UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Preliminary map of uranium provinces in the conterminous United States

by

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This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature.

1. Denver, Colorado

1984
INTRODUCTION

The map is part of the atlas of metal and nonmetal provinces in the conterminous United States (Tooker, 1979, 1980a,b) and shows areas called provinces, listed in Table 1, that are based mainly on the geographical distribution of known uranium deposits and selected occurrences.

Uranium is a heavy radioactive metal principally used as a fuel in nuclear power generating facilities, which produced 11 percent of electricity in the United States in 1978 (Krymm and Charpentier, 1980). Smaller quantities of uranium are used in the fabrication of nuclear weapons and in the ceramic and chemical industries; depleted uranium, the tailings product after 235-enriched uranium is produced, is used in ordnance and shielding applications (Kirk, 1980; U.S. Bureau of Mines, 1981, p. 172-173).

Production of uranium in the U.S. in 1975 (the base year for the atlas survey, Tooker, 1980a) totalled 11,200 metric tons U(sub 3)O(sub 8) and in 1980 reached an all-time high of about 18,150 metric tons U(sub 3)O(sub 8) (U.S. Dept. Energy, 1980a). The average grade of 1980 production was about 0.11 per cent U(sub 3)O(sub 8) compared to 0.16 in 1975. 

Total resources of U(sub 3)O(sub 8) in the U.S. (excluding Alaska) is given by the U.S. Department of Energy (DOE, 1980b, Table 3) as 4,430,000 metric tons (4,003,000 short tons) at a forward cost of $100 or less per pound ("Forward-cost" is not market price; it refers roughly to the cost of production excluding, for example, exploration and mine-site development costs). Of this total, 849,000 metric tons are given as resources at a forward cost of $50 or less per pound U(sub 3)O(sub 8). Additional resources, only partly discovered, bring the total $50/lb U(sub 3)O(sub 8) resources to about 3,162,000 metric tons. Of this total, 849,000 metric tons U(sub 3)O(sub 8) is expected as a byproduct from phosphate (southeast U.S.) and copper-leach operations (Utah, Arizona, Montana) during the period 1980-2000. According to DOE, "Currently projected long-term requirements can be met through the year 2019 by production of resources available at $50 per pound of U(sub 3)O(sub 8), or less." (U.S. Dept. Energy, 1980b, p. 139).

Uranium is a geochemically persistent element. Uranium, a common uranium mineral, has been precipitated over a wide range of temperatures and pressures. In the U.S., uranium has precipitated at or near atmospheric temperatures and pressures in clastic host rocks, such as sandstones and conglomerates, that have high transmissivity for ground-water. Other uranium has precipitated at high temperatures and pressures in fracture systems (vein deposits) in less permeable rocks. The primary duff black, gray, and brown uranium ore minerals, pitchblende and uraninite, occur either in extensive bedded deposits in sedimentary rocks or in high-grade veins and pegmatites. Refractory primary uranium-bearing minerals are found in fossil placers of negligible economic importance. Secondary uranium ore minerals, such as carnotite, tuyauminate, torbernite, meta-torbernite, autunite, meta-autunite, uraninite, and uranium oxides, occur in oxidized zones of primary deposits. Vanadates such as carnotite are major secondary minerals in sandstone deposits. Autunite, torbernite, and uranophane are especially widespread uranil species found in oxidized vein deposits.

Production, reserve, and resource data as of January 1, 1976 shown in Table 2 are from the U.S. Energy Research and Development Administration (1976, p. 19), U.S. Bureau of Mines (1976, 1977), and Woodmansee (1975, p. 1178).
<table>
<thead>
<tr>
<th>Geologic region</th>
<th>Province 1/</th>
<th>Subprovince 1/</th>
</tr>
</thead>
</table>
B. Big Indian or Lisbon Valley mineral belt  
C. Uravan mineral belt  
D. Monument Valley and White Canyon mineral belts |
| II. Cordilleran Belt | 2. Tertiary basins, Wyoming and Colorado  
4. Northeast Washington  
5. Colorado Front Range, Northern and Southern Rockies  
6. Black Hills region, South Dakota and Wyoming  
7. Basin and Range  
10. Phosphoria basin (in Idaho and adjacent states)  
15. Pacific Coast, California |
| III. Coastal Plains | 3. Texas Gulf Coast  
9. Phosphate fields of Florida and South Carolina |
| IV. Central Plains | 8. Dakota lignite fields  
11. Permian and Triassic basins (in New Mexico, Texas and Oklahoma)  
13. Devonian marine black shale basins |
| V. Appalachian Belt | 12. Appalachian Highlands Paleozoic and Triassic basins |
| VI. Precambrian Shield | 14. Precambrian Shield area |

1/ Numbered in approximate order of economic importance.
Table 2.—Distribution of uranium production, reserves and potential resources as of January 1, 1976, by uranium province in the U.S. (Modified after U.S. Energy Research and Development Administration, 1976, table 3).

