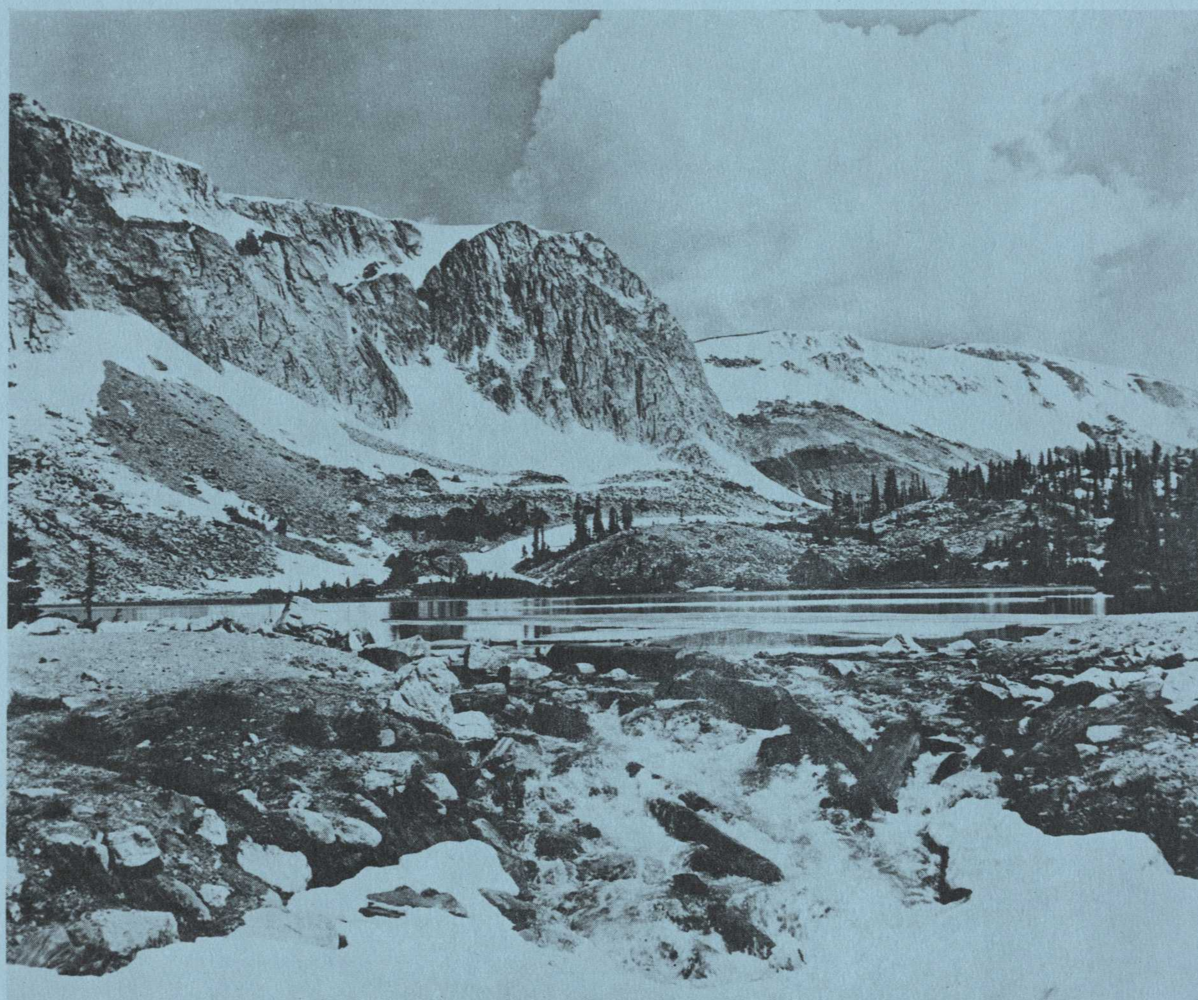
The Geological Survey of Wyoming
Daniel N. Miller, Jr., State Geologist

OCCURRENCES OF URANIUM IN PRECAMBRIAN AND YOUNGER ROCKS OF WYOMING AND ADJACENT AREAS



Public Information Circular 7

Edited and compiled by
David R. Lageson
W. Dan Hausel

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Cover photo:

The Snowy Range, Carbon County, Wyoming. Precambrian Medicine Peak Quartzite forms high ridge. Photo courtesy of Wyoming Travel Commission.

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INTRODUCTION

by
David R. Lageson
Geological Survey of Wyoming

This uranium symposium, emphasizing Precambrian occurrences, has been organized for this year's annual joint meeting between the Wyoming Geological Association, the Geological Survey of Wyoming, and the Department of Geology, University of Wyoming, scheduled for May 5th and 6th, 1978, in Laramie.

With regard to our nation's present and future energy demands, the exploration for energy-related commodities is becoming an unparalled challenge for the professional geological community. This symposium addresses the relatively new exploration frontier of Precambrian uranium deposits. Recent research by industry, academic institutions, and the federal and state surveys has revealed new data and concepts pertaining to uranium mineralization in Precambrian rocks, but has also created many new problems and questions. We hope in this symposium to unite forces for two days of listening, discussing, and debating the subject of uranium mineralization.

Abstracts contained in this publication have been submitted by symposium speakers. In addition, there are a few non-speaker abstracts of general interest. This publication literally "abstracts" many of the new findings dealing with uranium mineralization in Precambrian and younger rocks of Wyoming and adjacent areas, and will serve as a basic reference source.

I wish to thank Dr. R.S. Houston and his graduate students at the University of Wyoming for their extensive help in organizing this meeting. The eagerness and abundant help by members of the Geology Club of the University of Wyoming is also sincerely appreciated. The staff of the Geological Survey of Wyoming, particularly Dan Hausel, have provided much help, for which I am grateful.

INTRODUCTION TO PAPERS ON THE URANIUM POTENTIAL OF ROCKS OF PRECAMBRIAN AGE OF THE WYOMING PROVINCE

Houston, R.S., Department of Geology, University of Wyoming, Laramie, Wyoming 82071

The discovery of radioactive quartz-pebble conglomerate in Proterozoic metasedimentary rocks of the Black Hills of South Dakota and in similar units of the Sierra Madre and Medicine Bow Mountains of Wyoming extends the search for uranium to a group of rocks of greatly different age and geologic environment than that to which most explorationists in Wyoming are accustomed. We are in the early stages of understanding the geology and mineralogy of these radioactive conglomerates and to date (1978) no ore deposits have been reported.

