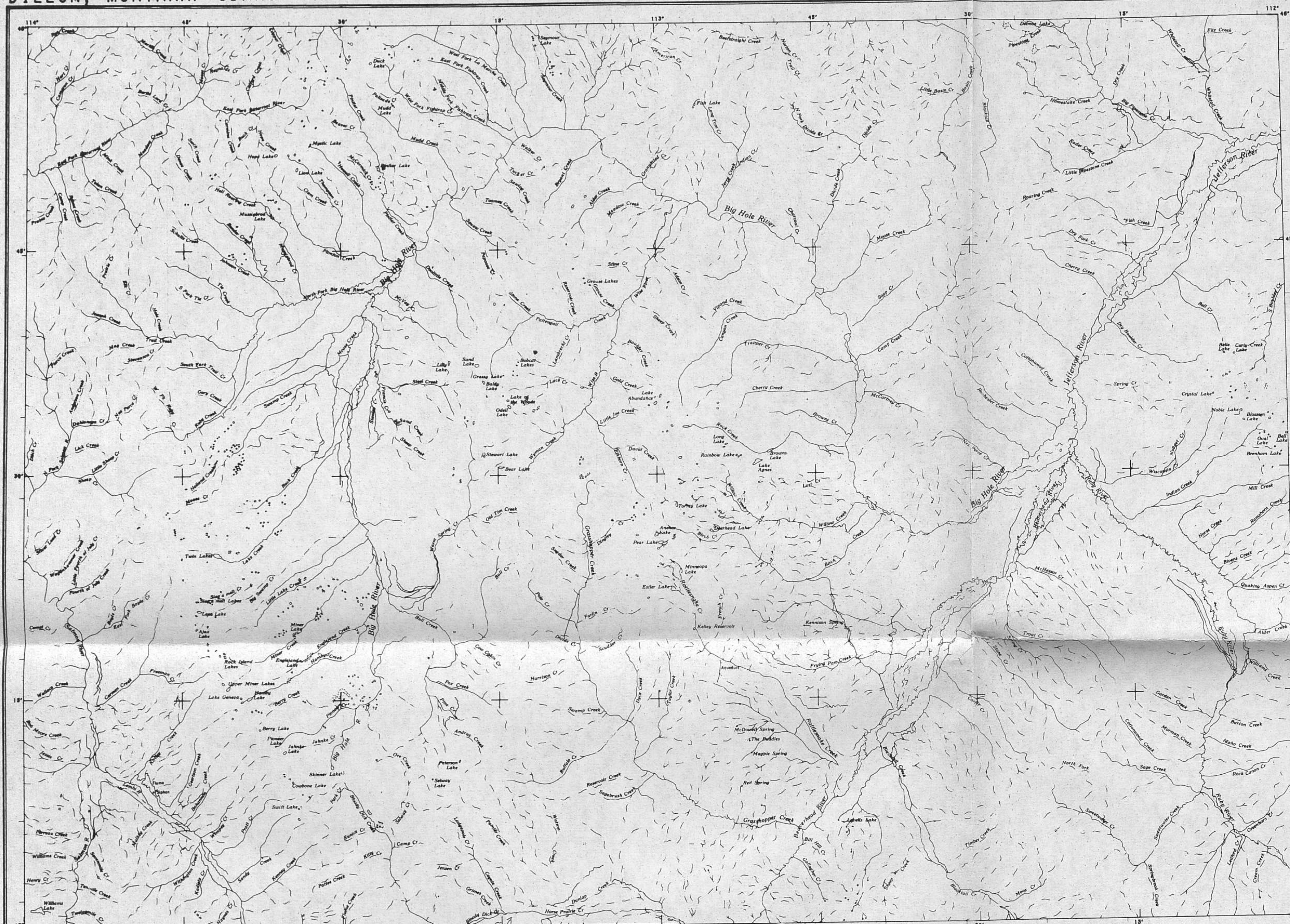
BASE MAP CONTROL FROM USGS

5 0 5 10 15 20 25 MILES

5 0 5 10 15 20 25 KILOMETERS

Plate 5d. LOCATION MAP OF ROCK GEOCHEMICAL SAMPLES

DILLON, MONTANA/ IDAHO



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

DILLON, MONTANA/ IDAHO

GEOLOGY COMPILED BY FUGRO, INC

5 0 5 10 15 20 25 MILES

5 0 5 10 15 20 25 KILOMETERS

Plate 7a. GEOLOGIC MAP

LEGEND

SEDIMENTARY

CENOZOIC

Qal — ALLUVIUM
River and floodplain deposits

Qls — LANDSLIDES

Qt — TERRACE GRAVEL

Qg — GLACIAL DEPOSITS
Till and outwash

VALLEY FILL (Tu)
Undifferentiated valley fill. In areas of photo interpretation only.

- **Tu, Tcm, Tkt** — COARSE-GRAINED VALLEY FILL
  Montana: Tu; Idaho: Tcm - Carmen Formation and Tkt - Kirtley Formation (Correlation between states is primarily based on age)
- **Tl, Tgs, Tky, Tkn** — FINE-GRAINED VALLEY FILL
  Montana: Tl; Idaho: Tgs - Geertson Formation; Tky and Tkn - Kenny Formation (Correlation between states is primarily based on age)

TKb, TKr — BEAVERHEAD/KRILEY FORMATIONS
Carbonate or quartzite conglomerates

MESOZOIC

COLORADO, MORRISON, ELIS GROUPS AND KOOTENAI FORMATION (JK)

- **K** — COLORADO GROUP, KOOTENAI FORMATION
  Shales, sandstones and limestones
- **J** — MORRISON, ELIS GROUPS
  Shales and sandstones

AMSDEN QUADRANT, PHOSPHORIA, DINWOODY FORMATIONS (PTr)
Limestone, quartzite, shale and phosphorite bedded chert

- **Tr** — TRIASSIC
- **Pp** — PERMIAN-PENNSYLVANIAN

PALEOZOIC

M — LODGEPOLE AND MISSION CANYON FORMATIONS
Limestone

D AND € (€D)
Undifferentiated

- **D** — JEFFERSON AND THREE FORKS FORMATION
  Dolomites and shales

UNCONFORMITY

- **€** — FLATHEAD, WOLSEY, MEAGHER, PARKS, PILGRIM, RED LION AND HASMARK FORMATIONS
  Sandstone, dolomite and shale

UNCONFORMITY

PRECAMBRIAN

BELT SUPER GROUP

- **Aq, P€q, P€s, P€sr** — IDAHO
  Aq - fine-grained, dark gray, impure quartzitic rocks; P€q - quartzite; P€s/P€sr - Swauger quartzite with pale reddish beds (P€sr) at base
- **P€m, P€mu, P€bm** — MISSOULA GROUP
  Quartzites, siltites, and argillites
- **P€nb** — NORTH BOULDER GROUP
  Coarse-grained component of Belt series, conglomerate and sandstone
- **P€b, P€pi, P€n, P€w, P€r, P€p** — MIDDLE AND LOWER BELT
  Wallace and Helena (P€w), Newland (P€n), Prichard (P€p) formations and Piegan (P€pi) and Ravalli (P€r) groups, carbonates, quartzites, and siltites
- **P€l** — LEMHI GROUP
  Quartzites and siltites. Included as part of the Belt series in Idaho and pre-Belt (?) in Montana

IGNEOUS

Qv — QUATERNARY VOLCANICS

Tg — TERTIARY GRANITE

Tmd — DACITE AND QUARTZ LATITE PORPHORY
Dikes and small stocks

Tv, Tb, Tv, Tc, Tcb, Tcv — TERTIARY VOLCANICS
Montana: Tv - Lowland creek volcanics, Challis volcanics and equivalents; Tb - Tertiary basalt; Tc - Challis volcanics Idaho: Tcb - basalt member of the Challis volcanics; Tcv - Challis volcanics

Tsd — SYENODIORITE
Dikes in Idaho only

KTqm, Kgm — QUARTZ MONZONITE

Kg, KTgd — GRANODIORITE
Boulder and Idaho batholith plutons

Kib — BORDER ZONE OF IDAHO BATHOLITH AND ASSOCIATED ROCKS

Kd — INTRUSIVES
Dikes, sills and thick sheet diorite porphory

Kv — ELKHORN MOUNTAIN VOLCANICS

Jmg — METAGABBRO
Dikes in Idaho only

P€g — PRECAMBRIAN GRANITE

METAMORPHIC

PONY AND CHERRY CREEK GROUPS (P€gs)

- **P€p** — PONY GROUP
- **Dg** — DILLON GRANITE GNEISS
- **Mi** — MIGMATITE
- **CHERRY CREEK GROUP** (P€c)
  - qg — Quartzofeldspathic gneiss
  - ag — Anthrophyllite garnet gneiss
  - p — Peridotite
  - am — Amphibolite
  - hg — Hornblend gneiss
  - m — Marble

PCA — PRE-CHERRY CREEK GROUP (?)
Quartzofeldspathic gneiss

gfg — BASEMENT

Age scale: QUATERNARY (PLEISTOCENE TO HOLOCENE); TERTIARY (PLIOCENE; EOCENE TO MIOCENE); LATE CRETACEOUS TO EARLY TERTIARY; CRETACEOUS; JURASSIC; TRIASSIC; PERMIAN - PENNSYLVANIAN; MISSISSIPPIAN; DEVONIAN; CAMBRIAN; PRECAMBRIAN