<table>
<thead>
<tr>
<th>Index number to geologic region and uranium province (See Table 1)</th>
<th>Area</th>
<th>Production</th>
<th>Percent of total production plus reserves ($30/lb U₃O₈)</th>
<th>Estimated value in billion dollars (1975 dollar value at $8.45/lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Region Province</td>
<td>Area</td>
<td>Metric tons</td>
<td>Production plus reserves ($30/lb U₃O₈)</td>
<td>Production plus reserves (1975 dollar value at $8.45/lb)</td>
</tr>
<tr>
<td>I 1 Colorado Plateau</td>
<td>179,440</td>
<td>57</td>
<td>8.9</td>
<td>19.7</td>
</tr>
<tr>
<td>II 2 Tertiary basins, Wyoming, Colorado</td>
<td>53,700</td>
<td>32</td>
<td>4.9</td>
<td>7.2</td>
</tr>
<tr>
<td>III 3 Texas Gulf Coast region</td>
<td>7,530</td>
<td>5.6</td>
<td>0.9</td>
<td>4.3</td>
</tr>
<tr>
<td>II 7 Basin and Range</td>
<td>1,270</td>
<td>0.3</td>
<td>0.05</td>
<td>7.5</td>
</tr>
<tr>
<td>II 4 Northeast Washington</td>
<td>3,000</td>
<td>2</td>
<td>0.28</td>
<td>1.6</td>
</tr>
<tr>
<td>II 6 Black Hills region</td>
<td>3,175</td>
<td>1</td>
<td>0.17</td>
<td>2.0</td>
</tr>
<tr>
<td>II 15 Pacific Coast</td>
<td>1/</td>
<td>2/</td>
<td>0.02</td>
<td>1.8</td>
</tr>
<tr>
<td>II 5 Colorado Front Range, Northern and Southern Rockies</td>
<td>5,800</td>
<td>1.7</td>
<td>0.26</td>
<td>1.4</td>
</tr>
<tr>
<td>IV 11 Central Lowlands, Colorado Kansas</td>
<td>1/</td>
<td>2/</td>
<td>0.02</td>
<td>1.1</td>
</tr>
<tr>
<td>III 8 Dakota Lignite</td>
<td>3/</td>
<td>2/</td>
<td>3/</td>
<td>3/</td>
</tr>
<tr>
<td>II 5 Southern Rockies New Mexico (vein)</td>
<td>3/</td>
<td>2/</td>
<td>3/</td>
<td>3/</td>
</tr>
<tr>
<td>IV 11 Eastern New Mexico, west Texas, and Oklahoma</td>
<td>1.5</td>
<td>2/</td>
<td>0.02</td>
<td>0.3</td>
</tr>
<tr>
<td>II 5,10 Northern Rockies and Columbus Plateau (Idaho, Montana, Wyoming)</td>
<td>1,355</td>
<td>0.3</td>
<td>0.02</td>
<td>1.1</td>
</tr>
<tr>
<td>V 12 Appalachian Highlands</td>
<td>1/</td>
<td>2/</td>
<td>0.02</td>
<td>1.3</td>
</tr>
<tr>
<td>VI 14 Precambrian Shield area (Wisconsin, New York, Michigan)</td>
<td>0</td>
<td>2/</td>
<td>3/</td>
<td>3/</td>
</tr>
<tr>
<td>Totals (rounded)</td>
<td>256,085</td>
<td>100.0</td>
<td>15.56</td>
<td>49.3</td>
</tr>
</tbody>
</table>

1/ Reported as less than 1,000 short tons. Probably on the order of 1 metric ton.
2/ Less than 0.1 percent.
order to be comparable to other maps of the atlas series and U.S. Bureau Mines Bull. 666, the estimated values for production, reserves, and resources in table 2 are in a 1975-dollar value of $8.45 per pound of U$_3$O$_8$ (approximately $18,600 per metric ton). The principal uranium mines and mining companies active in 1975 are listed in Table 3.

In compiling the uranium province map, some new districts discovered since 1975 have been added, such as Date Creek basin, Arizona (Otton, 1981a; b), and the McHenry district, Nevada-Oregon (Sharp, 1956; Ryuba and Glansman, 1979).

