NATIONAL URANIUM RESOURCE EVALUATION, PRELIMINARY REPORT

JUNE 1976

UNITED STATES
ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
GRAND JUNCTION OFFICE
GRAND JUNCTION, COLORADO

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INTRODUCTION

This report contains the results of the initial phase of the National Uranium Resource Evaluation (NURE). NURE was initiated by the U.S. Atomic Energy Commission (AEC) in 1974 and is being continued by the U.S. Energy Research and Development Administration (ERDA). It is a comprehensive nationwide program to evaluate uranium resources and to identify areas favorable for uranium exploration.

This report is divided into two parts. Part I presents estimates of uranium ore reserves and potential resources available at costs (not prices) of $10, $15, and $30 per pound U_3O_8 (uranium oxide). These estimates comprise the national uranium resource position. They are, however, preliminary because limitations of time and available geologic data prevented adequate assessment of some areas that may be favorable for potential resources.

Part II presents the potential uranium resources for each of 13 regions, shown in Figure 1, whose boundaries have been drawn chiefly on geologic considerations. The general geology is summarized, and the types of uranium deposits are described.

Although limited geologic reconnaissance was done in various parts of the country, the report is based primarily on the compilation and evaluation of data in ERDA files. Mining companies furnished a substantial amount of information on exploration results, development, production, and future plans. Published, manuscript, and open-file reports by government agencies, universities, and research organizations were reviewed. In addition, many individuals affiliated with universities and with state and federal agencies provided supplemental geologic information. This was particularly helpful in the eastern and central states and in Alaska, where information on uranium occurrences is limited.

NURE Program

The major objectives of the NURE program are to develop an authoritative, comprehensive assessment of the nation's uranium resources, and to provide industry with data and technology useful for the timely discovery and exploitation of uranium ores. The major program milestone is the publication of a comprehensive report in 1981. In the interim, updated uranium reserve and potential resource statistics will be published yearly.

To fulfill the NURE objectives, several large-scale investigations of varied nature have been initiated. These investigations largely are being implemented under contractual arrangements with a variety of companies, universities, and laboratories. Results of the investigations are being released promptly for public use.

1. Aerial radiometric surveys of the conterminous United States and Alaska - Airborne gamma-spectrometric equipment is used to measure values of uranium, thorium, and potassium. The primary objective is to accomplish nationwide reconnaissance surveying on flight lines spaced an average of 5 miles apart. As of June 1, 1976, 78,000 line miles had been completed and the data placed on open file.

2. Hydrogeochemical surveys of the conterminous United States and Alaska - Surface waters, stream sediments, and ground waters are being sampled to determine variations in uranium and other selected elements as guides for uranium search. The sampling and analytical work is accompanied by geochemical, geological, and geostatistical studies to assist in the interpretation of results.

3. Regional investigations of geologic environments - Areas considered promising for uranium are under study for better understanding of favorable geologic environments.

4. Geologic drilling - Holes are being drilled in selected geologic terranes where surface information alone is inadequate to determine favorability for uranium.

Other investigations underway or planned include: (1) application of remote sensing techniques to the identification of favorable areas; (2) development of new borehole logging systems; (3) improvement of radon and helium sampling for use in exploration; (4) investigation of new methodologies for uranium resource estimation; and (5) development of improved mining and milling technology.

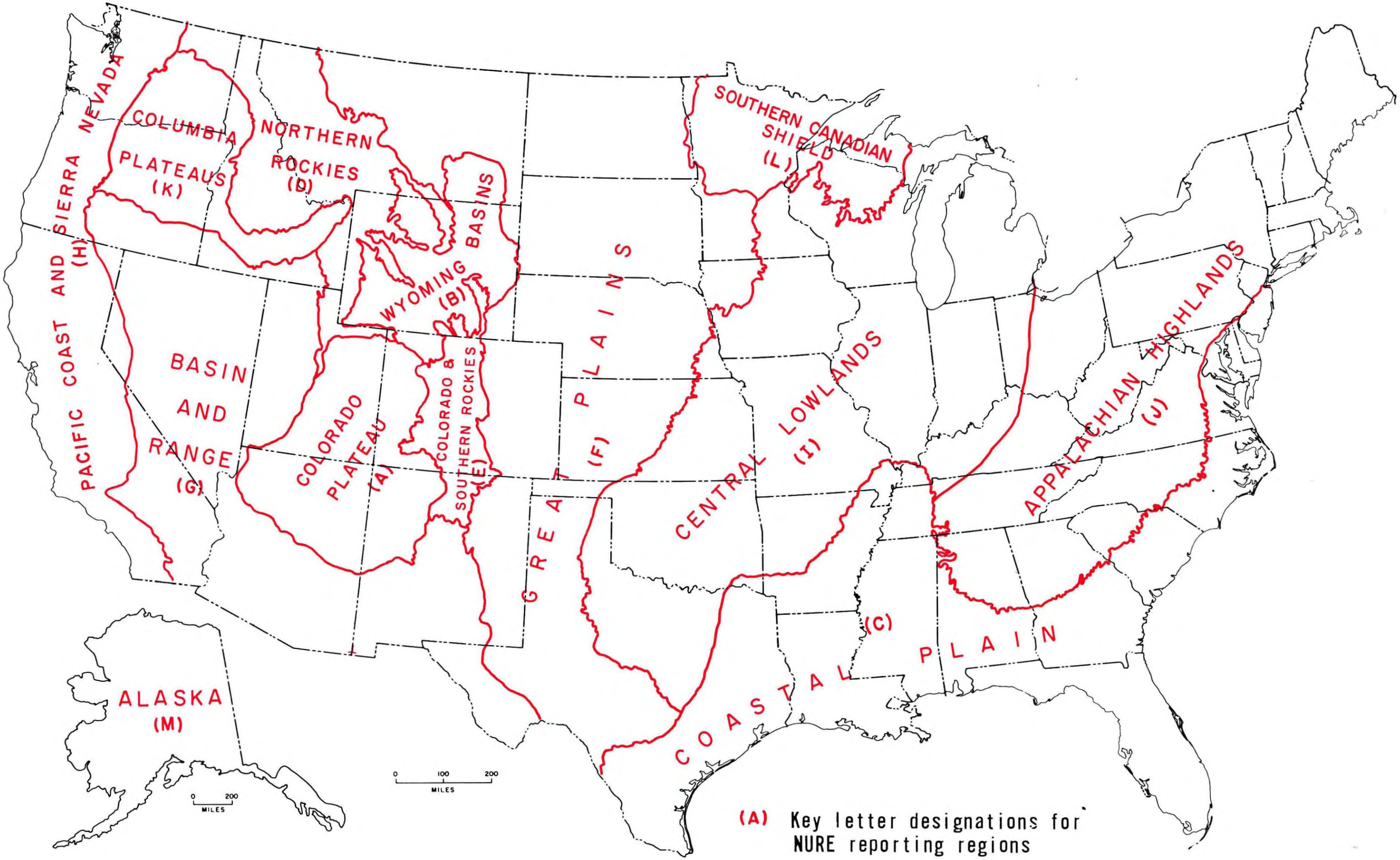


Figure 1. Regional outlines used for the preliminary National Uranium Resource Evaluation

SUMMARY OF UNITED STATES URANIUM RESOURCES

The following table summarizes the January 1, 1976, uranium resource position of the United States:

TABLE 1. United States uranium resources as of January 1, 1976

$/lb. U_3O_8 Cutoff Cost	Tons U_3O_8			
		Potential		
	Reserves	Probable	Possible	Speculative
$10	270,000	440,000	420,000	145,000
$10-15 increment	160,000	215,000	255,000	145,000
$15	430,000	655,000	675,000	290,000
$15-30 increment	210,000	405,000	595,000	300,000
$30	640,000	1,060,000	1,270,000	590,000
By-product 1976-2000 1/	140,000	--	--	--
	780,000	1,060,000	1,270,000	590,000

1/ Estimated by-product of phosphate and copper production.

FUTURE DEVELOPMENTS IN THE URANIUM RESOURCE POSITION

Although it is difficult to forecast developments in the Nation's uranium resource position, some comments can, nevertheless, be made now.

1. Guarded optimism is warranted that significant increases in the present resource estimates will result from current and future investigations.

2. Conventional sandstone-type resources may well be further expanded in and near the producing districts as well as in nonproducing areas.

3. Future discoveries may include deposits of types different from the sandstone-type ores that form the bulk of the known resources in the United States. There is a reasonable opportunity for discovery of deposits similar to those now known in Australia, Canada, and South Africa. However, only limited parts of this nation may be geologically favorable for such deposits.

4. Prompt and vigorous exploration and development will be required to make new discoveries and to convert potential resources to reserves at a rate adequate to support projected nuclear power expansion.

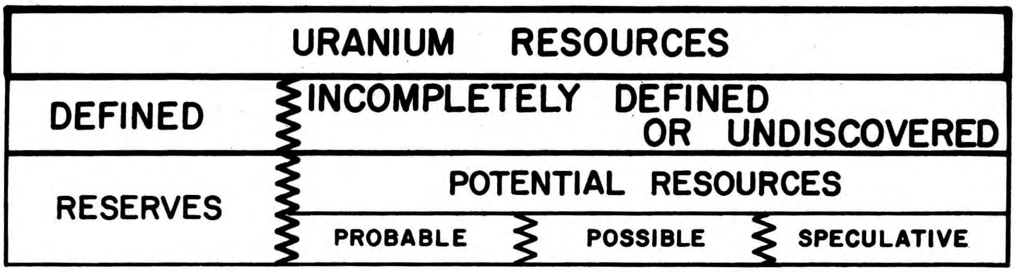
PART I

URANIUM RESOURCES

URANIUM RESOURCES

ERDA estimates of uranium resources in the United States, as of January 1, 1976, are stated in Table 1. These estimates consist of reserves and potential resources. Potential resources are further divided into probable, possible, and speculative classes. Reserves are the firmest element of resources, comprising deposits that have been delineated by drilling or other direct sampling methods. Probable, possible, and speculative potential resources are estimates, in declining order of reliability, of the quantity of uranium believed to be present in deposits that are incompletely defined or undiscovered.

The relationship of reserves to potential resources is illustrated below:



In this report the estimated resources are grouped into cost categories selected to cover an economic range of current interest. These categories are identified by the highest cost in increments of this range, expressed in dollars per pound of U_3O_8 to produce concentrate from these resources.

The costs used are those operating and capital costs, in 1975 dollars, not yet incurred at the time an estimate is made. Operating costs cover labor, materials, ore transport, power, royalties, and taxes directly applicable to the operation. Capital costs cover mine development and construction of mill and related facilities required for a production unit. Profit and costs already incurred, such as past expenditures for property acquisition, exploration, and mine development, are not included. Therefore, the various costs are independent of the market price at which the estimated resources would be sold. Unless otherwise specified, resources in each category embrace the resources in all lower-cost categories. Thus, resources in the $30 per pound category also include resources in the $15 and $10 categories.

Reserves

Uranium reserves are estimates of the quantity of uranium in ore that satisfy certain criteria, including minimum grade and thickness. Reserves are the most reliable class of resources with respect to location, size, grade, and economic availability, being based on direct measurements from drilling and sampling of the deposits. Estimates of total United States reserves in the \$10 and \$15 categories are judged to be reliable within a range of $\pm$ 20 percent. However, estimates of reserves in the \$30 category are less reliable because of fewer sample measurements and the lack of industry mining experience with the lower-grade materials that comprise most of this reserve category.

Reserves are calculated for each individual deposit, based on sample results and interpretation of gamma-ray drill-hole logs made available by uranium companies to the Grand Junction Office of ERDA. The amount of uranium that could be produced from a deposit at maximum costs of \$10, \$15, and \$30 per pound U_3O_8 is calculated by using established engineering, geologic, and economic techniques.

The regional distribution of reserves in the \$30 per pound cost category is shown in Figure 2 and in Table 2 (page 19). Most of the reserves are in areas of past or current production in the western United States, shown in Figure 3. The Colorado Plateau, Wyoming Basins, and Coastal Plain of Texas contain approximately 96 percent of the Nation's \$30 reserves. The Northern Rockies, Colorado and Southern Rockies, Great Plains, Basin and Range, Central Lowlands, and Pacific Coast and Sierra Nevada regions contain the remaining 4 percent.

Detailed historical and current information on ore reserves and related topics is published annually in the ERDA reports, "Statistical Data of the Uranium Industry" (GJO-100) which is a sale item of the Grand Junction Office library.

Potential Resources

Classes and definitions

With the inception of the NURE program, the previously used single category of potential uranium resources was expanded to accommodate the wide variety of geological environments under investigation in a nationwide assessment. The expanded classification is patterned after that of the Potential Gas Committee, and entails the division of potential resources into three classes--probable, possible, and speculative--as defined below:

> "Probable" potential resources are those estimated to occur in known productive uranium districts:

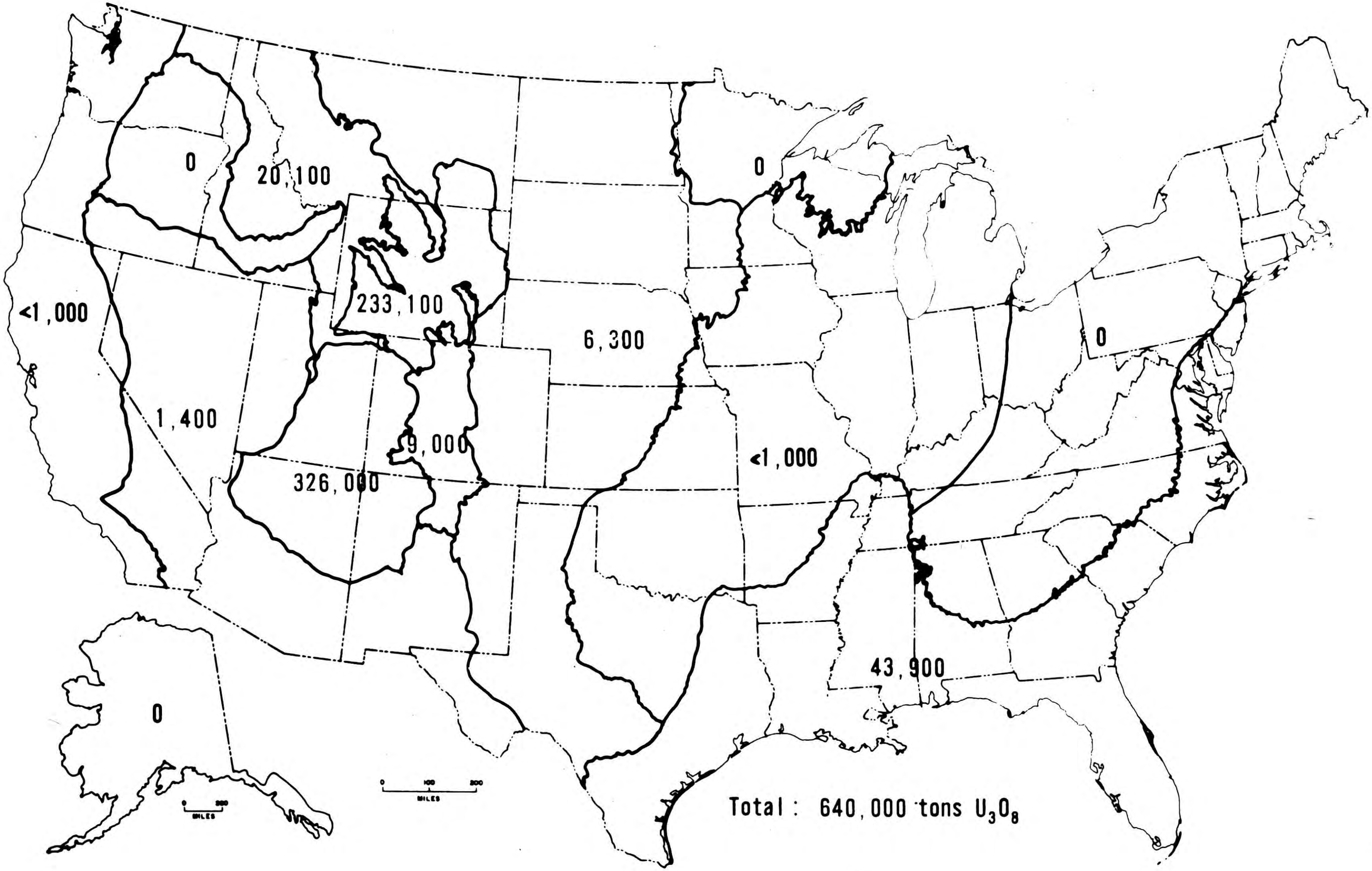


Figure 2. Uranium ore reserves at $30/lb. U_3O_8 (January 1,1976).

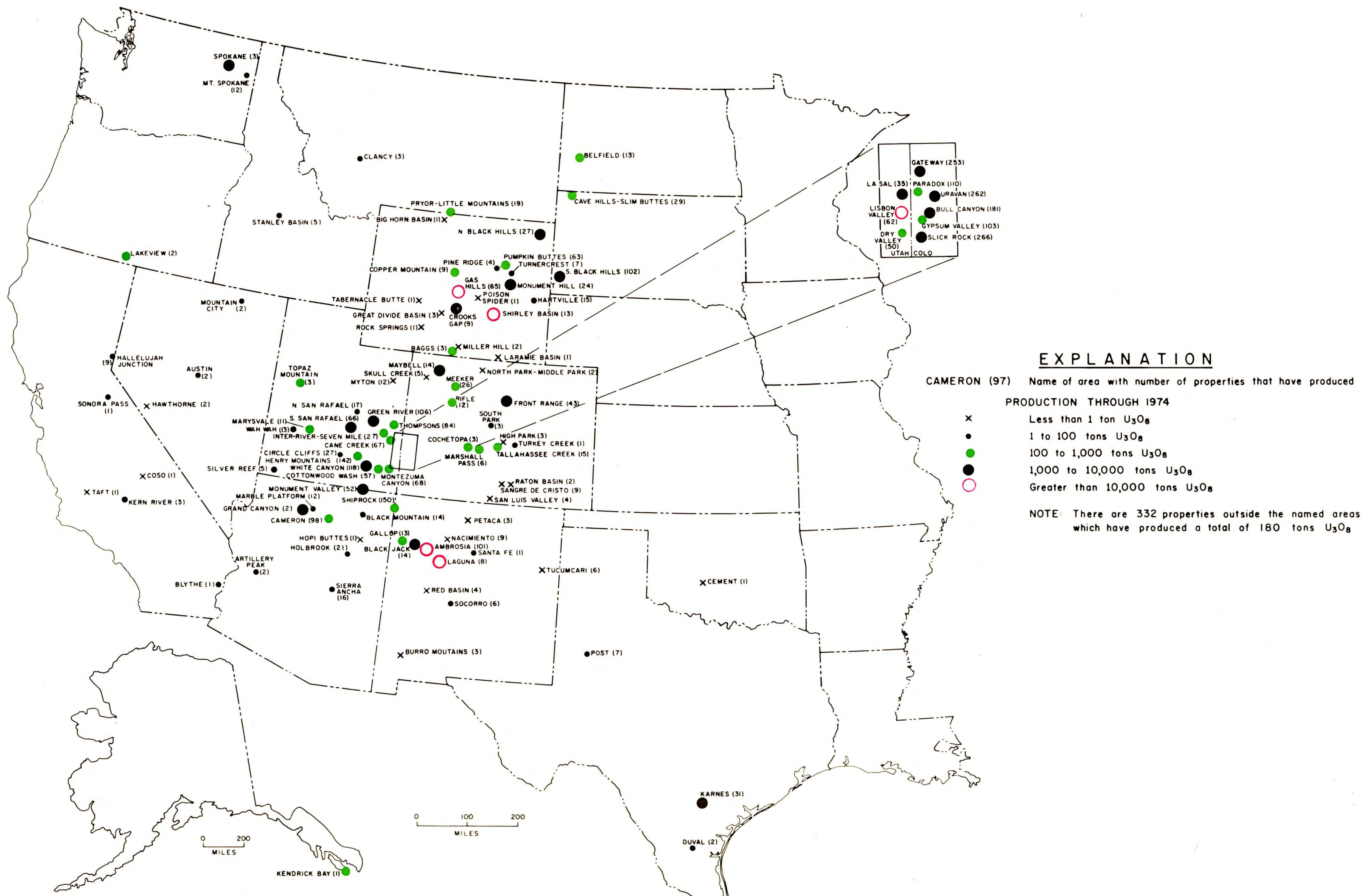


Figure 3. Areas of uranium production in the Western United States

1. in extensions of known deposits, or

2. in undiscovered deposits within known geologic trends or areas of mineralization.

"Possible" potential resources are those estimated to occur in undiscovered or partly defined deposits in formations or geologic settings productive elsewhere within the same geologic province.

"Speculative" potential resources are those estimated to occur in undiscovered or partly defined deposits:

1. in formations or geologic settings not previously productive within a productive geologic province, or

2. within a geologic province not previously productive.

NOTE: "Productive" means that past production plus known reserves exceed 10 tons U_3O_8.

Rationale and methods of potential estimation

The study of uranium deposits has shown an association of certain geologic characteristics with specific types of deposits. From knowledge of these characteristics, criteria of favorability for types of deposits can be developed, thus providing a basis for quantifying estimates of potential resources in inadequately explored areas. The recognition and assessment of these favorability criteria in known areas, and their extrapolation to areas under appraisal, is the basis for ERDA estimates of potential resources. Details on the geology of resource regions and specific favorability criteria are contained in Part II.

The basic assumption is that the potential resources of an area being appraised may be approximately equal to those of a thoroughly explored area, provided that both are similar with respect to size and certain key physical and geologic characteristics. The area under evaluation is compared with a known, or control area, where the habits of the ore bodies are well understood from exposures both in and adjacent to mines. A mineralization factor (T) is based on past production plus ore reserves. The factor (T) is usually expressed as tons of U_3O_8 per unit area, volume, or length and is applied to (1) the areal extent of a geological environment, (2) the volume of a lithologic unit, or (3) the length of a specific geologic feature such as a paleostream channel, roll front, or vein.

Characteristics that need to be evaluated for favorability include the depositional environment and lithology of sedimentary rocks; the type and distribution of igneous rocks; rock alteration; radioelement distribution; regional tectonics; local structure; reductants; deposits of other minerals; and other chemical elements that may be associated with uranium. The relative importance of these characteristics may vary markedly by area and by type of deposit. Numerical values are assigned to express the relative importance and degree of development of the favorable characteristics, after which a favorability factor (F) is derived by comparing the values for the area being appraised with those of the control area.

The procedures used in potential estimation are basically as follows:

1. Comparison of criteria that identify favorable ground in the control area with characteristics of the area to be evaluated.

2. Delineation of the favorable ground (N), measured in square miles, linear miles, or cubic miles.

3. Derivation of the geologic favorability factor (F) from evaluation of applicable criteria.

4. Determination of the percent of unexplored favorable ground (U).

5. Application of the mineralization factor (T), measured in tons U_3O_8 per square mile or other appropriate unit of measure, to the favorable ground.

The magnitude of potential uranium resources in the area being appraised is then determined by use of the formula, Potential = N x F x U x T.

Following is a hypothetical example of potential estimation:

Geologic studies of an area of certain Tertiary sedimentary rocks in Wyoming indicate that 35 linear miles (N) are potentially favorable for uranium in roll fronts. A comparison of the favorability criteria in a uranium-producing area (the control area) having a similar geologic setting indicates that the area being appraised is only 40 percent (F) as favorable. It is determined that 70 percent (U) of the area being evaluated is unexplored. Production and reserves from the control area indicate a mineralization factor of 2,000 tons of U_3O_8 per linear mile (T) of roll front. Substituting these factors in the aforementioned formula results in: Potential = 35 x .40 x .70 x 2,000; thus, the potential of the hypothetical area being evaluated would be 19,600 tons of U_3O_8.

The grade of potential resources is estimated by comparing the characteristics that affect the tenor of uranium deposits in the control area with those of the area being appraised.

Reliability of potential estimates

Potential resource estimates are based on geologic judgment, so their reliability is dependent on the quality and extent of geologic knowledge. Reliability differs for each of the three potential resource classes. It is greatest for probable potential resources because of the greater knowledge base resulting from the advanced stage of exploration and development in established producing districts where most of the resources in this class are located. Reliability is least for speculative potential resources because no significant deposits are known, and favorability is inferred from limited geologic data.

An appropriate statistical basis for establishing confidence limits for the potential estimates presented in this report has not yet been developed. Research into possible application of statistical methodology to NURE estimation procedures is underway.

Estimates of potential resources will be revised as new geologic concepts are postulated, as new types of uranium ore bodies are discovered, and as improved geophysical and geochemical techniques are developed and applied. Advances in technology that permit the exploitation of deep or low-grade deposits or the processing of ores of previously uneconomic metallurgical types also will affect the estimates.

Distribution of $30 potential resources

The regional distribution of potential uranium resources in the $30 per pound cost category is presented in Table 2 and in Figure 4. The Colorado Plateau, Wyoming Basins, Basin and Range, and Coastal Plain of Texas contain approximately 90 percent of the probable, 85 percent of the possible, and 46 percent of the speculative potential resources. Essentially all of the resources in these regions are in stratiform or roll-front deposits in Mesozoic and Tertiary strata. The distribution of $30 potential resources by type and age of host rock is shown in Tables 3 and 4.

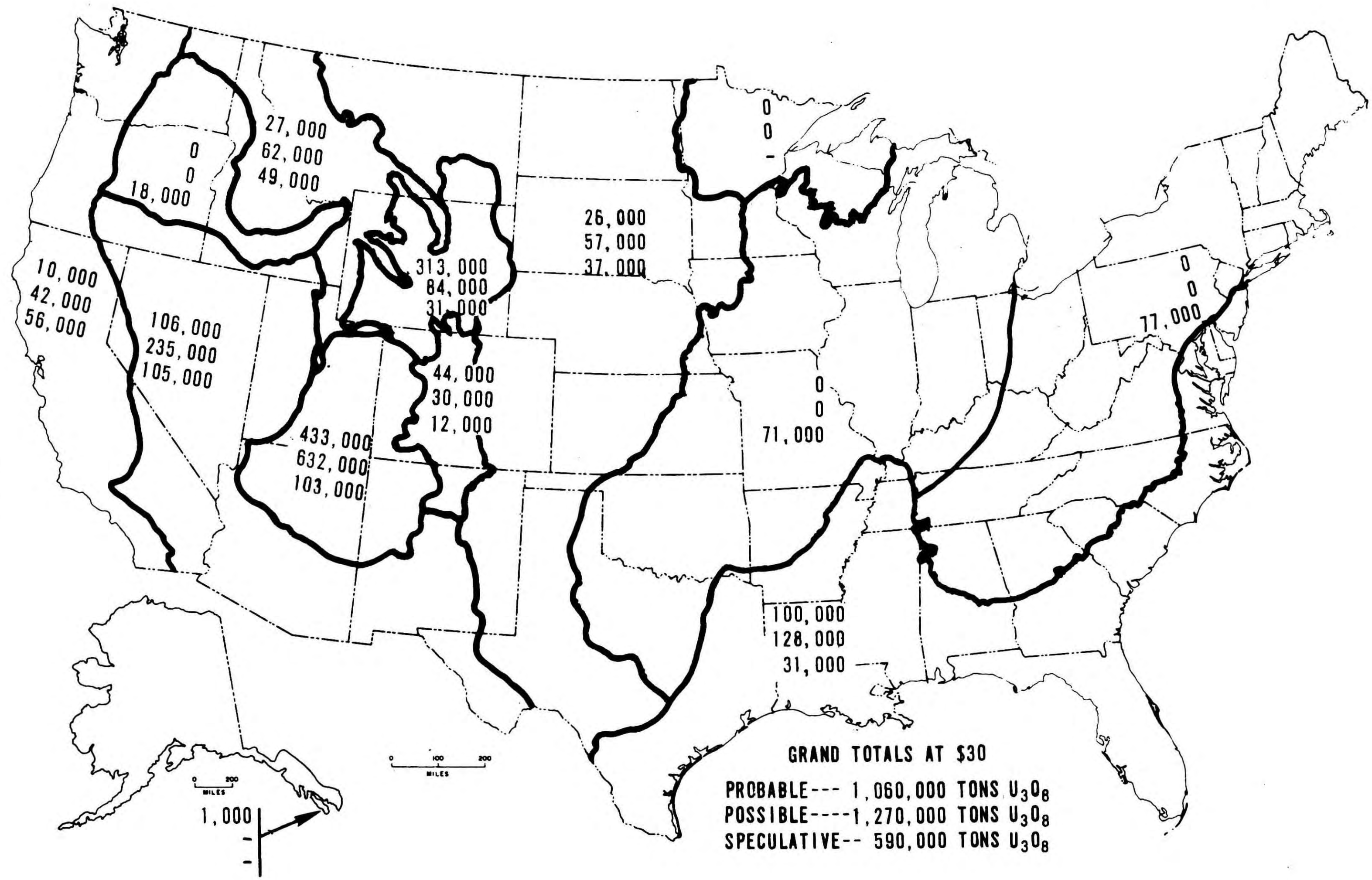


Figure 4. Distribution of probable, possible, and speculative potential uranium resources at $30/lb. U_3O_8.