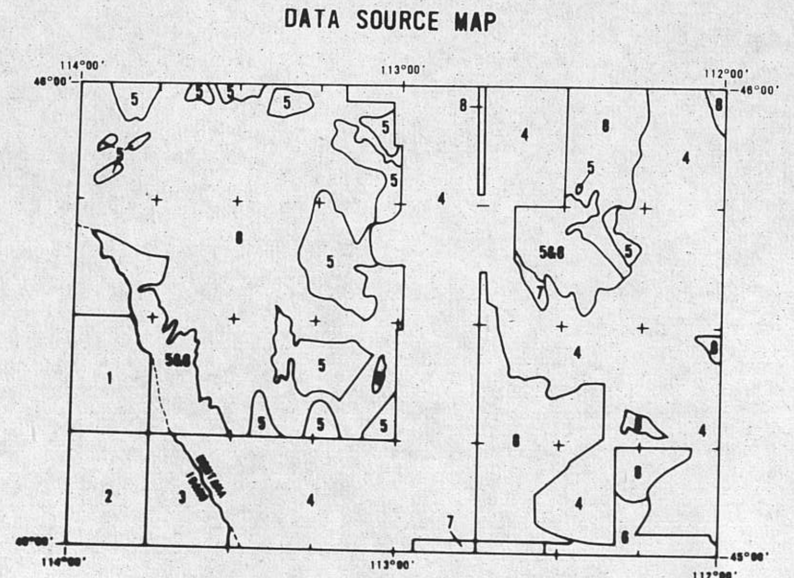
GEOLOGIC SYMBOLS

Formation contact. Dashed where approximately located, queried where location uncertain.

Fault showing relative vertical movement, U, up and D, down. Dashed where approximately located, dotted where concealed, and queried where location uncertain. Barbs indicate thrust or low-angle reverse fault.

Syncline, showing axial trace.

DATA SOURCE MAP



DATA SOURCES

1. Anderson, A.L., 1959, Geology and Mineral Resources of the North Fork quadrangle, Lemhi County, Idaho: Idaho Bur. Mines and Geology pamph. 118, Pl. 1, 1:63,360.
2. ________, 1956, Geology and Mineral Resources of the Salmon quadrangle, Lemhi County, Idaho: Idaho Bur. Mines and Geology pamph. 106, Pl. 1, 1:63,360.
3. ________, 1957, Geology and Mineral Resources of the Baker quadrangle, Lemhi County, Idaho: Idaho Bur. Mines and Geology pamph. 112, Pl. 1, 1:63,360.
4. Montana Bureau of Mines and Geology, compiled portions of the Dillon quadrangle, post 1965 sources: Montana Bur. Mines and Geology, mylar overlay, 1:250,000.
5. Ross, Clyde P., 1963, The Belt Series in Montana: U.S. Geol. Surv. Prof. Paper 346, Pl. 1, 1:250,000.
6. Klepper, M.R., 1950, A Geologic Reconnaissance of parts of Beaverhead and Madison Counties, Montana: U.S. Geol. Surv Bull. 969-C, Pl. 16, 1:250,000.
7. Scholten, Robert, Keenmon, K.A., and Kupsch, W.O., 1955, Geology of the Lima Region, Southwestern Montana and Adjacent Idaho: Geol. Soc. America Bull., v. 66, No. 4, Pl. 1, 1:126,720.

ORIGINAL PHOTOGRAPHIC INTERPRETATION

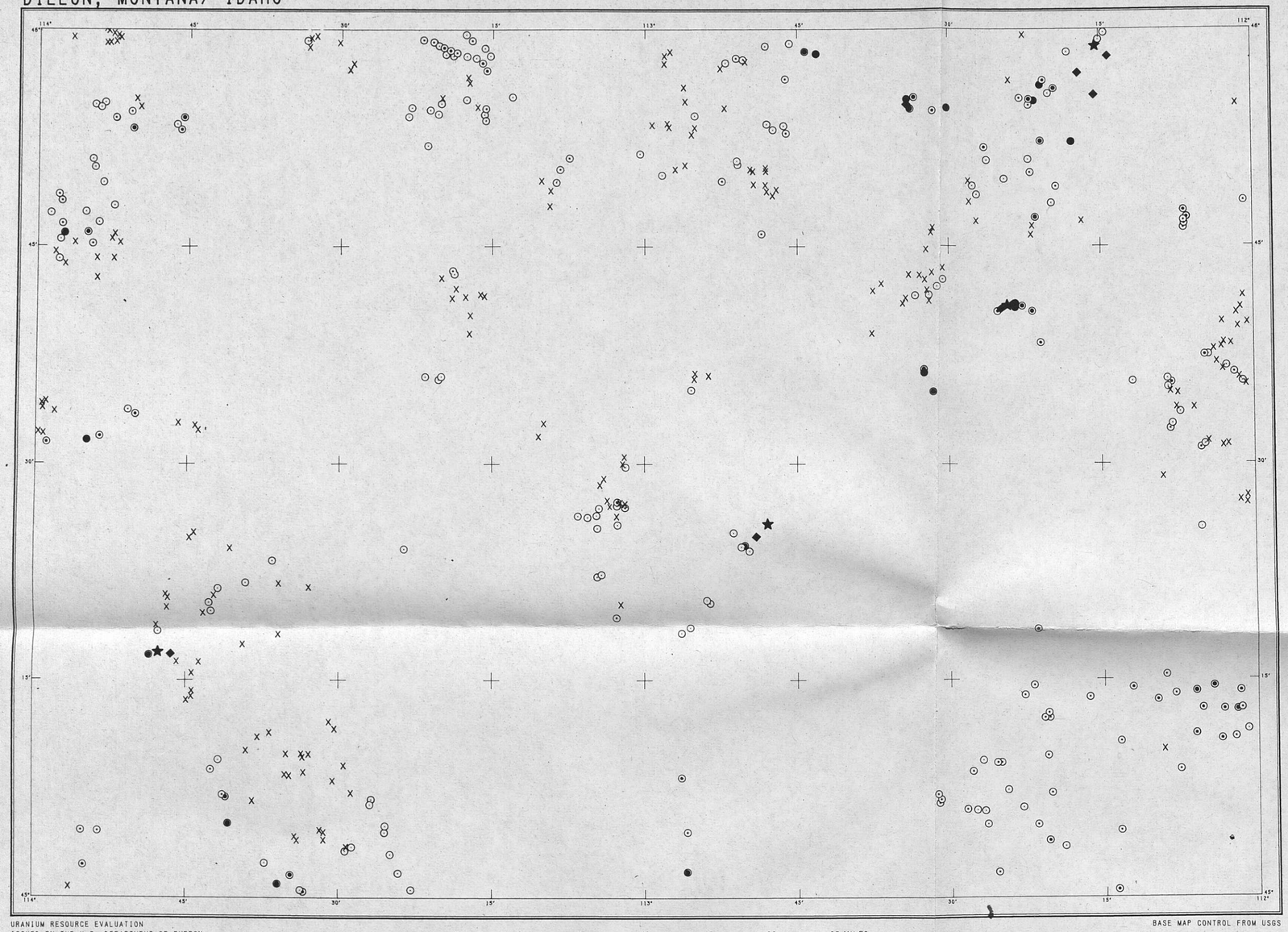
8. Fugro Inc., 1978, Photogeologic interpretation of 1:50,000 and 1:80,000 scale aerial photographs.

GENERAL REFERENCE

9. U.S. Geological Survey, 1966, Geologic Map of Montana, 1:500,000 scale.

Plate 7b. GEOLOGIC LEGEND

DILLON, MONTANA/ IDAHO



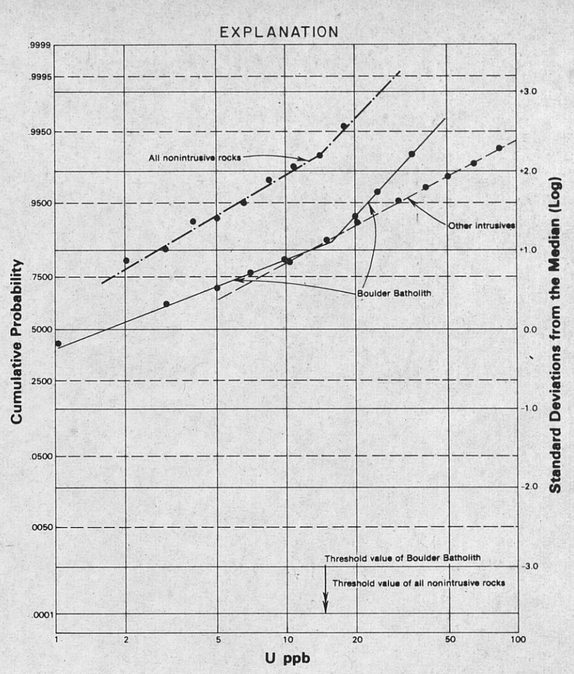
URANIUM RESOURCE EVALUATION
ISSUED BY THE U.S. DEPARTMENT OF ENERGY

BASE MAP CONTROL FROM USGS

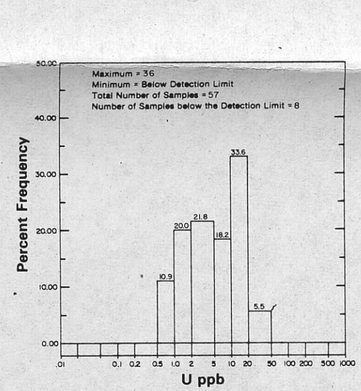
5 0 5 10 15 20 25 MILES

5 0 5 10 15 20 25 KILOMETERS

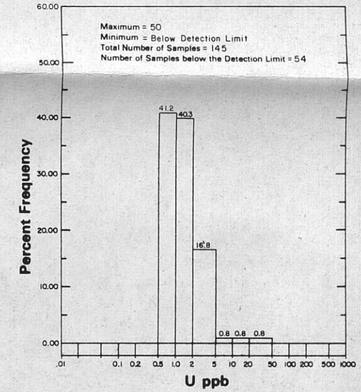
Plate 8a. STREAM-WATER ANALYTIC RESULTS



Cumulative probability plot for uranium concentration in stream waters draining Boulder Batholith, other intrusives, and all nonintrusive rocks