In the Sierra Madre and Medicine Bow Mountains surface outcrops of radioactive conglomerate are oxidized to the extent that pyrite is largely removed. Vugs, cavities, and limonite pseudomorphs are evidence of its former presence. In surface outcrops, thorium/uranium ratios are high (average 6), with a maximum thorium content of 916 ppm and a maximum uranium content of 141 ppm. Study of drill core from the northeast Medicine Bow Mountains shows that uranium is more abundant relative to thorium in unaltered conglomerate and that pyrite is fresh and constitutes as much as twenty percent of some conglomerate layers. Unfortunately, these core samples are from an area subject to almandine amphibolite facies metamorphism and the pyrite and probably the uranium-thorium minerals are largely recrystallized, making it difficult to verify a placer origin for the minerals.

Despite unanswered questions on mineralogy, the Wyoming radioactive quartz-pebble conglomerate has many characteristics in common with the conglomerate ore at Blind River in Canada and Vaal Reef in South Africa, and warrants the interest of explorationists on this basis. Certainly the Black Hills and southeast Wyoming occurrences are not the only metasedimentary rocks in the Wyoming Province that may contain radioactive quartz-pebble conglomerate, and exploration need not be confined to early Proterozoic metasedimentary rocks. If the atmospheric evolution model is used in exploration, any moderately to well sorted metasedimentary rock sequence with beds of fluvial origin might be an exploration target if it is older than about two billion years. The explorationist should also keep in mind the fact that uranium and thorium minerals are not the only heavy minerals that may constitute ore. Too little attention has been given Precambrian conglomerates by explorationists in general and especially by those in the United States. A careful look for uranium might turn up metals of equivalent or greater value. In other words, non-radioactive fluvial conglomerate should be sampled during any uranium exploration program.

The Precambrian part of this program is designed to introduce geologists to the general Precambrian geology and geochronology of the Wyoming Province, to acquaint them with the Precambrian stratigraphy in areas where radioactive conglomerate has been found and to discuss other types of uranium deposits found in the Precambrian rocks of this area that may be as important or more important than the radioactive conglomerate.

A careful look at the potential for uranium in Precambrian rocks of the Wyoming Province may not turn uranium exploration in the Wyoming Province upside down, but it may lead to the development of additional reserves at a time when national priorities suggest we need them.

A GUIDE TO THE PUBLISHED REPORTS ON THE HYDROGEOCHEMICAL AND STREAM SEDIMENT RECONNAISSANCE CONDUCTED BY THE LOS ALAMOS SCIENTIFIC LABORATORY

Broxton, Dave, NURE, Group G-5, White Rock, New Mexico 87545

The Los Alamos Scientific Laboratory (LASL) is conducting a Hydrogeochemical and Stream Sediment Reconnaissance (HSSR) in the states of New Mexico, Colorado, Wyoming, Montana, and Alaska. The HSSR is part of the National Uranium Resource Evaluation (NURE) program sponsored by the U.S. Department of Energy (DOE). The purpose of the HSSR is to identify areas having higher than normal concentrations of uranium in ground waters, surface waters, and water-transported sediments. HSSR data will ultimately be combined with data from other NURE programs (e.g. airborne radiomentric surveys and geological investigations) to provide an improved assessment of the potential uranium resources in the U.S. and to indicate areas favorable for uranium exploration by the private sector. This presentation provides a practical guide to the LASL's reports on the HSSR.

LASL HSSR reports fall into six categories: 1. general reports that outline the LASL's philosophy and sampling methodology, 2. technical reports that describe specific aspects of the program (e.g. analytical techniques and data base management), 3. quarterly reports that outline the progress of the program, 4. pilot studies that test various sampling methodologies, 5. data releases (both uranium-only and multielement) which make available the data collected in HSSR studies, but without a discussion of the results, and 6. reconnaissance reports (also as uranium-only or multielement) which presents HSSR data and includes a brief discussion of the results.

At the present time there are several published (or soon to be published) HSSR data releases and reconnaissance reports pertinent to uranium exploration in Wyoming. These reports were able to delineate areas in which water and/or sediment samples have uranium concentrations that are notable higher than surrounding background concentrations.

CLASSIFICATION OF URANIUM DEPOSITS

Childers, M.O., Power Reseources Corporation, Denver Colorado 80222

I. Strata controlled

A. Sandstone - conglomerate hosts

1. Trend deposits: ore bodies distributed along mineralized belts or trends; ore bodies generally tabular in habit sub-parallel to gross stratification.

a. Mineralized trends parallel to trends of hosts (Paleodrainage control). Examples: Westwater Canyon deposits in Ambrosia Lake trend, New Mexico; Chinle deposits in Lisbon Valley, White Canyon, and Monument Valley trends, Utah and Arizona.

b. Mineralized trends generally crossing paleodrainage patterns. Examples: Salt Wash deposits in Uravan mineral belt, Colorado and Utah.

2. Roll front deposits: ore bodies distributed along lateral and distal margins of altered complexes in sandstones and conglomerates; ore bodies occur in permeable hosts generally discordant to stratification.

a. Bifacies roll fronts occur in formations with both oxidized and reduced facies. Examples: uranium occurrences in Wind River, Wasatch, and Battle Spring Formations of Wyoming; Goliad, Oakville, and Catahoula deposits in south Texas.

b. Monofacies roll fronts occur in formations which are uniformly reducing. Examples: Inyan Kara, Fox Hills, Lance and Fort Union deposits of Wyoming and nearby areas; Jacksonville deposits of south Texas.

3. Stack deposits: irregular shapes associated with trend ore frequently controlled in part by structures. Example: Westwater Canyon "redistributed ore" occurrences in Grants uranium region, New Mexico.

4. Precambrian heavy mineral deposits: uraninite and other heavy minerals concentrated along stratification in sandstones and pebbly conglomerates. (Appear to represent placer concentrations in ancient reducing atmosphere). Examples: Witwatersrand, South Africa, Elliot Lake, Canada.

B. Carbonate hosts

1. Reef-trend deposits: ore bodies occur along reef fronts. Example: Todilto deposits in Grants uranium region, New Mexico.

2. Calcrete deposits: irregular distribution of carnotite in calcareous material (caliche or calcrete) distributed in roughly horizontal tabular bodies along major drainageways in arid to semi-arid regions. Example: Yeelirrie, Western Australia.