TABLE 2. Summary by region of uranium production, reserves, and potential

Region	Tons U_3O_8 Production to 1/1/76	Tons U_3O_8 ($30/lb.) 1/1/76 Reserves	1/1/76 Potential Resources Probable	Possible	Speculative
(A) Colorado Plateau	197,800	326,000	433,000	632,000	103,000
(B) Wyoming Basins	59,200	233,100	313,000	84,000	31,000
(C) Coastal Plain	8,300	43,900	100,000	128,000	31,000
(D) Northern Rockies	4,800	20,100	27,000	62,000	49,000
(E) Colorado and Southern Rockies	6,400	9,000	44,000	30,000	12,000
(F) Great Plains	3,500	6,300	26,000	57,000	37,000
(G) Basin & Range	1,400	1,400	106,000	235,000	105,000
(H) Pacific Coast and Sierra Nevada	<1,000	200	10,000	42,000	56,000
(I) Central Lowlands	<1,000	0	1/	1/	71,000
(J) Appalachian Highlands	<1,000	0	1/	1/	77,000
(K) Columbia Plateaus	<1,000	0	1/	1/	18,000
(L) Southern Canadian Shield	0	0	1/	1/	1/
(M) Alaska	<1,000	0	1,000	1/	1/
Totals	282,400	640,000	1,060,000	1,270,000	590,000

1/ Resources not estimated because of inadequate knowledge

TABLE 3. Distribution of $30/lb. potential resources by type of host rock

Host Rock	Tons U_3O_8 Probable	(%)	Possible	(%)	Speculative	(%)
Sandstone	875,000	(83)	880,000	(69)	372,000	(63)
Conglomerate	56,000	(5)	77,000	(6)	53,000	(9)
Granitic and Metamorphic	46,000	(4)	85,000	(7)	130,000	(22)
Volcanic rocks	35,000	(3)	220,000	(17)	16,000	(3)
Limestone	33,000	(3)	6,000	(<1)	15,000	(3)
Lignite	15,000	(2)	2,000	(<1)	4,000	(<1)
Totals	1,060,000	(100)	1,270,000	(100)	590,000	(100)

TABLE 4. Distribution of \$30/lb. potential resources by age of host rock

	Tons U_3O_8					
Age	Probable	(%)	Possible	(%)	Speculative	(%)
Quaternary	0		1,000	(<1)	6,000	(1)
Tertiary	550,000	(52)	478,000	(38)	262,000	(44)
Cretaceous	22,000	(2)	74,000	(6)	80,000	(14)
Jurassic	365,000	(34)	517,000	(41)	24,000	(4)
Triassic	47,000	(4)	67,000	(5)	26,000	(4)
Paleozoic	38,000	(4)	68,000	(5)	133,000	(23)
Precambrian	38,000	(4)	65,000	(5)	59,000	(10)
Total	1,060,000	(100)	1,270,000	(100)	590,000	(100)

Past Production

Production of uranium ore in the United States has been obtained from some 3,670 properties, of which approximately 200 account for 96 percent of total production. The distribution of production by regions is shown in Table 2 and Figure 5, and by areas in Figure 3.

Total production through 1975 was about 282,400 tons of U_3O_8 from 124 million tons of ore. The 1975 production was 12,300 tons U_3O_8 in ore from 155 properties; 20 percent of these properties accounted for 90 percent of this production. Forty-seven percent of the capacity of the 17 processing mills (Fig. 6) is in New Mexico and 33 percent is in Wyoming; the remaining capacity is in Colorado, Florida, Texas, Utah, and Washington. Construction of several additional mills is planned or under way.

Although about 50 percent more ore was processed in 1975 than 10 years ago, uranium concentrate production increased only about 10 percent because the average grade of ore and the percentage recovery of uranium contained in the ore have decreased. The average grade of processed ore decreased from 0.24 percent U_3O_8 in 1965 to 0.16 percent U_3O_8 in 1975 and the average recovery of contained U_3O_8 declined from about 95 to 93 percent.

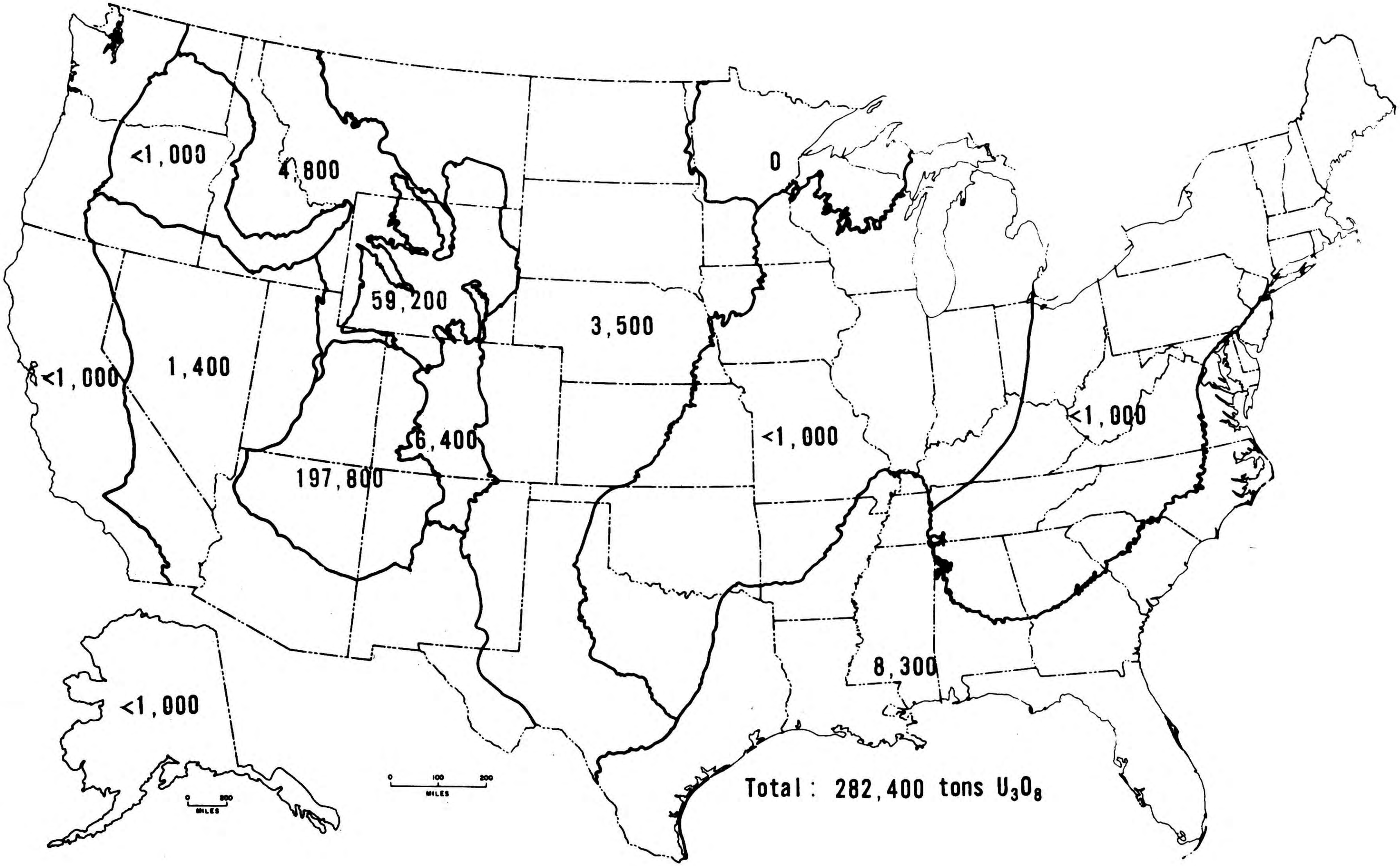


Figure 5. Uranium production cumulative to 1/1/76

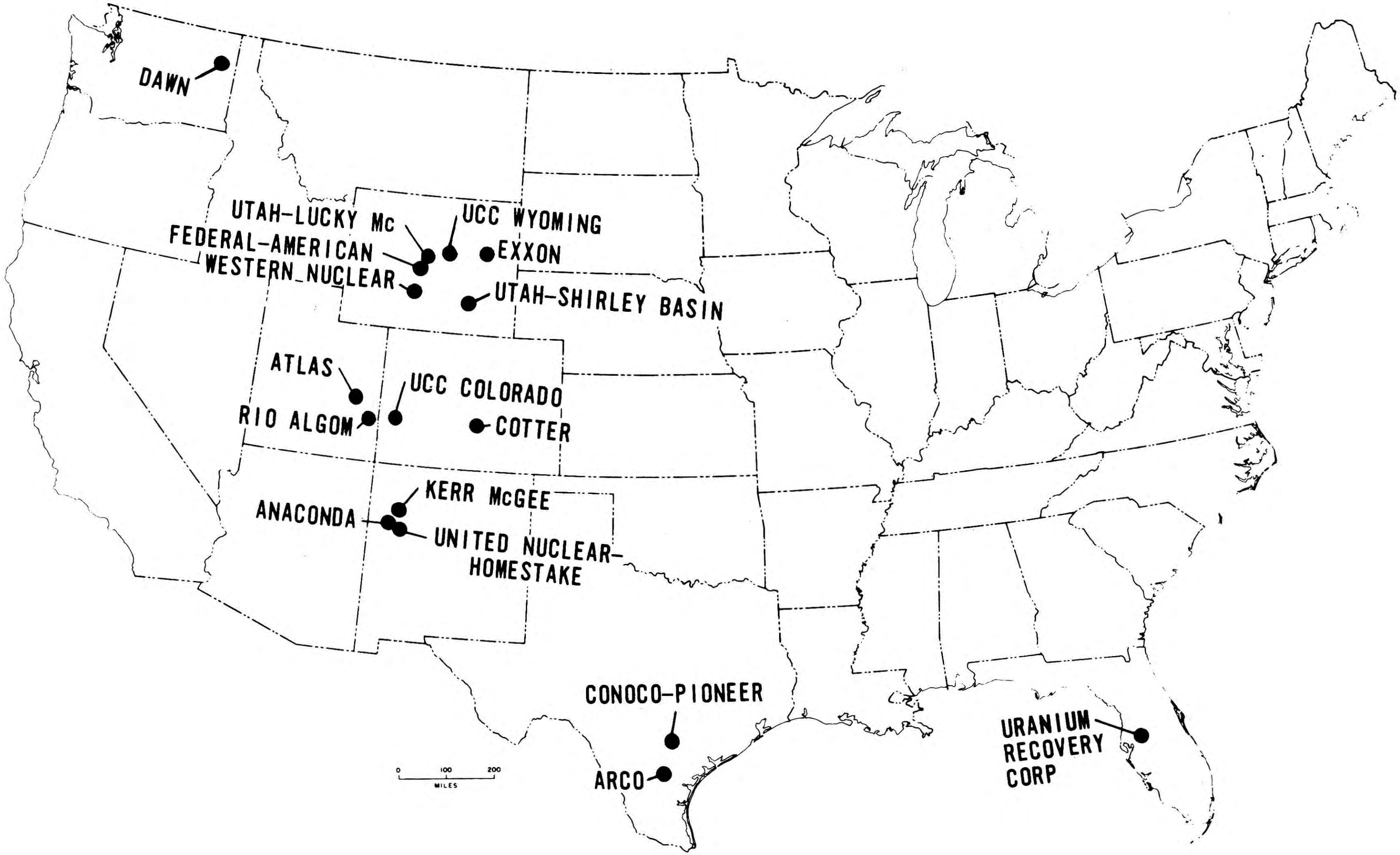


Figure 6 Operating uranium mills in the United States

PART II

GENERAL DESCRIPTION OF POTENTIAL URANIUM AREAS

GENERAL DESCRIPTION OF POTENTIAL URANIUM AREAS

Introduction

Part II contains brief descriptions of the geologic settings, uranium occurrences, and potential uranium resources in each of 13 reporting regions (Fig. 1). Known resource areas and relevant geologic features are shown in Figures 7 and 8. Ore reserves and past production are given in Tables 1 and 2 of Part I. Selected references to more detailed geologic discussions of the resource regions are appended.

Potential uranium resources for each region are tabulated by $10, $15, and $30 cost categories for each of the three classes, probable, possible, and speculative. The distribution of these resources by rock unit is identified in tables and figures accompanying the geologic descriptions of the resource regions. Special presentations of potential distribution by area are included for the Colorado Plateau, Wyoming Basins, and Coastal Plain regions.

Plate 1 shows the general location of estimated potential resources. Plate 2 includes examples of additional areas considered favorable for uranium deposits but requiring more study before potential resources can be estimated.

For most of the regions discussed, a chart is included in which the geologic characteristics of favorable rock units are shown. These charts are meant to identify characteristics which may, individually or collectively, constitute a favorable uranium environment. The following section on uranium geology should aid in the understanding of these charts.

Uranium Geology

Uranium, the basic raw material of nuclear energy, is a hard, nickel-white, metallic element. It occurs in all rocks and natural waters, but generally in such low concentrations that its presence can be detected only through the use of sensitive instruments or analytical techniques. Uranium is chemically active in nature and combines readily with other elements to form a large number of primary and secondary minerals. Natural uranium consists of three radioactive isotopes: U-238 (99.28 percent); U-235 (0.71 percent); and U-234 (0.005 percent). More than 150 uranium minerals are known, but only a few have been found in sufficient quantities to be of economic value. The most abundant uranium ore minerals are uraninite (uranium oxide) and coffinite (uranium silicate). On oxidation, these yield a host of brightly colored minerals, the most common of which are carnotite (potassium uranyl vanadate), tyuyamunite (calcium uranyl vanadate), autunite (calcium uranyl phosphate), uranophane (calcium uranyl silicate), and torbernite (copper uranyl phosphate).

In the igneous environment, uranium concentrations are greatest in rocks low in iron and magnesium and high in the alkali elements sodium and potassium. These include intrusive rocks such as granites, and extrusive rocks such as rhyolitic volcanic flows and tuffaceous ash. In the intrusives, uranium occurs in three ways: (1) as films of generally unknown composition on fractures and around the common rock-forming minerals, (2) as discrete uranium minerals, and (3) as impurities in various accessory minerals.

The accessory uranium-bearing minerals of igneous rocks generally resist oxidation and decomposition and may be concentrated by fluvial processes to form placer deposits. Such deposits generally are of little value for uranium because of their small size and the refractory nature of the uranium minerals. The uraniferous films on fractures and the discrete uranium minerals in igneous rocks oxidize readily, releasing water-soluble hexavalent uranium to surface and ground waters. Uranium may be precipitated or adsorbed when such solutions pass through permeable sandstone strata containing reducing substances such as (1) carbonaceous materials, (2) sulfide minerals, or (3) hydrogen sulfide. Reduction of hexavalent uranium to the tetravalent state and its precipitation from ground water is the principal process by which uranium ores are formed in sedimentary rocks.

Much dissolved uranium is carried into the oceans by rivers; thus, seawater contains 3 parts per billion uranium. Uranium has been precipitated from seawater into black carbonaceous shales to produce low-grade deposits; for example, the Chattanooga Shale of the southeastern United States contains a widespread unit that averages about 65 parts per million U_3O_8. Uranium also has been adsorbed by marine phosphorites from seawater. The phosphorite deposits in the southeastern and the western United States contain 50 to 250 parts per million U_3O_8.

Sandstone-type deposits

The host rocks for sandstone-type deposits are chiefly limited to fluvial, lacustrine, and marginal-marine sandstones that are interbedded with mudstone and occupy structural basins of fairly large areal extent. Tuffaceous material is present in some host sandstones and is common in overlying and interbedded mudstones. Depending on the sediment source, the host rocks are typically feldspathic, arkosic, or quartzose. Some uranium ore is in fine-grained sandstones, but most ore is in medium- to coarse-grained, poorly sorted sandstones. The degree of sorting may be very important because it is a factor controlling permeability. Nearly all of the host sandstones contain pyrite as well as organic matter, which occurs in the form of coalified plant remains or introduced humic material.

The reducing environment necessary for deposition and preservation of the deposits is reflected in the gray, green, or tan color of the sandstones and the gray to green color of the mudstones. The outcrops of host sandstones within uranium areas commonly are stained by limonite and/or hematite. Tan to reddish sandstones are usually bleached near ore in some areas; this feature is regarded as another expression of the reducing conditions that promote deposition of uranium. In many places, vanadium, copper, molybdenum, or selenium are associated with uranium.

Vein deposits

The term "vein deposit" is used here in the broad sense to include all deposits in which fractures are the major control of uranium localization. Fault-controlled deposits, intrusive contact deposits, and breccia-pipe deposits are considered varieties of vein deposits. Uranium veins occur in a variety of Precambrian to Tertiary host rocks in numerous localities in the United States, but only a few have been developed into important mines.

The selection of favorability criteria for vein deposits is more difficult than for sandstone-type deposits because of the greater variety of depositional environments. Vein deposits are usually located in regions of tectonic activity, igneous activity, and metallization in fold belts. Limonitic, hematitic, and argillic alteration, and silicification commonly are associated with vein deposits. Anomalous quantities of uranium, and the presence of silicic intrusive rocks, complex local faults and fractures, and other metallic minerals commonly associated with uranium, are important favorability characteristics.

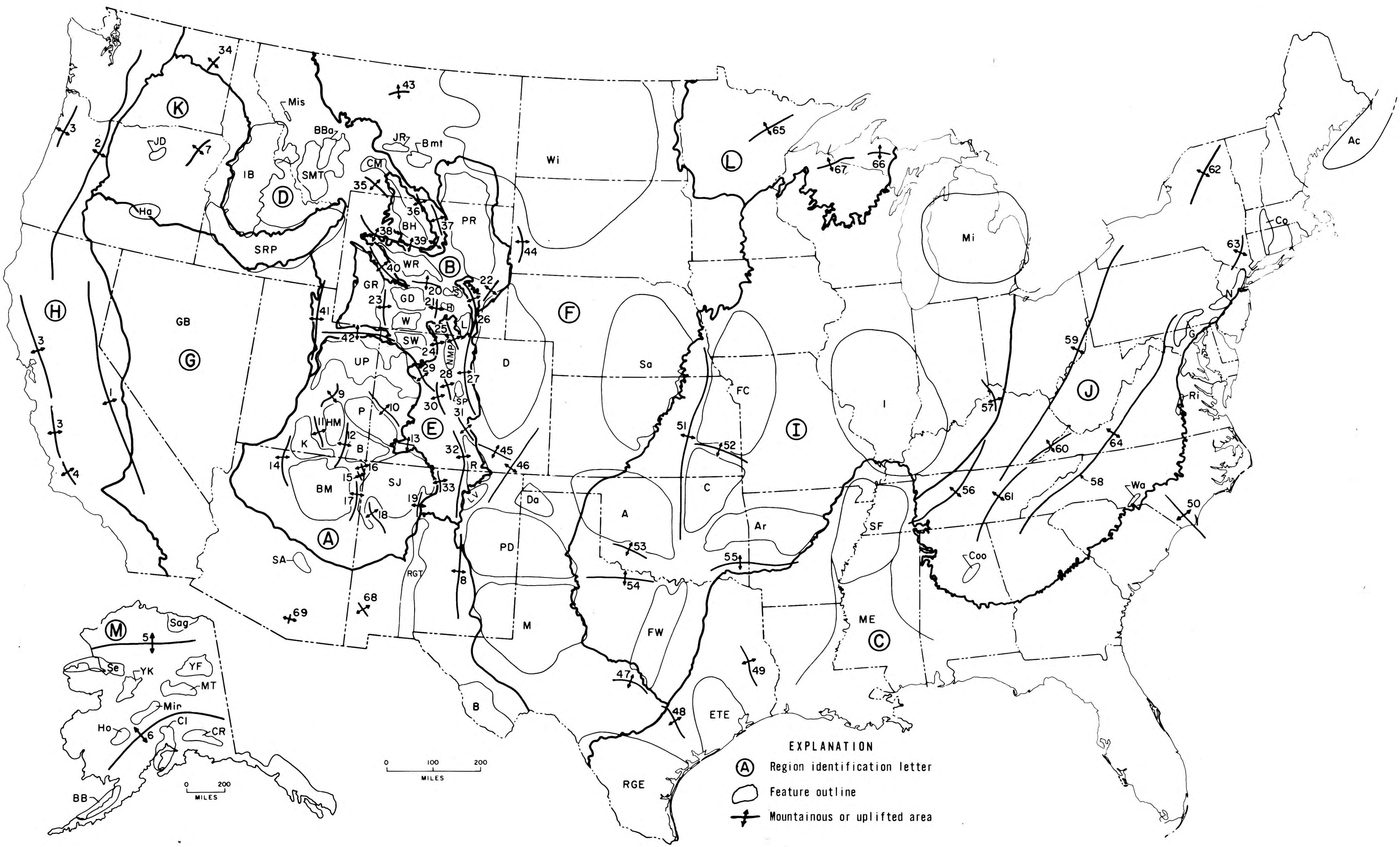


Figure 7. Significant geologic features of the United States referred to in text.

Figure 7. Significant geologic features of the United States referred to in text - *Continued*

(A) Colorado Plateau

9 - San Rafael Swell
10 - Uncompahgre Uplift
11 - Circle Cliffs Uplift
12 - Monument Upwarp
13 - San Juan Mountains
14 - Kaibab Uplift
15 - Lukachukai Mountains
16 - Carrizo Mountains
17 - Defiance Uplift
18 - Zuni Uplift
19 - Nacimiento Uplift
B - Blanding Basin
BM - Black Mesa Basin
HM - Henry Mountains Basin
K - Kaiparowits Basin
P - Paradox Basin
SJ - San Juan Basin
UP - Uinta - Piceance Basin

(B) Wyoming Basins

20 - Granite Mountains
21 - Rawlins Uplift
22 - Hartville Uplift
23 - Rock Springs Uplift
BH - Bighorn Basin
GD - Great Divide Basin
GR - Green River Basin
H - Hanna Basin
L - Laramie Basin
PR - Powder River Basin
S - Shirley Basin
SW - Sand Wash Basin
W - Washakie Basin
WR - Wind River Basin

(C) Gulf and Atlantic Coastal Plains

48 - San Marcos Arch
49 - Sabine Arch
50 - Cape Fear Arch
ETE - East Texas Embayment
ME - Mississippi Embayment
RGE - Rio Grande Embayment
Ri - Richmond Basin
SF - St. Francis Basin
Wa - Wadesboro Basin

(D) Northern Rockies

34 - Loon Lake Batholith
35 - Beartooth Mountains
36 - Pryor - Little Mountains
37 - Big Horn Mountains
38 - Washakie Uplift
39 - Owl Creek Mountains
40 - Wind River Range
41 - Wasatch Range
42 - Uinta Uplift
BBa - Boulder Batholith
IB - Idaho Batholith
Mis - Missoula Basin
SMT - SW Montana Tertiary Basins

(E) Colorado and Southern Rockies

24 - Sierra Madre
25 - Medicine Bow Range
26 - Laramie Range
27 - Front Range
28 - Park Range
29 - White River Uplift

(E) Colorado and Southern Rockies - (cont'd)

30 - Sawatch Range
31 - Wet Mountains
32 - Sangre de Cristo Range
33 - Brazos Uplift
NMP - North and Middle Park
R - Raton Basin
SP - South Park

(F) Great Plains

43 - Bearpaw Mountains
44 - Black Hills Uplift
45 - Apishapa Arch
46 - Sierra Grande-Las Animas Arch
47 - Llano Uplift
Bmt - Bull Mountain Basin
CM - Crazy Mountains Basin
D - Denver Basin
Da - Dalhart Basin
JR - Judith River Basin
LV - Las Vegas Basin
M - Midland Basin
PD - Palo Duro Basin
Sa - Salina Basin
Wi - Williston Basin

(G) Basin and Range

GB - Great Basin
8 - Pedernal Uplift
RGT - Rio Grande Trench
BRM - Burro Mountains
S - Sierrita Mountains
SA - Sierra Ancha
B - Big Bend area

(H) Pacific Coast and Sierra Nevada

1 - Sierra Nevada
2 - Cascade Range
3 - Coastal Ranges
4 - Temblor Range

(I) Central Lowlands

51 - Nemaha Ridge
52 - Bourbon Arch
53 - Wichita Mountains
54 - Red River Uplift
55 - Ouachita Uplift
56 - Nashville Dome
57 - Cincinnati Arch
A - Anadarko Basin
Ar - Arkoma Basin
C - Cherokee Basin
Fc - Forest City Basin
FW - Fort Worth Basin
I - Illinois Basin
Mi - Michigan Basin

(J) Appalachian Highlands

58 - Grandfather Mountain
59 - Appalachian Plateaus
60 - Cumberland Mountains
61 - Cumberland Plateau
62 - Adirondack Mountains
63 - Catskill Mountains

(J) Appalachian Highlands - (cont'd)

64 - Blue Ridge Mountains
Ac - Acadia Basin
Co - Connecticut Basin
Coo - Coosa Basin
G - Gettysburg Basin
N - Newark Basin
Wa - Wadesboro Basin
Ri - Richmond Basin

(K) Columbia Plateaus

7 - Blue Mountains
Ha - Harney Basin
JD - John Day Basin
SRP - Snake River Plain

(L) Southern Canadian Shield

65 - Mesabi Range
66 - Marquette Range
67 - Gogebic Range

(M) Alaska

5 - Brooks Range
6 - Alaska Range
BB - Bristol Bay Basin
CI - Cook Inlet Basin
CR - Copper River Basin
Ho - Holitna Basin
Min - Minchumina Basin
MT - Middle Tanana Basin
Sag - Sagavanirktok Basin
Se - Selawik Basin
YF - Yukon Flats Basin
YK - Yukon - Koyukuk Basin

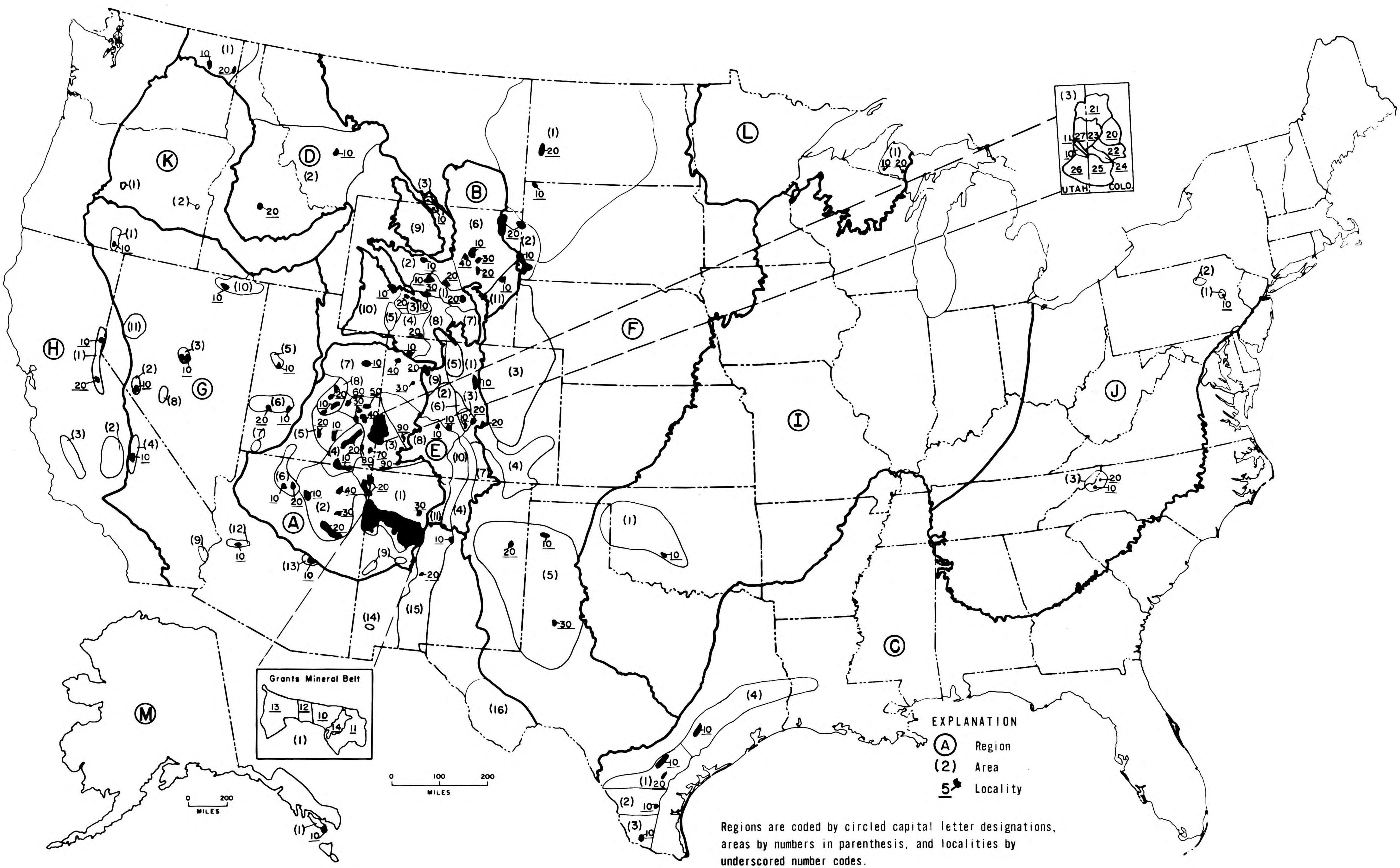


Figure 8. Uranium resource areas of the United States.