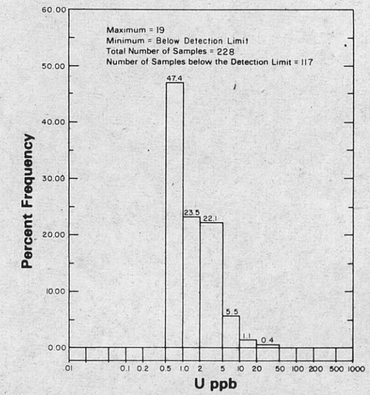
Logarithmic histogram of total-uranium concentration in stream sediments derived from Boulder Batholith



Logarithmic histogram of total-uranium concentration in stream sediments derived from all other intrusive rocks

SYMBOLS USED ON MAP

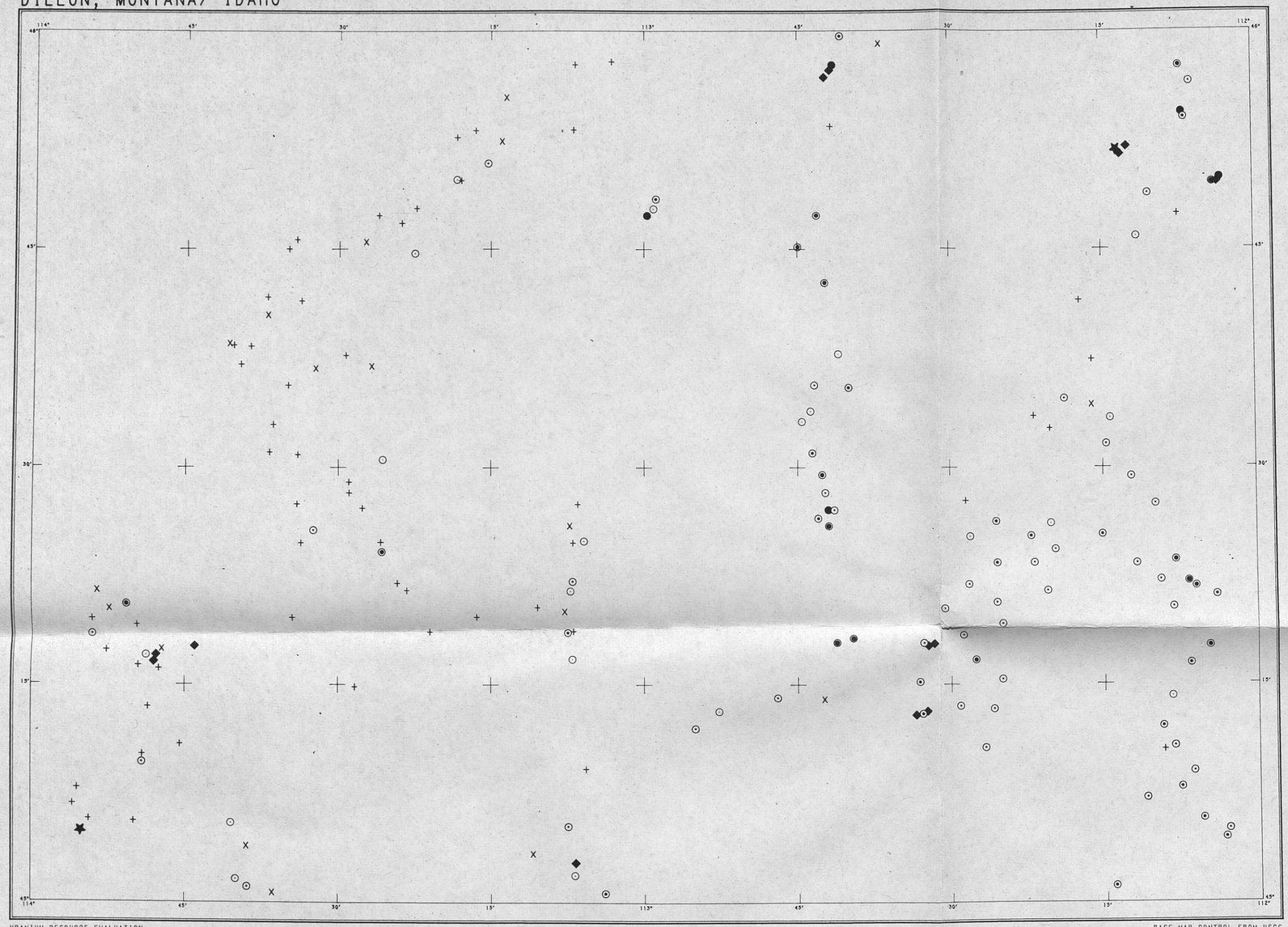
U ppb	
X	<1
⊙	1 to 2
⊙	2 to 3
⊙	3 to 5
⊙	5 to 7
●	7 to 10
●	10 to 15
◆	15 to 25
★	>25



Logarithmic histogram of total-uranium concentration in stream sediments derived from nonintrusive rocks

Plate 8a.