C. Lignite; black shale, and phosphatic rock hosts

1. Uraniferous lignites: irregular dissemination in lignite and associated carbonaceous shale and siltstone.

a. Low-grade wide distribution in lignites marginal to oxidizing environments. Example: Wasatch-Green River deposits of the Great Divide basin, Wyoming.

b. Deposits (including high-grade) in lignites associated with permeable sandstones below a regional unconformity. Example: Fort Union-Hell Creek deposits of the southwest Williston Basin in Montana, South Dakota and North Dakota.

2. Uraniferous black shales: low grade but widely disseminated deposits in reducing environments marginal to oxidizing environments. Examples: Chattanooga Shale in central Tennessee, Kentucky and Alabama; Phosphoria Formation eastern Utah, Idaho; lacustrine beds of Eocene age in Wyoming and Utah; Lodeve area southern France; black shales of Sweden.

II. Structure of fracture controlled (vein- and similar-type deposits)

A. Fractured and brecciated host rocks with pitchblende and other uranium minerals filling voids, coating fractures, and partially replacing host rock. Examples: Rabbit Lake, Key Lake, and Cluff Lake in Saskatchewan, Canada; Rum Jungle - Alligator Rivers province, Northern Territory, Australia; Front Range district, Colorado; and Midnite Mine, Washington.

III. Intrusive controlled

A. Igneous disseminated: Finely disseminated uranium minerals in alaskite, nepheline syenite, and other felsic igneous rocks. Examples: Ilimaussaq, Greenland, where uranium occurs in nepheline syenite; Rossing, South West Africa, where uraninite is disseminated in syntectic alaskite; Colorado Front Range where uranium is disseminated in dikes of bostonite.

GENERAL GEOLOGY OF CROOKS GAP, FREMONT COUNTY, WYOMING

Douglas, Steven G., Chief Geologist, Western Nuclear, Inc., Jeffrey City, Wyoming 82310

The Crooks Gap area is located in South Central Wyoming, near the southeast corner of Fremont County. The formations within the area range from Precambrian granitics to Recent sediments.

Paleozoic and Mesozoic sediments of the area exhibit evidence of no less than two episodes of folding, as well as a period of compressional faulting. A later period of gravity faulting is indicated by displacement of Tertiary beds and Precambrian granitics.

Economic reserves of petroleum are being recovered from the folded Mesozoic and upper Paleozoic sediments. Economic deposits of uranium are currently being mined from an Eocene arkose derived from the erosion of Precambrian granitics and overlying Paleozoic and Mesozoic sediments.

Sediments of middle to upper Tertiary and Quarternary age mantle a subordinate amount of the study area. These younger sediments are not known to be of economic value within the vicinity of Crooks Gap.

STRATIGRAPHY OF PROTEROZOIC METASEDIMENTS IN THE SIERRA MADRE, WYOMING AND CORRELATION WITH A SIMILAR SEQUENCE IN THE MEDICINE BOW MOUNTAINS, WYOMING

Graff, Paul, University of Wyoming, Laramie, Wyoming 82071

Precambrian metasediments exposed in the Sierra Madre, Wyoming are divided into three groups. 1) Archean (oldest) layered amphibole gneisses, quartzites, and metavolcanic rocks which are infolded and interlayered with felsic gneisses.

2) The Early Proterozoic Phantom Lake Group which consists of metavolcanic rocks, graywackes, paraconglomerates, metadolomites and mature clastic rocks. This group is not divided into formations at the present time, but can be separated into three units representing major changes in depositional environment and source rocks. The rocks of these three units are dominated by fluvial, volcanogenic, and mass-movement origins respectively. These three units appear to be intercalated, but the unit dominated by fluvial processes is separated into an upper and lower sequence. This division is defined by the occurrence of an unconformity which is directly overlain by a uraniferous quartz-pebble conglomerate.

3) The Early Proterozoic Deep Lake Group (youngest) is a sequence which represents gradual but fluctuating change from fluvial to near-shore marine deposition. This group is divided into seven formations that are dominated by mature clastic rocks and contain uraniferous quartz-pebble conglomerates, quartzites, green phyllites, paraconglomerates, quartzites, phyllites, quartz-pebble conglomerates, massive sheared quartzites, calcareous phyllite and metadolomites.

Correlation of the Sierra Madre metasediments with those occurring in the Medicine Bow Mountains can be accomplished using the following characteristics: 1) a similar age of deposition (Early Proterozoic) is suggested by ages determined for underlying Archean terranes (2450 m.y.) and post-depositional granites (1800 m.y.); 2) similarities in lithologies of equivalent formations; 3) uraniferous marker horizons occur in both ranges; 4) cyclical sedimentary units are recognized in both areas; 5) four deformational events affected both areas in the same sequence and style.

URANIUM DEPOSITS OF THE SHIRLEY BASIN, WYOMING

Harshman, E.N., Consultant, Woodward-Clyde Consultants, Denver, Colorado 80225

The Shirley Basin contains one of the major uranium ore reserves in the United States. It is in Albany, Carbon, Converse, and Natrona Counties Wyoming, about 35 miles south of Casper. The area is of moderate relief and lies at an elevation of about 7000 feet. The deposits have been or are being mined by Getty Oil Company, Kerr McGee Corporation, Petrotomics Company, and Utah International Inc. Most of the ore from the several open pit mines has been converted to yellow-cake in two mills in the Basin. Underground and solution mining methods were tried by Utah International but were abandoned in favor of open pit methods.

Rocks in the area range in age from Precambrian to Quaternary. They consist of granitic rocks in the cores of the mountains that flank the Basin, and marine and continental sedimentary rocks on the mountain flanks and in the Basin. The pre-Tertiary rocks were moderately folded and faulted during the Laramide orogeny and the ore-bearing Tertiary continental sediments were subsequently deposited in a basin (with exterior drainage) eroded principally in Cretaceous shales.

The groundwater table in the area lies at depths of from a few feet to about 100 feet below the surface and is tributary to the surface drainage. The principal anions in the groundwater are sulfate and bicarbonate; radioelements include uranium, radium and radon. Measurements of groundwater pH range from 6.6 to 8.3 and average about 7.7.