Figure 8. Uranium resource areas of the United States - *Continued*

(NURE regions are coded by capital letter designations, uranium areas by number codes in parentheses, and uranium localities by underscored number codes)

A Colorado Plateau
- (1) San Juan Basin
  - 10 Ambrosia
  - 11 Laguna
  - 12 Black Jack
  - 13 Gallup
  - 14 Mt. Taylor
  - 20 Shiprock
  - 30 Nacimiento
- (2) Black Mesa Basin
  - 10 Cameron
  - 20 Holbrook
  - 30 Hopi Buttes
  - 40 Black Mountain
- (3) Paradox Basin
  - 10 SW Lisbon Valley
  - 11 NE Lisbon Valley
  - 20 Uravan
  - 21 Gateway
  - 22 Bull Canyon
  - 23 Paradox
  - 24 Gypsum Valley
  - 25 Slick Rock
  - 26 Dry Valley
  - 27 La Sal
  - 30 Inter-River - Seven Mile
  - 40 Cane Creek
  - 50 Thompsons
  - 60 Green River
  - 70 Montezuma Canyon
  - 80 Cottonwood Wash
  - 90 Placerville - Rico
- (4) Monument Upwarp
  - 10 Monument Valley
  - 20 White Canyon
- (5) Henry Mountains
  - 10 Henry Mountains
  - 20 Circle Cliffs
- (6) Kaibab Uplift
  - 10 Grand Canyon
  - 20 Marble Platform
- (7) Uinta-Piceance Basin
  - 10 Myton
  - 20 Meeker
  - 30 Rifle
  - 40 Skull Creek
- (8) San Rafael Swell
  - 10 Southern San Rafael Swell
  - 20 Northern San Rafael Swell
- (9) Red Basin

B Wyoming Basins
- (1) Central Wyoming
  - 10 Gas Hills
  - 20 Shirley Basin
  - 30 Crooks Gap
- (2) Wind River Basin
  - 10 Copper Mountain
  - 20 Poison Spider
- (3) Great Divide Basin
  - 10 Lost Creek
  - 20 Picket Lake
- (4) Washakie-Sand Wash Basin
  - 10 Maybell
  - 20 Baggs
- (5) Rock Springs Uplift
- (6) Powder River Basin
  - 10 Pumpkin Buttes
  - 20 Monument Hill
  - 30 Turnercrest
  - 40 Pine Ridge

B Wyoming Basins (cont'd)
- (7) Laramie-Hanna Basin
- (8) Miller Hill-Rawlins Uplift
- (9) Big Horn Basin
- (10) Green River Basin
  - 10 Tabernacle Butte
- (11) Hartville Uplift
  - 10 Lance Creek

C Coastal Plains
- (1) Central Coast
  - 10 Karnes
  - 20 Live Oak
- (2) Duval
  - 10 Palangana
- (3) Starr
  - 10 Kelsey
- (4) East Texas
  - 10 Lignite

D Northern Rockies
- (1) Loon Lake Batholith
  - 10 Loon Lake
  - 20 Mt. Spokane
- (2) Idaho-Montana
  - 10 Boulder Batholith (Clancy)
  - 20 Basin Creek
- (3) Northern Bighorn Uplift
  - 10 Pryor-Little Mountains

E Colorado and Southern Rockies
- (1) Front Range-Laramie-Medicine Bow Mountains
  - 10 Eastern Margin
  - 20 Turkey Creek
- (2) Sawatch Range
  - 10 Marshall Pass
- (3) Thirtynine Mile Volcanic Field
  - 10 Tallahassee Creek
  - 20 High Park
- (4) Sangre de Cristo Range
- (5) North Park-Middle Park Basin
- (6) South Park
- (7) Raton Basin
- (8) San Juan Mountains
  - 10 Cochetopa
- (9) Park Range-Sierra Madre Uplift
- (10) San Luis Valley
- (11) Jemez-Brazos Uplift

F Great Plains
- (1) Williston Basin
  - 10 Cave Hills-Slim Buttes
  - 20 Belfield
- (2) Black Hills
  - 10 Southern Hills
  - 20 Northern Hills
- (3) Denver Basin
- (4) Sierra Grande-Las Animas Arch
- (5) Midland Basin
  - 10 Tascosa
  - 20 Tucumcari
  - 30 Post

G Basin and Range
- (1) Lake County
  - 10 Lakeview
- (2) Walker Lake
  - 10 Hawthorne
- (3) North Toiyabe Range
  - 10 Austin
- (4) Owens Lake
  - 10 Coso
- (5) Thomas Range
  - 10 Topaz Mountain
- (6) Beaver Trend
  - 10 Marysvale
  - 20 Wah Wah Mountains
- (7) Silver Reef
- (8) Tonopah
- (9) Blythe
- (10) Mountain City
  - 10 Mountain City
- (11) Winnemucca Lake
- (12) Artillery Mountains
  - 10 Artillery Peak
- (13) Globe
  - 10 Sierra Ancha
- (14) Burro Mountains
- (15) Rio Grande Trench
  - 10 Santa Fe
  - 20 Socorro
- (16) Big Bend

H Pacific Coast and Sierra Nevada
- (1) Northern Sierra
  - 10 Hallelujah Junction
  - 20 Sonora Pass
- (2) Kern River
- (3) Taft-McKittrick

I Central Lowlands
- (1) Anadarko Basin
  - 10 Cement

J Appalachian Highlands
- (1) Carbon County
  - 10 Jim Thorpe
- (2) Sullivan County
- (3) Grandfather Mountain
  - 10 Spruce Pine
  - 20 Grandfather Mountain

K Columbia Plateaus
- (1) Crook County
- (2) Malheur County

L Southern Canadian Shield
- (1) Keweenaw Bay
  - 10 Iron County
  - 20 Dickinson County

M Alaska
- (1) Prince of Wales Island
  - 10 Bokan Mountain (Kendrick Bay)

Colorado Plateau

The Colorado Plateau includes parts of Colorado, Utah, Arizona, and New Mexico (A, Fig. 1). The region contains a large number of well-established mining areas, including the Grants mineral belt, which is the largest producing area in the United States; other large producing areas are Lisbon Valley and the Uravan mineral belt (Table 6, Fig. 8). The potential uranium resource estimates are summarized in Table 5.

TABLE 5. Potential uranium resources of the Colorado Plateau

Cost Category	Tons U_3O_8 1/		
	Probable	Possible	Speculative
$10	210,000	281,000	56,000
$15	288,000	415,000	68,000
$30	433,000	632,000	103,000

1/ Resources in each class include all lower cost resources in that class.

Regional geologic setting

The Colorado Plateau is a region of high plateaus, sedimentary basins, uplifts, laccoliths, and volcanic fields. Sedimentary rocks ranging in age from Paleozoic through early Tertiary are widespread. Precambrian granitic and metamorphic rocks crop out in the Uncompahgre Plateau, Black Canyon of the Gunnison, Zuni uplift, and Grand Canyon.

Paleozoic strata are exposed in the San Rafael, Monument, Kaibab, Defiance, and Zuni uplifts and in the Paradox Basin. Sedimentary rocks of Mesozoic age are common throughout the region. Tertiary strata crop out in the San Juan, Uinta, and Piceance Basins and east of the Defiance uplift. Tertiary laccoliths include the Henry, Abajo, La Sal, Ute, La Plata, Navajo, and Carrizo Mountains. Volcanic rocks in the Datil and San Francisco volcanic fields, New Mexico and Arizona, and dikes and diatremes elsewhere are of late Cenozoic age.

The Colorado Plateau was stable during most of the Paleozoic Era. Deformation began in Pennsylvanian time with the elevation of the Uncompahgre and Zuni uplifts. The San Juan, Black Mesa, Uinta, and Piceance Basins and the Zuni, Monument, Kaibab, Defiance, San Rafael, and Circle Cliffs uplifts were formed or rejuvenated during the Laramide orogeny. Additional deformation of these structures occurred during the Miocene and Pliocene epochs.

Overview of uranium resources

Fluvial sandstones, conglomerate, and mudstone are the predominant host rocks for uranium deposits. Limestone, evaporites, and marine and eolian sandstones are less important. Uranium ore is known in sedimentary formations ranging in age from Pennsylvanian to Tertiary. However, most production has come from (1) the Morrison Formation of Jurassic age in the Grants mineral belt, New Mexico, and from the Uravan mineral belt in Colorado and Utah, and (2) the Chinle Formation of Triassic age in Lisbon Valley, Utah, and Monument Valley, Arizona, and White Canyon, Utah.

Production also has come from a breccia pipe in the Coconino and Supai Formations of Permian age in the Grand Canyon of Arizona (Orphan Lode mine); from bedded deposits in the Cutler Formation of Permian age in the Paradox Basin, Utah; and from the Todilto Limestone of Jurassic age in the Grants mineral belt, New Mexico. Minor production has been derived from deposits in Cretaceous rocks - the Dakota Sandstone in the San Juan Basin and the Toreva Formation in the Black Mesa Basin.

Uranium is associated with vanadium deposits in a north-trending belt in the eolian Entrada Sandstone of Jurassic age along the eastern margin of the Colorado Plateau between Rico and Rifle, Colorado. Production from this source has come chiefly from the Rifle area.

Ore-bearing rocks of the Morrison and Chinle Formation are quartzose or arkosic, lenticular, crossbedded, fluvial sandstones containing interbedded clay or mudstone lenses. The sandstones form paleochannels that range in width from a few feet to broad flood-plain systems many miles wide. Uranium emplacement was primarily controlled by sedimentary structures, but locally was affected by fracture systems. Localization of uranium was enhanced by reducing environments created by indigenous carbonaceous debris or by introduced humic substances and hydrogen sulfide.

The uranium is thought to have been derived from either tuffaceous material in or overlying the host rocks or from eroded granitic rocks which contributed detritus to the host sediments. Many deposits, particularly in sandstone, probably were emplaced soon after sedimentation; however, uranium has been redistributed in numerous places. In the Grants mineral belt, uranium redistribution evidently was influenced by fractures.

Potential uranium resources (Tables 5, 6, 7, and 8; Figs. 9, 10, and 11)

Most of the probable and possible potential resources estimated for this region are in the Morrison Formation in the San Juan and Paradox Basins, from which most of the production has been obtained. The Morrison Formation contains more than than 80 percent each of the probable and possible potential resources, much of which are in the Westwater Canyon Member in the San Juan Basin. Most of the remaining potential resources in the Morrison Formation are in the Salt Wash Member in the Paradox Basin and in the Brushy Basin Member in the Paradox and San Juan Basins.

Other rock units with significiant quantities of estimated probable and possible potential resources include the Chinle Formation in the Paradox Basin, San Rafael Swell, and Black Mesa Basin. Also, relatively large potential resources were estimated for vein-like deposits in collapsed pipe structures that penetrate upper Paleozoic sedimentary rocks on the Kaibab uplift.

Most of the speculative potential resources were estimated to be in the San Juan Basin, Paradox Basin, and the Kaibab uplift in several sedimentary rock units with little or no exploration or production history.

Potential uranium host rocks are 200 to 5,000 feet deep, although most potential deposits are estimated to be less than 3,000 feet deep.

TABLE 6. Uranium resources and mining areas of the Colorado Plateau

Uranium Resource Area	Mining Area
San Juan Basin	Grants mineral belt Shiprock Nacimiento
Black Mesa Basin	Cameron Holbrook Hopi Buttes Black Mountain
Paradox Basin	Lisbon Valley Uravan mineral belt Dry Valley La Sal Inter-River-Seven Mile Cane Creek Thompsons Green River Montezuma-Cottonwood Rico-Placerville
Monument Upwarp	Monument Valley White Canyon
Henry Mountains	Henry Mountains
Kaibab Uplift	Grand Canyon
Uinta-Piceance Basin	Myton Meeker Rifle
San Rafael Swell	San Rafael Swell
Red Basin	Red Basin

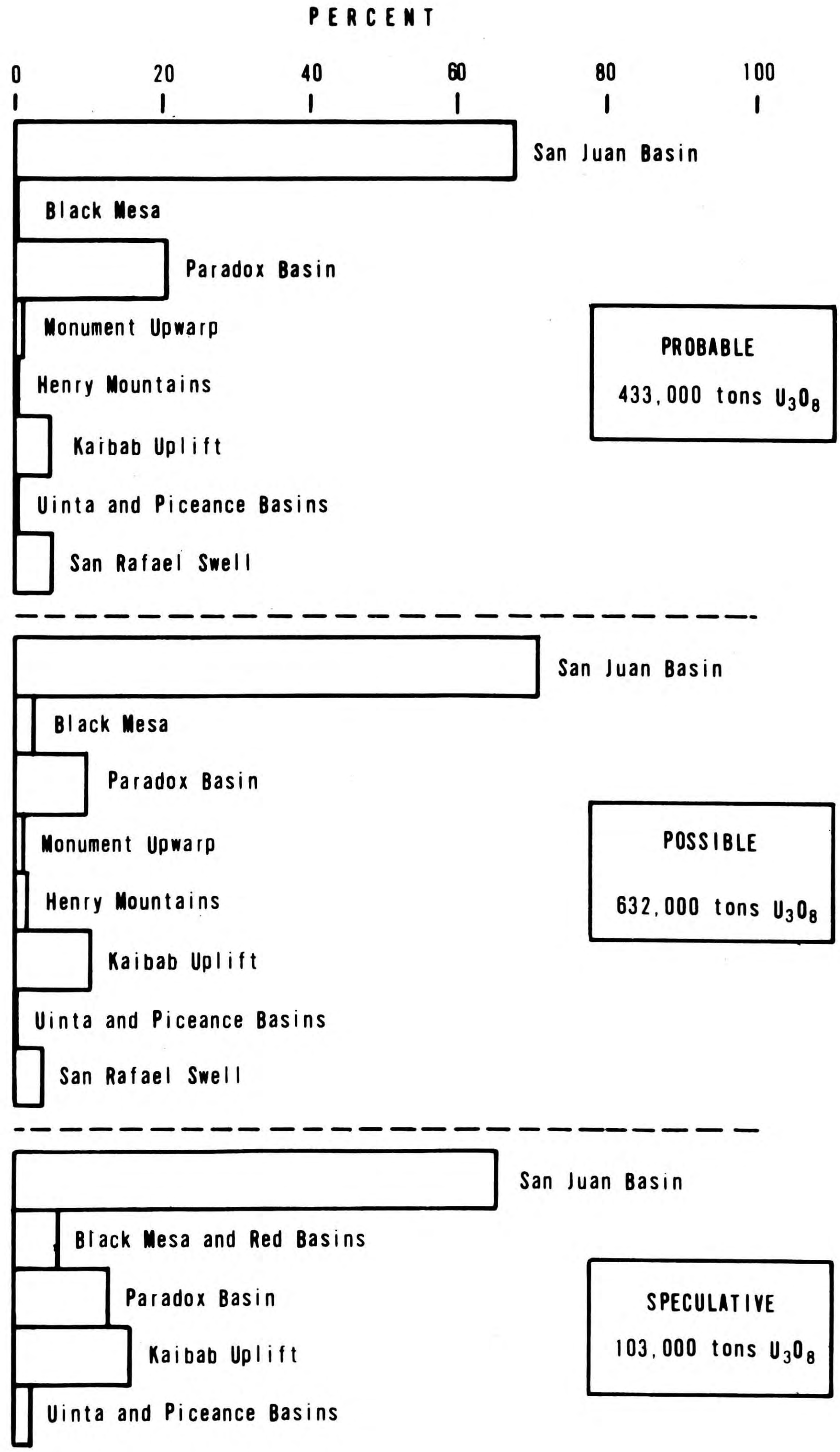


Figure 9. Distribution of $30 potential uranium resources for the Colorado Plateau.

TABLE 7. Distribution of $30 potential uranium resources in the Colorado Plateau

Host rock units	Plate 1 Symbol 1/	Tons U_3O_8 Probable	Possible	Speculative
Baca Formation	A1	--	--	4,000
Uinta Formation	A2	--	--	2,000
Wasatch Formation	A3	--	--	2/
San Jose Formation	A4	--	--	20,000
Nacimiento and Animas Formations	A5	--	--	16,000
Ojo Alamo Sandstone	A6	--	--	19,000
Menefee Formation	A7	--	--	7,000
Crevasse Canyon Formation	A8	--	--	6,000
Toreva Formation	A9	400	500	--
Dakota Sandstone	A10	800	7,000	--
Burro Canyon Formation	A11	1,300	2,500	1,000
Morrison Formation, undivided	A12	--	25,000	--
Brushy Basin Member	A13	35,200	37,500	--
Westwater Canyon Member	A14	251,000	393,500	--
Recapture Member	A15	400	500	--
Salt Wash Member	A16	68,600	51,000	--
Todilto Limestone	A17	2,200	3,000	--
Entrada Sandstone	A18	3,500	500	--
Dolores Formation	A19	--	--	11,000
Chinle Formation, undivided	A20	22,200	--	--
Petrified Forest Member, sandstone and mudstone member	A21	500	1,500	--
Moss Back Member	A22	19,800	22,500	--
Shinarump Member	A23	4,700	22,000	--
Permian rocks, undivided	A24	1,700	3,000	--
Kaibab Limestone	A25	--	--	2,000
Supai Formation	A26	--	9,000	--
Paradox Formation	A27	--	--	2/
Temple Butte Limestone, Tonto Group, and Precambrian metamorphic and igneous rocks	A28	--	--	14,000
Vein deposits in breccia pipes	A29	20,700	53,000	--
TOTALS		433,000	632,000	103,000

1/ Refer to Plate 1 for explanation

2/ Substantially less than 1,000 tons U_3O_8 but included in speculative total

TABLE 8. Areas and rock units in the Colorado Plateau that require further study before assessment for potential uranium resources

Area	Plate 2 Symbol 1/	Rock units
Smith's Fork	Aa	Entrada Sandstone
Delta	Ab	Morrison Formation
Whitewater	Ac	Morrison Formation
Cisco-Rabbit Valley	Ad	Morrison Formation
Bookcliffs-Crescent Junction	Ae	Morrison Formation
Southeastern Utah	Af	Cedar Mesa Sandstone Member of the Cutler Formation
Vernal-Rangely	Ag	Mesaverde Formation, Iles Formation, Burro Canyon Formation, Curtis Formation, and Gartra Member of the Chinle Formation
Promontory Butte	Ah	Supai Formation
Bidahochi	Ai	Bidahochi Formation
Farmington	Aj	Fruitland Formation
Moenkopi	Ak	Kayenta and Moenkopi Formations
San Rafael Swell	Al	Coconino Sandstone and Chinle Formation

1/ Refer to Plate 2 for explanation

COLORADO PLATEAU REGION						
PERIOD	EPOCH	NW NEW MEXICO	NORTHERN ARIZONA	EASTERN UTAH	SW COLORADO	NW COLORADO
TERTIARY	PLIOCENE		(Bidahochi Formation)			
	MIOCENE					
	OLIGOCENE					
	EOCENE	Baca Formation San Jose Formation		Uinta Formation Wasatch Formation		
	PALEOCENE	Animas Formation; Nacimiento Fm. Ojo Alamo Ss.				
CRETACEOUS	UPPER	(Fruitland Formation) Menefee Formation Crevasse Canyon Formation DAKOTA SANDSTONE	TOREVA FORMATION	(Mesaverde Formation)		(Iles Formation)
	LOWER	Burro Canyon Formation (?)			Burro Canyon Formation	
JURASSIC	UPPER	MORRISON FM.: BRUSHY BASIN MBR. WESTWATER CANYON MBR. RECAPTURE MBR. SALT WASH MBR. TODILTO LIMESTONE	MORRISON FM.: Brushy Basin Mbr. Westwater Canyon Mbr. SALT WASH MBR.	MORRISON FM.: BRUSHY BASIN MBR. Westwater Canyon Mbr. Recapture Mbr. SALT WASH MBR.	MORRISON FM.: BRUSHY BASIN MBR. SALT WASH MBR.	MORRISON FM.: SALT WASH MBR. (Curtis Formation)
	MIDDLE				ENTRADA SANDSTONE	ENTRADA SANDSTONE
	LOWER		(Kayenta Formation)			NAVAJO SANDSTONE
TRIASSIC	UPPER		(Moenave Fm.) (Dinosaur Canyon Mbr.) CHINLE FM.: PETRIFIED FOREST MEMBER SANDSTONE AND MUDSTONE MEMBER SHINARUMP MBR.	CHINLE FM.: Churchrock Mbr. MOSS BACK MBR. MONITOR BUTTE MBR. SHINARUMP MBR. TEMPLE MOUNTAIN MBR.	CHINLE FM.: MOSS BACK MBR Dolores Fm.	CHINLE FM.: Shinarump Mbr. (Gartra Mbr.)
	MIDDLE					
	LOWER					
PERMIAN	UPPER					
	LOWER		Kaibab Limestone Coconino Sandstone Supai Formation	Coconino Sandstone CUTLER FM. (Cedar Mesa Mbr.)		
PENN.	UPPER		(Supai Formation)	Paradox Formation		
	MIDDLE					
	LOWER					
M.						
DEV.	UPPER		Temple Butte Limestone			
	MIDDLE					
	LOWER					
CAMB.	UPPER					
	MIDDLE		Tonto group: Muav Formation Bright Angel Shale Tapeats Sandstone			
	LOWER					
Pc	Z 1/					
	Y		Metamorphic & plutonic rocks undifferentiated			
	X					
	W					

Chart shows only general lateral time equivalence of favorable rock units between geographical areas.

1/ Subdivisions of Precambrian time (U.S. Geol. Survey Bull. 1372-A, 1972).

Units that have uranium production and/or reserves and potential resources are capitalized. Units that have estimated potential uranium resources are lower cased. Units that may contain potential resources are in parentheses.

Figure 10. Favorable rock units of the Colorado Plateau

X - Dominant or of primary importance
0 - Subordinate or of secondary importance
Blank - Undetermined or doubtful significance, absent, or inapplicable

ROCK UNITS	DEPOSIT CHARACTERISTICS: Known uranium deposits	Surficial uranium minerals	Anomalous radioactivity at outcrop	Co-metals	Other associated metals	LITHOLOGIC AND ORE CONTROL CHARACTERISTICS: Clastic rocks: (C) Coarse (F) Fine (A) Arkosic (Ca) Calcareous (Fs) Feldspathic (Q) Quartzose (V) Volcanic	Other sedimentary: (Ca) Carbonates (C) Chert (E) Evaporites (L) Lignites (P) Phosphates	Volcanics: (E) Extrusive (F) Felsic (I) Intrusive (M) Mafic (T) Tuffaceous (V) Vitric	Plutonic: (F) Felsic (M) Mafic (P) Pegmatitic	Metamorphic: (C) Contact (I) Isochemical	Uranium provenance: (G) Granitic (V) Volcanic	Continental: (C) Paleochannel (D) Deltaic (E) Eolian (F) Fan (L) Lacustrine (P) Paludal	Marine: (A) Abyssal (B) Bathyal (D) Deltaic (L) Littoral (S) Sabkhal	Structural: (B) Breccia (C) Contact (D) Dissemination (F) Fracture (P) Pipe (V) Vein (U) Unconformity (Z) Fold	Reductants: (A) Asphaltite (C) Carbon (H) H_2S (N) Natural gas (S) Sulfide minerals (P) Petroleum	Permeability: (G) Good (F) Fair (P) Poor	Alteration: (B) Bleaching (C) Chlorite (H) Hematite (L) Limonite (S) Sericite	Cementation: (C) Calcite (H) Hematite (L) Limonite (P) Phosphate (S) Silica
Baca Formation	X	X	X			CQ					V	CF		UZ	CS	G	L	S
Uinta Formation	X	X	X			CAQ		EFT			V	C			CS	F	L	C
Wasatch Formation	X	X	X			CAQ		EFT			V	C			C		L	C
San Jose Formation		X	X			CAQ					GV	C		U	C	G	L	S
Nacimiento and Animas Formations						CFFs	L	EF			V	CL			C	G	L	S
Ojo Alamo Sandstone		X	X			CAQ					V	C			C	G	HL	S
Menefee Formation	0	X	X			CQ	L				V	CL			CS	F		CS
Crevasse Canyon Formation	0	X	X			CQ	L				V	CL			CS	G	BL	C
Toreva Formation	X	X	X			CQ	L					CL	D		CS	G	L	CS
Dakota Sandstone	X	X	X			CAQ	L				V	CL	D	F	CS	G	BL	CS
Burro Canyon Formation	X	X	X			CAQ	L				GV	CD	D	U	CS	G	BL	C
Morrison Formation																		
Brushy Basin Member	X	X	X	V		CAQ		FT			V	CL		FU	CS	G	BHL	CS
Westwater Canyon Member	X	X	X		V,MoSe	CAQ		FT			V	CFL		FUZ	CS	G	BHL	CS
Recapture Member	X	X	X		V,Mo	CAQ					V	CF		U	CS	G	HL	CS
Salt Wash Member	X	X	X	V	Cu	CAQ		FT			V	CF		UZ	CS	G	BL	CS
Todilto Limestone	X	X	X	V	Mo		Ca				V		LS	BFZ	CHS	P	H	C
Entrada Sandstone	X	X	0	V		Q						E		U	S	G	BL	C
Dolores Formation			0			FQ		EFT			G	C	L	Z	CS	F	BL	CS
Chinle Formation																		
Petrified Forest Member	X	X	X			FAQ		FT			V	CL			CS	F	BL	CS
Sandstone and mudstone member	X	X	X	V,Cu		FAQ		FT			V	CL		FZ	CS	F	L	CS
Moss Back Member	X	X	X	Cu	V,Mo	FAQ		FT			V	CL		FUZ	CS	F	BL	S
Shinarump Member	X	X	X	V,Cu		CQ	C				V	C		FUZ	CS	G	BL	CS
Permian, undivided	X	X	X	Cu	V	CA					G	CL		UZ	CS	G	BH	S
Kaibab Limestone			0		Cu		C						BL	BFU		P		C
Coconino Sandstone	X	0	X		Cu	FQ							L	P		G	BL	S
Supai Formation	X	0	X		Cu	CAQ						C		FUZP	C	G	BL	S
Paradox Formation	X	0	0		V	FCa	C						BL	FZ	S	P		C
Temple Butte Limestone						FCa	C						BL	FU		P		C
Tonto Group													BL	FU		F		C
Precambrian igneous and metamorphic rocks									F	I				FUZ				

Figure 11. Characteristics of favorable rock units in the Colorado Plateau.

Wyoming Basins

The Wyoming Basins region includes much of Wyoming and small parts of adjacent states (B, Fig. 1). Important uranium mining areas are the Gas Hills, Shirley Basin, Crooks Gap, and Powder River Basin, which together account for about 30 percent of the current uranium production of the United States. Less important areas are Maybell, Baggs, and Copper Mountain (Fig. 8). The potential uranium resource estimates are summarized in Table 9.

TABLE 9. Potential uranium resources in the Wyoming Basins

Cost Category	Tons U_3O_8 1/ Probable	Possible	Speculative
$10	127,000	28,000	11,000
$15	209,000	52,000	21,000
$30	313,000	84,000	31,000

1/ Resources in each class include all lower cost resources in that class.

Regional geologic setting

The Wyoming Basins region includes the Powder River, Wind River, Shirley, Washakie, Great Divide, Laramie, Hanna, Sand Wash, Green River, and Big Horn Basins, as well as the Rock Springs, Rawlins, and Hartville uplifts (Fig. 7). In the basins, extensive continental strata of Tertiary age overlie Paleozoic and Mesozoic marine and continental sedimentary rocks that crop out on the flanks of most bordering mountain ranges.

The ranges and basins were formed during the Laramide orogeny. Detritus eroded from the mountains partly filled the basins during late Paleocene and early Eocene time. The resulting sediments are predominantly fine-grained sand and silt reworked from older strata, but wedges of coarse arkosic sand and gravel, eroded from Precambrian granitic cores of the ranges, occur locally. Tuffaceous sediments of middle Eocene to Pliocene age subsequently buried the basins and most of the adjacent ranges. During Pliocene time, broad regional uplift took place. As the mid-Tertiary fill was removed, the mountains were exhumed, exposing the lower Tertiary strata.

Overview of uranium resources

The Wasatch, Wind River, and Battle Spring Formations of early Eocene age contain most of the important deposits; others are in the Fort Union Formation of Paleocene age in the Powder River Basin. Some of these deposits are in fan-like sedimentary accumulations, as at Crooks Gap, Copper Mountain, and Gas. Hills. The uranium probably was introduced during Miocene time. In the Washakie and Sand Wash Basins, production has come from shallow deposits in the Miocene Browns Park Formation, which is in part eolian. At Maybell and Baggs, hydrogen sulfide, natural gas, and residual oil may have served as uranium reductants along fracture zones. In central Wyoming, the deposits in the Teapot Member of the Mesaverde Formation are in fluvial, fine-grained sandstone containing abundant carbonaceous trash.

Drill holes have intersected uraniferous zones at depths as great as 2,000 feet, but present mine depths are less than 1,000 feet. Vanadium has been recovered as a by-product only from Powder River Basin ore, although it occurs in small quantities in many of the uranium deposits.

Most of the uranium occurrences are in the form of "roll fronts" (Fig. 15) along redox interfaces in sandstones where migrating uranium-bearing solutions altered the host rock. Hematite, limonite, and/or kaolinite generally distinguish altered from unaltered, gray rock; ore bodies lie along the interface between altered and unaltered rock. Iron-oxide staining associated with oxidation is prevalent in the Powder River Basin, but color changes indicative of alteration are more subtle in the Gas Hills and Shirley Basin.

Uranium was probably derived from Precambrian granites and/or tuffaceous material contained in Tertiary sedimentary rocks. The uranium probably moved in ground water from these source rocks into sandstones where it precipitated under reducing conditons.

Potential uranium resources (Tables 9, 10, and 11; Figs. 12, 13, and 14)

Gently dipping flanks of intermontane basins are the most favorable areas for uranium deposits in Wyoming. Almost all potential resources are postulated to occur as roll-front deposits in fluvial, arkosic sandstone of Tertiary age. In addition, potential resources are estimated in fine-grained eolian and fluvial sandstone of the Browns Park Formation, fluvial sandstone of the Mesaverde, Ericson, and Lance Formations, and mudstone and fine-grained sandstone of the Morrison and Cloverly Formations.

Most of the potential resources are assigned to areas in or near major producing areas (Fig. 11). Outside these producing areas, sandstones of Late Cretaceous age in most basins and in the Fort Union Formation of Paleocene age in the Big Horn Basin appear to be most favorable for uranium.

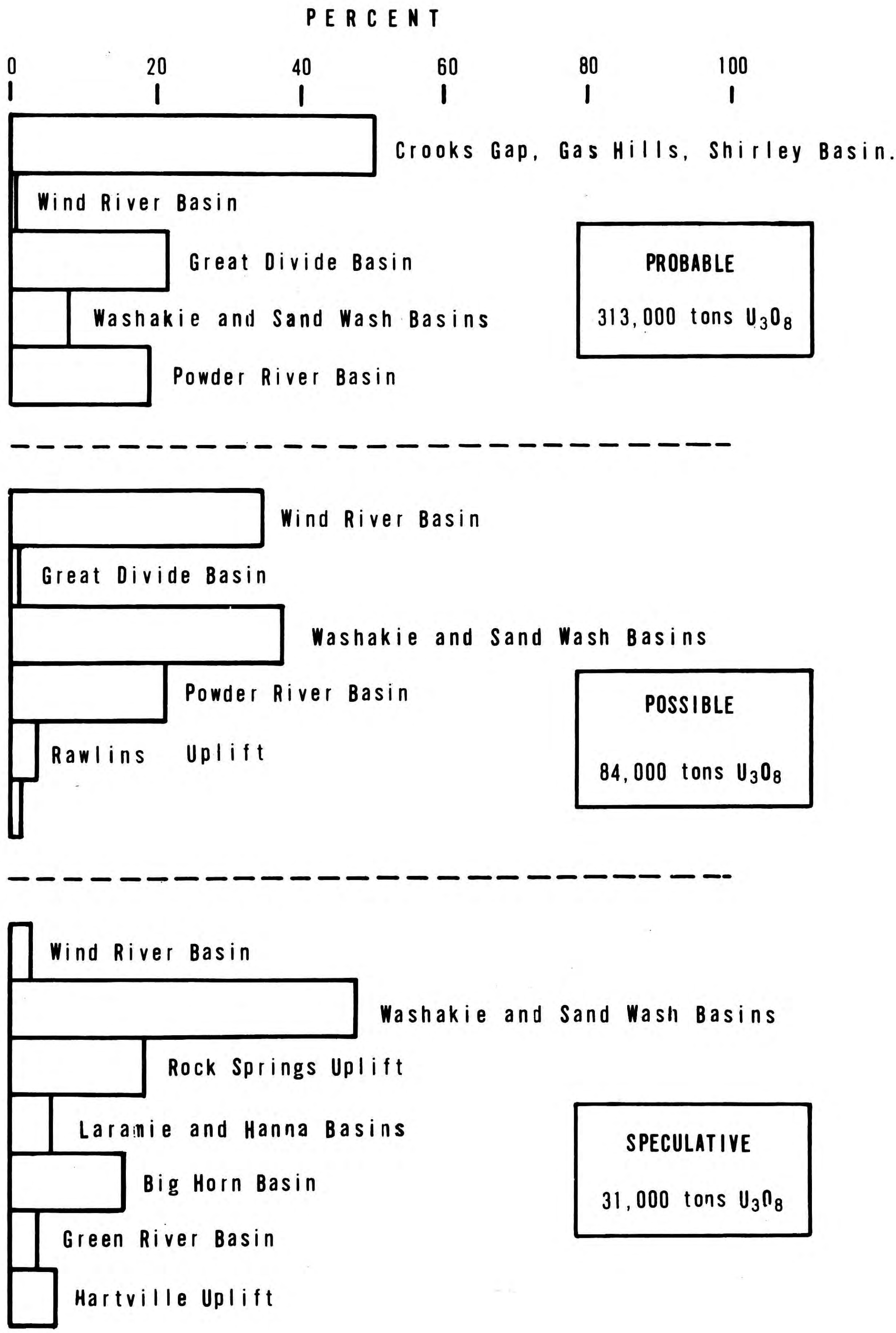


Figure 12. Distribution of $30 potential uranium resources for the Wyoming Basins.