DILLON, MONTANA/ IDAHO



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

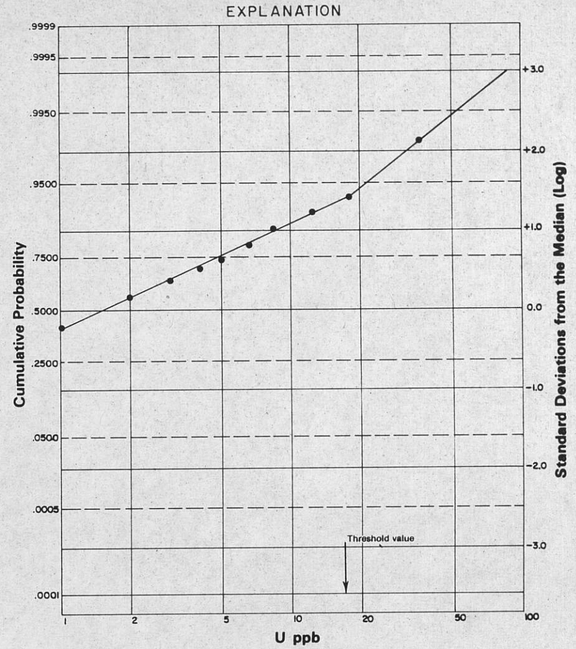
BASE MAP CONTROL FROM USGS

5 0 5 10 15 20 25 MILES

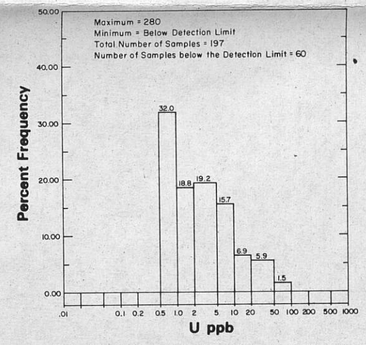
5 0 5 10 15 20 25 KILOMETERS

Plate 8b. ANALYTIC RESULTS OF WELL AND SPRING GEOCHEMICAL SAMPLES

EXPLANATION



Cumulative probability plot for uranium concentration in well water

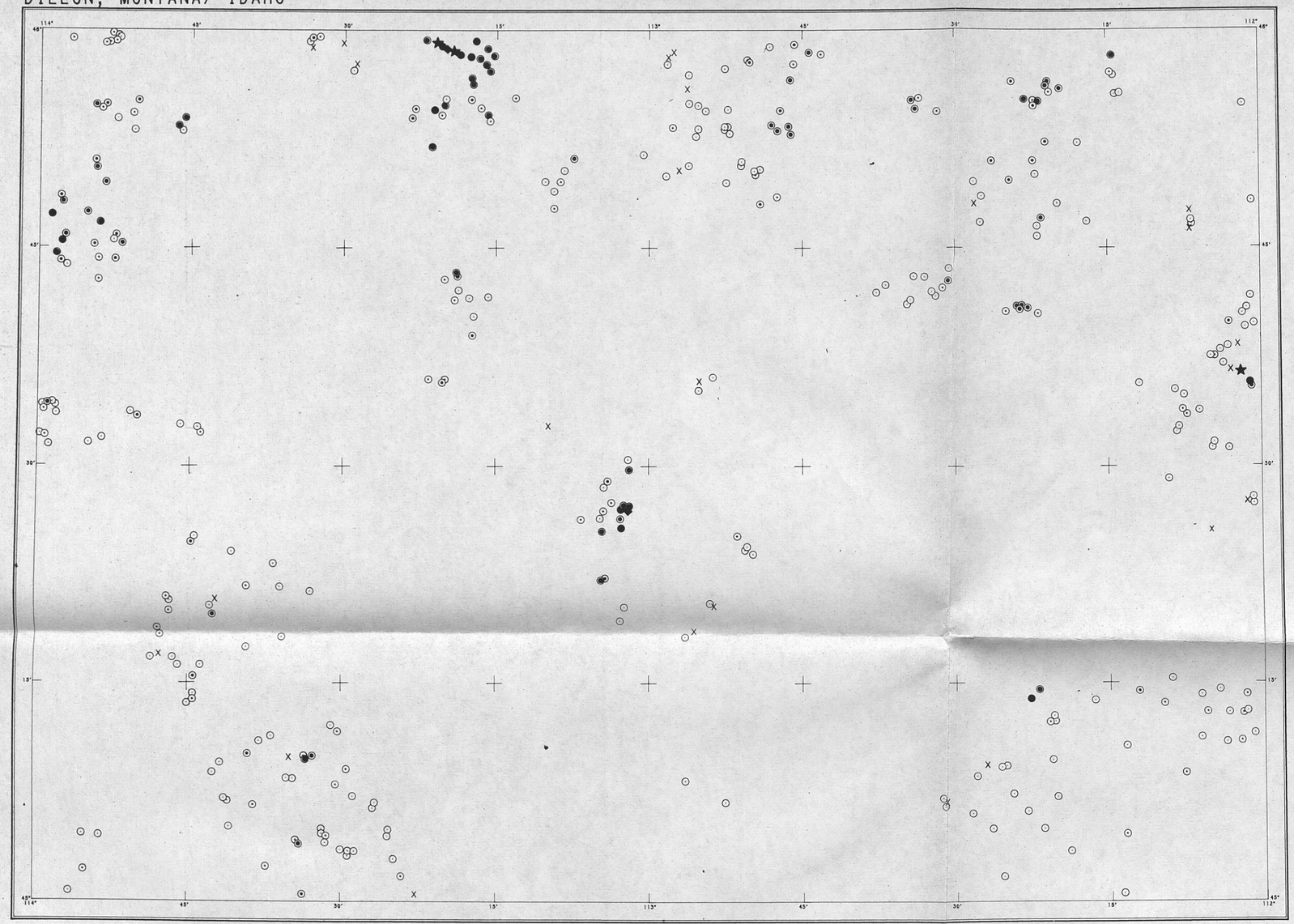


Logarithmic histogram of uranium concentration in well water

SYMBOLS USED ON MAP

	U ppb
+	<1
X	1 to 2
⊙	2 to 3
⊙	3 to 5
⊙	5 to 7
◉	7 to 10
●	10 to 15
●	15 to 20
◆	20 to 50
★	>50

DILLON, MONTANA/ IDAHO



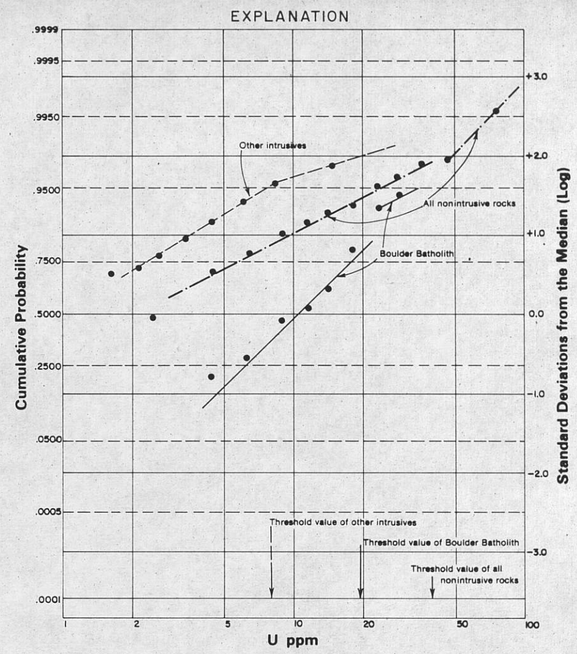
URANIUM RESOURCE EVALUATION
ISSUED BY THE U.S. DEPARTMENT OF ENERGY

BASE MAP CONTROL FROM USGS

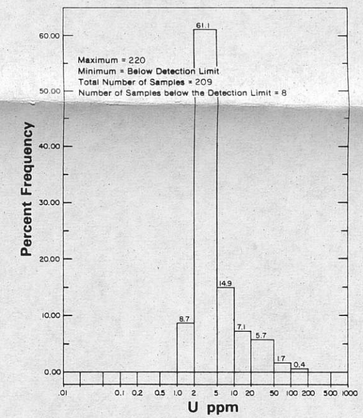
5 0 5 10 15 20 25 MILES

5 0 5 10 15 20 25 KILOMETERS

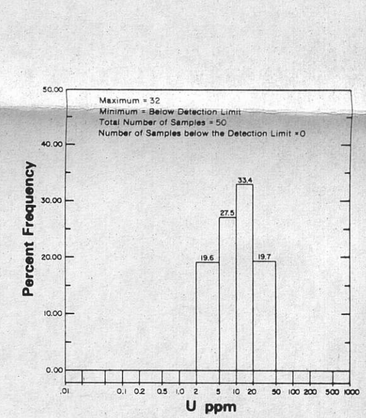
Plate 9a. STREAM-SEDIMENT ANALYTIC DATA OF TOTAL URANIUM



Cumulative probability plot for total-uranium concentration in stream sediments derived from Boulder Batholith, other intrusives, and all nonintrusive rocks



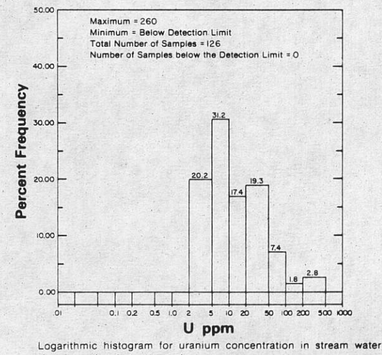
Logarithmic histogram for uranium concentration in stream water draining all nonintrusive rocks



Logarithmic histogram for uranium concentration in stream water draining Boulder Batholith