The locations of uranium deposits on the map were compiled from published reports (Butler and Byers, 1969; Butler and others, 1962; Byers, 1978; Eargle and others, 1971; Finch, 1967; Finch and others, 1959, 1978; Hilpert, 1969; Schnabl, 1955; Coney and Reynolds, 1980); unpublished records of uranium resource specialists; and data from the Mineral Resource Data System (MRDS), formerly the Computerized Resource Information Bank (CRIB) of the U.S. Geological Survey. The assistance of R. R. Wahl and C. A. Phillips in providing computerized data is gratefully acknowledged.

Distinguishing Map Features

The map shows the distribution of various types of uranium deposits in the conterminous United States, the outlines of the provinces that contain the most productive deposits, and some of the possibly favorable areas for other uranium deposits as poorly defined or not yet discovered. The shape of the symbol indicates the type of deposit; three groupings of types of deposits are shown on the map. They are: circles for sandstone and related deposits in sedimentary rocks; triangles for classical vein, breccia zone, pipe, contact, and related types; and squares for others, which includes volcanogenic deposits too poorly described to classify. The character of the symbol indicates the relative size of a deposit or group of closely spaced deposits; those that have more than 10,000 metric tons of contained U$_3$O$_8$ are shown by a large solid symbol; in 1,000 to 10,000 by a small solid symbol, those 1 to 1,000 by a small half-darkened symbol, and those less than 1 metric ton or any size at a cutoff-grade between 0.01 and 0.049 percent U$_3$O$_8$ by an open symbol. A large star overprint indicates that the deposit was being actively mined in 1975 (Table 3).

The boundaries of uranium provinces and sub-provinces are drawn only where they are reasonably distinct; many are indicated only by a number in the center of the general area of the known occurrences and their favorable rocks and geologic setting. Those boundaries delineated on the map by lines are at best inferred and follow physiographic provinces, basin outlines, and distribution of potential host rocks. Boundaries of some major geologic regions and the zones of accreted oceanic and island-arc crust bordering the old continental crust are shown in order to conform to other maps of the atlas series even though they may not in every case relate to the distribution of uranium deposits.

Uranium Provinces

For purposes of this report following the guidelines in Tooker (1979, 1980a,b), 14 uranium provinces are shown in the 6 major geologic regions of the conterminous United States, Table 1. The most important province, the Colorado Plateau, is divided into 4 sub-provinces. The uranium provinces are indicated on the map and keyed to tables 1 and 2. Almost 95 percent of the total production plus reserves of uranium in 1975, the base year for the Atlas survey (Tooker, 1980a), occurs in the first three uranium provinces described below.

The Colorado Plateau, map province no. 1 (Fischer, 1968, 1970, 1974; Fischer and Hilpert, 1952; Webber, 1947), is the major source of uranium in the U.S. and within the Plateau the San Juan Basin is the dominant district. In essence the Colorado Plateau has been an uranium province since Late Precambrian time because Precambrian igneous rocks beneath and around the Colorado Plateau probably contained anomalously high amounts of uranium as suggested by the anomalously radioactive zircons from these rocks with contents of 2 to 20 times the normal content (Silver, 1976). The Morrison Formation of Late Jurassic age is the principal uranium-bearing formation and consists of a coalesced sequence of large, low-gradient, alluvial fans derived from source areas to the south and southwest (Craig and others, 1955). The stratiform or peneconcordant uranium deposits were formed by ground waters that moved along the sandstone host beds. The ore minerals were precipitated in pockets having strong reducing capacity (Hostetler and Garrels, 1962). Estimated production plus reserves for the Colorado Plateau were almost 475,000 metric tons of contained U$_3$O$_8$ ($30/lb or less) as of January 1, 1976 (U.S. ERDA, 1976, p. 19) or 57 percent of the U.S. total. The Colorado Plateau contains four principal generally linear uranium-productive subprovinces whose trends are shown on the map: (A) the Grants mineral belt in the San Juan Basin, New Mexico; (B) the Big Indian or Lisbon Valley mineral belt, Utah; (C) the Uravan mineral belt, Colorado; and (D) the Monument Valley and White Canyon mineral belts, Utah and Arizona. Other productive districts include the Henry Mountains and San Rafael in eastern Utah, and Rock in northeast Arizona and Cameron in Coconino County, Arizona.