TABLE 10. Distribution of $30 potential uranium resources in the Wyoming Basins

Host rock units	Plate 1 Symbol 1/	Tons U_3O_8 Probable	Possible	Speculative
North Park Formation	B1	--	3,500	--
Browns Park Formation	B2	24,900	31,500	--
Green River Formation	B3	--	--	6,000
Battle Spring and Wasatch Formations	B4	179,500	1,000	--
Wasatch/Wind River and Fort Union Formations	B5	108,600	34,500	11,000
Willwood Formation	B6	--	--	1,000
Hanna Formation	B7	--	--	1,000
Ericson Formation	B8	--	--	3,000
Mesaverde and Lance Formations	B9	--	13,500	5,000
Cloverly and Morrison Formations	B10	--	--	2,000
Precambrian and Paleozoic rocks, undivided	B11	--	--	2,000
TOTALS		313,000	84,000	31,000

1/ Refer to Plate 1 for explanation

TABLE 11. Areas and rock units in the Wyoming Basins that require further study before assessment for potential uranium resources

Area	Plate 2 Symbol 1/	Rock units
Granite Mountains	Ba	Precambrian granite
Haystack Mountains	Bb	Mesaverde Formation
Kindt Basin	Bc	Mesaverde Formation
Flat Top	Bd	Cloverly and Morrison Formations
Como Ridge	Be	Cloverly and Morrison Formations
Garrett	Bf	Casper Formation
Laramie	Bg	Casper Formation
Sand Creek	Bh	Cloverly and Morrison Formations
Desert Rose	Bi	Cloverly and Morrison Formations

1/ Refer to Plate 2 for explanation

WYOMING BASINS REGION												
		BASINS								UPLIFTS		
PERIOD	EPOCH	SHIRLEY	WIND RIVER	GREAT DIVIDE	WASHAKIE SAND WASH	POWDER RIVER	LARAMIE HANNA	BIG HORN	GREEN RIVER	ROCK SPRINGS	RAWLINS MILLER HILL	HARTVILLE
TERTIARY	PLIOCENE				BROWNS PARK FM.							
	MIOCENE										North Park Fm.	
	OLIGOCENE											(White River Fm.)
	EOCENE	WIND RIVER FM.	WAGON BED WIND RIVER FM.	BATTLE SPRING and Wasatch Fms.	Green River Fm. Wasatch Fm.	WASATCH FM.	Wind River Hanna Fms.	Willwood Fm.	Wasatch Fm.	Wasatch Fm.		
	PALEOCENE				Ft. Union Fm.	FT. UNION FM.		Ft. Union				
CRETACEOUS	UPPER		Mesaverde Fm.		Mesaverde Fm.	Lance Fm. Mesaverde Fm. TEAPOT MBR.		Mesaverde Fm.		Ericson Ss.	Mesaverde Fm.	
	LOWER						(Cloverly Fm.)	Cloverly Fm.				
JURASSIC	UPPER						(Morrison Fm.)	Morrison Fm.				
	MIDDLE											
	LOWER											
TRIAS.												
PERM.												
PENN.	UPPER											
	MIDDLE						(Casper Fm.)					
	LOWER											
CAMB.	UPPER											Deadwood Fm.
	MIDDLE											
	LOWER											
Pє	Z											
	Y		Plutonic and metamorphic rocks									
	X											Plutonic and metamorphic rocks
	W											

Chart shows only general lateral time equivalence of favorable rock units between geographical areas.

Units that have uranium production and or reserves and potential resources are capitalized. Units that have estimated potential uranium resources are lower cased. Units that may contain potential resources are in parentheses.

Figure 13. Favorable rock units of the Wyoming Basins.

X - Dominant or of primary importance
O - Subordinate or of secondary importance
Blank - Undetermined or doubtful significance, absent, or inapplicable

ROCK UNITS	DEPOSIT CHARACTERISTICS					LITHOLOGIC AND ORE CONTROL CHARACTERISTICS												
	Known uranium deposits	Surficial uranium minerals	Anomalous radioactivity at outcrop	Co-metals	Other associated metals	Clastic rocks: (C) Coarse (F) Fine (A) Arkosic (Ca) Calcareous (Fs) Feldspathic (Q) Quartzose (V) Volcanic	Other sedimentary: (Ca) Carbonates (C) Chert (E) Evaporites (L) Lignites (P) Phosphates	Volcanics: (E) Extrusive (F) Felsic (I) Intrusive (M) Mafic (T) Tuffaceous (V) Vitric	Plutonic: (F) Felsic (M) Mafic (P) Pegmatitic	Metamorphic: (C) Contact (I) Isochemical	Uranium provenance: (G) Granitic (V) Volcanic	Continental: (C) Paleochannel (D) Deltaic (E) Eolian (F) Fan (L) Lacustrine (P) Paludal	Marine: (A) Abyssal (B) Bathyal (D) Deltaic (L) Littoral (S) Sabkhal	Structural: (B) Breccia (C) Contact (D) Dissemination (F) Fracture (P) Pipe (V) Vein (U) Unconformity (Z) Fold	Reductants: (A) Asphaltite (C) Carbon (H) H_2S (N) Natural gas (S) Sulfide minerals (P) Petroleum	Permeability: (G) Good (F) Fair (P) Poor	Alteration: (B) Bleaching (C) Chlorite (H) Hematite (L) Limonite (S) Sericite	Cementation: (C) Calcite (H) Hematite (L) Limonite (P) Phosphate (S) Silica
North Park Formation	O	X	X			FCa	CaC	ET			V	CL			C	F	L	CS
Browns Park Formation	X	X	X		Se,Mo,V	CAQ					V	CE			CNS	G	L	C
White River Formation	O	O			Mo,V	CQ		FT			V	CL			CNP	F	L	C
Green River Formation			O			CQFs	CPE					LC				P		CL
Wind River Formation	X	X	X		V,Mo,Se	CA					VG	CF			CS	G	LHB	CS
Wasatch and Battle Spring Formations	X	X	X		Mo,V	CA	L				GV	FPC			CS	G	LHB	CS
Fort Union Formation	X	X	X		V,Mo	CAQ	L				GV	FPC			CS	G	BHL	CS
Lance Formation	X		X			FQFs					V	C			CS	F	L	CL
Mesaverde Formation	X	O	O		V	CQF	L				GV	D	DL		CHS	F	LH	CL
Cloverly Formation	O	X	X		V	FQC	C				V	C	D		SC	G	BLH	CS
Morrison Formation	O	X	X		V	FQ	C				V	C			CS	P	HL	CH
Casper Formation						FQ	C				G	C	L		P	G		SC
Deadwood Formation	X	X	X	Cu,Ag		CQ					G	C	DL	V		G		S
Precambrian plutonic and metamorphic rocks	O	O	O						F		G			V	S	G	BL	

Figure 14. Characteristics of favorable rock units in the Wyoming Basins.

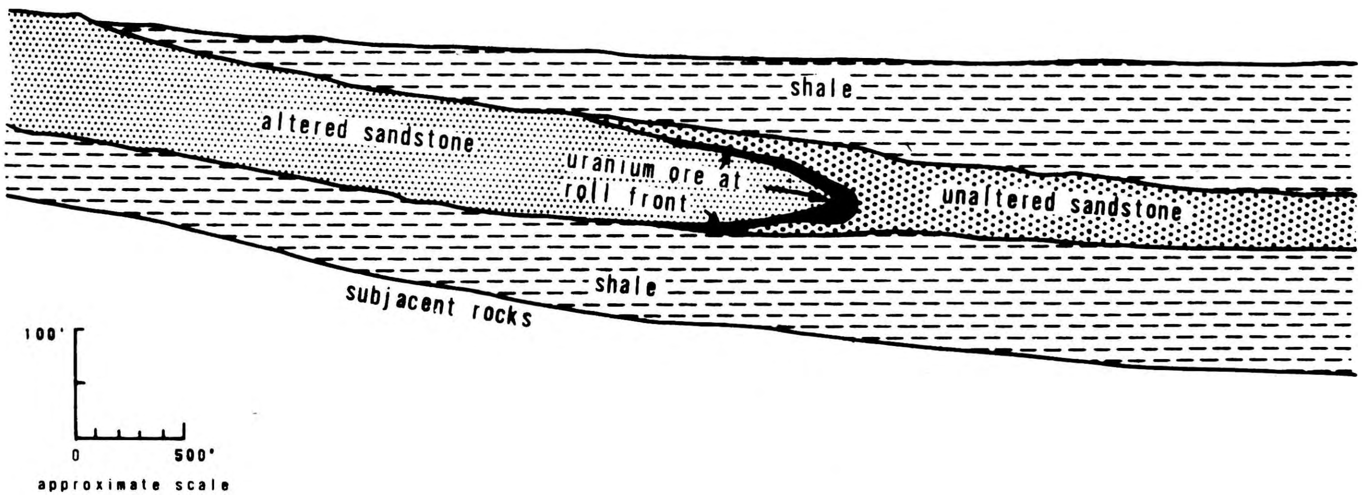


Figure 15. Generalized section through roll-front uranium deposit.

Coastal Plain

The Coastal Plain extends from Texas to New Jersey along the Gulf of Mexico and the Atlantic Ocean (C, Fig. 1). In spite of the large area involved, estimated potential resources are confined to Texas and Louisiana. The principal uranium-producing areas are in Karnes and Live Oak Counties, Texas (Fig. 8). The potential uranium resource estimates are summarized in Table 12.

TABLE 12. Potential uranium resources in the Coastal Plain

Cost Category	Tons U_3O_8 1/ Probable	Possible	Speculative
$10	40,000	38,000	4,000
$15	54,000	54,000	6,000
$30	100,000	128,000	31,000

1/ Resources in each class include all lower cost resources in that class.

Regional geologic setting

The Coastal Plain is underlain by a seaward thickening wedge of Upper Cretaceous, Tertiary, and Quaternary sediments that were deposited in near-coast marine and continental environments. At the inner margin, the sedimentary wedge is largely unconformable on older sedimentary, metamorphic, and igneous rocks. Gently dipping, poorly consolidated, terrigenous sediments of Tertiary age immediately underlie the greater part of the plain, although in Florida equivalent rocks are mainly carbonates. During the middle Tertiary, thick tuffaceous beds were deposited in the western Gulf Coastal Plain Basin, and phosphatic beds were deposited in Florida and in the southern Atlantic Coastal Plain Basin.

Overview of uranium resources

In the Texas Coastal Plain, uranium deposits are known only in Tertiary strata. Deposits are mined to depths of 275 feet in open pits and to 600 feet by solution mining.

Most uranium deposits in the Jackson Group of Eocene age are in tuffaceous sandstone, bentonitic claystone, and lignite within strand plain and barrier bar environments. Nearly all of the uranium in the Catahoula Formation of Oligocene (?) age is associated with tuffaceous channel-fill sandstone. Most deposits in the Oakville Sandstone of Miocene age and the Goliad Sand of Pliocene age are adjacent to growth faults and to structures formed over salt domes.

Weathering of tuffaceous material in the Catahoula Formation is believed to have enriched ground water with uranium. Hydrogen sulfide in natural gas, which migrated along faults from underlying petroleum reservoirs, may have reduced and precipitated the uranium to form the characteristic roll-type deposits. The convex sides of the roll fronts generally are oriented downdip, and the deposits trend subparallel with the strike of host sandstones. The ore deposits probably formed as early as Miocene, but later erosion cycles redistributed the uranium. Tonnage and grade of the deposits are controlled by the geometry, permeability, and porosity of the host rocks, by the relation of the host rocks to faults, and by the chemistry of the ground water.

<u>Potential uranium resources</u> (Tables 12, 13, and 14; Figs. 16, 17, and 18)

The most promising possibilities for additional deposits of uranium in south Texas are in strand plain and barrier bar sandstones in the Jackson Group beneath the Catahoula Formation. East Texas and Louisiana are expected to provide new discoveries in deltaic sandstone, mudstone, and lignite of the Jackson Group. In addition, potential resources have been assigned to Tertiary deltaic beds peripheral to salt domes. These structures are considered favorable because of the presence of reductants and faults along which uranium and hydrogen sulfide can migrate. The Palangana dome, Texas, is a notable example of the uranium potential of these geochemical traps.

Potential uranium resources of Louisiana and east Texas are associated with southeast-trending paleochannel sandstones of Oligocene to Pliocene age. The Catahoula Formation is less favorable in this region than in south Texas because it contains less tuffaceous detritus, is thinner, and has greater continuity. The latter may have permitted wide dispersion of uranium and decreased the possibilities for uranium concentration.

Sandstones of the Dexter Member of the Upper Cretaceous Woodbine Formation in northeastern Texas are considered favorable because of their content of volcanic ash that may have been a source of uranium. High radioactivity has been noted in oil-well logs where drilling has penetrated faults, suggesting that uranium deposits may exist in the Woodbine as deep as 3,500 feet. Fluvial deltaic beds of the Wilcox Formation of Eocene age also offer possibilities for uranium deposits.

The Mississippi embayment is another favorable area for uranium in association with fluvial and deltaic sandstone beds of Late Cretaceous to Pleistocene age. The Wilcox Formation offers perhaps the greatest promise for future discoveries in this area.

Farther to the east, in the middle Atlantic Coastal Plain, fluvial and tidal sandstones of the Black Creek Formation of Late Cretaceous age have possibilities.

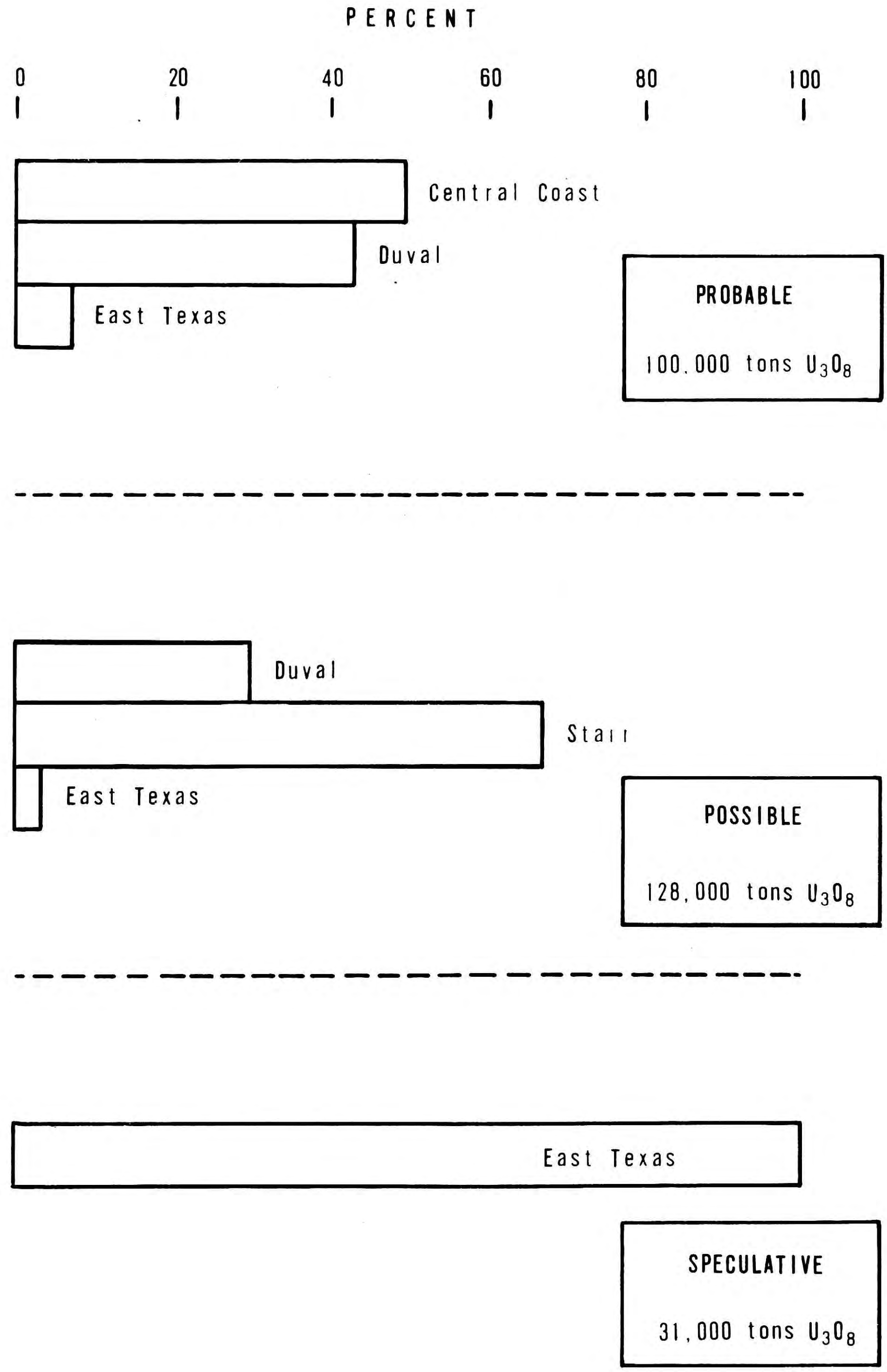


Figure 16. Distribution of $30 potential uranium resources for the Coastal Plain.

TABLE 13. Distribution of $30 potential uranium resources in the Coastal Plain

Host rock units	Plate 1 Symbol 1/	Tons U_3O_8 Probable	Possible	Speculative
Willis Sand	C1	--	--	2,000
Goliad Sand	C2	6,800	7,500	6,000
Oakville Sandstone	C3	35,800	44,500	2,000
Fleming and Oakville Formations	C4	--	--	20,000
Catahoula Formation	C5	24,400	28,500	--
Whitsett Formation	C6	33,000	47,500	--
Manning Formation	C7	--	--	2/
Wellborn Formation	C8	--	--	2/
TOTALS		100,000	128,000	31,000

1/ Refer to Plate 1 for explanation
2/ Substantially less than 1,000 tons U_3O_8 but included in speculative total

TABLE 14. Areas and rock units in the Coastal Plain that require further study before assessment for potential uranium resources

Area	Plate 2 Symbol 1/	Rock units
Texas Coast	Ca	Jackson Group, Catahoula Formation, Oakville Sandstone, and Goliad Sand
Texarkana, Texas and Arkansas	Cb	Woodbine Formation
Northeast Arkansas and southeast Missouri	Cc	Wilcox Formation
Eastern South Carolina, North Carolina, and Virginia	Cd	Black Creek Formation
Luling - Mexia, Texas	Ce	Wilcox Formation

1/ Refer to Plate 2 for explanation

COASTAL PLAIN REGION			
PERIOD	EPOCH	GULF COASTAL PLAIN WEST OF MISSISSIPPI RIVER	GULF AND ATLANTIC COASTAL PLAIN EAST OF MISSISSIPPI RIVER
QUATERNARY	PLEISTOCENE	Willis Sand	
TERTIARY	PLIOCENE	Goliad Sand	
	MIOCENE	OAKVILLE SANDSTONE ? — ? Fleming Formation	
	OLIGOCENE	CATAHOULA FM.	
	EOCENE	JACKSON GP.: WHITSETT FM.	
		JACKSON GP.: Manning Clay	
		JACKSON GP.: Wellborn Sandstone	
		(Wilcox Formation)	
	PALEOCENE		
CRETACEOUS	UPPER	(Woodbine Formation)	(Black Creek Formation)
	LOWER		

Chart shows only general lateral time equivalence of favorable rock units between geographical areas.

Units that have uranium production and/or reserves and potential resources are capitalized. Units that have estimated potential uranium resources are lower cased. Units that may contain potential resources are in parentheses.

Figure 17. Favorable rock units of the Coastal Plain.

X - Dominant or of primary importance

0 - Subordinate or of secondary importance

Blank - Undetermined or doubtful significance, absent, or inapplicable

ROCK UNITS	DEPOSIT CHARACTERISTICS					LITHOLOGIC AND ORE CONTROL CHARACTERISTICS												
	Known uranium deposits	Surficial uranium minerals	Anomalous radioactivity at outcrop	Co-metals	Other associated metals	Clastic rocks: (C) Coarse (F) Fine (A) Arkosic (Ca) Calcareous (Fs) Feldspathic (Q) Quartzose (V) Volcanic	Other sedimentary: (Ca) Carbonates (C) Chert (E) Evaporites (L) Lignites (P) Phosphates	Volcanics: (E) Extrusive (F) Felsic (I) Intrusive (M) Mafic (T) Tuffaceous (V) Vitric	Plutonic: (F) Felsic (M) Mafic (P) Pegmatitic	Metamorphic: (C) Contact (I) Isochemical	Uranium provenance: (G) Granitic (V) Volcanic	Continental: (C) Paleochannel (D) Deltaic (E) Eolian (F) Fan (L) Lacustrine (P) Paludal	Marine: (A) Abyssal (B) Bathyal (D) Deltaic (L) Littoral (S) Sabkhal	Structural: (B) Breccia (C) Contact (D) Dissemination (F) Fracture (P) Pipe (V) Vein (U) Unconformity (Z) Fold	Reductants: (A) Asphaltite (C) Carbon (H) H_2S (N) Natural gas (S) Sulfide minerals (P) Petroleum	Permeability: (G) Good (F) Fair (P) Poor	Alteration: (B) Bleaching (C) Chlorite (H) Hematite (L) Limonite (S) Sericite	Cementation: (C) Calcite (H) Hematite (L) Limonite (P) Phosphate (S) Silica
Willis Sand			X			CQF					V	C			HS	G		
Goliad Sand	X	X	X	Mo		CAQF	C	FT			V	C		FUZ	HS	G	H	C
Fleming Formation			X			CQCaF		FT			V	C		UZF	HS	G		C
Oakvilie Sandstone	X	X	X	Mo		CVCaQF	C	FT			V	C		FUZ	HS	G	BH	C
Catahoula Formation	X	X	X	Mo		CVCaF	CL	FT			V	C		FUZ	CHS	G	L	CS
Whitsett Formation	X	X	X	Mo		CQVF	L	FT			V	CD		FUZ	CHS	G	BL	CS
Manning Formation			X			CQF	L	FT			V	D		UZ	CS	F		S
Wellborn Formation			X			CQF					V	D	DL	U	S	F		S
Wilcox Formation			X	Fe		CQF	L				V	CD			CS	G	BHL	S
Woodbine Formation						CQF		T			V	CD		FUZ	CHS	G		S
Black Creek Formation						CFQ	L				G	CD		U	CS	F		C

Figure 18. Characteristics of favorable rock units in the Coastal Plain.

Northern Rockies

This region includes the Northern and Middle Rocky Mountains from northeastern Washington to northwestern Wyoming and northeastern Utah (D, Fig. 1). The largest production has come from the Spokane Indian Reservation in northeastern Washington. Areas with minor production include Mt. Spokane, Washington; Basin Creek, Idaho; and the Pryor-Little Mountains along the Wyoming-Montana border (Fig. 8). The potential uranium resource estimates are summarized in Table 15.

TABLE 15. Potential uranium resources in the Northern Rockies

Cost Category	Tons U_3O_8 1/		
	Probable	Possible	Speculative
\$10	10,000	19,000	12,000
\$15	17,000	39,000	27,000
\$30	27,000	62,000	49,000

1/ Resources in each class include all lower cost resources in that class.

Regional geologic setting

Most of the Northern Rocky Mountain region consists of complex mountain belts with intervening basins of small to moderate size. Structural features similar to the Basin and Range province are dominant in east-central Idaho, northern Utah, and southwestern Montana. Large granitic batholiths of Cretaceous to early Tertiary age intruded Upper Precambrian metasedimentary rocks in northeastern Washington, northern and central Idaho, and southwestern Montana. In northwestern Wyoming, lava and many cubic miles of tuffs and other pyroclastics were extruded during Cretaceous to Pliocene time. Elsewhere in Wyoming, uplifted anticlines with Precambrian granitic and metamorphic cores are dominant structural features. Similar uplifts affect a thick section of Upper Precambrian metasedimentary rocks in western Montana.

Overview of uranium resources

The most important deposits occur on the Spokane Indian Reservation in rocks of the Togo Formation of the Precambrian Deer Trail Group. These deposits are in argillaceous metamorphic rocks near contacts with porphyritic quartz monzonite of the Loon Lake batholith of Cretaceous age.

Subeconomic quantities of zinc, iron, molybdenum, and copper minerals occur near or in the ore bodies. Uranium probably was emplaced about the time of quartz monzonite intrusion during Late Cretaceous time, possibly by hydrothermal processes or remobilization of authigenic uranium minerals.

Stratiform uranium deposits also have been found on the Spokane Indian Reservation in thick arkosic conglomerate and sandstone lenses of probable Eocene age. The sediments are overlain by pyroclastic rocks of the Gerome Andesite of Oligocene age and are underlain by porphyritic quartz monzonite of the Loon Lake batholith. The ore bodies have been displaced downward along the west side of north-trending normal faults bounding the Spokane River graben. Uranium is associated with abundant carbonaceous debris and sparse sulfide minerals in sandstone and conglomerate within paleochannels. Depths to ore range from 20 to 400 feet.

The uranium deposits in the Mt. Spokane area in northeastern Washington are in fractured Tertiary alaskite intruded by numerous pegmatites. The uranium occurs in shear zones and as coatings on fractures. Some of the uranium was deposited in Recent time.

The Basin Creek area near Stanley, Idaho, contains uranium in association with abundant carbonaceous debris and pyrite in Tertiary arkosic sandstone overlying granitic rocks. The deposits are less than 300 feet deep.

The Madison Limestone of Mississippian age is the chief host rock in the Pryor and Little Mountains of Montana and Wyoming. Small, shallow uranium deposits occur in silty debris and collapse breccia within fracture-controlled solution cavities in the limestone. The vanadium-uranium ratio in these deposits is about 1:1, and vanadium is a possible economic by-product.

<u>Potential uranium resources</u> (Tables 15, 16, and 17; Figs. 19 and 20)

Fractured metasedimentary rocks near contacts with granitic plutons, coarse Tertiary arkosic sandstone and conglomerate near silicic plutons, veins in fracture zones in granite, and debris in limestone caverns constitute the most favorable sites for uranium deposits in this region. Granites and tuffs may be both host rocks and a source of uranium.

Most potential uranium resources are assigned to deposits in igneous and metasedimentary rocks of Precambrian age at depths less than 1,000 feet. Fractured granitic rocks in fold belts and metasedimentary rocks intruded by Cretaceous plutons are favorable settings.

Other potential resources are assigned to continental sedimentary rocks (mostly of Eocene age) within 500 to 3,000 feet of the surface. The favorable settings are grabens and elongated rifts near large granitic plutons. Carbonaceous debris and pyrite enhance the favorability of these sites.

TABLE 16. Distribution of $30 potential uranium resources in the Northern Rockies

Host rock units	Plate 1 Symbol 1/	Tons U_3O_8 Probable	Possible	Speculative
Bozeman Group	D1	--	--	15,000
Unnamed Tertiary rocks in the Missoula Basin	D2	--	--	2,000
Northeastern Washington Tertiary rocks	D3	4,500	9,000	5,000
Challis Volcanics	D4	--	--	5,000
Unnamed Tertiary strata, Basin Creek area	D5	--	4,500	--
Kriley Formation	D6	--	--	2,000
Northeastern Washington silicic plutons	D7	--	5,000	--
Boulder Batholith (quartz monzonite)	D8	--	--	4,000
Idaho Batholith, Basin Creek area	D9	--	--	3,000
Twin Creek Limestone	D10	--	--	1,000
Madison Limestone	D11	100	--	--
Covada Group	D12	--	--	4,000
Paleozoic metasedimentary rocks	D13	--	--	3,000
Precambrian rocks	D14	22,400	43,500	5,000
TOTALS		27,000	62,000	49,000

1/ Refer to Plate 1 for explanation

TABLE 17. Areas and rock units in the Northern Rockies that require further study before assessment for potential uranium resources

Area	Plate 2 Symbol 1/	Rock units
Long and Cascade Valley	Da	Unnamed sedimentary rocks
Gibbonsville	Db	Precambrian metamorphic rocks
Sawtooth Valley	Dc	Unnamed sedimentary rocks
Sawtooth Batholith	Dd	Tertiary granitic rocks
Northern Big Horn Basin	De	Flathead Sandstone
Wanship	Df	Frontier Formation
Evanston	Dg	Ephraim Conglomerate
Kaycee	Dh	Tensleep Sandstone and Phosphoria Formation
Lander	Di	Tensleep Sandstone and Phosphoria Formation

1/ Refer to Plate 2 for explanation

NORTHERN ROCKIES REGION

PERIOD	EPOCH	NORTHEASTERN WASHINGTON	NORTHERN IDAHO, N.W. MONTANA	IDAHO BATHOLITH AREAS	EAST CENTRAL IDAHO	SOUTHWESTERN MONTANA
TERTIARY	PLIOCENE					
	MIOCENE	Tiger Fm.	unnamed sedimentary rocks	(unnamed sedimentary rocks)	unnamed tuff	Bozeman Group
	OLIGOCENE	GEROME ANDESITE & ASSOC. SED. ROCKS		Challis Volcanics	Challis Volcanics	
	EOCENE	ALASKITE		UNNAMED SEDIMENTARY ROCKS (granite)	Kriley Fm.	
	PALEOCENE	quartz monzonite				quartz monzonite
CRETACEOUS	UPPER			quartz monzonite		
	LOWER					
JURASSIC						
TRIASSIC						
PERMIAN		Covada Group				
PENN.						
MISS.						
DEVONIAN						
SILURIAN						
ORDOVICIAN		metasedimentary rocks				
CAMBRIAN						
PRECAMBRIAN	Z					
	Y	DEER TRAIL GP.	Ravalli Gp.		(Belt Supergroup)	
	X					
	W					

Chart shows only general lateral time equivalence of favorable rock units between geographical areas.