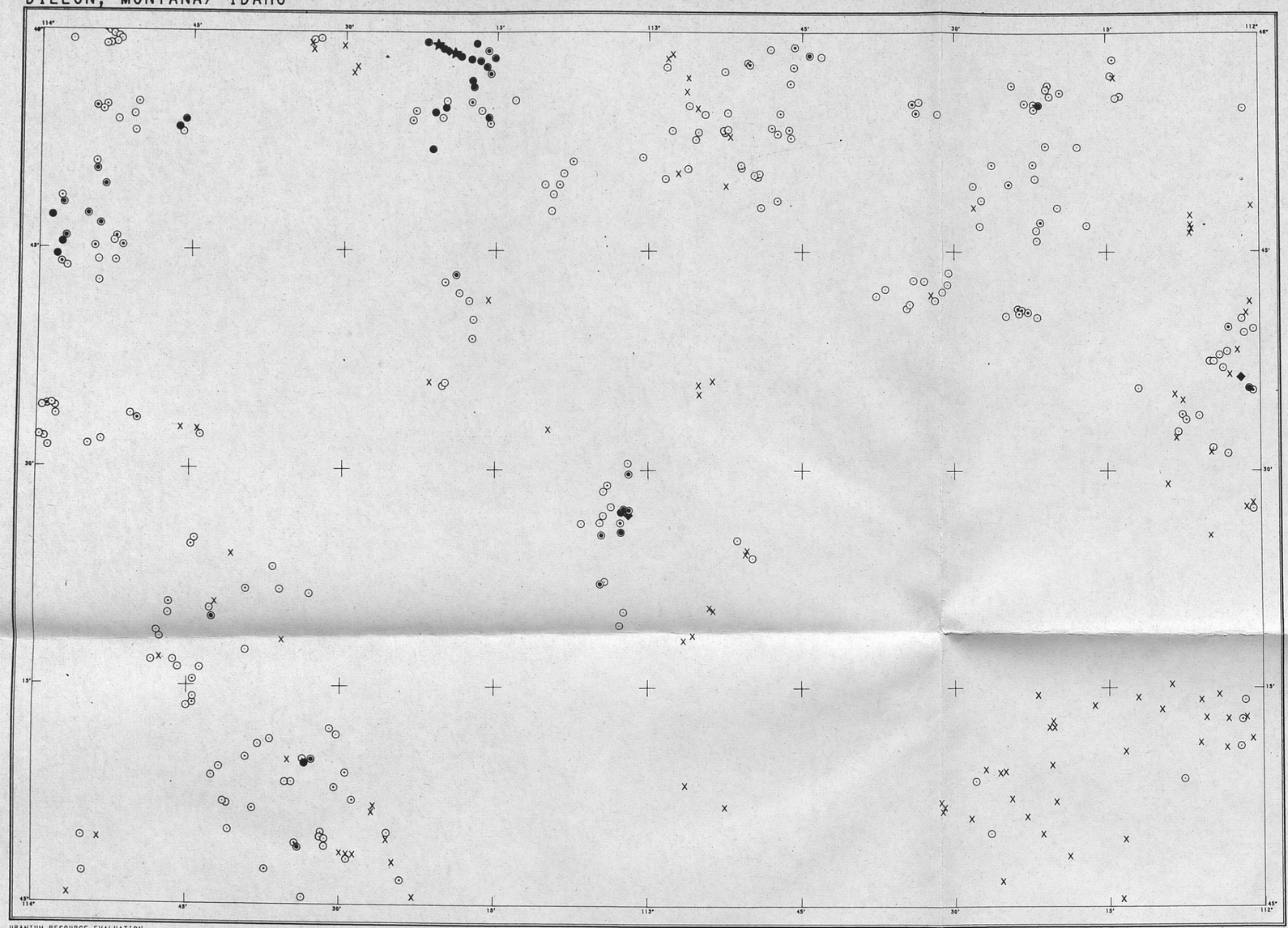
SYMBOLS USED ON MAP

U ppm	
X	<2
⊙	2 to 5
⊙	5 to 10
⊙	10 to 15
⊙	15 to 25
●	25 to 50
●	50 to 100
◆	100 to 200
★	>200



Logarithmic histogram for uranium concentration in stream water draining other intrusive rocks

DILLON, MONTANA/ IDAHO



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

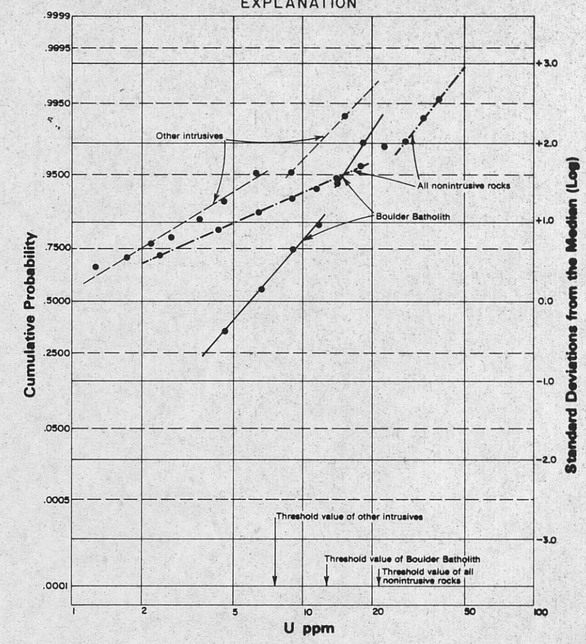
BASE MAP CONTROL FROM USGS

5 0 5 10 15 20 25 MILES

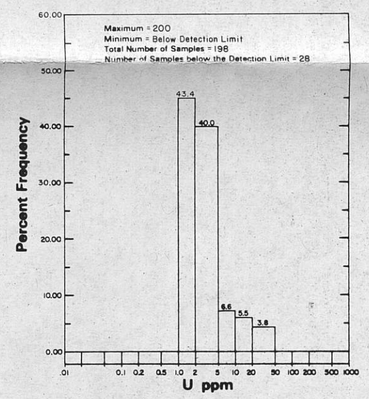
5 0 5 10 15 20 25 KILOMETERS

Plate 9b. STREAM-SEDIMENT ANALYTIC DATA OF COLD EXTRACTABLE URANIUM

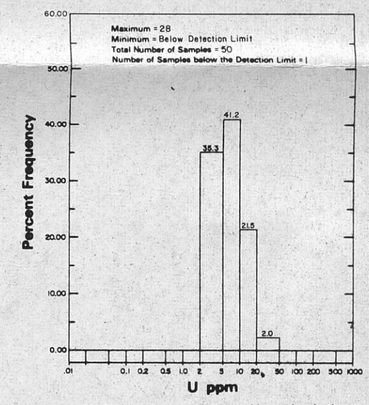
EXPLANATION



Cumulative probability plot for cold extractable uranium in stream sediments derived from Boulder Batholith, other intrusives and nonintrusive rocks



Logarithmic histogram of cold extractable uranium in stream sediments derived from nonintrusive rocks

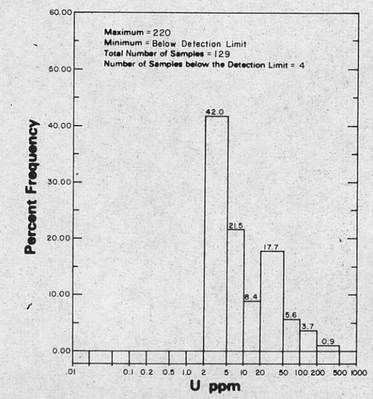


Logarithmic histogram of cold extractable uranium in stream sediments derived from Boulder Batholith

SYMBOLS USED ON MAP

U ppm

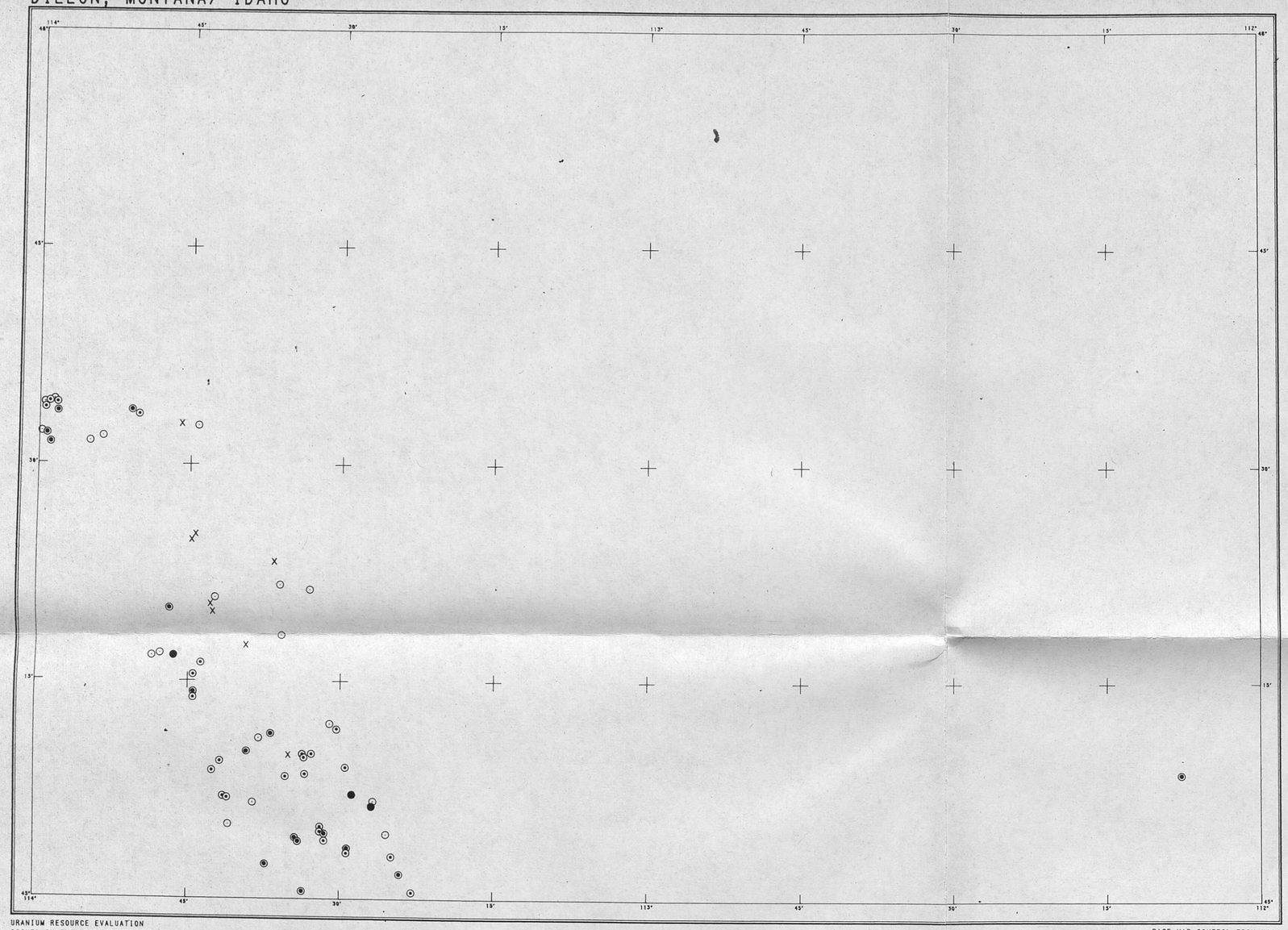
X	<2
⊙	2 to 5
⊙	5 to 10
◉	10 to 15
◉	15 to 25
●	25 to 50
●	50 to 100
◆	100 to 200
★	>200



Logarithmic histogram of cold extractable uranium in stream sediments derived from all other intrusives

Plate 9b.