The uranium deposits of the Shirley Basin are in the Wind River Formation of early Eocene age. This formation consists of a sequence of fluvial conglomerates, sands, silts, clays, lignites and muds deposited in a northwesterly trending basin by streams originating principally to the west and southwest. Some contribution of detritus was made by streams originating to the east. The Wind River Formation has a maximum thickness of about 550 feet in the central part of the Basin, near the ore deposits, and it pinches out on the flanks of the Basin where it laps on the older rocks. It is well compacted but poorly cemented. The lack of cementation makes underground mining difficult and costly. Ore is found in 2 permeable sandstone horizons separated by 50 to 75 feet of impermeable siltstone, lignite and claystone. The lower horizon is near the base of the Wind River Formation. It consists of medium-to-coarse-grained, poorly sorted, feldspathic sandstone and conglomerate deposited by streams flowing on a somewhat irregular pre-Eocene erosion surface. The upper horizon, 70 feet more or less above the lower one, contains similar detritus but somewhat less conglomerate. The ore bearing sandstones generally range from 30 to 50 feet thick.

The Shirley Basin uranium deposits are spacially and genetically related to margins of 2 tongues of altered sandstone, one tongue in each of the previously mentioned horizons. The upper tongue is broken into several horizontal lobes by relatively impermeable beds in the predominantly sandy interval. The upper altered tongue is about 5 miles long in a northwesterly direction and as much as 3 miles wide. The lower tongue is shorter but of similar width. Near their edges the tongues are a few feet thick and "float" within the sandy interval. Back from the edges an altered tongue may occupy the entire sandy interval. An altered tongue is broadly conformable with the enclosing sandstone but in detail the alteration may cut sharply across minor sedimentary features.

The greenish-yellow, red, or orange colors of an altered tongue contrasts with the grey of the unaltered sandstone. The color change results from passage of an ore-bearing solution through the more permeable parts of the sandstone interval, and the resulting oxidization of iron-bearing minerals, carbon, and carbonate, as well as from the addition of iron to the clay minerals in the sandstone.

The major Shirley Basin ore bodies are at the edges of the altered sandstone tongues in zones that separate the altered from the unaltered sandstone. Their inner contacts with altered sandstone are sharp; their outer contacts with unaltered sandstone are gradational. In its simple form an ore body is crescentic in cross section and in plan it is elongate along the edges of the altered tongue. These ore bodies have been called rolls. Complex ore bodies consist of several interconnected rolls possibly combined with lenticular bodies of ore. Some ore is found in lenticular bodies on the top and bottom surface of the altered tongues.

Ore bodies contain from a few to as much as several hundred thousand tons of ore. Grades range from a few hundredths to as much as 10 percent or more U_3O_8. Physically the ore bodies are small; the larger ones may extend as much as 200 feet laterally from the altered sandstone tongue but generally they extend from a few to several tens of feet laterally. Ore thicknesses range up to 30 feet. The edge of an altered tongue is mineralized but it is not everywhere ore bearing.

The Shirley Basin ore is of simple mineral composition. The principal epigenetic minerals are pyrite, marcasite, uraninite, ferroselite, native selenium, hematite, and calcite. The ore is unoxidized and contains very little vanadium or molybdenum.

The Shirley Basin ore deposits were probably deposited from oxidizing, alkaline, ore-bearing solutions that leached uranium from the tuffaceous rocks that overlay the ore-bearing Wind River Formation or from the granitic rocks in the mountains that flank the Basin. These solutions moved laterally through the more permeable zones in the Wind River Formation and reacted with the host sandstone. These reactions oxidized the minerals in that part of the host sandstone now identified as the altered tongue, and by so doing caused a lowering of the Eh and pH of the solutions and deposition of the ore minerals. The zone of deposition is considered to have been a dynamic feature, migrating basinward by oxidation and solution of the ore minerals on the updip sides of the ore bodies and reduction and deposition on their downdip side.

Age determinations on the Shirley Basin ore have ranged widely but suggest an age of from 25 to 30 million years for the youngest ore.

UPDATE ON THE STATE-LINE DIAMOND DISTRICT

Hausel, W. Dan, Geological Survey of Wyoming, Laramie, Wyoming 82071

The State-Line District is situated on the northern margin of the Virginia Dale ring-dike complex in the southern Laramie Range. Precambrian rocks, in this area, include two "granitic" facies of Sherman Granite, and numerous joint controlled alaskite, hornblende-quartz monzonite, biotite-quartz monzonite, and younger "andesitic" dikes. Paleozoic rocks include kimberlitic diatremes and associated limestone xenoliths.

Fourteen kimberlite diatremes have been mapped on state, Union Pacific, and private lands on the Wyoming side of the state line. The emplacement of all fourteen diatremes appear to be controlled by joints. Twelve of the fourteen diatremes approximate four linear dike-like trends striking between N40°W to N23°W. The two remaining diatremes are associated with separate joint controlled linear features; one straddles a porphyritic andesite dike trending N23°W, while the second lies adjacent to a hornblende-quartz monzonite dike trending N11°W. It would appear that the diatremes were emplaced along deep-seated north-northwest trending joints during a Mid-Paleozoic tectonic disturbance.

In the field, two diatremes were recognized by their unique rock exposures, while the remaining diatremes were identified by the presence of one or more of the following: blue ground, carbonate rock, rounded pyrope garnet, chrome diopside, magnesium ilmenite, and peridotite. Since the diatremes are characterized by deeply weathered surfaces covered by grus, many of the diatremes were mapped by examining dirt piles of burrowing animals for kimberlitic material.

The chemistry and mineralogy of kimberlite represent samples of rock from mantle to shallow crustal environments. Some of the more unique nodules suggest minimum depth of genesis. Mafic nodules (eclogite) limits the depth of origin to depths greater than the basalt-eclogite transition. Garnet-bearing ultramafics and diamond further restrict the depth of origin to the high pressure side of the spinel peridotite-garnet peridotite and graphite-diamond transitions, respectively. Estimates of pressure-temperature crystallization of nodules in kimberlite can be determined by comparing mineral phase chemistry with experimental data. The chromium-poor nodules are suggested to represent the highest P,T environment or minimum depth of origin (180 km) of the Colorado-Wyoming diatremes (McCallum and Mabarak, 1976).

Nearly all of the diatremes located in the Wyoming State-Line District are known to be diamondiferous. The grade of the diamond-bearing rock has not been determined, but the presence of diamonds warrants further consideration and evaluation. The State of Wyoming and Rocky Mountain Energy Company are presently soliciting exploration proposals from industry in order to evaluate the potential resource.