Units that have uranium production and/or reserves and potential resources are capitalized. Units that have estimated potential uranium resources are lower cased. Units that may contain potential resources are in parentheses.

Figure 19. Favorable rock units of the Northern Rockies.

NORTHERN ROCKIES REGION						
PERIOD	EPOCH	BEARTOOTH UPLIFT MONTANA	PRYOR-LITTLE MTS., WYO., MONT.	WASATCH MTS., UTAH	WYOMING OVERTHRUST BELT	WIND RIVER-OWL CREEK-BIGHORN MTS., WYOMING
TERTIARY	PLIOCENE					
	MIOCENE					
	OLIGOCENE					
	EOCENE					
	PALEOCENE					
CRETACEOUS	UPPER			(Frontier Fm.)		
	LOWER				(Ephraim Cgl.)	
JURASSIC				Twin Creek Ls.		
TRIASSIC						
PERMIAN						(Phosphoria Fm.)
PENN.						(Tensleep Ss.)
MISS.			MADISON LS.			
DEVONIAN						
SILURIAN						
ORDOVICIAN						
CAMBRIAN		(Flathead Ss.)				
PRECAMBRIAN	Z			Farmington Canyon Complex		
	Y					
	X					
	W					Plutonic and metamorphic rocks

Chart shows only general lateral time equivalence of favorable rock units between geographical areas.

Units that have uranium production and/or reserves and potential resources are capitalized. Units that have estimated potential uranium resources are lower cased. Units that may contain potential resources are in parentheses.

Figure 19. Favorable rock units of the Northern Rockies - *Continued.*

X - Dominant or of primary importance

0 - Subordinate or of secondary importance

Blank - Undetermined or doubtful significance, absent, or inapplicable

ROCK UNITS	Deposit characteristics: Known uranium deposits	Deposit characteristics: Surficial uranium minerals	Deposit characteristics: Anomalous radioactivity at outcrop	Deposit characteristics: Co-metals	Deposit characteristics: Other associated metals	Lithologic and ore control characteristics: Clastic rocks: (C) Coarse (F) Fine (A) Arkosic (Ca) Calcareous (Fs) Feldspathic (Q) Quartzose (V) Volcanic	Other sedimentary: (Ca) Carbonates (C) Chert (E) Evaporites (L) Lignites (P) Phosphates	Volcanics: (E) Extrusive (F) Felsic (I) Intrusive (M) Mafic (T) Tuffaceous (V) Vitric	Plutonic: (F) Felsic (M) Mafic (P) Pegmatitic	Metamorphic: (C) Contact (I) Isochemical	Uranium provenance: (G) Granitic (V) Volcanic	Continental: (C) Paleochannel (D) Deltaic (E) Eolian (F) Fan (L) Lacustrine (P) Paludal	Marine: (A) Abyssal (B) Bathyal (D) Deltaic (L) Littoral (S) Sabkhal	Structural: (B) Breccia (C) Contact (D) Dissemination (F) Fracture (P) Pipe (V) Vein (U) Unconformity (Z) Fold	Reductants: (A) Asphaltite (C) Carbon (H) H_2S (N) Natural gas (S) Sulfide minerals (P) Petroleum	Permeability: (G) Good (F) Fair (P) Poor	Alteration: (B) Bleaching (C) Chlorite (H) Hematite (L) Limonite (S) Sericite	Cementation: (C) Calcite (H) Hematite (L) Limonite (P) Phosphate (S) Silica
Unnamed Tertiary strata, Idaho											GV	CF						
Unnamed Tertiary tuff			X		Th	V		FT			V	EL		U	C	F		S
Unnamed Oligocene, Miocene and Pliocene strata, Montana			0			CQ		FT			V	CL		FU	C	F		
Bozeman Group		X	X			CAQ	L	FT			GV	CFL		FU	CHS	G	L	
Tiger Formation		X	X			CFs		FT			GV	CFL		FU	CS	G	HL	S
Challis Volcanics		X	X			CVFs		FT			GV	CL		FU	CS	F	L	
Gerome Andesite and sedimentary rocks	X	X	X		Cu	CA	L	EFT			GV	CF		FU	CS	G	L	
Kriley Formation			0			FQ					GV	CF		FUZ		G	H	
Unnamed Tertiary sedimentary rocks, Idaho	X	X	X		Cu,As	CA		FT			GV	CF		FV	CS	G	L	
Unnamed Tertiary alaskite, Washington	X	X	X						FP		G			F				
Sawtooth granite, Idaho		0	X		Mo,Be				F					D		G		
Unnamed Cretaceous-Tertiary quartz monzonite, Idaho	0	X	X		Cu,Sb				F		G			V			S	
Unnamed Cretaceous-Paleocene quartz monzonite, Montana	0	X	X		Cu,Au				F		G			BV	S		CHS	
Unnamed Cretaceous quartz monzonite, Washington	0	X	X						FP		G			VF				
Frontier Formation	0	0	X			CFsQ		T			G	CL	L	UZ		F	L	C
Ephraim Conglomerate	0	X	X			CFsQ					G	CF		UZ	CS	S	L	
Twin Creek Limestone	X	X	X				C					B		Z				C
Covada Group		0	X			FQ	C			I	G		B	FZ	S			
Phosphoria Formation	0	X	X								V		B	FZ			L	S
Tensleep Sandstone	0	X	X			CQ	C				GV		BL	FZ		G	L	
Madison Limestone	X	X	X	V	F	CaC					V		B	BU			L	CS
Unnamed Cambrian and Ordovician metasedimentary rocks		0	X			FQ				I			BL	VUZ	S	G	H	
Flathead Sandstone		0	X			CQ							L	UZ				
Belt Supergroup		X	X		Cu	F				I	V		B	V	S		H	
Ravalli Group		0	X			CFsQ				I	G		BL	Z	S	F		
Deer Trail Group	X	X	X		Cu,Mo					CI			B	BCZ	S	G	CHS	
Farmington Canyon Complex	0	X	X						P		G							
Unnamed Precambrian plutonic and metamorphic rocks	X	X	X		Cu,Mo				F	I	GV			F			LH	

Figure 20. Characteristics of favorable rock units in the Northern Rockies.

Colorado and Southern Rockies

This region includes the Rocky Mountains of southern Wyoming, Colorado, and northern New Mexico (E, Fig. 1). Production has come chiefly from the Front Range, Tallahassee Creek, Marshall Pass, and Cochetopa areas, all in Colorado (Fig. 8). The potential uranium resource estimates are summarized in Table 18.

TABLE 18. Potential uranium resources in the Colorado and Southern Rockies

Cost Category	Tons U_3O_8 1/ Probable	Possible	Speculative
$10	27,000	12,000	2,000
$15	34,000	16,000	6,000
$30	44,000	30,000	12,000

1/ Resources in each class include all lower cost resources in that class.

Regional geologic setting

During Cambrian to Mississippian time, about 2,000 feet of quartzite, dolomite, and limestone were deposited in shallow seas. Pennsylvanian, Permian, and Cretaceous rocks of the region have marine and continental origins, whereas Mesozoic rocks are chiefly continental.

North- to northwest-trending en echelon mountain ranges formed during the Laramide orogeny in late Mesozoic and early Tertiary time. Major movements along reverse and normal faults developed during several stages of uplift accompanied by large-scale volcanic and plutonic activity. Precambrian crystalline rocks are exposed in most high ranges, which commonly are bounded by tilted blocks of Paleozoic and Mesozoic strata. The San Juan Mountains in Colorado are underlain by a thick sequence of Tertiary volcanic rocks. The intermontane basins are filled with thick deposits of Cenozoic sedimentary and volcanic rocks.

Overview of uranium resources

Uranium deposits are widespread. Vein deposits are associated with Precambrian to Mesozoic metamorphic, igneous, and sedimentary rocks. Stratiform deposits occur in Permian, Cretaceous, and Tertiary continental and marginal-marine sedimentary rocks. The vein deposits are related spatially, and probably also genetically, to the Colorado mineral belt, which contains important base- and precious-metal deposits. The veins and some stratiform deposits appear to have been emplaced in Tertiary time.

The uranium vein deposits occurring along the eastern margin of the Front Range in Colorado are commonly associated with complexly branched segments of major northwest-trending faults in the Idaho Springs Formation of Precambrian age. Some of the uranium is disseminated in the wall rock, particularly in garnetiferous biotite-quartz, calc-silicate, and hornblende gneisses. The Schwartzwalder mine, which has been developed to a depth of about 2,400 feet, comprises the largest and most deeply explored uranium-bearing vein system in the region. In the Sawatch Range of Colorado, the mineralized veins generally occur in north- and northwest-trending fault systems cutting Paleozoic and Mesozoic strata. To the west, uranium also is in veins in Miocene plutons of the San Juan Mountains in Colorado.

The stratiform uranium deposits in the Sangre de Cristo Range in Colorado occur in asphaltic and carbonaceous arkosic sandstone and siltstone of the Sangre de Cristo Formation of Permian age.

In the Front Range, deposits in the Dakota Sandstone of Cretaceous age commonly were emplaced in sandstone paleochannels containing abundant carbon trash and interbedded shale lenses, and also in marginal-marine sandstones. In the Wet Mountains, Colorado, the Dakota Sandstone contains uranium associated with fluorite.

The Colorado intermontane basins have important uranium deposits within several Tertiary formations. The host rocks are dominantly volcaniclastics and underlying fluvial arkosic strata. The largest deposits are in the Thirtynine Mile volcanic field near Tallahassee Creek.

<u>Potential uranium resources</u> (Tables 18, 19, and 20; Figs. 21 and 22)

Two-thirds of the estimated potential resources of the region is assigned to veins and intrusive igneous rocks, and the remainder to stratiform deposits. Most of the potential is in veins in Precambrian metamorphic rocks along the eastern margin of the Front Range and in veins in Paleozoic strata in the Sawatch Range of Colorado. Discovery possibilities exist in rocks adjoining the Thirtynine Mile volcanic field of central Colorado, particularly in fluvial volcaniclastic and arkosic strata underlying a thick section of volcanic flows of Oligocene and Miocene age.

TABLE 19. Distribution of $30 potential uranium resources in the Colorado and Southern Rockies

Host rock units	Plate 1 Symbol 1/	Tons U_3O_8 Probable	Possible	Speculative
Quaternary peat bogs	E1	--	--	2/
Santa Fe Formation	E2	--	--	1,000
North Park and Troublesome Formations	E3	--	--	1,000
Antero Formation	E4	1,300	3,000	--
Florissant Lake Beds	E5	200	500	--
Tallahassee Creek Conglomerate and unnamed Tertiary sedimentary rocks	E6	3,900	1,000	--
Farisita Conglomerate	E7	500	500	--
Huerfano Formation	E8	--	--	2/
Poison Canyon Formation	E9	--	--	1,000
Middle Park Formation	E10	--	--	2/
Laramie Formation	E11	--	500	--
Dakota Sandstone	E12	1,300	1,500	--
Morrison Formation	E13	5,700	6,000	--
Sangre de Cristo Formation	E14	--	--	3,000
Fountain, Minturn, and Belden Formations	E15	13,000	1,000	--
Harding and Sawatch Quartzites	E16	3,200	500	--
Precambrian granite and pegmatite	E17	--	500	3,000
Metamorphic rocks (includes Idaho Springs Formation)	E18	14,900	15,000	1,000
Miocene volcanic rocks	E19	--	--	1,000
Tertiary volcanic rocks	E20	--	--	2/
TOTALS		44,000	30,000	12,000

1/ Refer to Plate 1 for explanation
2/ Substantially less than 1,000 tons U_3O_8 but included in speculative total

TABLE 20. Areas and rock units in the Colorado and Southern Rockies that require further study before assessment for potential uranium resources

Area	Plate 2 Symbol 1/	Rock units
Fort Collins	Ea	Precambrian granite and metamorphic rocks
North and Middle Park	Eb	Tertiary rocks, undivided
Boulder	Ec	Precambrian granite and metamorphic rocks
Kenosha and East Kenosha Pass	Ed	Precambrian granite and metamorphic rocks
Badger Flats	Ee	Precambrian granite and metamorphic rocks
St. Peters Dome	Ef	Precambrian granite and metamorphic rocks
Antero Basin	Eg	Antero Formation
Vail	Eh	Pennsylvanian rocks, undivided
Cotopaxi	Ei	Precambrian granite and metamorphic rocks
Garo	Ej	Garo Formation

1/ Refer to Plate 2 for explanation

COLORADO AND SOUTHERN ROCKIES REGION

PERIOD	EPOCH	NORTHERN COLORADO AND WYOMING	SOUTHERN COLORADO AND NEW MEXICO
QUATERNARY	PLEISTOCENE	peat bogs	
TERTIARY	PLIOCENE		
	MIOCENE	Thirtynine Mile Andesite North Park & Troublesome Fms.	Santa Fe Fm. volcanic rocks undivided
	OLIGOCENE	UNNAMED SEDIMENTARY ROCKS: Antero Fm. Florissant Lake Beds TALLAHASSEE CREEK CGL.	
	EOCENE		Farisita Cgl. Huerfano Fm.
	PALEOCENE	Middle Park Fm.	Poison Canyon Fm.
CRETACEOUS	UPPER	Laramie Fm. DAKOTA SS.	DAKOTA SS.
	LOWER		
JURASSIC	UPPER	Garo Fm.	MORRISON FM.
	MIDDLE		
	LOWER		
TRIASSIC	UPPER	Chinle Fm. Shinarump Mbr.	
	MIDDLE		
	LOWER		
PERMIAN	UPPER		
	LOWER		Sangre de Cristo Fm.
PENNSYLVANIAN	UPPER		
	MIDDLE	Minturn Fm. Fountain Fm.	BELDEN FM.
	LOWER		
ORDOVICAN	UPPER		
	MIDDLE		HARDING QUARTZITE
	LOWER		
CAMBRIAN	UPPER		Sawatch Quartzite
	MIDDLE		
	LOWER		
PRECAMBRIAN		granites and pegmatites metamorphic rocks IDAHO SPRINGS GNEISS	granites and pegmatites metamorphic rocks

Chart shows only general lateral time equivalence of favorable rock units between geographical areas.

Units that have uranium production and/or reserves and potential resources are capitalized. Units that have estimated potential uranium resources are lower cased.

Figure 21. Favorable rock units of the Colorado and Southern Rockies.

X - Dominant or of primary importance

0 - Subordinate or of secondary importance

Blank - Undetermined or doubtful significance, absent, or inapplicable

ROCK UNITS	DEPOSIT CHARACTERISTICS					LITHOLOGIC AND ORE CONTROL CHARACTERISTICS												
	Known uranium deposits	Surficial uranium minerals	Anomalous radioactivity at outcrop	Co-metals	Other associated metals	Clastic rocks: (C) Coarse (F) Fine (A) Arkosic (Ca) Calcareous (Fs) Feldspathic (Q) Quartzose (V) Volcanic	Other sedimentary: (Ca) Carbonates (C) Chert (E) Evaporites (L) Lignites (P) Phosphates	Volcanics: (E) Extrusive (F) Felsic (I) Intrusive (M) Mafic (T) Tuffaceous (V) Vitric	Plutonic: (F) Felsic (M) Mafic (P) Pegmatitic	Metamorphic: (C) Contact (I) Isochemical	Uranium provenance: (G) Granitic (V) Volcanic	Continental: (C) Paleochannel (D) Deltaic (E) Eolian (F) Fan (L) Lacustrine (P) Paludal	Marine: (A) Abyssal (B) Bathyal (D) Deltaic (L) Littoral (S) Sabkhal	Structural: (B) Breccia (C) Contact (D) Dissemination (F) Fracture (P) Pipe (V) Vein (U) Unconformity (Z) Fold	Reductants: (A) Asphaltite (C) Carbon (H) H_2S (N) Natural gas (S) Sulfide minerals (P) Petroleum	Permeability: (G) Good (F) Fair (P) Poor	Alteration: (B) Bleaching (C) Chlorite (H) Hematite (L) Limonite (S) Sericite	Cementation: (C) Calcite (H) Hematite (L) Limonite (P) Phosphate (S) Silica
Quaternary peat bogs	X		X		Cu		L											
Santa Fe Formation			X			CAQ		FT			V							
North Park and Troublesome Formations	X	X	X	V	Cu	CAQ		FT			V	C		FU	CS	G	BL	C
Antero Formation	X	X	X		Cu	CAQ		FT			G	C		U	CS	G	BL	C
Florissant Lake Beds	X	X	X					FT			V	L				G	BL	C
Tallahassee Creek Conglomerate	X	X	X		Cu	CA		FT			G	C			CS	G	BL	CS
Farisita Conglomerate	X	X	X		Cu	CA		FT			V	CF			S	G	BL	CS
Huerfano Formation	0	0	0			CA		FT			V	CF				G	BL	C
Poison Canyon Formation	0	0	0			CAQ					G	C		UZ		G	L	CS
Middle Park Formation	X	X	X		Cu	CA		FT			V	CF			CS	G	BL	C
Laramie Formation	X	X	X		Cu	CQ	L				G			FZ	CHS	F	L	S
Dakota Sandstone	X	X	X		Cu	CAQ					G	C		FUZ	CHS	F	L	S
Morrison Formation	X	X	X	V	Cu,As	CAQ		FT			V	C		DFU	CS	G	L	CS
Sangre de Cristo Formation	X	X	X		Cu,V	CAQ					G	C		FBUZ	ASC	P	BH	CS
Fountain Formation	X		0			CAQ					G	C	L	BUF	CHS	F		S
Minturn Formation	X	0	0		Cu	CAQ		FT			G	C	L	BU	CS	F		S
Belden Formation	X	X	0		Cu		C	FT			G		B	DF	CS	F		CS
Harding and Saguache Quartzite	0	0	0		Cu								BL	FBUZ		P		
Idaho Springs Formation	X	X	X		Cu,F					C				BFEZ		P	CLS	S
Precambrian granite and pegmatites	X	X	X		Cu,Pb				F					BCFZ		P	CLS	S
Unnamed metamorhpic rocks	X	0	X		Cu,Pb					C				BCFZ		P	C	
Miocene volcanic rocks	X	X	X		Cu,Pb			FT						BFZ		G	L	S

Figure 22. Characteristics of favorable rock units in the Colorado and Southern Rockies.

Great Plains

This region includes part of the central United States from Montana and North Dakota southward to Texas (F, Fig. 1). The principal uranium mining areas are in the Black Hills in Wyoming and South Dakota; Cave Hills-Slim Buttes, South Dakota; and Belfield, North Dakota (Fig. 8). The potential uranium resource estimates are summarized in Table 21.

TABLE 21. Potential uranium resources in the Great Plains

Cost Category	Tons U_3O_8 1/		
	Probable	Possible	Speculative
$10	10,000	13,000	3,000
$15	19,000	34,000	13,000
$30	26,000	57,000	37,000

1/ Resources in each class include all lower cost resources in that class.

Regional geologic setting

During most of the Paleozoic Era the region was submerged and covered by a thick sequence of marine sedimentary rocks. The Mesozoic Era was characterized by alternating continental and marine deposition up to the time of the Larmide orogeny. The Great Plains has subsequently been a stable area on which continental strata derived chiefly from the Rocky Mountains were deposited. More than half of the region had most of its Tertiary cover removed by erosion in late Cenozoic time, exposing pre-Tertiary rocks.

The major structures of the Great Plains are the Williston, Denver, Palo Duro, and Midland Basins, the Black Hills uplift, and the Sierra Grande-Las Animas arch.

Overview of uranium resources

Cretaceous host rocks are fluviatile, cross-stratified, carbonaceous sandstone of the Dakota Sandstone in the Canon City embayment and the Salina Basin; the Inyan Kara Group of the Black Hills; and the Laramie and Fox Hills Formations in the Denver Basin. Thin lignite beds in the Fort Union Formation of Paleocene age have been mined for uranium in the Cave Hills-Slim Buttes and Belfield areas in the western Williston Basin.

Uranium deposits in the Black Hills are both tabular and roll type. The ore occurs in fine- to medium-grained quartzose sandstone of the Fall River and Lakota Formations of the Inyan Kara Group. Altered rock commonly contains hematite and limonite. Uranium mines have been developed to a depth of about 350 feet, but mineralized zones are known as deep as 2,000 feet. Vanadium has been recovered as a by-product from the Black Hills ore.

The most likely source of uranium in this region is tuffaceous material of Oligocene and younger ages that once blanketed the area. Uranium was probably leached from the tuffs and carried by ground water through permeable sandstone to sites favorable for deposition. In some areas, particularly where arkoses are well developed, granitic rocks may have been the dominant uranium source.

Potential uranium resources (Tables 21, 22, and 23; Figs. 23 and 24)

Potential resources have been assigned to sandstone units of the Dockum and Inyan Kara Groups and Laramie, Fox Hills, Dawson, and White River Formations. Both lignite and sandstone in the Fort Union Formation contain potential resources, particularly in the western Williston Basin. The potential resources are located primarily along the western margin of the Great Plains.

TABLE 22. Distribution of $30 potential uranium resources in the Great Plains

Host rock units	Plate 1 Symbol 1/	Tons U_3O_8 Probable	Possible	Speculative
White River Formation	F1	--	--	5,000
Dawson Arkose	F2	--	--	3,000
Fort Union Formation	F3	9,600	15,500	--
Laramie, Lance, and Fox Hills Formations	F4	--	25,000	10,000
Inyan Kara Group	F5	16,400	16,500	--
Dockum Group (includes Chinle Formation)	F6	--	--	7,000
Tertiary intrusive rocks	F7	--	--	12,000
TOTALS		26,000	57,000	37,000

1/ Refer to Plate 1 for explanation

TABLE 23. Areas and rock units in the Great Plains that require further study before assessment for potential uranium resources

Area	Plate 2 Symbol 1/	Rock units
Southeastern New Mexico	Fa	Dockum Group
Colorado, Kansas, Oklahoma, and New Mexico	Fb	Dakota Sandstone and Dockum Group
Canon City embayment	Fc	Dakota Sandstone
Fort Peck Reservoir	Fd	Fort Union Formation and Upper Cretaceous rocks, undivided
Bull Mountain Basin	Fe	Fort Union Formation and Upper Cretaceous rocks, undivided
Sweet Grass Arch	Ff	Upper Cretaceous rocks, undivided
Minnesota and Red River valleys	Fg	Lower Cretaceous strata and Precambrian granitic, volcanic, and metamorphic rocks
Nebraska and Kansas	Fh	Dakota Sandstone
Nebraska and Wyoming	Fi	White River Formation
Las Vegas Basin	Fj	Sangre de Cristo Formation
Western Williston Basin	Fk	Fort Union Formation
Southwestern Williston Basin	Fl	Lance and Fox Hills Formations
Llano Uplift area	Fm	Hickory Sandstone and Precambrian granitic and metamorphic rocks

1/ Refer to Plate 2 for explanation

GREAT PLAINS REGION								
PERIOD	EPOCH	W. NEBRASKA, E. WYOMING, E. COLORADO, W. KANSAS	OKLAHOMA PANHANDLE, W. TEXAS	EASTERN NEW MEXICO	BLACK HILLS, SOUTH DAKOTA	WILLISTON BASIN, NORTH & SOUTH DAKOTA	CENTRAL & WESTERN MONTANA	MINNESOTA, NORTH & SOUTH DAKOTA
TERTIARY	PLIOCENE		(Ogallala Fm.)					
	MIOCENE	(Arikaree Gp.)						
	OLIGOCENE	(White River Fm.)			White River Fm.			
	EOCENE	Dawson Fm.						
	PALEOCENE					FORT UNION FM.	(Fort Union Fm.)	
CRETACEOUS	UPPER	Laramie Fm. Fox Hills Ss.				Lance Fm. Fox Hills Ss.	(sedimentary rocks undivided)	
	LOWER	(Dakota Ss.)			INYAN KARA GP: FALL RIVER FM. LAKOTA FM.		(Dakota Gp): (First Cat Creek Ss.) (Kootenai Fm.)	(Dakota Ss.)
JURASSIC								
TRIASSIC	UPPER		Dockum Group	Chinle Fm.: Cuervo Mbr.				
	MIDDLE							
	LOWER							
PERMIAN	UPPER							
	LOWER			(Sangre de Cristo Fm.)				
CAMBRIAN	UPPER		(Hickory Ss.)					
	MIDDLE							
	LOWER							
PRECAMBRIAN	Z							
	Y		(granitic and metamorphic rocks)					
	X							
	W							(granitic, volcanic, & metamorphic rocks)

Chart shows only general lateral time equivalence of favorable rock units between geographical areas.

Units that have uranium production and or reserves and potential resources are capitalized. Units that have estimated potential uranium resources are lower cased. Units that may contain potential resources are in parentheses.

Figure 23. Favorable rock units of the Great Plains.

X - Dominant or of primary importance

O - Subordinate or of secondary importance

Blank - Undetermined or doubtful significance, absent, or inapplicable

ROCK UNITS	DEPOSIT CHARACTERISTICS					LITHOLOGIC AND ORE CONTROL CHARACTERISTICS												
	Known uranium deposits	Surficial uranium minerals	Anomalous radioactivity at outcrop	Co-metals	Other associated metals	Clastic rocks: (C) Coarse (F) Fine (A) Arkosic (Ca) Calcareous (Fs) Feldspathic (Q) Quartzose (V) Volcanic	Other sedimentary: (Ca) Carbonates (C) Chert (E) Evaporites (L) Lignites (P) Phosphates	Volcanics: (E) Extrusive (F) Felsic (I) Intrusive (M) Mafic (T) Tuffaceous (V) Vitric	Plutonic: (F) Felsic (M) Mafic (P) Pegmatitic	Metamorphic: (C) Contact (I) Isochemical	Uranium provenance: (G) Granitic (V) Volcanic	Continental: (C) Paleochannel (D) Deltaic (E) Eolian (F) Fan (L) Lacustrine (P) Paludal	Marine: (A) Abyssal (B) Bathyal (D) Deltaic (L) Littoral (S) Sabkhal	Structural: (B) Breccia (C) Contact (D) Dissemination (F) Fracture (P) Pipe (V) Vein (U) Unconformity (Z) Fold	Reductants: (A) Asphaltite (C) Carbon (H) H_2S (N) Natural gas (S) Sulfide minerals (P) Petroleum	Permeability: (G) Good (F) Fair (P) Poor	Alteration: (B) Bleaching (C) Chlorite (H) Hematite (L) Limonite (S) Sericite	Cementation: (C) Calcite (H) Hematite (L) Limonite (P) Phosphate (S) Silica
Ogallala Formation			O			CQ		FT			V	CEF		U	C	G		C
Arikaree Formation						CQ		FT			V	CE		U	C	G		
White River Formation		O	O			CQ		FT			V	CL		U	C	F	L	C
Dawson Arkose			O			CAQ		FT			G	CL		U		G		S
Fort Union Formation	X	X	X		Mo	FQ	L					CLP			C	F		C
Laramie Formation	X	O	X		Cu	CQ	L				G	CP		UZ	CHS	G		CS
Fox Hill's Sandstone			O		Cu	CQ							L	UZ	CS	G		S
Dakota Sandstone	X	X	X		Cu	CQ	L				G	C	DL	UZ	CS	G		S
Fall River Formation	X	X	X	V		FQ					V	CP	L			G		CS
Lakota Formation	X	X	X	V		CQ					V	CPF				G		CS
First Cat Creek Sandstone						CQ							BL			G		
Kootenai Formation						CQ						C				G		
Dockum Group	X	X	X		Cu,Mo	CAQ	C	FT			V	CL		U	CS	F	BL	CQ
Chinle Formation																		
Cuerro Sandstone Member	X	X	X		Cu,Mo	CAQ	C	FT			V	CL			CS	F	BL	CQ
Sangre de Cristo Formation	O	O	X	Mo	Cu	CAQ					G	CL	L	FZ	CS	F		CQ

Figure 24. Characteristics of favorable rock units in the Great Plains.

Basin and Range

This region extends from southern Oregon to western Texas (G, Fig. 1). Marysvale and Topaz Mountain, Utah, and Lakeview, Oregon, have been the most important uranium-producing areas. Areas with minor production include the Wah Wah Mountains and Indian Creek, Utah; Coso, California; Austin and Mountain City, Nevada; and Sierra Ancha and Artillery Peak, Arizona (Fig. 8). The potential uranium resource estimates are summarized in Table 24.

TABLE 24. Potential uranium resources in the Basin and Range

Cost Category	Tons U_3O_8 1/		
	Probable	Possible	Speculative
$10	12,000	17,000	25,000
$15	28,000	41,000	53,000
$30	106,000	235,000	105,000

1/ Resources in each class include all lower cost resources in that class.

Regional geologic setting

The Basin and Range is characterized by northerly-trending fault-block mountains separated by broad, alluvium-filled valleys. Mountain ranges are composed of Precambrian and younger sedimentary, metamorphic, and igneous rocks. The complex structure of the region results from deformations during the Laramide and older orogenies and from widespread thrust faulting that started in late Mesozoic time and block faulting in Tertiary time. Tertiary volcanic rocks and clastic strata mask older rocks in broad area. Mesozoic and Tertiary granitic plutons and Tertiary rhyolitic intrusions are widespread.

Overview of uranium resources

Some uranium deposits in the Basin and Range are in Tertiary and Mesozoic arkosic and tuffaceous rocks which, in places, have been intruded by rhyolite and andesite plugs. Near Lakeview, Oregon, an ore body extends from a rhyolite plug into an adjacent sandstone.

Uraniferous veins occur throughout the region in granitic, volcanic, and metamorphic rocks of diverse ages. The most productive deposits are in quartz monzonite and rhyolite at Marysvale, Utah. Uranium ore has been mined to a depth of about 1,600 feet from three northeast-trending veins. Numerous uranium deposits and occurrences are associated with Tertiary volcanic rocks in a belt extending west from Marysvale, particularly in the Tushar and Wah Wah Mountains.