DILLON, MONTANA/ IDAHO



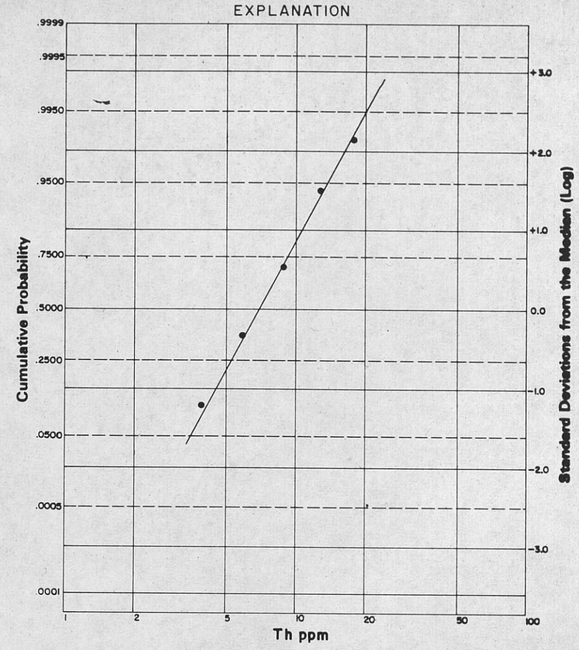
URANIUM RESOURCE EVALUATION
ISSUED BY THE U.S. DEPARTMENT OF ENERGY

5 0 5 10 15 20 25 MILES

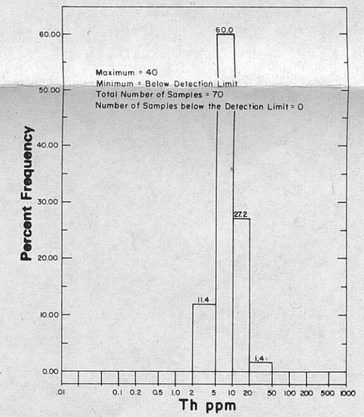
5 0 5 10 15 20 25 KILOMETERS

BASE MAP CONTROL FROM USGS

EXPLANATION



Cumulative probability plot for total thorium concentration in stream sediments



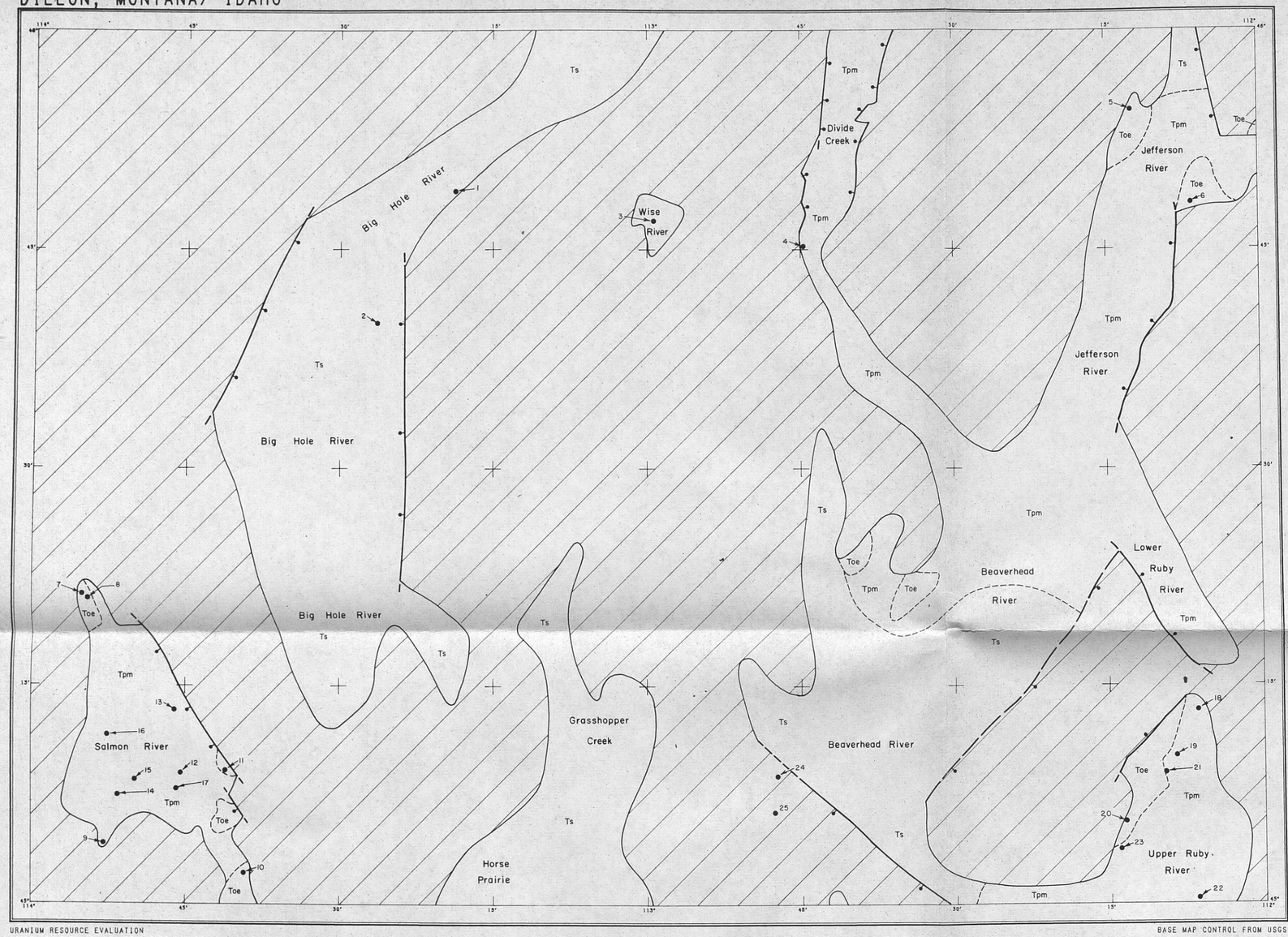
Logarithmic histogram of total thorium concentration in stream sediments

SYMBOLS USED ON MAP

Th ppm	
X	>5
⊙	5 to 7
◉	7 to 10
◉	10 to 15
●	15 to 20
★	>20

Plate 9c. STREAM-SEDIMENT ANALYTIC DATA OF TOTAL THORIUM

DILLON, MONTANA/ IDAHO



EXPLANATION

QUATERNARY		Gravel
TERTIARY Undifferentiated	Miocene–Pliocene	Tpm — Sedimentary rocks
	Eocene–Oligocene	Toe — Sedimentary rocks
		Mudstone or siltstone
		Tuffaceous mudstone or siltstone
		Sand or sandstone
		Tuffaceous sand or sandstone
		Conglomerate
		Altered conglomerate
		Lignite
		Breccia
		Tuffaceous breccia
		Airfall tuff
		Welded tuff
		Rhyolite
		Basalt
		Felsic intrusive
PRE-TERTIARY includ. PRECAMBRIAN		Undifferentiated basement rocks
CRETACEOUS		Andesite
PRECAMBRIAN		Gneiss and other metamorphic rocks

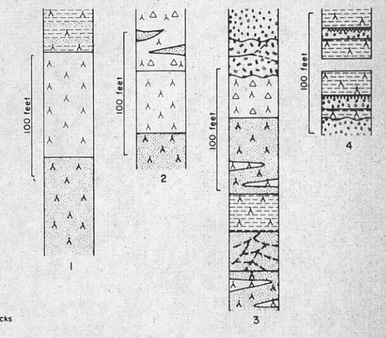
Boundary of Tertiary basins and between various stratigraphic and lithological units

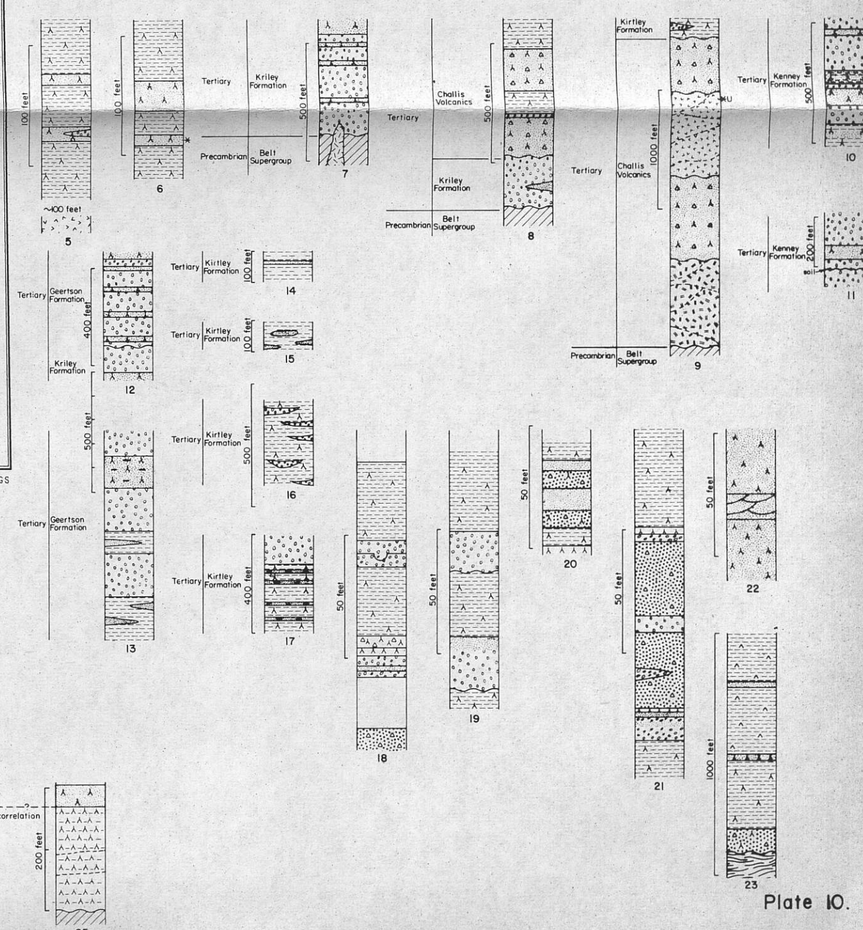
Fault – dashed where concealed, bar and ball on downthrown side