The Grants mineral belt, map province no. 1A (Kelley, 1963; Kelley and others, 1968; Granger, 1963, 1968; Granger and others, 1961; Granger and Warren, 1969; Hilpert, 1969; Hilpert and Moench, 1960; Moench and Schlee, 1967; Brookins, 1976; Chenoweth, 1977; Chapman, 1978, Inc., 1977; Enfield, 1977; Haugen, 1980; Leventhal, 1980b; Scarborough, 1981; Adams and Saucier, 1981), contains the largest known concentration of uranium ore in the United States and accounted for more than 42 percent of the total U.S. production plus reserves as of January 1, 1976 (Byers, 1978). The mines active in 1975 are listed in Table 3. Adams and Saucier (1981) pointed out that projection of known ore trends provide the greatest potential for major new discoveries in the Grants mineral belt, and that future exploration will be deeper and more expensive. The deposits are peneconcordant, range in size from small to very large, and lie from at the surface outcrop to about 1-2 kilometers below the surface. They are mostly in relatively thick sandstone masses in the Morrison Formation of Late Jurassic age along and near the south margin of the boundary of the Jurassic basin of deposition. They occur in stream-laid sandstone lenses interbedded with lacustrine and overbank mudstone.

The Big Indian or Lisbon Valley mineral belt, map subprovince no. 1B (Butler and Fischer, 1978; Fischer, 1974; Wood, 1968), contains uranium deposits in the Moss Back Member of the Chinle Formation of Late Triassic age. Production and reserves as of January 1, 1976 in the belt comprised about 9.5 percent of the U.S. total. The mines active in 1975 are listed in Table 3. Fischer (1974) pointed out that ground water seeping downward along the crest of the ancestral Lisbon Valley anticline could have leached uranium from the volcanic mudstones in the upper part of the Chinle Formation and carried it down into the Moss Back Member of the Chinle to a favorable reducing environment, probably somewhere below the paleo-water table.

The Uravan mineral belt, map subprovince no. 1C (Fischer, 1969, 1972; Byers and Adams, 1952; Byers, 1968; Motica, 1968; Fischer, 1974; Butler and Fischer, 1978; Granger and Warren, 1981), contains more than 1,000 mines ranging in size from a few metric tons of U$_3$O$_8$ in isolated locations to clusters totalling as much as 0.75 million tons of contained U$_3$O$_8$. The most productive districts and locations to clusters totalling as much as 0.75 million tons of contained U$_3$O$_8$. The most productive districts plus reserves as of January 1, 1976 for the Uravan mineral belt comprised about 7 percent of the U.S. total. The uranium-vanadium deposits are in the Salt Wash Member of the Morrison Formation. The
Table 3.—Principal uranium mines and mining companies active in 1975 (Mining Magazine, 1976, Table B; files)

<table>
<thead>
<tr>
<th>Uranium province and map number (See Table 1)</th>
<th>Mine or area</th>
<th>Company</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colorado Plateau, Grants mineral belt, 1A</td>
<td>Ambrosia Lake deposits (includes Sec. 23 mine, T. 14 N., R. 10 W.; Sec. 25 mine, T. 14 N., R. 10 W.; Sec. 17 mine, T. 14 N., R. 9 W.)</td>
<td>United Nuclear Corp., Inc.</td>
<td>Ambrosia district, McKinley County, New Mexico</td>
</tr>
<tr>
<td></td>
<td>Church Rock I</td>
<td>Kerr-McGee Corp.</td>
<td>“</td>
</tr>
<tr>
<td></td>
<td>Johnny M</td>
<td>Ranchers Exploration and Development Corp.</td>
<td>“</td>
</tr>
<tr>
<td></td>
<td>Jackpile and Paguate</td>
<td>Anaconda Co.</td>
<td>Laguna district, Valencia County, New Mexico</td>
</tr>
<tr>
<td></td>
<td>Sec. 1, T. 13 N., R. 9 W.</td>
<td>Kerr-McGee Corp.</td>
<td>Ambrosia district, McKinley County, New Mexico</td>
</tr>
<tr>
<td></td>
<td>Sec. 19, T. 14 N., R. 9 W.</td>
<td>“</td>
<td>“</td>
</tr>
<tr>
<td></td>
<td>Sec. 30, T. 14 N., R. 9 W.</td>
<td>“</td>
<td>“</td>
</tr>
<tr>
<td></td>
<td>Sec. 24, T. 14 N., R. 9 W.</td>
<td>“</td>
<td>“</td>
</tr>
<tr>
<td>Colorado Plateau, Big Indian (or Lisbon Valley) mineral belt, 1B</td>
<td>Humeca</td>
<td>Rio Algom Mines, Ltd.</td>
<td>Lisbon Valley district, San Juan Co., Utah</td>
</tr>
<tr>
<td>Colorado Front Range, 5</td>
<td>Schwartzwalder</td>
<td>Cotter Corp.</td>
<td>Front Range, Jefferson Co., Colorado</td>
</tr>
<tr>
<td></td>
<td>Highland</td>
<td>Exxon Nuclear Co.</td>
<td>Powder River Basin, Converse Co., Wyoming</td>
</tr>
<tr>
<td></td>
<td>Pay Aljob</td>
<td>Union Carbide Corp.</td>
<td>East Gas Hills district, Natrona Co., Wyoming</td>
</tr>
<tr>
<td>Texas Gulf Coast, 3</td>
<td>Felder</td>
<td>Mobile Oil Co.</td>
<td>Live Oak Co., Texas</td>
</tr>
<tr>
<td></td>
<td>Butler-Weddington</td>
<td>Conoco &amp; Pioneer Nuclear</td>
<td>Karnes, Co., Texas</td>
</tr>
</tbody>
</table>
Salt Wash was deposited as a broad alluvial fan by a distributary stream system (Craig and others, 1955; Thunn and others, 1980) and consists of interbedded fluvial sandstone and flood-plain type mudstone units.