In the Sierra Ancha of Arizona, vein deposits occur in a thinly stratifed sandy siltstone in the Dripping Spring Quartzite of Precambrian age, mostly within 300 feet of diabase sills. In the Burro Mountains, New Mexico, small uranium deposits in Precambrian granite commonly are associated with copper-bearing quartz-pyrite veins.

At Topaz Mountain, Utah, secondary uranium minerals are disseminated in a tuffaceous sandstone underlain by Tertiary volcanic rocks. Nearby are deposits of uraniferous fluorspar and a beryllium-bearing volcanic tuff that also contains uranium.

Lake beds in the Chapin Wash Formation of Tertiary age within a small intermontane basin near Artillery Peak, Arizona, contain uranium in carbonaceous mudstone beds in a partly silicified limestone, siltstone, and tuff sequence.

In the Rio Grande Trench, small discontinuous pods of ore occur in a brecciated fault zone in altered volcanic and clastic rocks of the Espinaso Formation of Miocene age, and along the faulted contact between Precambrian granite and the Popotosa Formation of Miocene age.

Contact zones between granite intrusives and metamorphic rocks are also favorable for uranium deposits. The largest known contact deposit in the region was mined near Austin, Nevada. Similar occurrences are near Winnemucca Lake and Belmont, Nevada, and Bishop, California. Most uranium deposits in the region were emplaced during Tertiary time.

Other possible environents for uranium occurrences are playa sediments and calcrete deposits that occur in many areas of the region.

Potential uranium resources (Tables 24, 25, and 26; Figs. 25 and 26)

Potential resources have been estimated for numerous areas of the Basin and Range. Much of the potential resources were assigned to Tertiary rocks such as the beryllium tuffs of west-central Utah; arkosic fanglomerates of the Coso Formation in east-central California; the volcanic rocks in the Marysvale, Utah, area; and sedimentary rocks intruded by Tertiary rhyolite plugs, such as at Lakeview, Oregon. Other environments for which potential resources were estimated include veins near contacts of granites with metasedimentary rocks, and uraniferous granites, rhyolites, and tuffs. Likely depths range from the surface to 500 feet for the Tertiary beds and to 2,000 feet for the veins.

The region is favorable for large low-grade uranium deposits in granitic and rhyolitic stocks and volcanic tuffs. Uranium also is enriched locally in brines beneath playas in Nevada and California.

TABLE 25. Distribution of $30 potential uranium resources in the Basin and Range

Host rock units	Plate 1 Symbol 1/	Tons U_3O_8 Probable	Possible	Speculative
NORTHERN AND CENTRAL BASIN AND RANGE:				
Coso Formation	G1	45,300	5,500	--
Truckee Formation	G2	--	--	5,000
Virgin Valley Formation	G3	--	1,500	--
Chapin Wash and Artillery Formations	G4	4,300	1,500	--
Panaca Formation	G5	--	--	3,000
Verde Valley Formation	G6	--	--	1,000
Humboldt Formation	G7	4,200	8,000	--
Cedarville Formation	G8	7,000	21,000	--
Mount Belknap Rhyolite	G9	27,100	--	--
Beryllium tuff	G10	5,500	162,000	--
Esmeralda Formation	G11	--	3,000	--
"Siebert tuff" (Esmeralda Formation)	G12	2,500	12,500	--
Big Sandy Formation	G13	--	--	3,000
Horse Spring Formation	G14	--	--	1,000
Silver Reef Formation	G15	--	--	3,000
Ely Springs Formation	G16	--	--	1,000
Unnamed sedimentary rocks of Tertiary age in:				
Owens Valley - Panamint Valley	G17	--	--	3,000
Mojave Desert	G18	--	--	5,000
Long Ridge	G19	--	500	--
Topaz Mountain	G20	1,900	--	--
Tonopah area	G21	--	--	4,000
North Toiyabe	G22	--	--	1,000
Railroad Valley	G23	--	--	1,000
Black Rock Desert	G24	--	--	1,000
Desert Valley	G25	--	--	1,000
Winnemucca Lake	G26	--	--	1,000
Muggins Mountains	G27	--	500	--

TABLE 25. Distribution of $30 potential uranium resources in the Basin and Range - *Continued*

Host rock units	Plate 1 Symbol 1/	Tons U_3O_8 Probable	Possible	Speculative
Unnamed volcanic rocks in Tertiary age in:				
Railroad Valley	G28	--	--	1,000
Tonopah area	G29	--	--	2,000
Mojave area	G30	--	--	5,000
Mountain City area	G31	600	1,000	--
Needles - Wah Wah Ranges	G32	--	500	--
Staatz Plug	G33	200	--	--
Kings River area	G34	700	500	--
Nightingale Range	G35	--	--	9,000
Coaldale area	G36	--	--	1,000
Scottys Junction area	G37	--	--	2/
Bullfrog Hills	G38	--	--	2,000
Beatty area	G39	--	--	1,000
Pike Creek area	G40	--	--	1,000
Unnamed granitic rocks in:				
Kings River area	G41	--	--	1,000
Owens Valley	G42	--	--	9,000
Sheeprock Mountains	G43	--	--	1,000
Nightingale Range	G44	--	3,500	--
Lovelock area	G45	--	--	5,000
Austin area	G46	1,400	2,500	--
Marysvale area	G47	1,800	500	--
Toquima Range	G48	--	--	3,000
Gabbs area	G49	--	--	1,000
Marietta area	G50	--	--	1,000
North Toiyabe Range	G51	--	--	2/
Rawhide Mountains	G52	700	500	--
Cerbat Mountains	G53	--	500	--
Bagdad area	G54	--	1,500	--

TABLE 25. Distribution of $30 potential uranium resources in the Basin and Range - *Continued*

Host rock units	Plate 1 Symbol 1/	Tons U_3O_8 Probable	Possible	Speculative
Big Maria Mountains	G55	--	--	2,000
Wickenburg area	G56	--	--	2,000
Searchlight area	G57	--	--	1,000
Central Nevada	G58	--	--	2/
Salton Sea area	G59	--	--	2/
Unnamed Mesozoic metamorphic rocks in:				
McCoy Mountains	G60	100	500	--
SOUTHERN AND SOUTHEASTERN BASIN AND RANGE:				
Popotosa Formation	G61	100	500	--
Galisteo Formation	G62	--	--	2/
Thurman and Palm Park Formations	G63	--	--	2/
Espinaso Formation	G64	100	500	--
Parajito Lavas	G65	--	--	1,000
Morrison Formation	G66	--	--	1,000
Chinle Formation	G67	--	--	2/
San Andres Limestone	G68	--	--	2/
Dripping Spring Quartzite	G69	2,500	6,500	--
Precambrian granite	G70	--	--	1,000
Sheep Canyon Formation	G71	--	--	4,000
Pruett Formation	G72	--	--	8,000
Javelina Formation	G73	--	--	1,000
Aguja Formation	G74	--	--	3,000
Tertiary rocks, undivided	G75	--	--	2,000
TOTALS		106,000	235,000	105,000

1/ Refer to Plate 1 for explanation
2/ Substantially less than 1,000 tons U_3O_8 but included in speculative total

TABLE 26: Areas and rock units in the Basin and Range that require further study before assessment for potential uranium resources

Area	Plate 2 Symbol 1/	Rock units
Southeastern New Mexico	Ga	Yates Formation
Hueco Mountains	Gb	Quaternary gravel and alluvium and veins in upper Paleozoic limestone
Franklin Mountains	Gc	Veins in Precambrian granite
Tonto Basin	Gd	Tertiary sedimentary rocks
Lakeview, Oregon area	Ge	Cedarville Formation
Northwestern Nevada	Gf	Tertiary sedimentary and volcanic rocks, and Triassic and Jurassic metasedimentary rocks
Mojave Desert	Gg	Quaternary lake beds, Tertiary volcanic rocks, and Mesozoic granite
Northeastern Nevada	Gh	Humboldt Formation, Tertiary volcanic rocks, and Mesozoic granite
Austin, Nevada area	Gi	Quaternary lake beds. Tertiary sedimentary and volcanic rocks, Mesozoic granite, and Paleozoic metamorphic rocks
Tonopah, Nevada area	Gj	Quaternary lake beds, Esmeralda Formation, and Mesozoic granite
Beatty, Nevada area	Gk	Tertiary volcanic rocks
Owens Valley	Gl	Quaternary lake beds. Mesozoic granite and Precambrian granite
Beaver-Pioche area	Gm	Quaternary lake beds, Tertiary sedimentary and volcanic rocks, Tertiary granite, and Paleozoic limestone
Sheeprock - Thomas Range area	Gn	Quaternary lake beds, Tertiary sedimentary and volcanic rocks, and Tertiary granite
Blythe - Yuma area	Go	Tertiary sedimentary rocks, Mesozoic metamorphic rocks, and Precambrian granite
Artillery Peak area	Gp	Tertiary sedimentary and volcanic rocks, and Precambrian granite
Verde Valley	Gq	Tertiary sedimentary and volcanic rocks, and Precambrian granite
Sierrita Mountains	Gr	Cretaceous granite
Southern Nevada	Gs	Quaternary lake beds and Precambrian granitic rocks

1/ Refer to Plate 2 for explanation

BASIN AND RANGE REGION						
PERIOD	EPOCH	N. CALIFORNIA & S OREGON	CALIFORNIA	WESTERN NEVADA	N. NEVADA S. IDAHO	SOUTHEASTERN NEVADA
QUATERNARY		(unnamed lacustrine sediments)	(unnamed lacustrine sediments)	(unnamed lacustrine sediments)	(unnamed lacustrine sediments)	(unnamed lacustrine sediments)
TERTIARY	PLIOCENE		Coso Formation	Truckee Formation	Thousand Creek Fm.; Virgin Valley and Humboldt Formations	Panaca Formation
TERTIARY	MIOCENE	unnamed rhyolite intrusive rocks; CEDARVILLE FM.	unnamed volcanic rocks	unnamed volcanic rocks; Esmeralda Formation ("Siebert Tuff")	unnamed volcanic rocks; Virgin Valley and Humboldt Formations	
TERTIARY	OLIGOCENE					Horse Spring Fm.
TERTIARY	EOCENE					
TERTIARY	PALEOCENE					
CRETACEOUS	UPPER	unnamed granitic rocks	unnamed granitic rocks	unnamed granitic rocks	unnamed granitic rocks	unnamed granitic rocks
CRETACEOUS	LOWER	unnamed granitic rocks	unnamed granitic rocks	unnamed granitic rocks	unnamed granitic rocks	unnamed granitic rocks
JURASSIC	UPPER	unnamed granitic rocks	unnamed granitic rocks	unnamed granitic rocks	unnamed granitic rocks	
JURASSIC	MIDDLE	unnamed granitic rocks	unnamed granitic rocks	unnamed granitic rocks	unnamed granitic rocks	
JURASSIC	LOWER	unnamed metamorphic rocks	unnamed metamorphic rocks	unnamed metamorphic rocks		
TRIASSIC	UPPER	unnamed metamorphic rocks	unnamed metamorphic rocks	unnamed metamorphic rocks		
TRIASSIC	MIDDLE	unnamed metamorphic rocks	unnamed metamorphic rocks	unnamed metamorphic rocks		
TRIASSIC	LOWER	unnamed metamorphic rocks	unnamed metamorphic rocks	unnamed metamorphic rocks		
PERMIAN						
ORDOVICIAN				unnamed metamorphic rocks		Ely Springs Fm.; Eureka Qtz.
CAMBRIAN				unnamed metamorphic rocks		
PRECAMBRIAN	Z					
PRECAMBRIAN	Y					
PRECAMBRIAN	X		unnamed metamorphic rocks; unnamed granitic rocks			
PRECAMBRIAN	W					

Chart shows only general lateral time equivalence of favorable rock units between geographical areas.

Units that have uranium production and or reserves and potential resources are capitalized. Units that have estimated potential uranium resources are lower cased. Units that may contain potential resources are in parentheses.

Figure 25, Favorable rock units of the Basin and Range.

BASIN AND RANGE REGION						
PERIOD	EPOCH	WESTERN UTAH Marysvale, Beaver, Leeds	WESTERN UTAH Thomas Range, Sheeprock	SOUTHERN ARIZONA NEW MEXICO	BIG BEND AREA, TEXAS	CENTRAL AND SOUTH NEW MEXICO
QUATERNARY		(unnamed lacustrine sediments)	(unnamed lacustrine sediments)			
TERTIARY	PLIOCENE			Verde Valley Fm. CHAPIN WASH FM.		
	MIOCENE	Mt. BELKNAP RHYOLITE	UNNAMED SANDSTONE beryllium tuff Sheeprock granite	unnamed volcanic rocks Big Sandy Fm.		POPOTOSA FM. ESPINASO FM.
	OLIGOCENE	GRANITIC ROCKS unnamed Bullion Canyon Volcanics				Thurman Formation
	EOCENE			Artillery Fm.	Sheep Canyon Fm. Pruett Fm.	Galisteo Fm.
	PALEOCENE					
CRETACEOUS	UPPER			Fort Crittenden Fm.	Javelina Fm. Aguja Fm.	
	LOWER			Parajito Lavas (unnamed granitic rocks)		
JURASSIC	UPPER					Morrison Formation
	MIDDLE					
	LOWER					
TRIASSIC	UPPER	Silver Reef Ss.				Chinle Formation
	MIDDLE					
	LOWER					
PERMIAN				(Yates Fm.)		San Andres Limestone
ORDOVICIAN						
CAMBRIAN				Bolsa Quartzite		
PRECAMBRIAN	Z					
	Y			DRIPPING SPRING QUARTZITE		
	X			unnamed metamorphic rocks unnamed granitic rocks		
	W					

Chart shows only general lateral time equivalence of favorable rock units between geographical areas.

Units that have uranium production and or reserves and potential resources are capitalized. Units that have estimated potential uranium resources are lower cased. Units that may contain potential resources are in parentheses.

Figure 25. Favorable rock units of the Basin and Range - *Continued.*

X - Dominant or of primary importance

0 - Subordinate or of secondary importance

Blank - Undetermined or doubtful significance, absent, or inapplicable

ROCK UNITS	DEPOSIT CHARACTERISTICS: Known uranium deposits	Surficial uranium minerals	Anomalous radioactivity at outcrop	Co-metals	Other associated metals	LITHOLOGIC AND ORE CONTROL CHARACTERISTICS: Clastic rocks: (C) Coarse (F) Fine (A) Arkosic (Ca) Calcareous (Fs) Feldspathic (Q) Quartzose (V) Volcanic	Other sedimentary: (Ca) Carbonates (C) Chert (E) Evaporites (L) Lignites (P) Phosphates	Volcanics: (E) Extrusive (F) Felsic (I) Intrusive (M) Mafic (T) Tuffaceous (V) Vitric	Plutonic: (F) Felsic (M) Mafic (P) Pegmatitic	Metamorphic: (C) Contact (I) Isochemical	Uranium provenance: (G) Granitic (V) Volcanic	Continental: (C) Paleochannel (D) Deltaic (E) Eolian (F) Fan (L) Lacustrine (P) Paludal	Marine: (A) Abyssal (B) Bathyal (D) Deltaic (L) Littoral (S) Sabkhal	Structural: (B) Breccia (C) Contact (D) Dissemination (F) Fracture (P) Pipe (V) Vein (U) Unconformity (Z) Fold	Reductants: (A) Asphaltite (C) Carbon (H) H_2S (N) Natural gas (S) Sulfide minerals (P) Petroleum	Permeability: (G) Good (F) Fair (P) Poor	Alteration: (B) Bleaching (C) Chlorite (H) Hematite (L) Limonite (S) Sericite	Cementation: (C) Calcite (H) Hematite (L) Limonite (P) Phosphate (S) Silica
NORTHERN AND CENTRAL																		
Coso Formation	X	0	X			CAV		FT			V	F		U	S	G	L	
Truckee Formation	X	0	X			CAV		FT			V	CF		U	S	G	L	
Virgin Valley Formation		0	X			CV		EFT			V	L		U	S	G	L	
Chapin Wash and Artillery Formations	X	X	X			CAV					G	C		U	S	G	L	
Panaca Formation	0	0	0			CV					G	C		U	S	G	L	
Verde Valley Formation						FFS					V	C		U		F	L	
Humboldt Formation		0	X			CAV		EPT			V	CF		U	S	G	L	
Cedarville Formation	X	0	X	Mo,Hg	As	FV		FT			V	C		U	S	P	L	
Mount Belknap Rhyolite	X	X	X					ET			V	F		U		P		
Beryllium tuff	0	0	X	Be	F			EFT			V	CF		U		G	BL	
Esmeralda Formation	0	0	X			CAV		T			V	CF		U	S	G	L	
"Siebert tuff" (Esmeralda Formation)	0	0	X			FV		T			V	CF		U	S	G	L	
Big Sandy Formation						CA					G	C		U	S	G	L	
Horse Spring Formation	0	0	0			CQ						C		F		G		
Silver Reef Formation	X	0	X	Cu,Ag		CAQ					V	C		U	C	G	C	
Ely Springs Formation	X		0		Au		C	F					B	P		F		
Unnamed sedimentary rocks of Tertiary age in:																		
Owens Valley			0			CAV					V	C		U	S	G	L	
Mohave Desert	0	0	X			CAV		EFT			V	C		U	S	G	L	
Long Ridge	0	0	X			CAV		EFT			V	C		U	S	G	L	
Tonopah	0	0	X			CAV		EFT			V	C		U	S	G	L	
North Toiyabe	0	0	X			CAV		EFT			V	C		U	S	G	L	
Railroad Valley			0			CAV		EFT			V	C		U	S	G	L	
Black Rock Desert			0			CAV		EFT			V	C		U	S	G	L	
Muggins Mountains		0	0			CA		EFT			V	C		U	S	G	L	
Winnemucca Lake			0			CA		EFT			V	C		U	S	G	L	
Unnamed volcanic rocks of Tertiary age in:																		
Railroad Valley	0	X	X					EFT						FU		P		
Tonopah	0	X	X					EFT						FU		P		
Mohave Desert	0	X	X					EFT						FU		P		
Mountain City	0	X	X					EFT						FU		P		
Needles - Wah Wah	0	X	X					EFT						FU		P		
Staats Plug	X	X	X					IFT						FU		P		
Kings River	X	X	X					EFT						FU		P		
Nightingale	0	X	X					EFT						FU		P		
Coaldale	X	X	X					EFT						FU		P		
Scottys Junction	0	X	X					EF						FU		P		
Bullfrog Hills	X	X	X					EF						FU		P		
Beatty	X	X	X					EF						FU		P		
Pike Creek	X	X	X					EFT						FU		P		

Figure 26. Characteristics of favorable rock units in the Basin and Range.

X - Dominant or of primary importance
0 - Subordinate or of secondary importance
Blank - Undetermined or doubtful significance, absent, or inapplicable

ROCK UNITS	DEPOSIT CHARACTERISTICS: Known uranium deposits	Surficial uranium minerals	Anomalous radioactivity at outcrop	Co-metals	Other associated metals	LITHOLOGIC AND ORE CONTROL CHARACTERISTICS: Clastic rocks: (C) Coarse (F) Fine (A) Arkosic (Ca) Calcareous (Fs) Feldspathic (Q) Quartzose (V) Volcanic	Other sedimentary: (Ca) Carbonates (C) Chert (E) Evaporites (L) Lignites (P) Phosphates	Volcanics: (E) Extrusive (F) Felsic (I) Intrusive (M) Mafic (T) Tuffaceous (V) Vitric	Plutonic: (F) Felsic (M) Mafic (P) Pegmatitic	Metamorphic: (C) Contact (I) Isochemical	Uranium provenance: (G) Granitic (V) Volcanic	Continental: (C) Paleochannel (D) Deltaic (E) Eolian (F) Fan (L) Lacustrine (P) Paludal	Marine: (A) Abyssal (B) Bathyal (D) Deltaic (L) Littoral (S) Sabkhal	Structural: (B) Breccia (C) Contact (D) Dissemination (F) Fracture (P) Pipe (V) Vein (U) Unconformity (Z) Fold	Reductants: (A) Asphaltite (C) Carbon (H) H_2S (N) Natural gas (S) Sulfide minerals (P) Petroleum	Permeability: (G) Good (F) Fair (P) Poor	Alteration: (B) Bleaching (C) Chlorite (H) Hematite (L) Limonite (S) Sericite	Cementation: (C) Calcite (H) Hematite (L) Limonite (P) Phosphate (S) Silica
Unnamed granitic rocks in:																		
Kings River									F		G			F		P		
Owens Valley									F		G			F		P		
Sheeprock			0		Be				F		G			F		P		
Nightingale			0						F		G			F		P		
Lovelock					W				F		G			F		P		
Austin									F		G			F		P		
Marysvale	X	X	X						F		G			F		P		
Toquima Range	0	0	0						F		G			F		P		
Gabbs									F		G			F		P		
Marietta	0	0							F		G			F		P		
North Toiyable									F		G			F		P		
Rawhide Mountains	0	0	0						F		G			F		P		
Cerbat Mountains	0	0	0						F		G			F		P		
Bagdad	X	0	0						F		G			F		P		
Big Maria Mountains	0	0	0						F		G			F		P		
Wickenburg									F		G			F		P		
Searchlight									F		G			F		P		
Central Nevada									F		G			F		P		
Salton Sea									F		G			F		P		
Unnamed Mesozoic metasedimentary rocks:																		
McCoy Mountains	X	0	X							C						P		
SOUTHERN AND SOUTHEASTERN																		
Popotosa Formation	X	X	X	Cu		CFV		EFT			V	C		CF	C	G	L	L
Galisteo Formation	X		X			CQ		T			V	C			C	G	L	S
Thurman and Palm Park Formations						CA		EFT			V	C		F	C	G	L	
Espinaso Formation	X		0			CFV		EFT			V	C		F		G	L	S
Parajito Lavas	0			Pb,Cu				EFT			V			FU		F		
Morrison Formation			0			CAQ		FT			V	CF			CS	G	BL	CS
Chinle Formation	X	0	X	V		CFA		FT			V	CL			CS	F	BL	CS
San Andres Limestone	X	X	X				C						B	F		F		
Dripping Spring Quartzite	X	X	X			CFQ				I		C		F	C	P	L	S
Precambrian granite			X						F		G					P		
Sheep Canyon Formation		X	0			FQ	Ca	EFT			V	CL			C	F		CS
Pruett Formation		X	0			CACa		EFT			V	C		U	C	G	L	CS
Javelina Formation			0			CQ					V	C		U	C	G	B	S
Aguja Formation			0			CQ	L				V	CP	L		C		B	S
Tertiary rocks, undivided			0			CA					V	C		U	C	G		

Figure 26. Characteristics of favorable rock units in the Basin and Range - *Continued.*

Pacific Coast and Sierra Nevada

This region, which includes most of California and the western parts of Nevada, Oregon, and Washington (H, Fig. 1), contains no large uranium mining areas. Small stratiform deposits have been mined in the Sonora Pass, Hallelujah Junction, and Taft-McKittrick areas in California. Uraniferous veins occur in granitic, metamorphic, and volcanic rocks in the Sierra Nevada and Kern River areas where a minor amount of ore was produced (Fig. 8). The potential uranium resource estimates are summarized in Table 27.

TABLE 27. Potential uranium resources in the Pacific Coast and Sierra Nevada

Cost Category	Tons U_3O_8 1/		
	Probable	Possible	Speculative
$10	4,000	12,000	8,000
$15	6,000	24,000	22,000
$30	10,000	42,000	56,000

1/ Resources in each class include all lower cost resources in that class.

Regional geologic setting

Two belts of north-trending ranges, the Coast Ranges along the Pacific Ocean and the Cascade Range and Sierra Nevada to the east, extend almost the entire length of the Pacific Coast. They are partially separated by valley systems in central California, northern Oregon, and Washington.

The tectonic framework of the region is dominated by batholithic intrusions in the Sierra Nevada, volcanism in the Cascade Range, and late Cenozoic orogenic and epeirogenic uplifts. Coastal California is composed of deformed Tertiary sedimentary rocks that overlie Mesozoic metasedmentary and older basement rocks. The rocks have been tilted uplifted, and displaced by normal and lateral faults. The mountains and valleys of coastal Washington and Oregon are part of a broad geanticline.

The region has a wide variety of igneous, metamorphic, and marine sedimentary rocks that are predominantly of Mesozoic and Tertiary ages; some late Paleozoic sedimentary and volcanic rocks are exposed in

California. The Precambrian basement is generally concealed except for some exposures of metamorphic rocks in southern California. Emplacement of the Sierra Nevada batholith and resultant widespread metamorphism occurred during the Nevadan and Laramide orogenies in late Mesozoic time. The Coast Ranges were folded and uplifted in middle Tertiary time, almost simultaneously with renewal of extensive volcanic activity in the northern two-thirds of the region. This volcanic activity subsided in late Cenozoic time with the building of a volcanic mountain chain in the Cascade Range. Renewed uplift of the Sierra Nevada also took place during late Cenozoic time.

Overview of uranium resources

Uranium deposits occur in arkosic and tuffaceous beds of Tertiary age, locally intruded by rhyolite plugs, and in veins that transect granitic, volcanic, and metamorphic rocks. Uranium deposits occur in the Santa Margarita, Truckee, Sespe, and Coldwater Formations in the Taft-McKittrick, Ventura, and Reno areas.

Most production from the region has come from a fluvial, arkosic sandstone within an unnamed Tertiary unit near Sonora Pass, California. The uranium occurs in cobble-filled stream channels as much as 200 feet thick, scoured into water-laid tuff of Miocene age. The deposit is associated with carbonaceous debris along bedding planes and fractures and is overlain by a thick sequence of andesite breccia. Deposits at Hallelujah Junction, California, contain secondary uranium minerals in fractures in the Truckee Formation and in subjacent tuff and granodiorite. East of Bakersfield, California, ore has been mined from veins in granites of the Kern River area. The vein deposits are probably of Mesozoic age, and the sandstone-type deposits were probably peat bogs emplaced in late Tertiary time.

Potential uranium resources (Tables 27, 28, and 29; Figs. 27 and 28)

Most of the potential uranium resources have been assigned to Tertiary arkosic and tuffaceous beds, veins in igneous and metamorphic rocks, and deposits in peat bogs and pegmatites. Granitic rocks in the Sierra batholith and metamorphic rocks near Placerville, California, are also potential host rocks. These potential resources average less than 1,000 feet of depth, although some vein deposits may be as deep as 2,000 feet.

TABLE 28. Distribution of $30 potential uranium resources in the Pacific Coast and Sierra Nevada

Host rock units	Plate 1 Symbol 1/	Tons U_3O_8 Probable	Possible	Speculative
Quaternary peat bogs	H1	--	1,000	4,000
Truckee Formation	H2	--	10,000	--
Santa Margarita Formation	H3	--	--	3,000
Sespe Formation	H4	--	--	2/
Coldwater Sandstone	H5	--	--	2/
Unnamed Tertiary rocks	H6	9,500	14,000	13,000
Unnamed Mesozoic metamorphic rocks, Placerville area	H7	--	500	4,000
Unnamed volcanic rocks	H8	--	15,000	11,000
Unnamed granite	H9	500	1,500	20,000
TOTALS		10,000	42,000	56,000

1/ Refer to Plate 1 for explanation
2/ Substantially less than 1,000 tons U_3O_8 but included in speculative total

TABLE 29. Areas and rock units in the Pacific Coast and Sierra Nevada that require further study before assessment for potential uranium resources

Area	Plate 2 Symbol 1/	Rock units
Northwestern Washington	Ha	Mesozoic-Cenozoic granite and Tertiary continental sandstone
Southwestern Oregon	Hb	Tyee Formation
Northern California and Southern Oregon	Hc	Unnamed Miocene volcanic rocks and Mesozoic granite
Placerville	Hd	Unnamed Mesozoic metasedimentary rocks
Temblor Range	He	Unnamed Tertiary continental sandstone
Northern Sierra Nevada	Hf	Unnamed Mesozoic granite

1/ Refer to Plate 2 for explanation

PACIFIC COAST AND SIERRA NEVADA REGION

PERIOD	EPOCH	WASHINGTON AND OREGON	CALIFORNIA COAST	WESTERN NEVADA AND SIERRA NEVADA RANGE
QUATERNARY			(lacustrine and playa sediments)	Peat bog sediments
TERTIARY	PLIOCENE	unnamed granitic rocks		Truckee Formation
	MIOCENE	(unnamed volcanic rocks)	Santa Margarita Formation	UNNAMED SEDIMENTARY ROCKS unnamed volcanic rocks
	OLIGOCENE		Sespe Formation	Hartford Hill Rhyolite
	EOCENE	(Tyee Formation)	Coldwater Sandstone	
	PALEOCENE	(Swauk and Chuckanut Formations)		
CRETACEOUS	UPPER			
	LOWER		(unnamed granitic rocks)	unnamed granitic rocks
JURASSIC				unnamed metamorphic rocks
TRIASSIC				

Chart shows only general lateral time equivalence of favorable rock units between geographical areas.

Units that have uranium production and/or reserves and potential resources are capitalized. Units that have estimated potential uranium resources are lower cased. Units that may contain potential resources are in parentheses.

Figure 27. Favorable rock units of the Pacific Coast and Sierra Nevada.

X - Dominant or of primary importance
0 - Subordinate or of secondary importance
Blank - Undetermined or doubtful significance, absent, or inapplicable

ROCK UNITS	DEPOSIT CHARACTERISTICS: Known uranium deposits	DEPOSIT CHARACTERISTICS: Surficial uranium minerals	DEPOSIT CHARACTERISTICS: Anomalous radioactivity at outcrop	DEPOSIT CHARACTERISTICS: Co-metals	DEPOSIT CHARACTERISTICS: Other associated metals	LITHOLOGIC AND ORE CONTROL CHARACTERISTICS: Clastic rocks: (C) Coarse (F) Fine (A) Arkosic (Ca) Calcareous (Fs) Feldspathic (Q) Quartzose (V) Volcanic	Other sedimentary: (Ca) Carbonates (C) Chert (E) Evaporites (L) Lignites (P) Phosphates	Volcanics: (E) Extrusive (F) Felsic (I) Intrusive (M) Mafic (T) Tuffaceous (V) Vitric	Plutonic: (F) Felsic (M) Mafic (P) Pegmatitic	Metamorphic: (C) Contact (I) Isochemical	Uranium provenance: (G) Granitic (V) Volcanic	Continental: (C) Paleochannel (D) Deltaic (E) Eolian (F) Fan (L) Lacustrine (P) Paludal	Marine: (A) Abyssal (B) Bathyal (D) Deltaic (L) Littoral (S) Sabkhal	Structural: (B) Breccia (C) Contact (D) Dissemination (F) Fracture (P) Pipe (V) Vein (U) Unconformity (Z) Fold	Reductants: (A) Asphaltite (C) Carbon (H) H_2S (N) Natural gas (S) Sulfide minerals (P) Petroleum	Permeability: (G) Good (F) Fair (P) Poor	Alteration: (B) Bleaching (C) Chlorite (H) Hematite (L) Limonite (S) Sericite	Cementation: (C) Calcite (H) Hematite (L) Limonite (P) Phosphate (S) Silica
Truckee Formation	X	O	X			CAV		T			G	CF		U	S	G		
Santa Margarita Formation	O	O	X								G	C	D	F		F		
Sespe Sandstone	O		O			FQ					G				C	F		
Coldwater Sandstone	O		O			FQ					G				C	F		
Tyee Formation			O			CQFs		T				C				F		
Chuckanut Formation						CA					G	C		U	C	G		
Swauk Formation						CA					G	C		U	C	G		
Unnamed Tertiary rocks at Sonora Pass	X	X	X			CAV					G	C		U	C	G		
Unnamed Mesozoic metamorphic rocks, Placerville area	O	O	O							C	G			F		P	C	
Unnamed volcanic rocks at Hartford Hill	X	X	X					EFV			V			FU		P		
Unnamed granite			O						F		G			F		P		

Figure 28. Characteristics of favorable rock units in the Pacific Coast and Sierra Nevada.