*U — Uranium-bearing occurrence

● 4 — Location of measured stratigraphic sequence

Areas external to basins





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

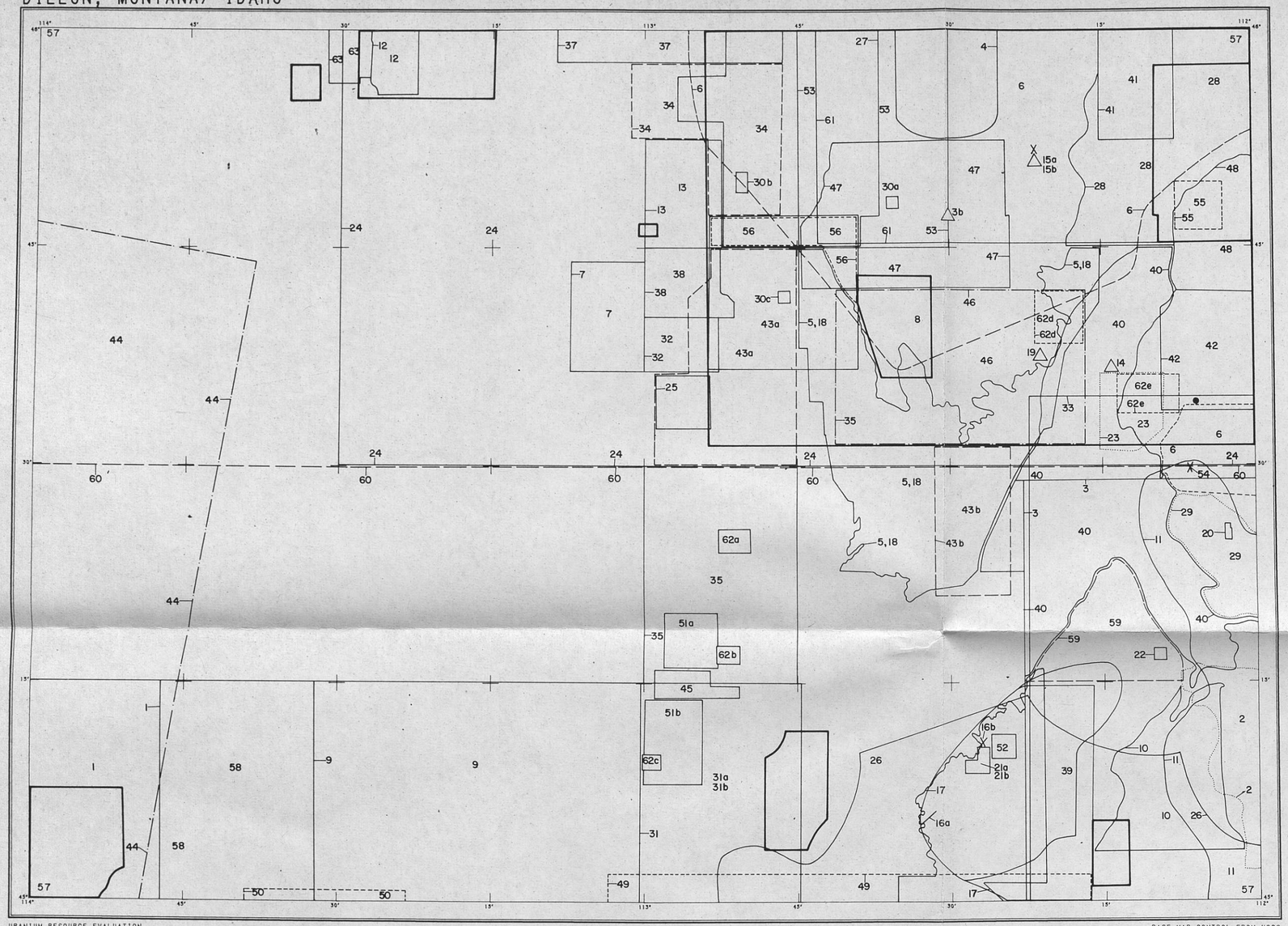
BASE MAP CONTROL FROM USGS

5 0 5 10 15 20 25 MILES

5 0 5 10 15 20 25 KILOMETERS

Plate 10. LOCATION OF TERTIARY BASINS AND MEASURED STRATIGRAPHIC COLUMNS

DILLON, MONTANA/ IDAHO



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

BASE MAP CONTROL FROM USGS

5 0 5 10 15 20 25 MILES

5 0 5 10 15 20 25 KILOMETERS

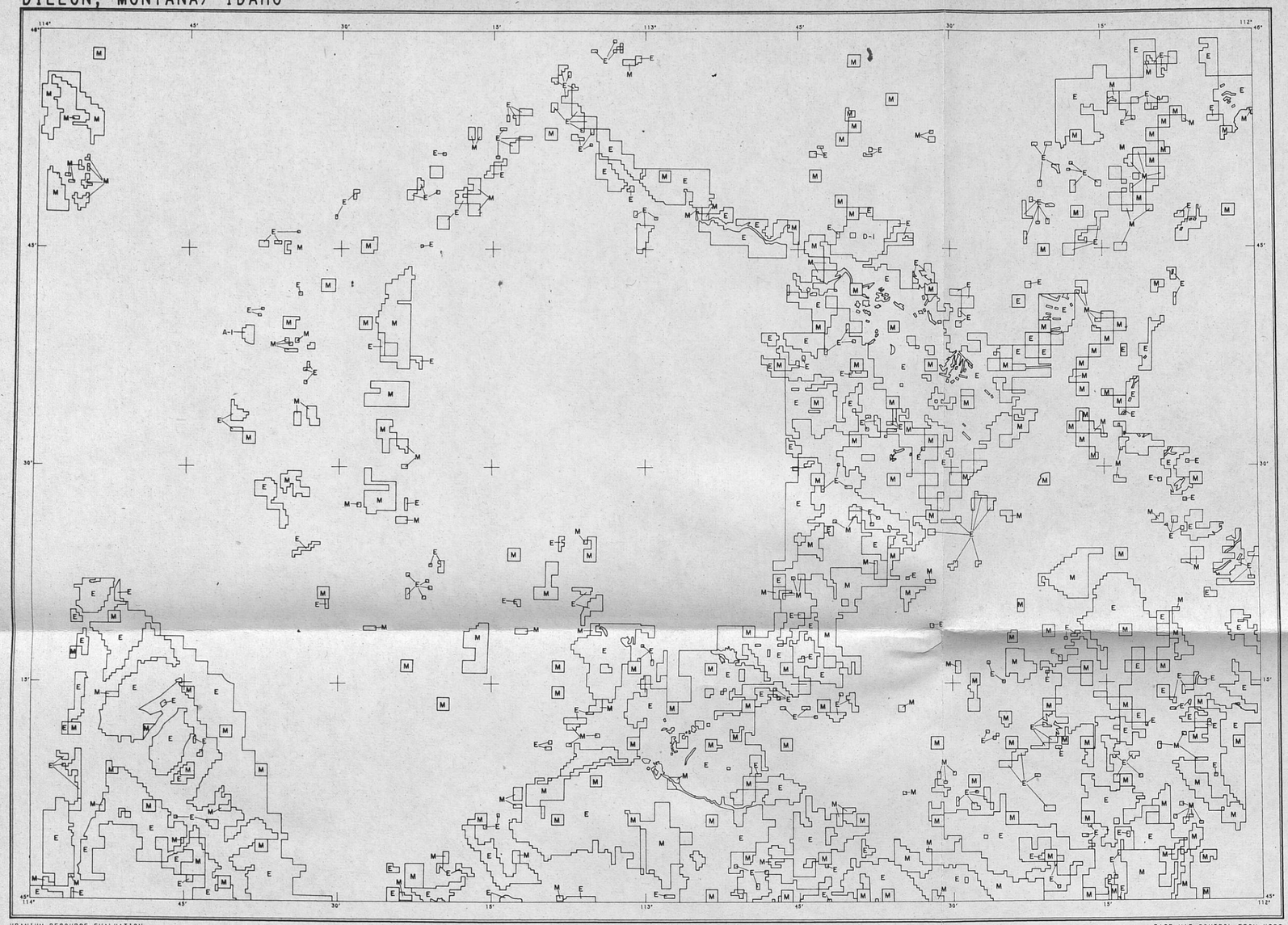
Plate II. GEOLOGIC-MAP INDEX

INDEX

1. Anderson, 1956, scale 1:63,000.
2. Berg, 1976, scale 1:24,000.
3. Billings Geological Society, 1960, scale 1:250,000.
4. Botz, 1969, scale 1:63,360.
5. Brumbaugh and Dresser, 1976, various scales.
6. Burger, 1969, scale 1:48,000.
7. Calbeck, 1975, various scales.
8. Castor and Robins, 1978, scale 1:470,588.
9. Coppinger, 1974, various scales.
10. Dorr and Wheeler, 1964, various scales.
11. Egbert, 1960, scale 1:24,000.
12. Flood, 1975, scale not given.
13. Fraser and Waldrop, 1972, scale 1:24,000.
14. Full and Armstrong, 1945, scale 1:2,400.
15a. Heinrich, 1949a, scales 1:420, 1:720, and 1:480.
15b. Heinrich, 1949b, scales 1:440 and 1:720.
16a. Heinrich, 1950a, scale 1:21,120.
16b. Heinrich, 1950b, scale 1:2,400.
17. Heinrich, 1960, scale 1:32,000.
18. Hoffman, 1971, various scales.
19. James, 1943, scale 1:600.
20. James and Wier, 1962, scale 1:2,400.
21a. James, Wier, and Shaw, 1969, scale 1:20,000.
21b. James and Wier, 1972, scale 1:3,600.
22. James and Wier, 1961, scale 1:3,500.
23. Johns, 1961, scale 1:31,680.
24. Johnson, Henderson, and Tyson, 1965, scale 1:250,000.
25. Karlstrom, 1948, scales 1:12,000 and 1:31,680.
26. Klepper, 1951, scale 1:250,000.
27. Konizeski, McMurtrey, and Brietkrietz, 1968, scale 1:62,500.
28. Kuenzi and Richard, 1969, scale not given.
29. Levandowski, 1956, various scales.
30. Lowell, 1955, (a) scale 1:35,000, (b) scale 1:35,000, (c) scale 1:32,000.
31a. Lowell, 1965, scale 1:31,680.
31b. Lowell, 1953, scale 1:31,680.
32. Mero, 1962, scale not given.
33. Montana Geological Society, 1967, scale 1:250,000.
34. Moore, 1956, scale not given.