THE PRECAMBRIAN OF THE ROCKY MOUNTAIN REGION

Hedge, Carl E., U.S. Geological Survey, Denver, Colorado 80225
*Houston, Robert **S.**, University of Wyoming, Laramie, Wyoming 82071*
Tweto, Ogden L., U.S. Geological Survey, Denver, Colorado 80225
Reid, Rolland R., University of Idaho, Moscow, Idaho 83843
Harrison, Jack E., U.S. Geological Survey, Denver, Colorado 80225
Peterman, Zell, U.S. Geological Survey, Denver, Colorado 80225

Precambrian crystalline rocks of the Rocky Mountain region represent two age provinces. The older province (greater than 2500 m.y. old), which occupies Wyoming and adjacent parts of Utah, Montana, and South Dakota, is mostly felsic gneisses and associated metasedimentary rocks that were metamorphosed about 2800 m.y. ago. Tonalitic to granodioritic plutons were emplaced in this terrane 2500 to 2760 m.y. ago.

A younger crystalline terrane (ca. 1,600 to 1,800 m.y.), represented by sparse exposures west and northwest of the older terrane, is well exposed to the south, in Colorado, where a thick sequence of volcanic and sedimentary rocks was deposited between 2000 and 1800 m.y. ago. These were metamorphosed and intruded by numerous granodioritic plutons about 1700 m.y. ago. This province was invaded by granitic plutons 1400 m.y. ago and again, in central Colorado, 1020 m.y. ago.

Shelf-type sedimentary sequences were deposited on the older crust during the interval from 2,500 to 1,800 m.y. ago and are preserved in a belt from southern Wyoming to the Black Hills. A younger sequence, 1500 to 1700 m.y. in age, is preserved only as the Uncompahgre Formation in southwestern Colorado. Still younger is the miogeoclinal Belt Supergroup, 900 to 1500 m.y. in age, which is widespread in western Montana and northern Idaho. Roughly equivalent rocks, isolated from the Belt Supergroup, include the Uinta Mountain Group of northeastern Utah and northwestern Colorado. Eugeoclinal rocks, including diamictites, were deposited west of the miogeoclinal rocks beginning approximately 850 m.y. ago.

EARLY PROTEROZOIC TECTONICS OF SOUTHERN WYOMING AND NORTHERN COLORADO AND THE TECTONIC SETTING OF THE RADIOACTIVE PRECAMBRIAN CONGLOMERATES

Hills, F. Allan, U.S. Geological Survey, P.O. Box 25046, MS 916, Denver Federal Center, Denver, Colorado 80225
Houston, Robert S., Department of Geology, University of Wyoming, Laramie, Wyoming 82071

Archean (greater than 2500-Ma-old) granitic gneiss of the Wyoming Province is separated from lower Proterozoic (1600- to 2500-Ma-old) plagioclase and hornblende gneiss of the Central United States Province by the Mullen Creek-Nash shear zone, which ranges in width from several hundred meters to approximately 11 km. Immediately north of the shear zone, lower Proterozoic ensialic metasedimentary rocks of greenschist and amphibolite facies are preserved in a series of synclinoria. These metasedimentary rocks were metamorphosed between 1620 and 1750 Ma ago. Calc-alkalic igneous rocks younger than 2400 Ma old are virtually unknown north of the shear zone, and kyanite is widespread within approximately 10 km of the shear zone on its northern side.

South of the shear zone, lower Proterozoic gneisses of apparently ensimatic origin are intruded by numerous plutons of gabbroic and of calc-alkalic affinity. Pre-orogenic or synorogenic granitic rocks yield Rb/Sr whole-rock ages of 1725 to 1665 Ma. Sillimanite, rather than kyanite, is widespread immediately south of the shear zone, but andalusite and cordierite occur extensively farther south in the Front Range of Colorado. The shear zone cuts 1725-Ma-old granite in the southern Medicine Bow Mountains, Wyoming, and is cut by 1635-Ma-old post-orogenic red granite in the Sierra Madre, Wyoming. The apparently anorogenic anorthosite-syenite complex near Laramie, Wyoming, and the Sherman Granite and related granites were intruded mainly south of the shear zone approximately 1440 Ma to 1385 Ma ago.

The timing of metamorphism and plutonism, the distribution of calc-alkalic plutons and of ensialic and ensimatic lower Proterozoic metasedimentary rocks, and apparently a paired metamorphic belt (consisting of a moderatly-high-pressure and low-temperature metamorphic belt immediately north of the shear zone and a low-pressure and high temperature metamorphic belt in the Front Range), suggest the following plate tectonics model: an Atlantic-type continental margin developed along the southern edge of the Wyoming Province during early Proterozoic time. Southerly flowing rivers deposited an apron of radioactive gravels and sand on a coastal plain, which formed along this margin. A complex and inclompletely known history that includes vulcanism, possibly glaciation, and several cycles of onlap sedimentation are recorded in strata of the Deep Lake Formation and of the overlying Libby Creek Group (Houston and others). Approximately 1725 to 1635 Ma ago, the coastal plain collided with and was partially subducted beneath a volcanic arc. The hypothesized subduction zone dipped toward the southeast.

URANIUM, THORIUM, AND GOLD IN THE ESTES CONGLOMERATE OF EARLY PROTEROZOIC AGE, NEMO DISTRICT, LAWRENCE COUNTY, SOUTH DAKOTA

Hills, F. Allan, U.S. Geological Survey, P.O. Box 25046, MS 916, Denver Federal Center, Denver, Colorado 80225

The Estes Conglomerate, which is exposed in the Nemo District on the northeastern flank of the Black Hills, South Dakota, is inferred to be of early Proterozoic age (early Precambrian X) and to be resting on late Archean (late Precambrian W) granitic continental crust. The Estes contains beds of quartzite-pebble and quartz-pebble conglomerate (oligomictic conglomerate) with matrices of miceceous quartzite estimated to contain, locally, 5 to 25 percent dispersed pyrite. Highly oxidized outcrop samples of the oligomictic conglomerate have anomalously high contents of uranium (10 to 100 ppm), thorium (20 to 800 ppm), and gold (as much as 1.4 ppm).

High thorium and gold values in the oligomictic conglomerate favor a placer mechanism for the concentration of radioactive minerals, and high thorium values appear to eliminate the possibility of low-temperature epigenetic processes. Uranium in the Estes Conglomerate may have an origin similar to that of the economically very important uranium deposits in the Matinenda Formation of the Elliot Lake District, Ontario, and of deposits in the Witwatersrand, South Africa. Because uranium is rapidly dissolved in acidic, oxygenated ground water, such as is present where pyrite is weathering, most of the uranium originally present in the analyzed samples has probably been leached out. Lead isotope analyses appear to confirm this speculation, and they support the view that conglomerate located below the zone of weathering and oxidation has potential for economic uranium deposits.