Central Lowlands

This region extends from the Great Lakes to central Texas (I, Fig. 1). It contains no important uranium-mining areas, although a small amount of ore was mined in 1956 at Cement, Oklahoma (Fig. 8). The potential uranium resource estimates are summarized in Table 30.

TABLE 30. Potential uranium resources in the Central Lowlands

Cost Category	Tons U_3O_8 Probable	Possible	Speculative
$10	--	--	19,000
$15	--	--	32,000
$30	--	--	71,000

1/ Resources in each class include all lower cost resources in that class.

Regional geologic setting

Sedimentary rocks of Paleozoic age predominate in this region. In Texas, these rocks are overlain unconformably by Cretaceous strata. From Texas northward to Wisconsin, Precambrian rocks crop out sporadically and are relatively shallow in the northwestern quarter of the region. Broad epeirogenic warping and development of arches and synclines during Paleozoic time resulted in marked local differences in thicknesses of the formations.

Overview of uranium resources

At Cement, Oklahoma, uranium minerals fill fractures that intersect the Rush Springs Formation of Permian age. Irregular pods of secondary minerals grade into fractured pyritic sandstone and are enveloped by concentric bands of iron oxide. In the Red River area of Texas and Oklahoma, red-bed copper-uranium deposits occur in lenticular, discontinuous paleochannel sandstone of the Wichita Formation of Permian age. The uranium in these areas probably was derived from a granitic source.

Anomalous radioactivity has been observed in petroleum and natural-gas reservoir rocks in Oklahoma, and small amounts of uranium are known to be associated with phosphate rock in Arkansas.

Potential uranium resources (Tables 30, 31, and 32; Figs. 29 and 30)

Some sandstones of Paleozoic age in northern Texas, central Arkansas, northeastern and southwestern Oklahoma, and eastern Kansas are favorable for uranium, and the potential is largely assigned to these rocks. In northeastern Oklahoma uranium is associated with calcareous sandstone and limestone. Disseminated and vein deposits may occur in the Magnet Cove, Arkansas, alkalic pluton. Estimates of potential resources have been made for discontinuous, small, high-grade ore deposits in arkose and for thin, low-grade deposits in sandstone within the Permian red-bed sequences. Ore depths as great as 2,500 feet are possible in northeastern Oklahoma and Texas.

TABLE 31. Distribution of $30 potential uranium resources in the Central Lowlands

Host rock units	Plate 1 Symbol 1/	Tons U_3O_8 Probable	Possible	Speculative
Magnet Cove alkalic intrusive rocks	I1	--	--	1,000
Doxey Formation	I2	--	--	2/
Rush Springs Formation	I3	--	--	2,000
Duncan Sandstone	I4	--	--	2,000
San Angelo Sandstone	I5	--	--	2/
Clear Fork Group	I6	--	--	2,000
Garber Formation	I7	--	--	2,000
Wichita Group	I8	--	--	7,000
Pontotoc Formation	I9	--	--	24,000
Wann and Chanute Formations	I10	--	--	3,000
Coffeyville Formation Layton Sandstone	I11	--	--	4,000
Marmaton Group	I12	--	--	4,000
Boggy Formation Bluejacket Member (Bartlesville sandstone bed)	I13	--	--	8,000
Ordovician rocks of Atokan age	I14			11,000
TOTALS		--	--	71,000

1/ Refer to Plate 1 for explanation
2/ Substantially less than 1,000 tons U_3O_8 but included in speculative total

TABLE 32. Areas and rock units in the Central Lowlands that require further study before assessment for potential uranium resources

Area	Plate 2 Symbol 1/	Rock units
Kansas and Oklahoma	Ia	Pennsylvanian rocks of Missouri and Des Moines age
Cleburne	Ib	Sedimentary rocks of Atoka age
Fort Worth Basin	Ic	Permian and Pennsylvanian rocks
Wichita Mountains area	Id	Strawn, Canyon, and Cisco Groups and Pontotoc and Wichita Formations

1/ Refer to Plate 2 for explanation

CENTRAL LOWLANDS REGION

PERIOD	SERIES	NORTH CENTRAL TEXAS	WESTERN OKLAHOMA	NORTHWEST MISSOURI	NORTHEASTERN OKLAHOMA	CENTRAL ARKANSAS
TERT.						
CRET.						Magnet Cove (K?) intrusive
JUR.						
TRI.						
PERMIAN	OCHOA		Doxey Fm.			
	GUADALUPE		Rush Springs Fm.			
		San Angelo Ss.	Duncan Ss.			
	LEONARD	Clear Fork Gp.	Clear Fork Fm.			
			Garber Fm.			
	WOLFCAMP	Wichita Gp.	Wichita Fm.			
			Pontotoc Fm.			
PENNSYLVANIAN	VIRGIL	(Cisco Group)				PENNSYLVANIAN
	MISSOURI	(Canyon Group)		(Various fluviatile channel sandstones in Pennsylvanian section)	Wann Fm.	
					Chanute Fm.	
					Layton Ss.	
	DES MOINES	(Strawn Group)			Marmaton Group	
					(Sonora Fm.)	
					Bartlesville Ss.	
	ATOKA				Speculative potential assigned to various units subjacent to unconformity in northeastern Oklahoma. These rocks are judged favorable in central Arkansas.	
	MORROW				MORROW, ATOKA	
MISSISSIPPIAN						
DEVONIAN						
ORDOVICIAN					ORD. DEV. MISS. PENN.	

Chart shows only general lateral time equivalence of favorable rock units between geographical areas.

Units that have estimated potential uranium resources are lower cased. Units that may contain potential resources are in parentheses.

Figure 29. Favorable rock units of the Central Lowlands

X - Dominant or of primary importance

0 - Subordinate or of secondary importance

Blank - Undetermined or doubtful significance, absent, or inapplicable

ROCK UNITS	DEPOSIT CHARACTERISTICS: Known uranium deposits	Surficial uranium minerals	Anomalous radioactivity at outcrop	Co-metals	Other associated metals	LITHOLOGIC AND ORE CONTROL CHARACTERISTICS: Clastic rocks: (C) Coarse (F) Fine (A) Arkosic (Ca) Calcareous (Fs) Feldspathic (Q) Quartzose (V) Volcanic	Other sedimentary: (Ca) Carbonates (C) Chert (E) Evaporites (L) Lignites (P) Phosphates	Volcanics: (E) Extrusive (F) Felsic (I) Intrusive (M) Mafic (T) Tuffaceous (V) Vitric	Plutonic: (F) Felsic (M) Mafic (P) Pegmatitic (A) Alkalic	Metamorphic: (C) Contact (I) Isochemical	Uranium provenance: (G) Granitic (V) Volcanic	Continental: (C) Paleochannel (D) Deltaic (E) Eolian (F) Fan (L) Lacustrine (P) Paludal	Marine: (A) Abyssal (B) Bathyal (D) Deltaic (L) Littoral (S) Sabkhal	Structural: (B) Breccia (C) Contact (D) Dissemination (F) Fracture (P) Pipe (V) Vein (U) Unconformity (Z) Fold	Reductants: (A) Asphaltite (C) Carbon (H) H_2S (N) Natural gas (S) Sulfide minerals (P) Petroleum	Permeability: (G) Good (F) Fair (P) Poor	Alteration: (B) Bleaching (C) Chlorite (H) Hematite (L) Limonite (S) Sericite	Cementation: (C) Calcite (H) Hematite (L) Limonite (P) Phosphate (S) Silica
Magnet Cove alkalic pluton		X	X	V	Zr,Mo Nb,Ti				A					F		P		
Doxey Formation		X	X		V	FQ						C		U	C	F	BH	C
Rush Springs Formation	X	X	X	Mo		CFQ	E,Ca					C	LS	FUZ	SH	G	BHL	CS
Duncan Sandstone			0		Cu	CFQ						C		FUZ	SH	G	BHL	CS
San Angelo Formation					Cu	CFQ	L					CD	LS	U	CS	F	BH	C
Clear Fork Group			X	Cu		CFQ						CD		FU	CS	F	BH	C
Garber Formation			X		Cu	CAQ					G	CD			CSA	G		C
Wichita Group		X	X	Cu	F	CAQ					G	CFD			CS	G	HL	CS
Pontotoc Formation		X	X		F	CAQ					G	CF		U	CHS	G	HL	CS
Wann and Chanute Formations			X			CFA					G	C		U	CAH	G	HL	CS
Coffeyville Formation																		
Layton Sandstone			X			FCQFs					G	C			CAH	G	HL	CS
Marmaton Group						FQCa	Ca				G			U	P	P		C
Boggy Formation																		
Bluejacket Member			X			FCQFs	L				G	C		U	CNP	G	L	CS

Figure 30. Characteristics of favorable rock units in the Central Lowlands.

Appalachian Highlands

The Appalachian Mountains and the eastern part of the Interior Lowlands extending from northern Alabama northward into Canada, make up this resource region (J, Fig. 1). Small quantities of uranium ore were mined in the 1950s from deposits near Jim Thorpe, Pennsylvania, and Cranberry Lake, New Jersey. Other small deposits are known in the Grandfather Mountain area of North Carolina; in the Penn Haven Junction area in Carbon County, Pennsylvania; and in Columbia, Lycoming, and Sullivan Counties of Pennsylvania (Fig. 8). The potential uranium resource estimates are summarized in Table 33.

TABLE 33. Potential uranium resources in the Appalachian Highlands

Cost Category	Tons U_3O_8 1/ Probable	Possible	Speculative
$10	--	--	--
$15	--	--	30,000
$30	--	--	77,000

1/ Resources in each class include all lower cost resources in that class.

Regional geologic setting

Paleozoic strata in the Valley and Ridge province and western New England are tightly folded, and locally overturned and thrusted. Plutonic, metamorphic, and volcanic rocks occur to the east in New England and are dominant in the Blue Ridge and Piedmont provinces. Volcanic and sedimentary rocks fill several downfaulted troughs of Triassic age in southern New England and the Piedmont. To the west, the Appalachian Plateau is composed of gently folded to nearly flat-lying upper Paleozoic strata, and to the north, in northeastern New York, the Adirondack Mountains are composed of Precambrian igneous and metamorphic rocks.

Overview of uranium resources

The uranium deposits near Penn Haven Junction and Jim Thorpe, Pennsylvania, are in continental sandstone of the Catskill Group of Devonian age and in an interformational conglomerate between the Pocono and Mauch Chunk Groups of Mississippian age. Near Williamsport, Pennsylvania, uranium minerals locally are associated with copper minerals in gray sandstone of the Catskill Group.

In northern Vermont, uranium minerals are present in an Ordovician karst breccia developed in the Clarendon Springs Formation of Cambrian age. The Triassic arkosic sandstone of the Connecticut and Newark Basins contains uranium in association with oxidized copper minerals.

The uranium and thorium deposits near Cranberry Lake, New Jersey, are in a granitic pegmatite that intruded gneiss of the Reading Prong complex. Uranium is associated with magnetite in this metamorphic and igneous complex, which extends into Pennsylvania and New York.

Near Grandfather Mountain, North Carolina, uranium minerals occur in graphite and in phyllonite zones of metamorphosed volcanic and clastic rocks. At Spruce Pine, North Carolina, uranium minerals are associated with muscovite and rare-earth minerals in a Paleozoic granodiorite.

Potential uranium resources (Tables 33, 34, and 35; Figs. 31 and 32)

This is essentially a nonproducing region which has had very limited exploration for uranium. However, uranium occurs in a wide variety of settings embracing the three major rock types, sedimentary, igneous, and metamorphic.

Favorable sedimentary rocks include red beds and other continental and deltaic sandstones that contain disseminated carbonaceous material and hydrocarbons. Potential resources in sedimentary rocks are in the Devonian Catskill and Mississippian Mauch Chunk Groups in northeastern Pennsylvania, and in the Triassic Shuttle Meadow Arkose, New Haven Formation, Hammer Creek Conglomerate, and Stockton Formation in the Newark and Connecticut Basins. Favorable environments for uranium deposits in igneous and metamorphic crystalline rocks include pegmatites, and brecciated and hydrothermally altered rocks. Potential resources are in the Grandfather Mountain Formation, the Wilson Creek Gneiss, and the Cranberry Gneiss of North Carolina, and in the Reading Prong complex of Pennsylvania and New Jersey.

TABLE 34. Distribution of $30 potential uranium resources in the Appalachian Highlands

Host rock units	Plate 1 Symbol 1/	Tons U_3O_8 Probable	Possible	Speculative
Shuttle Meadow Arkose	J1	--	--	4,000
New Haven Formation	J2	--	--	5,000
Hammer Creek Conglomerate	J3	--	--	3,000
Stockton Formation	J4	--	--	4,000
Mauch Chunk Group	J5	--	--	5,000
Catskill Group	J6	--	--	33,000
Grandfather Mountain Formation) Wilson Creek Gneiss, and) Cranberry Gneiss)	J7	--	--	11,000
Granite near Reading Prong	J8	--	--	9,000
Spruce Pine leucocratic granodiorite	J9	--	--	3,000
TOTALS		--	--	77,000

1/ Refer to Plate 1 for explanation

TABLE 35. Areas and rock units in the Appalachian Highlands that require further study before assessment for potential uranium resources

Area	Plate 2 Symbol 1/	Rock units
Wilson Creek	Ja	Wilson Creek Gneiss and Cranberry Gneiss
Northern Alabama	Jb	Pottsville Group
Western Georgia	Jc	Paleozoic granitic rocks
Southern Tennessee	Jd	Anakeesta Formation and Thunderhead Formation
North Carolina, Tennessee, and Virginia	Je	Wilson Creek Gneiss and Cranberry Gneiss
Kentucky	Jf	Monongahela, Conemaugh, Allegheny, and Pottsville Groups
West Virginia	Jg	Berea Sandstone
Ohio and West Virginia	Jh	Dunkard Group and Berea Sandstone
New York, Pennsylvania, and Maryland	Ji	Catskill Group
Western Pennsylvania	Jj	Monongahela, Conemaugh, and Allegheny Groups
Southern piedmont	Jk	Paleozoic granitic rocks
Adirondack Mountains	Jl	Precambrian metamorphic rocks
Reading Prong	Jm	Undifferentiated Precambrian granites
Vermont	Jn	Clarendon Springs Formation
Southwestern Virginia	Jo	Mount Rogers Formation
North Carolina, South Carolina, and Georgia	Jp	Uwharrie Formation
Connecticut	Jq	Paleozoic granite
New Hampshire	Jr	Paleozoic granite
Southern Pennsylvania	Js	Mauch Chunk Group

1/ Refer to Plate 2 for explanation

APPALACHIAN HIGHLANDS REGION								
		NORTHERN APPALACHIANS		BLUE RIDGE				
PERIOD	EPOCH	N.H., VT., MASS., CONN.	MAINE	N.C., TENN., VA.	GRANDFATHER MTN. AREA	N.C., TENN. GA.	READING PRONG	ADIRONDACK UPLIFT
TRIASSIC		Shuttle Meadow Fm. New Haven Fm.	Sedimentary rocks undifferentiated)					
PERMIAN								
PENN.	UPPER							
	MIDDLE		(pegmatites)					
	LOWER				?			
MISS.	UPPER				Spruce Pine leucograno-diorite.			
	LOWER							
DEVONIAN	UPPER	(binary granite-quartz monzonite)			?			
	MIDDLE							
	LOWER							
SILURIAN								
ORDOVICIAN								
CAMBRIAN	UPPER	(Clarendon Springs Fm.)						
	MIDDLE							
	LOWER							
PRECAMBRIAN	Z			(Mount Rogers Fm.)	Grandfather Mtn. Fm. Wilson Creek Gneiss	(Anakeesta Fm.) (Thunderhead Fm.) Cranberry Gneiss	? granites and associated rocks undifferentiated. ?	? (gneisses, amphibolites, pegmatites, and meta-sedimentary rocks) ?
	Y							
	X							
	W							

Chart shows only general lateral time equivalence of favorable rock units between geographical areas.

Units that have estimated potential uranium resources are lower cased. Units that may contain potential resources are in parentheses.

Figure 31. Favorable rock units of the Appalachian Highlands.

APPALACHIAN HIGHLANDS REGION							
PERIOD	EPOCH	W. OHIO C. KENTUCKY	APPALACHIAN PLATEAUS	VALLEY AND RIDGE	PIEDMONT SOUTHERN	PIEDMONT CENTRAL	PIEDMONT NORTHERN
TRIASSIC						(Sedimentary rocks undifferentiated)	Hammer Ck. Cgl. Stockton Fm.
PERMIAN			(Dunkard Gp.)		?		
PENN.	UPPER		(Monongahela Gp.)		(granites of the Carolina Slate Belt)		
	MIDDLE		(Conemaugh Gp.) (Allegheny Gp.)				
	LOWER		(Pottsville Gp.)	(Pottsville Gp.)			
MISS.	UPPER		Mauch Chunk Gp.& Pennington Gp.	Mauch Chunk Gp.& Pennington Gp.			
	LOWER	(Berea Ss.)	(Pocono, Price, & Grainger Gps.)	(Pocono, Price, & Grainger Gps.)	?		
DEVONIAN	UPPER			Catskill Gp. & Hampshire Fm.			
	MIDDLE						
	LOWER						
SILURIAN							
ORDOVICIAN					? (Uwharrie Fm.) ?		
CAMBRIAN	UPPER						
	MIDDLE						
	LOWER						
PRECAMBRIAN	Z						
	Y						
	X						
	W						

Chart shows only general lateral time equivalence of favorable rock units between geographical areas.

Units that have estimated potential uranium resources are lower cased. Units that may contain potential resources are in parentheses.

Figure 31.. Favorable rock units of the Appalachian Highlands - *Continued.*

X - Dominant or of primary importance

O - Subordinate or of secondary importance

Blank - Undetermined or doubtful significance, absent, or inapplicable

ROCK UNITS	DEPOSIT CHARACTERISTICS: Known uranium deposits	Surficial uranium minerals	Anomalous radioactivity at outcrop	Co-metals	Other associated metals	LITHOLOGIC AND ORE CONTROL CHARACTERISTICS: Clastic rocks: (C) Coarse (F) Fine (A) Arkosic (Ca) Calcareous (Fs) Feldspathic (Q) Quartzose (V) Volcanic	Other sedimentary: (Ca) Carbonates (C) Chert (E) Evaporites (L) Lignites (P) Phosphates	Volcanics: (E) Extrusive (F) Felsic (I) Intrusive (M) Mafic (T) Tuffaceous (V) Vitric	Plutonic: (F) Felsic (M) Mafic (P) Pegmatitic	Metamorphic: (C) Contact (I) Isochemical	Uranium provenance: (G) Granitic (V) Volcanic	Continental: (C) Paleochannel (D) Deltaic (E) Eolian (F) Fan (L) Lacustrine (P) Paludal	Marine: (A) Abyssal (B) Bathyal (D) Deltaic (L) Littoral (S) Sabkhal	Structural: (B) Breccia (C) Contact (D) Dissemination (F) Fracture (P) Pipe (V) Vein (U) Unconformity (Z) Fold	Reductants: (A) Asphaltite (C) Carbon (H) H_2S (N) Natural gas (S) Sulfide minerals (P) Petroleum	Permeability: (G) Good (F) Fair (P) Poor	Alteration: (B) Bleaching (C) Chlorite (H) Hematite (L) Limonite (S) Sericite	Cementation: (C) Calcite (H) Hematite (L) Limonite (P) Phosphate (S) Silica
Shuttle Meadow Arkose		X	X	Cu		CAQ		EM			G	CF		FU	N	G	L	S
New Haven Formation		X	X	Cu		CAQ		EM			G	CF		FU	N	G	L	S
Hammer Creek Conglomerate			X			CAQ		EM			G	F		BFU	CS	G	L	S
Stockton Formation		X	X	Cu,Fe		CAQ		EMT			G	CF		FU	CS	F	L	S
Mauch Chunk Group	X	X	X	V		CQ	CL				G	CP	D	FUZ	CS	F	L	S
Catskill Group	X	X	X	Cu	Th,Pb	CQ	CL				G	CP	D	FUZ	CS	F	L	S
Grandfather Mountain Formation		X	X		Cu,Au	CQ		T	F	I	G			BFUZ	C			
Spruce Pine leucocratic granodiorite		X	X						F		G			F				
Unnamed granite, Reading, Pa.	X	X	X	Fe	Cu,Au				F	I	G			FUZ				

Figure 32. Characteristics of favorable rock units in the Appalachian Highlands.

Columbia Plateaus

This region includes the Columbia Plateaus and Snake River Plain (K, Fig. 1) of Oregon, Washington, and Idaho. The only ore that has been produced in the region came from a prospect in Crook County, Oregon (Fig. 8) in the early 1960s. The potential uranium resource estimates are summarized in Table 36.

TABLE 36. Potential uranium resources in the Columbia Plateaus

Cost Category	Tons U_3O_8 1/ Probable	Possible	Speculative
$10	--	--	5,000
$15	--	--	12,000
$30	--	--	18,000

1/ Resources in each class include all lower cost resources in that class.

Regional geologic setting

The Columbia Plateaus and Snake River Plain separate the Basin and Range region to the south from the Northern Rockies region to the north. Several episodes of deformation and intrusive activity preceded Permian volcanic activity. The Idaho batholith to the north, the Wallowa batholith in the Blue Mountains, and the Silver City pluton south of the Snake River Plain were emplaced during the Mesozoic Era. Rhyolitic tuffs were ejected in Eocene and Oligocene times. Flood basalts in massive eruptions, especially during the Miocene Epoch, formed a thick volcanic pile, the eastern part of which was later downwarped. Tensional displacement along major faults formed the Snake River graben which received large quantities of sediments from the adjacent silicic plutons. Subsequently, the western part of the Snake River graben was divided into basins by movements along north-trending faults, and the Blue Mountains were deformed into broad folds. The Harney Basin of southeast Oregon was a major caldera during Tertiary time. Basaltic volcanism and subsidence persisted in the Snake River Plain during Quaternary time.

Overview of uranium resources

Uranium occurs as fracture coatings in rhyolite tuff and breccia in the Clarno Formation of Eocene age at a prospect in central Oregon. Also in this area, a similar minor uranium occurrence is known in tuffaceous beds of the John Day Formation of Eocene age. Both formations overlie favorable nonmarine conglomerate and sandstone in the Gable Creek Formation of Cretaceous age in the western Blue Mountains. Other minor uranium occurrences are present in the Grassy Mountain Formation of Pliocene age in southeastern Oregon.

Potential uranium resources (Tables 36 and 37; Figs. 33 and 34)

Speculative potential resources have been assigned to the Tertiary and Mesozoic nonmarine clastic rocks of intermontane basins. The uranium is believed to have been derived from the granites of the Idaho and Wallowa batholiths of Cretaceous age and/or the felsic volcanic units of Mesozoic and Tertiary age. Expected depths to potential resources range from 1,500 to 5,000 feet.

A considerable thickness of non-uraniferous Tertiary lava flows has hampered evaluation of underlying rocks and probably will deter exploration in much of the region.

TABLE 37. Distribution of $30 potential uranium resources in the Columbia Plateaus

Host rock units	Plate 1 Symbol 1/	Tons U_3O_8 Probable	Possible	Speculative
Grassy Mountain Formation	K1	--	--	1,000
Idaho Group	K2	--	--	9,000
Deer Butte Formation	K3	--	--	1,000
Payette Formation	K4	--	--	6,000
Gable Creek Formation	K5	--	--	1,000
TOTALS		--	--	18,000

1/ Refer to Plate 1 for explanation

COLUMBIA PLATEAUS REGION				
PERIOD	EPOCH	JOHN DAY BASIN	WESTERN SNAKE RIVER BASIN	
			MALHEUR CO., ORE.	IDAHO
TERTIARY	PLIOCENE		Grassy Mountain Fm.	Idaho Group
	MIOCENE		Deer Butte Fm.	Payette Fm.
	OLIGOCENE			
	EOCENE			
	PALEOCENE			
CRETACEOUS	UPPER			
	LOWER	Gable Creek Fm.		

Chart shows only general lateral time equivalence of favorable rock units between geographical areas.

Units that have estimated potential uranium resources are lower cased.

Figure 33. Favorable rock units of the Columbia Plateaus.

X - Dominant or of primary importance
O - Subordinate or of secondary importance
Blank - Undetermined or doubtful significance, absent, or inapplicable

ROCK UNITS	DEPOSIT CHARACTERISTICS: Known uranium deposits	Surficial uranium minerals	Anomalous radioactivity at outcrop	Co-metals	Other associated metals	LITHOLOGIC AND ORE CONTROL CHARACTERISTICS: Clastic rocks: (C) Coarse (F) Fine (A) Arkosic (Ca) Calcareous (Fs) Feldspathic (Q) Quartzose (V) Volcanic	Other sedimentary: (Ca) Carbonates (C) Chert (E) Evaporites (L) Lignites (P) Phosphates	Volcanics: (E) Extrusive (F) Felsic (I) Intrusive (M) Mafic (T) Tuffaceous (V) Vitric	Plutonic: (F) Felsic (M) Mafic (P) Pegmatitic	Metamorphic: (C) Contact (I) Isochemical	Uranium provenance: (G) Granitic (V) Volcanic	Continental: (C) Paleochannel (D) Deltaic (E) Eolian (F) Fan (L) Lacustrine (P) Paludal	Marine: (A) Abyssal (B) Bathyal (D) Deltaic (L) Littoral (S) Sabkhal	Structural: (B) Breccia (C) Contact (D) Dissemination (F) Fracture (P) Pipe (V) Vein (U) Unconformity (Z) Fold	Reductants: (A) Asphaltite (C) Carbon (H) H_2S (N) Natural gas (S) Sulfide minerals (P) Petroleum	Permeability: (G) Good (F) Fair (P) Poor	Alteration: (B) Bleaching (C) Chlorite (H) Hematite (L) Limonite (S) Sericite	Cementation: (C) Calcite (H) Hematite (L) Limonite (P) Phosphate (S) Silica
Grassy Mountain Formation		O	X			CA		FT			V	C		F	CS	F	L	
Idaho Group			O			CA		FT			G	CFL		FU	CHS	G	L	
Payette Formation						CA		FT			V	CL		U		F	L	
Deer Butte Formation			O			CA		FT			G	CF		U	C	G	L	
Gable Creek Formation						CQFs					V	C	D	UZ	C	F	L	

Figure 34. Characteristics of favorable rock units in the Columbia Plateaus.

Southern Canadian Shield

This region includes the Precambrian shield of Minnesota, Wisconsin, and Michigan (L, Fig. 1). (The Precambrian shield in northern New York is placed in the Appalachian Highlands region.) No uranium ore has been produced in the region and currently no potential resources are assigned.

Regional geologic setting

A great thickness of Lower Precambrian volcanic and sedimentary rocks were metamorphosed to interbedded greenschists and metasediments and intruded by granitic batholiths. These are overlain by more than 20,000 feet of miogeosynclinal and eugeosynclinal strata of the Middle Precambrian Animikie Series. Animikie rocks are intruded locally by silicic and mafic plutons and are overlain by mafic and silicic extrusive rocks and continental strata of the Late Precambrian Keweenawan Series.

The Duluth Gabbro dominates the terrane north of Lake Superior. Fold axes of the Lake Superior synclinorium and subordinate synclines such as the Mesabi, Gogebic, and Marquette Ranges, are subparallel to the Lake Superior Basin. Generalized Precambrian rock correlations of the Southern Canadian Shield are shown in Figure 35.

The region has a history of major orogenies separated by long periods of stability, peneplanation, and subsidence until the close of the Precambrian. Granitic intrusions commonly accompanied the orogenies. Except for epeirogenic subsidences, which resulted in the encroachment of early Paleozoic seas, and subsequent uplift, the region has been stable since Precambrian time. Uranium has been introduced or redistributed during episodes of plutonism, volcanism, and sedimentation in the complex history of the region.

Overview of uranium resources

Most of the known occurrences in the region occur in several iron mines in northern Michigan where uranium forms segregations within oxidized zones in the Middle Precambrian iron formation. Fault breccia in carbonaceous rocks of the Middle Precambrian Michigamme Slate is the host for small uranium veins. Uranium occurrences in Dickinson County are localized in schist near a contact with granite gneiss, and secondary uranium minerals coat fractures in granite at several other localities. Uranium also is present in biotite schlieren in granite near Big Falls, Wisconsin.

Two localities in Carlton County, Minnesota, contain very minor amounts of uranium in a pyrite zone in sheared graphitic slate in the Middle Precambrian Thompson Formation.

Potential uranium resources (Table 38 and Fig. 35)

Estimation of potential uranium resources in the Southern Canadian Shield has been deferred until additional data can be developed. Geologic investigations in progress will provide pertinent information concerning possible correlation of local rock units with known uranium-bearing rocks in southern Canada. Areas and uranium host rocks that require further study are listed in Table 38.