35. Myers, 1952, scale 1:31,680.
36. Newcomb, 1941, scale 1:1,000.
37. Noel, 1956, scale not given.
38. Obert, 1962, scale not given.
39. Perry, 1948, scale 1:125,000.
40. Petkewich, 1972, scale not given.
41. Prostka, 1966, scale 1:24,000.
42. Reid, 1957, scale 1:48,000.
43. Richards and Pardee, 1926, (a) scale 1:62,500, (b) scale 1:62,500.
44. Ross, 1963, scale 1:250,000.
45. Sahinen, 1934, scale 1:31,680.
46. Sahinen, 1939, scale 1:62,000.
47. Sahinen, 1950, scale 1:62,500.
48. Schmidt, 1975, scale not given.
49. Scholten, Keenmon, and Kupsch, 1955, scale 1:126,720.
50. Sharp and Cavender, 1963, scale 1:24,000.
51. Shenon, 1931, (a) scale 1:30,000, (b) scale 1:24,000.
52. Sinkler, 1942, scale 1:31,680.
53a. Smedes, 1966, scale 1:24,000.
53b. Smedes, 1967, scale 1:24,000.
54. Stoll, 1951, scale 1:480.
55. Tansley, Schafer, and Hart, 1933, scale 1:62,500.
56. Theodosis, 1956, scale not given.
57. Trites and Tooker, 1953, scale 1:250,000.
58. Tucker, 1975, scale not given.
59. Tysdal, 1970, scale 1:24,000.
60. U.S. Geological Survey, 1975, scale 1:250,000.
61. Weed, 1912, scale 1:250,000.
62. Winchell, 1914, (a) scale 1:63,360, (b) scale not given, (c) scale 1:48,000, (d) scale 1:63,360, (e) scale not given.
63. Wiswall, 1977, scale not given.

HEAVY OUTLINE ARE THOSE AREAS MAPPED IN DETAIL FOR THIS STUDY AND INCLUDED IN THE REPORT AS FIGURES 6-8, 10-12, AND 14-17.

DILLON, MONTANA/ IDAHO



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

BASE MAP CONTROL FROM USGS

5 0 5 10 15 20 25 MILES

5 0 5 10 15 20 25 KILOMETERS

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A. Areas Managed by National Park Service
A-1 Big Hole Battlefield National Monument

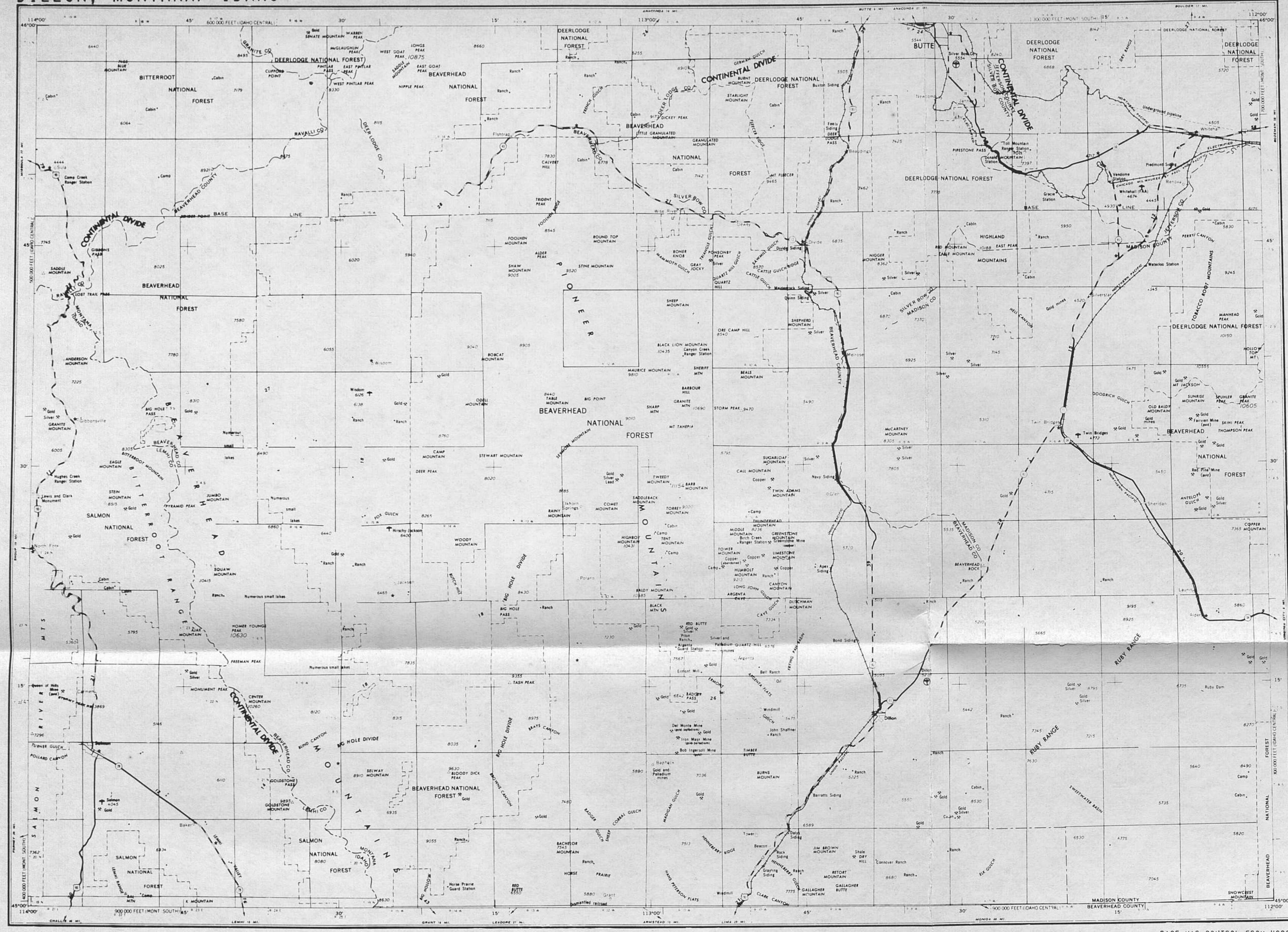
D. Bureau of Land Management Primitive Areas
D-1 Humbug Spires Primitive Area

E. Bureau of Land Management Withdrawn National Resource Lands and Bureau of Reclamation Withdrawals

M. State Withdrawals

Plate 12. GENERALIZED LAND STATUS

DILLON, MONTANA/ IDAHO



URANIUM RESOURCE EVALUATION
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BASE MAP CONTROL FROM USGS

5 0 5 10 15 20 25 MILES

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Plate 13. CULTURE