STRATIGRAPHY OF THE DEEP LAKE GROUP AND A REVIEW OF THE TECTONIC HISTORY OF THE MEDICINE BOW MOUNTAINS

Karlstrom, Karl E., University of Wyoming, Laramie, Wyoming 82071

The Medicine Bow Mountains of southeastern Wyoming contain a 13 km thick section of low-grade metasedimentary rocks that was deposited near the southern margin of the Wyoming Archean craton between 2500 and 1700 m.y. ago. These metasediments are divided into three groups which are separated by unconformities: Phantom Lake Group (oldest), Deep Lake Group, and Libby Creek Group (youngest).

The Phantom Lake Group (3 km thick), though poorly understood, is divided into a lower Phantom Lake Group containing dominantly metavolcanic rocks and an upper Phantom Lake Group containing dominantly micaceous quartzite. The lower and upper parts of the Phantom Lake Group appear to be separated by an unconformity which is overlain by a radioactive, arkosic, quartz-pebble conglomerate.

The Deep Lake Group (3.3 km thick) is divided into six formations. (1) The Magnolia Formation (570 m) contains a radioactive, arkosic, quartz-pebble conglomerate which grades up-section into a trough cross-bedded, coarse-grained quartzite. (2) The Lindsey Quartzite (440 m) is a fine-grained, trough cross-bedded quartzite. (3) The Campbell Lake Formation (75 m) is a thin paraconglomerate-phyllite sequence which serves as a stratigraphic marker. (4) The Cascade Quartzite (1500 m) is a pebble quartzite which contains distinctive black chert pebbles. (5) The Vagner Formation (350 m) unconformably overlies the Cascade Quartzite and contains paraconglomerate, marble, and phyllite. (6) The Rock Knoll Formation (380 m) contains quartzite, minor phyllite and quartzite-pebble conglomerate.

The formations of the Deep Lake Group were deposited during three sedimentary cycles. The first cycle is a fining-upwards fluvial sequence consisting of the Magnolia Formation and the Lindsey Quartzite. The second cycle began with (subaerial glacial?) deposition of paraconglomerates and marine deposition of shales of the Campbell Lake Formation, followed by fluvial deposition of the Cascade Quartzite. The third cycle began with glacial or glacio-marine deposition of paraconglomerates in the Vagner Formation followed by deposition of marine limestones and shales in the Vagner Formation and shallow marine and fluvial deposition of the Rock Knoll Formation. These cycles may represent regional tectonic and climatic fluctuations which could be used to correlate Early Proterozoic metasedimentary sequences in North America. Cyclical deposition ended prior to deposition of the thick shallow-water marine quartzites of the Libby Creek Group.

Paleocurrent study indicates that most of the Deep Lake Group and parts of the upper Phantom Lake Group were derived from a source area to the northeast which contained Archean metasedimentary and granitic rocks. The strong unimodal, low-variance distribution of paleocurrent measurements suggest that sediment was transported in rivers that flowed down a southwesterly dipping paleoslope.

The Precambrian tectonic history of the Medicine Bow Mountains involved at least five episodes of deformation. The oldest fold systems are north and northwest trending antiforms and synforms in Archean gneisses which may have formed during the regional thermal event which took place about 2500 m.y. ago.

Geometrical analysis of folds in the metasedimentary rocks of the Medicine Bow Mountains reveals four additional episodes of deformation. D(1) began during deposition of the upper Deep Lake Group and produced a gently plunging, east-northeast trending fold system. Tectonic uplifts during D(1) formed major unconformities at the base of the Vagner Formation and at the base of the Libby Creek Group. D(2) began after deposition of the Libby Creek Group and produced highly attenuated, gently plunging, northeast trending folds. D(3) marked a change from northwest-southeast compression to northeast-southwest compression. The earliest event during D(3) was emplacement of mafic intrusive bodies along bedding planes and faults. The intrusives and the earlier folds were then folded into open, northwest-southeast trending structures. D(4) involved a minor rotation of all preexisting structural elements about a sub-vertical fold axis and is interpreted to be contemporaneous with late movements on the Mullen Creek-Nash Fork shear zone.

Faults in the Deep Lake Group are longitudinal and transverse to the axial trace of F(1) and F(2) folds and probably formed as a result of stresses generated by concentric folding during D(1) and D(2). Most of the faulting predated D(3) but renewed movements on some faults accompanied D(3) and strike-slip movement on the Mullen Creek-Nash Fork shear zone accompanied D(4).

Correlation of tectonic events in the Libby Creek and Deep Lake Groups is complicated by limited data and large-scale reverse faults which bring Libby Creek Group rocks over Deep Lake Group rocks. However, preliminary results suggest that D(2) is the earliest deformation in the Libby Creek Group and that the large-scale reverse faults may be associated with this deformation. D(3) and D(4) are well developed in rocks of the Libby Creek Group and produced a variety of minor folds and redistributed fabric patterns.

Folds south of the Mullen Creek-Nash Fork shear zone plunge steeply northeast and have been complexly refolded. These folds were probably formed during the intense metamorphic and tectonic episode at 1700 m.y. that produced the amphibolite-facies gneisses south of the shear zone.

STRATIGRAPHY AND STRUCTURE OF THE LOWER PART OF THE PRECAMBRIAN LIBBY CREEK GROUP, CENTRAL MEDICINE BOW MOUNTAINS, WYOMING

Lanthier, L. Raymond, University of Wyoming, Laramie, Wyoming 82071

The Libby Creek Group is the youngest group of Early Proterozoic metasediments located in the Medicine Bow Mountains of southeastern Wyoming. The group consists of greenschist facies metasedimentary rocks (6.8 km thick) that lie unconformably on the Deep Lake Group. The upper contact of the Libby Creek Group is the Mullen Creek-Nash Fork shear zone. The beds have a general northeast-southwest strike and have near vertical dips. Stratigraphic top is to the southeast.

The Libby Creek Group is divided into eight formations. (1) The Headquarters Formation (680 m thick) consists of a basal diamictite, a quartzite containing lenticular bodies of diamictites and phyllites, and a phyllite which grades up-section into quartzite. (2) The Heart Formation (670 m thick) is primarily quartzite containing a discontinuous phyllite unit near the center of the formation. (3) The Medicine Peak quartzite (1700 m thick) is a coarse-grained quartzite containing quartz-pebble layers. (4) The Lookout Schist (0 to 400 m thick) is laminated quartz-muscovite schist. (5) The Sugarloaf Quartzite (580 m thick) is well sorted, homogeneous, fine to medium-grained quartzite. (6) The Nash Fork Formation (1980 m thick) is a stromatolitic metadolomite with lenticular bodies of calc-biotite phyllite and black slate. (7) The Towner Greenstone (180 to 490 m thick) is fine-grained amphibolite containing coarse-grained gabbroic bodies. (8) The French Slate (610 m thick) is black pyritic slate.