TABLE 38. Areas and rock units in the Southern Canadian Shield that require further study before assessment for potential uranium resources

Area	Plate 2 Symbol 1/	Rock units
Huron River	La	Precambrian slate
Lake Michigamme	Lb	Precambrian iron formation
Greens Creek	Lc	Precambrian slate
Princeton	Ld	Precambrian iron formation
Felch	Le	Precambrian granite and schist
Crystal Falls	Lf	Precambrian iron formation
Iron River	Lg	Precambrian iron formation
Big Falls	Lh	Precambrian granite

1/ Refer to Plate 2 for explanation

Era	1/	Age	Epoch	United States 2/ Minnesota	United States 2/ Wisconsin - Michigan	Eon	Era	Canada 3/ Elliot Lake, Ontario
PRECAMBRIAN	Z		UPPER			PROTEROZOIC	HYDRYNIAN	
	Y	0.8 b.y.						
		0.95 b.y.					HELIKIAN	- Grenvillian Orogeny -
		1.1 b.y.		Duluth Gabbro Keweenawan Series	Keweenawan Series			
		1.4 b.y.		Elsonian Orogeny	Elsonian Orogeny			
	X	1.6 b.y.	MIDDLE				APHEBIAN	
		1.7 b.y.		-Penokean Orogeny-	-Penokean Orogeny-			--Hudsonian Orogeny-
				Animikie Series	Animikie Series (Marquette Range Supergroup) Upper: Michigamme Slate Goodrich Quartzite Middle Negaunee Iron Fm. Siamo Slate Ajibik Quartzite Lower: Wewe Slate Kona Dolomite Mesnard Quartzite Enchantment Lake Fm.			Huronian Supergroup: Cobalt Group, Quirke Lake Group, Hough Lake Group, Elliot Lake Group
	W	2.5 b.y.	LOWER	Algoman Orogeny	Algoman Orogeny	ARCHEAN		Kenoran Orogeny
				Knife Lake Group	Dickinson Group			
				Laurentian Orogeny	Laurentian Orogeny			
				Keewatin Group				

Chart shows only general lateral time equivalence of favorable rock units between geographical areas.

1/ Subdivision of Precambrian time.

2/ Malan, R.C., and Sterling, D.M., 1969.

3/ Douglas, R.J.W., ed., 1971.

Figure 35. Generalized correlations of Precambrian rocks in the Southern Canadian Shield.

Alaska

The only production from Alaska (M, Fig. 1) was derived from a mine located on Bokan Mountain on Prince of Wales Island (Fig. 8). Available information is inadequate to permit assessment of uranium resources in most of Alaska; however, numerous investigations underway and planned will provide the information base required for future assessment. The potential uranium resource estimates are summarized in Table 39.

TABLE 39. Potential uranium resources in Alaska

Cost Category	Tons U_3O_8 Probable	Possible	Speculative
$10	--	--	--
$15	--	--	--
$30	1,000	--	--

Regional geologic setting

The tectonic framework of Alaska is controlled by Precambrian and Paleozoic structures. South and central Alaska is part of the circum-Pacific belt of seismicity and volcanism. Large thicknesses of subaerial and submarine eugeosynclinal rocks and two stable blocks comprise the tectonic framework of northern and central Alaska.

During Cretaceous time several subparallel broad, elongated basins were filled with sediments shed from the Brooks Range, the Seward Peninsula, and the Tanana and Ruby geanticlines. In Cenozoic time, subaerial basins were formed along the Tintina, Denali, and Kaltag lateral faults.

Alkalic-silicic plutons were intruded in the Alaska Range and southeastern Alaska from Jurassic through Oligocene time. The Cook Inlet-Matanuska graben south of the Alaska Range was a major tectonic feature during the Mesozoic and Tertiary. During five major episodes of deposition, the character of the strata changed from marine eugeosynclinal sediments in the Triassic Period to nonmarine and estuarine clastics in the Pleistocene Epoch.

Overview of uranium resources

The only uranium mine in Alaska is in a sodic peralkalic granite stock of Jurassic age at Bokan Mountain, Prince of Wales Island. Uranium-thorium minerals form veinlets and replacement pods and also are disseminated in granite, pegmatites, aplite dikes, and adjacent albitized rocks. Ore containing 0.5 to 3.0 percent U_3O_8 is enveloped by lower grade rock. All uranium and thorium ore within the Bokan Mountain area is probably related genetically to the granite.

Albitization is the principal type of rock alteration associated with the Bokan Mountain uranium deposits. Fluorite and hematite contents of adjacent rocks vary directly with the uranium content in the veins and segregations. The thorium-uranium ratio at Bokan Mountain ranges from 1:1 to 7:1. The ore contains less potassium and more iron, lead, aluminum, yttrium, and fluorine than the unmineralized granite.

The ore body was mined to a depth of 400 feet, where it terminated against a fault.

Potential uranium resources (Tables 39 and 40; Fig. 36)

Potential resources were estimated for Alaska only in the Bokan Mountain granite in extreme southeastern Alaska. Elsewhere in Alaska, alkalic silicic plutons of Mesozoic and Tertiary age and their aureoles, veins, and dikes may be favorable. The late silicic differentiates of alkalic magmas may contain deposits similar to those in the Bokan Mountain granite. Primary uranium-bearing minerals in igneous rocks of the region contain appreciable thorium, which could be a co-product.

Many of the sedimentary basins in Alaska have characteristics similar to the uranium-bearing basins in the conterminous United States. The probability of uranium deposits in these basins is enhanced because the sources of the basin sediments include uraniferous rocks such as alkalic and silicic plutons and volcanics. The nonmarine Mesozoic and Tertiary clastic strata in these basins have stratigraphic and lithologic characteristics similar to rocks in ore-bearing areas of the western United States. The Upper Cretaceous and Eocene formations listed in Figure 36 are probably the most favorable. However depths to mineralized zones may be excessive because many of the favorable beds dip more steeply than their counterparts in the conterminous United States. Redistribution of uranium by ground water may have been impeded by permafrost and shallow water tables, thereby reducing the likelihood of ore formation.

The potential uranium resources in nine Tertiary basins in Alaska are estimated by Klein (1975) to be approximately 243,000 tons U_3O_8. As Klein's methodology differs from that of ERDA, and since much additional geologic data will be developed through the NURE program, estimates of the state's uranium resources that will be made by ERDA during the next several years may differ.

TABLE 40. Areas and rock units in Alaska that require further study before assessment for potential uranium resources

Area	Plate 2 Symbol 1/	Rock units
Kuskokwim Mountains	Ma	Unnamed Tertiary granite plutons
Alaska Range	Mb	Unnamed granite plutons
Bristol Bay Basin	Mc	Unnamed continental sandstone and coal
Cook Inlet Basin	Md	Beluga, Tyonek, West Foreland, Chickaloon, Matanuska, and Naknek Formations, Hemlock Conglomerate, and Tuxedni Group
Copper River Basin	Me	Frederika, Gakona, and Matanuska Formations
Holitna Basin	Mf	Unnamed continental sandstone and conglomerate
Minchumina Basin	Mg	Unnamed continental sandstone and conglomerate
Middle Tanana Basin	Mh	Cantwell Formation
North Slope	Mi	Sagavanirktok and Prince Creek Formations
Selawik Basin	Mj	Unnamed continental conglomerate, coal, sandstone, mudstone, and Bergman Group
Yukon Flats Basin	Mk	Unnamed continental sandstone, conglomerate, and coal
Yukon-Koyukuk Basin	Ml	Unnamed continental sandstone and conglomerate, Kaltag, and Nulato Formations
Hyder	Mm	Unnamed quartz monzonite pluton
Skagway	Mn	Unnamed quartz monzonite pluton
Chicagof Island	Mo	William Henry Bay quartz monzonite pluton
Yakataga Basin	Mp	Unnamed Tertiary sandstone
Kodiak Island	Mq	Unnamed sandstone
East central Alaska	Mr	Unnamed quartz monzonite plutons, continental conglomerate, sandstone, shale and coal
Healy Basin	Ms	Unnamed Tertiary strata
Seward Peninsula	Mt	Kiwalik Bay strata, continental rocks of Kuzitrin lowland, Noxapaqa Formation, Serpentine granite pluton, Darby quartz-monzonite pluton, Brooks Mountain, and Ear Island granite stocks
Hogatza Plutonic Belt	Mu	Zane Hills, Selawik Hills, Hunter Creek, and Granite Mountain plutons
Talkeetna Basin	Mv	Beluga, Tyanek, West Foreland, Chickaloon, Matanuska and Naknek Formations, Hemlock Conglomerate, and Tuxedni Group
Matanuska Valley	Mw	Tsadaka, Wishbone, Arkose Ridge, Chickaloon, and Matanuska Formations

1/ Refer to Plate 2 for explanation

ALASKA REGION

PERIOD	EPOCH	SOUTHEAST ALASKA	COOK INLET BASIN 1/	COPPER RIVER BASIN	MATANUSKA VALLEY	GULF OF ALASKA	KODIAK ISLANDS	ALASKA RANGE
TERTIARY	PLIOCENE	(William Henry Bay quartz monzonite pluton)	(Beluga Fm.)					
	MIOCENE		(Tyonek Fm.) (Hemlock Cgl.)	(Frederika Fm.)	(Tsadaka Fm.)			
	OLIGOCENE		(West Foreland Fm.)		(Wishbone Fm.)		(unnamed sandstone)	
	EOCENE		(Chickaloon Fm.)	(Gakona Fm.)	(Arkose Ridge Fm.) (Chickaloon Fm.)	(Kustaka Fm.) (Kulthieth Fm.)	(unnamed sandstone)	
	PALEOCENE							(silicic plutons)
CRETACEOUS	UPPER		(Matanuska Fm.)	(Matanuska Fm.)	(Matanuska Fm.)			
	LOWER							
JURASSIC		BOKAN MOUNTAIN GRANITE	(Naknek Fm.) (Tuxedni Gp.)					
TRIASSIC								

Chart shows only general lateral time equivalence of favorable rock units between geographical areas.

1/ Kirschner and Lyon, 1973

Units that have uranium production and/or reserves and potential resources are capitalized. Units that have estimated potential uranium resources are lower cased. Units that may contain potential resources are in parentheses.

Figure 36. Favorable rock units in Alaska.

<table>
<tr><th colspan="9">ALASKA REGION</th></tr>
<tr><th>PERIOD</th><th>EPOCH</th><th>HOLITNA BASIN</th><th>MINCHUMINA BASIN</th><th>MIDDLE TANANA BASIN</th><th>YUKON FLATS BASIN</th><th>SELAWIK (KOTZEBUE) BASIN</th><th>BRISTOL BASIN</th><th>YUKON KOYUKUK BASIN</th></tr>
<tr><td rowspan="5">TERTIARY</td><td>PLIOCENE</td><td rowspan="5">(unnamed continental sandstone & conglomerate)</td><td rowspan="5">(unnamed continental sandstone & conglomerate)</td><td rowspan="5">(Cantwell Fm.)</td><td rowspan="5">(unnamed continental sandstone, congl., & coal)</td><td rowspan="5">(unnamed continental coal conglomerate, sandstone and mudstone)</td><td rowspan="5">(unnamed continental sandstone and coal)</td><td rowspan="3"></td></tr>
<tr><td>MIOCENE</td></tr>
<tr><td>OLIGOCENE</td></tr>
<tr><td>EOCENE</td><td rowspan="2">(unnamed continental sandstone & conglomerate)</td></tr>
<tr><td>PALEOCENE</td></tr>
<tr><td rowspan="2">CRETACEOUS</td><td>UPPER</td><td rowspan="4"></td><td rowspan="4"></td><td rowspan="4"></td><td rowspan="4"></td><td>(unnamed cont. coal, sandstone, & conglomerate)</td><td rowspan="4">(unnamed continental sandstone and coal)</td><td>(Kaltag and Nulato Fms.)</td></tr>
<tr><td>LOWER</td><td>(Bergman Gr.)</td><td rowspan="3"></td></tr>
<tr><td>JURASSIC</td><td></td><td rowspan="2"></td></tr>
<tr><td>TRIASSIC</td><td></td></tr>
</table>

Chart shows only general lateral time equivalence of favorable rock units between geographical areas.

Units that may contain potential resources are in parentheses.

Figure 36. Favorable rock units in Alaska – *Continued.*

ALASKA REGION

PERIOD	EPOCH	HOGATZA PLUTONIC BELT	SEWARD PENINSULA	ALASKA RANGE	NORTH SLOPE 2/	KUSKOKWIM RANGE	EAST CENTRAL ALASKA
TERTIARY	PLIOCENE				(Sagavanirktok Fm.)	(unnamed granite plutons)	
	MIOCENE		(Kiwalik Bay Strata) (Cont. rocks of Kuzitrin lowland) (Noxapaga Fm.)				
	OLIGOCENE			(unnamed granite plutons)			
	EOCENE			(unnamed granite plutons)			
	PALEOCENE		(Serpentine Granite Pluton)				
CRETACEOUS	UPPER	(alkalic-silicic rocks) (Zane Hills Pluton) (Selawik Hills Pluton) (Hunter Creek Pluton) (Granite Mtn. Pluton)	(unnamed continental rocks) (Darby Quartz Monzonite Pluton) (Brooks Mtn. & Ear Island Granite stocks)		(Prince Creek Fm.)		(unnamed quartz monzonite plutons) (unnamed continental conglomerate, ss., shale & coal)
	LOWER						
JURASSIC							

Chart shows only general lateral time equivalence of favorable rock units between geographical areas.

2/ Detterman, 1973

Units that may contain potential resources are in parentheses.

Figure 36 Favorable rock units in Alaska - *Continued*

Hawaii and Puerto Rico

Hawaii has no known uranium deposits, and there are no reports of anomalous radioactivity. Rocks of the islands are predominantly volcanics of mafic to intermediate composition. The environment is generally considered unfavorable for the occurrence of significant concentrations of uranium, and no potential resources, have been estimated.

No uranium resources are known in Puerto Rico, although a 1961 airborne radiometric survey by the U. S. Geological Survey, in cooperation with the Atomic Energy Commission, revealed a few areas of anomalous radioactivity. The highest observed radioactivity is in the Cibao Formation (Oligocene and Miocene) 8 miles northeast of San Sebastian in northwestern Puerto Rico. The Cibao consists of limestone beds with minor sandstone, claystone, and conglomerate. Anomalous radioactivity also was recorded on nearby outcrops of the Lares Limestones of Oligocene age. The radioactivity may be associated with insoluble residues in karst collapse structures in the area. Other radioactive anomalies occur along an east-trending fault of Cretaceous age in west-central Puerto Rico.

Low-Grade Uranium Resources

Small amounts of uranium occur in a myriad of geologic settings throughout the United States. However, most occurrences are unlikely to become significant sources of uranium in this century because of their low grade and small size. Some potential low-grade sources of uranium may become economic if uranium concentrate prices increase or stabilize near current levels and if technological developments improve the economics of production.

The locations of a number of low-grade uranium resources (less than 0.1 percent U_3O_8), which include by-product and co-product uranium, are shown in Figure 37. Numbers in parentheses in the following paragraphs refer to locations in that illustration.

Sources in igneous rocks

Beryllium-bearing rhyolite tuffs adjacent to the Spor Mountain area in west-central Utah (1) are a possible future source of uranium, as is the Musgrove tuff of Tertiary age in east-central Idaho (2). Cupriferous rhyolite and latite in northern Michigan (3) are less likely targets. In the Bearpaw Mountains, Montana (4), uranium is associated with rare earths and niobium in pegmatites in nepheline syenite. Possible future sources of uranium also include Granite Mountain, Alaska (5); a quartz monzonite stock in South Dakota (6); the Spruce Pine, North Carolina, granodiorite (7); the Concord (8) and Conway (9) Granites in New Hampshire; granites and metamorphic rocks in the Reading Prong of Pennsylvania (10); and granitic rocks of northern Wisconsin (11). Pegmatites in North Carolina (12), New York (13), and New Hampshire (14) contain uranium and may warrant attention.

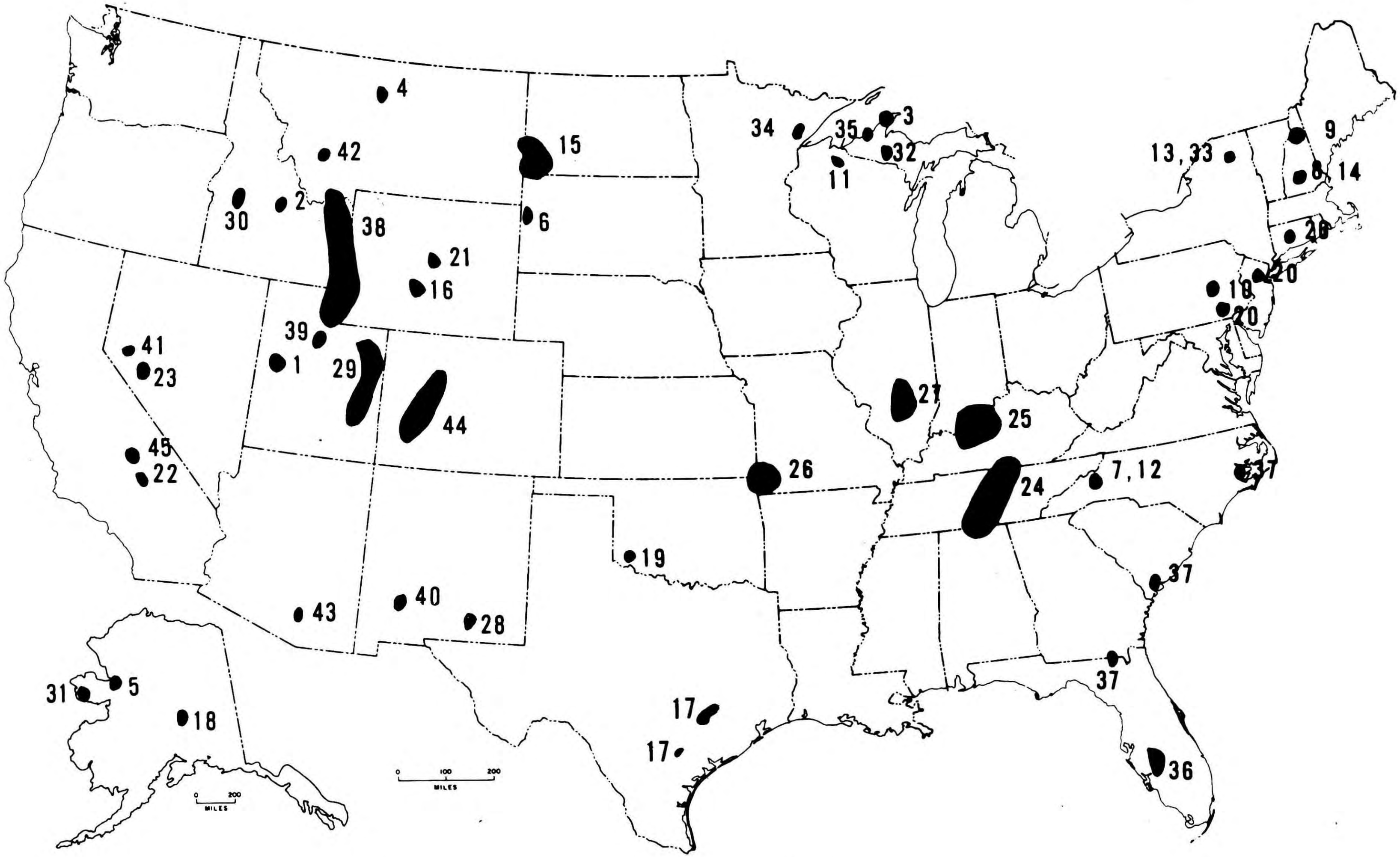


Figure 37. Low-grade and by-product uranium resources.

Sources in sedimentary rocks

Uranium deposits of low to moderate grade occur in Tertiary lignite in the Dakotas (15), Wyoming (16), and Texas (17); however, the cost of recovering uranium from lignite is high. Tertiary coal in the Healy Basin, Alaska (18) reportedly is uraniferous.

Uranium is present in red-bed copper deposits in Permian rocks in Oklahoma (19) and in Triassic rocks (20) in the northeastern United States. Tertiary lake beds and associated volcanic material in Wyoming (21) contain uranium. Recent playas and subsurface brines may be future sources of uranium in California (22) and Nevada (23). Huge tonnages of the Chattanooga Shale (24) of Devonian and Mississippian age and its Central Lowlands equivalents (25) contain 10 to 100 parts per million U_3O_8; oil and pyrite are possible co-products.

Pennsylvanian black shales in the Tri-State district (26) and the Illinois Basin (27) also are uraniferous. Minor amounts of uranium are associated with thucholite in Permian rocks in New Mexico (28) and in bituminous sandstone of Permian and younger ages in Utah (29). Uranium and thorium occur in placers in Idaho (30) and Alaska (31); their placer sources may contain other favorable targets.

Significant amounts of uranium have not been identified in Permian conglomerates in the United States. However, since these rocks are host to major resources in Canada, investigations are underway to determine their extent and favorability for similar deposits in the United States.

Sources in metamorphic rocks

Iron deposits in northern Michigan (32) and in the Adirondacks (33) are possible future sources of uranium. Uraniferous veins have been reported in Precambrian slates in Minnesota (34) and Michigan (35).

By-Product Uranium Resources

Location of possible sources of by-product uranium production are shown in Figure 37.

About 500 tons U_3O_8 was recovered in the 1950s and early 1960s as a by-product in the manufacture of wet-process phosphoric acid from central Florida (36) Tertiary phosphate rock, which contains 50 to 250 parts per million U_3O_8. Phosphate rock converted to phosphoric acid in 1975 from central Florida contained approximately 3,000 tons U_3O_8; however, only a small amount of this was recovered commencing late in the year. Production is expected to increase to about 1,000 tons U_3O_8 annually by 1978. The future quantity of by-product uranium output will be dependent on the demand for phosphoric acid. Deposits of phosphate rock in northern Florida, Georgia, North and South Carolina (37), as well as those in sedimentary rocks such as the Permian Phosphoria Formation of the western United States (38), also are potential sources of by-product uranium. Of the total 140,000 tons U_3O_8 available as a by-product of phosphate and copper production to the year 2000 (Table 1), 120,000 tons are available from phosphate production in the southeastern United States.

Uranium is a possible by-product of copper-leach production (estimated to be 20,000 tons U_3O_8) from porphyry deposits such as those that occur at Bingham, Utah (39); Santa Rita, New Mexico (40); Yerington, Nevada (41); Butte, Montana (42); and Twin Buttes, Arizona (43).

In western Colorado, by-product uranium recovery is anticipated from processing certain vanadium ores such as roscoelites that are quite low in uranium. The roscoelite ores occur in a poorly defined belt extending from Lightner Creek near Durango to Rifle, Colorado (44).

Uranium is a possible by-product of tungsten-bearing skarns near Bishop, California (45).

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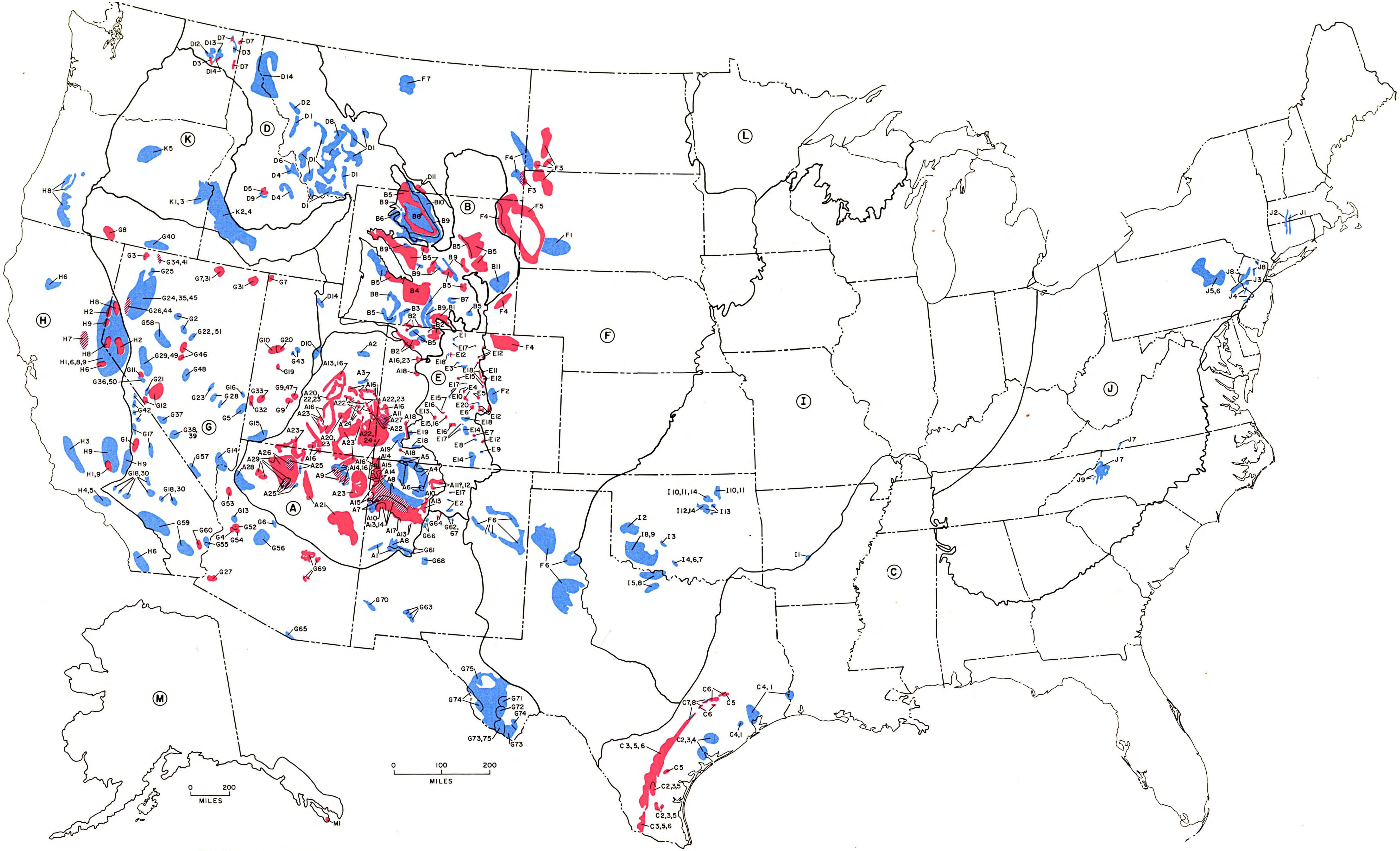


Probable and/or possible.

Speculative.

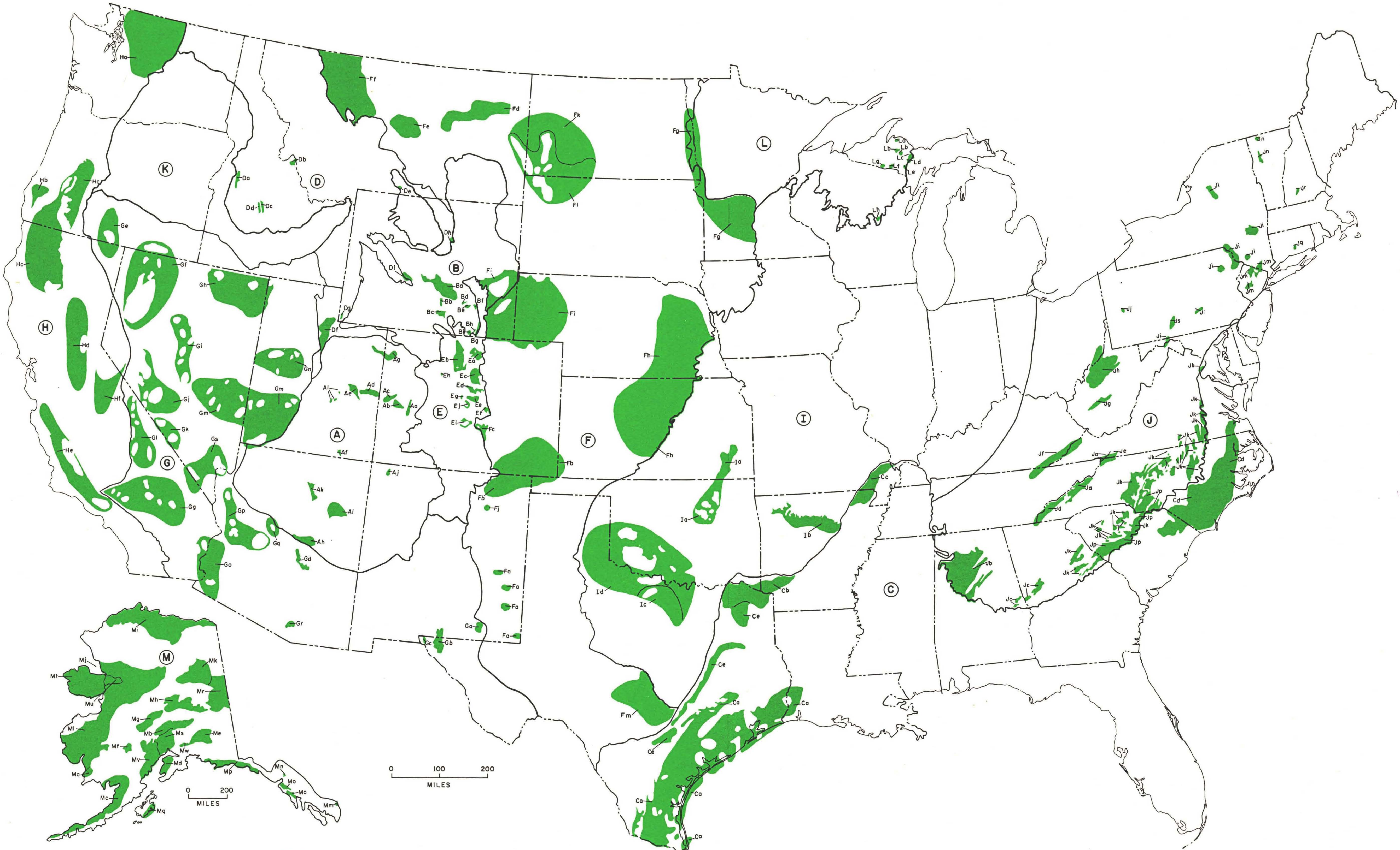
Probable and/or possible, and speculative.

A3 Area identification. Symbols keyed to chart for each region which lists $30 potential uranium resources by host rock units.

(A) Region identification.

Region boundary.

Plate 1. Areas in which potential uranium resources have been estimated.



Favorable for uranium resources; potential uranium resources not estimated because of insufficient data.

Aa Area identification. Symbols keyed to chart for each region which lists areas and rock units considered favorable.

(A) Region identification.

Region boundary.

Plate 2. Areas identified as favorable but with insufficient basis for estimation of potential uranium resources.

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