The lower part of the Libby Creek Group was deposited on a slowly subsiding marine shelf. The Headquarters Formation was deposited unconformably on the Deep Lake Group in a glacial-marine environment as is evidenced by polymictic paraconglomerates, and quartzites containing lenticular bodies of conglomerates and laminated phyllites. The Heart Formation represents a change from glacial-marine to marine deposition as evidenced by rapid deposition of coarse-grained sediments which resulted from glacial retreat. Fluvial, deltaic and pro-deltaic deposits are also preserved in some parts of the Headquarters and Heart Formations. The Medicine Peak Quartzite contains preserved deltaic, prodeltaic, beach and shallow shelf deposits. The uppermost beds of the Medicine Peak Quartzite fine upwards into the deeper water turbidites of the Lookout Schist.

The rocks of the Libby Creek Group have been subjected to three deformational episodes designated as F(1), F(2), and F(3). The first deformational episode, F(1), rotated bedding to near vertical attitudes around northeast-southwest trending fold axes. The second deformational episode, F(2), produced lesser folds with steeply plunging east-northeast trending fold axes in the upper Libby Creek Group and moderately plunging southeast trending fold axes in the lower Libby Creek Group. The third deformational episode, F(3), refolded F(1) and F(2) folds around a nearly vertical fold axis near the axis of the French Creek Syncline.

Lower Libby Creek Group rocks are complexly faulted by (1) longitudinal, high-angle reverse faults and (2) transverse faults. The high-angle reverse faults are the result of flexural slip mechanisms generated by F(1) folding. Two of these faults are characterized by stratigraphic displacement on the order of hundreds of meters. Movement on the Reservoir Lake Fault, which is the stratigraphically lower of the two major high-angle reverse faults, has moved rocks of the Libby Creek Group from southeast to northwest over rocks of the Deep Lake Group. Movement on the Lewis Lake Fault, also a major high-angle reverse fault, explains 1600 m of thinning in the Medicine Peak Quartzite near North Twin Lakes and the absence of the Sugarloaf Quartzite between Lewis Lake and Brooklyn Lake.

The majority of the transverse faults are located on the block bounded by the Reservoir Lake and Lewis Lake Faults. These faults developed and were injected with magma during F(2) folding which may be related to left lateral slip along the Mullen Creek-Nash Fork shear zone.

IRIGARAY URANIUM DEPOSITS

Noyes, Harry, Wyoming Mineral Corporation, Lakewood, Colorado 80235

The Irigaray uranium deposit is located approximately 75 miles north-northeast of Casper, Wyoming, in the central part of the Powder River Basin. Roll-type uranium mineralization is present in a fluvial, arkosic paleochannel of the Eocene Wasatch Formation. The mineralized sandstone ranges in thickness from 80 to 120 feet and is vertically bounded by impermeable mudstones and shales. Uranium mineralization is localized near a subtle redox interface which is tongue shaped in plan and multiple-S shaped in cross-section. Zoning near the mineralization consists of a hematite-geothite stained oxidized zone, selenium concentration on the oxidized side of the ore zone, vanadium associated with uranium, and arsenic concentration in the unoxidized zone. Organic detritus, pyrite, and calcite are present but not ubiquitous in the ore and unoxidized zones. Solution mining by the Wyoming Mineral Corporation is currently concentrated in the lower-most part of the frontal system at depths of approximately 250 to 350 feet. In addition to the generalized geological presentation, a presentation of the solution mining process as applied to the Irigaray ore body will be presented.

U, Th, AND K CONCENTRATION IN THREE PRECAMBRIAN GRANITES FROM WYOMING: IMPLICATIONS FOR URANIUM GEOLOGY

Stuckless, John S., U.S. Geological Survey, Denver Federal Center, Denver, Colorado 80225

Detailed studies of the granitic rocks from the Granite Mountains and preliminary studies of some granites from the Owl Creek Mountains and the Laramie Range have been completed. For all three areas, the results show that: (1) much uranium has been mobilized during exposure of the granites to Cenozoic surface conditions, (2) the present radioelement contents are generally anomalous, and (3) the ratios of radioelements are anomalous. These results suggest that the region of central Wyoming has been a uranium province since early Precambrian time and that the Precambrian granitic rocks are likely sources for uranium deposits within the granites and for those in nearby sedimentary rocks that are younger than early Precambrian.

In each of the three study areas, evidence of recent uranium mobility and high original uranium contents is based on evaluation of uranium, thorium, and lead concentrations and the isotopic composition of lead. Radiogenic Pb(208) and its parent isotope Th(232) are generally present in equilibrium amounts with respect to the known age of each granite. This suggests that neither isotope has been gained or lost for the analyzed sample. However, radiogenic Pb(206) is generally present in excess of the equilibrium amount for its parent U(238). Because of the apparent immobility of Pb(208), the Pb(206)-U(238) disequilibrium is attributed to uranium loss (or in a few samples, to uranium gain).

Granites that have recently lost large amounts of uranium generally contain more than 4 weight percent K, 50 ppm Th, and a large excess of Pb(206). The present K/U and Th/U for these same granites are generally much higher than ratios reported for average granites. The Th/U ratio is commonly greater than 10. Calculations for samples from the Granite Mountains based on radiogenic Pb(208) and Pb(206) indicated that the Th/U ratios would be less than 3 if uranium had not been lost. The radioelement contents and ratios of one radioelement to another provide data that may be useful in delineating the central Wyoming uranium province or in defining other uranium provinces.

ORIGIN OF MANTO OREBODIES IN THE LEADVILLE DISTRICT, COLORADO

Thompson, Tommy B., Department of Earth Resources, Colorado State University, Fort Collins, Colorado 80523

The Leadville District is near the center of the Colorado Mineral Belt where northeasterly-trending Precambrian shear zones are intersected by north-northwesterly-trending Laramide faults. Laramide intrusives have been localized by these fault systems and have intruded a Paleozoic section of carbonates and sandstone. Manto orebodies within the carbonate rocks occur in zones about the Breece Hill intrusive complex.

The periphery of the Breece Hill igneous complex is characterized by skarn magnetite mineralization. Serpentine, magnesite, siderite, secondary dolomite, and minor chalcopyrite are characteristic of the skarn assemblage. Many of the skarn bodies exhibit limited sulfide replacement around their margins, and recent studies point to nearly complete sulfide replacement of some with only relict magnetite preserved. Sulfide manto deposits beyond the contact zone have formed by direct replacement of dolomite.

Individual sulfide orebodies are tabular to ovoid. They exhibit mineralogical as well as textural banding, although zones of massive nonbanded sulfides are present. Where present, banding generally parallels bedding and/or fractures. Zoning of the orebodies is apparent as shown by decreasing Zn:Fe and Pb:Fe ratios from the center to the periphery of the ore zone. The bodies often have a pyritic border within which Zn-Pb concentrations are found. Zn/Pb ratios of the base metal zone range from 2.5:1 to 4:1. Trace metal dispersion haloes in adjacent igneous rocks show similar ratios, but at distances exceeding 125 meters from the orebodies, the ratios approach unity.

Orebody minerals include magnetite, magnesite, siderite, serpentine, pyrrhotite, pyrite, marcasite, sphalerite, chalcopyrite, galena, tetrahedrite, and gold. Late carbonate and quartz coat or fill fractures and vugs. Fluid inclusion analyses on carbonate and quartz indicate temperatures of homogenization between 285 to 300° C. Iron content of sphalerites indicate pressures of formation near 1 kb.

The data obtained to date are consistent with a hydrothermal origin for the Leadville manto orebodies. Metals and fluids appear to have been derived from the Breece Hill intrusive complex, about which district hydrothermal zonation occurs.

STRUCTURAL STYLE IN RELATION TO OIL & GAS EXPLORATION IN NORTH PARK-MIDDLE PARK BASIN, COLORADO

Wellborn, Robert E., Exploration Manager-Burton/Hawks, Inc., Casper, Wyoming 82601

North Park-Middle Park basin is one of the smaller of the intermontaine basins and one of the more structurally complex. Several stages of Laramide tectonism occurred, ultimately creating thrust faults with over 10,000 feet of displacement along the east and north margins of the basin, and within the basin itself. Thrusting was directed generally in a westerly and southwesterly direction. In places, pre-Tertiary erosion breached sediments on the intrabasin thrusts down to rocks of Dakota age or older.

Additional thrusting of a different type is found throughout the basin, occurring as bedding-plane thrusts or detachments. Thrusts appear to be present in all of the structures examined, some with displacements up to several thousand feet. Direction of bedding plane thrusting is generally out of the basin, as a result of sharp synclinal basin folding; in many cases detachment folds were formed, and these folds are thought by the author to contain most of the oil and gas production in the basin.

The basin is still in the early stages of exploration, with relatively few wildcat wells located away from the existing producing areas. The southern half of the basin is sparsely drilled, with no oil or gas production to date. Field geology must be coordinated with existing well control and seismic data, utilizing sound structural geologic techniques, to find hidden structures and to reevaluate unsuccessfully drilled structures. Attention should also be given to potential stratigraphic traps and fracture production within the basin.

COPPER MOUNTAIN, WYOMING URANIUM DEPOSIT--REDISCOVERED

Yellich, John A., Cramer, Ronald T., and Kendall, Robert G., Rocky Mountain Energy Company, 190 Pronghorn, Casper, Wyoming 82601

The Owl Creek Mountains of west-central Wyoming were formed during late Cretaceous-early Tertiary time when Laramide thrusting and subsequent adjustment placed Precambrian, Paleozoic, Mesozoic and Cenozoic rocks in juxtaposition. Mineral prospecting and mining for Cu, Au and Ag were conducted within the Precambrian sequence during the late 1800's and early 1900's with no production today. Uranium mineralization was discovered in the Eocene Teepee Trail sediments as early as 1953. Economic uranium mineralization was delineated in the late 1950's with production of approximately 500,000 pounds from 1955-1970.

The Copper Mountain area is located along the southeastern toe of the Owl Creek thrust plate where extensive brecciation and shearing have resulted in locally intense oxidation and alteration of the Precambrian rocks. Active exploration began in 1969 with the evaluation of the potential resources of the Last Hope Mine. Geological mapping, ground radiometrics and radon surveys were used to define targets. Further evaluation has been guided with the use of geophysical tools such as VLF-EM and magnetics. Drilling has intercepted deeper and more extensive mineralization under, and adjacent to, the early discoveries in the Copper Mountain area. Mineralization (uranophane, uraninite, coffinite) occurs in the Tertiary sediments as well as the structurally prepared quartz monzonite and metasedimentary assemblages, occasionally associated with a minor amount of visible hydrocarbons.

The primary theory for deposition of a major portion of the mineralization is a supergene origin, although a potential does exist for a hydrothermal deposit(s).

GENESIS OF THE SCHWARTZWALDER URANIUM DEPOSIT, JEFFERSON COUNTY, COLORADO

Young, E.J., U.S. Geological Survey, Box 25046, Denver Federal Center, Denver, Colorado 80225

A meteoric hydrothermal origin is proposed for the Schwartzwalder uranium deposit, occurring in fractured Precambrian metamorphic rocks. Three factors that contributed to formation of the deposit are (1) structures that provided conduits and open spaces for mineralization, (2) nearby sedimentary rocks for a source of uranium, and (3) a magmatic heat source. Data that support the meteoric hydrothermal origin are (1) pitchblende is rich in Mo but very poor in Th and rare earths, which is typical of sedimentary pitchblende, (2) unit cell edges of the pitchblende (uraninite) of about 5.42 Å fit sandstone and vein pitchblendes rather than pegmatitic (magmatic) uraninite; (3) amorphous carbon from sedimentary sources occurs in the veins; and (4) temperatures of ore solutions appear to have been low enough so that muscovite in pitchblende-veined pegmatite host rock retains Precambrian age according to K-Ar age determinations.

Published radiometric ages of the Ralston dike of mafic monzonite (an unlikely source of uranium) and of the uranium ore are consistent with the time frame required by the following sequence of events. After tilting of sedimentary strata caused by Laramide tectonism, meteoric water moved downdip along bedding planes, leaching uranium from the rocks and percolating into fractures and the Golden fault zone. Introduction of magmatic heat in and along the Golden fault zone by the dike intrusion about 62 m.y. ago instigated convective flow of ground water. A system of flow operated through the Golden fault zone and other deep faults such as the Rogers and Illinois. Parts of the Illinois and hanging wall faults west of the Illinois reopened and brecciated in response to shearing; these served as "depositional traps" for the pitchblende about 60 m.y. ago.

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