The Monument Valley and White Canyon mineral belts, map no. 1D (Thaden and others, 1968; Malan, 1968; Witkind and Thaden, 1963), have significant ore deposits in the carbonaceous sandstone and conglomerate of the basal Shinarump Member of the Chinle Formation of Late Triassic age. In Monument Valley, the Shinarump sediments fill shallow channels formed by streams that flowed from the south and southeast.

The economic deposits are all of the vanadium-uranium type (V<sub>2</sub>O<sub>5</sub>) in the White Canyon mineral belt. The Shinarump sediments fill shallow channels formed by streams that flowed from the northeast, and the significant deposits are all of the copper-uranium type (Cu > UO<sub>2</sub>). Production plus reserves as of January 1, 1976 in the two belts totalled about 1 percent of the U.S. total.

The Orphan Lode mine (in map province no. 1), Grand Canyon National Park, Arizona, is an important vein-type deposit that occurs in a collapsed and brecciated pipe within highly fractured and brecciated zones of Paleozoic sedimentary rocks (Finch, 1967, figs. 11, 12; Bowles, 1977; Rich and others, 1977).

In Tertiary basins, Wyoming and northern Colorado, map province no. 2, the major uranium deposits are in structural intermontane and/or erosional basins. The principal districts are the Shirley Basin in south central Wyoming, the Powder River Basin in northwest Wyoming, the Gas Hills area on the south flank of Wind River Basin in central Wyoming, and the Crooks Gap area on the north flank of the Great Divide Basin (Anderson, 1969; Armstrong, 1970; Bailey, 1969; Davis, 1969; Melin, 1969; Sharp and others, 1964; Harshman, 1972; Harshman and Adams, 1980; Seeland, 1978). The Shirley Basin uranium occurs in a Cretaceous to Eocene porphyritic quartz monzonite pluton that stocks the Mancos Shale and coarse-grained conglomeratic arkose. These rocks were derived in large part from granitic cores of uplifts and the older sedimentary rocks that flank the cores (Harshman, 1968a, 1968b, 1972). Stuckless (1979) suggests that the region of Central Wyoming has been an uranium province since early Precambrian time. The deposits contain from a few hundred to a few hundred thousand metric tons of ore, ranging in grade from 0.1 percent to 1.0 percent UO<sub>2</sub>. More than 95 percent of the reserves are in formations that are of Tertiary age. Production plus reserves as of January 1, 1976 in deposits in Tertiary sedimentary basins, including the Maybell deposits in the Sand Wash Basin in northwestern Colorado, accounted for 44 percent of the U.S. total, of which the Shirley Basin contributed more than half. The mines active in 1975 are listed in table 3.

In the Texas Gulf Coast, map province no. 3, deposits in Karnes, Live Oak, Atascosa, Starr, Duval, McMullen, and Gonzales Counties in south Texas have most of the production and reserves of uranium (Sarge and others, 1971; 1975; Dickinson, 1976a, b; c; Galloway and others, 1979b; Galloway and Kaiser, 1979; Adams and Smith, 1981). The uranium deposits occur in several Eocene to Paleocene formations. Uranium occurs chiefly in the shoreline, beach, and luvulent facies of the mainly upper Eocene Jackson Group and subordinately in highly tuffaceous fluvial beds of the Catabou Formation of Late Oligocene age. In all cases uranium occurs within regressive units that unconformably overlie transgressive sequences (Adams and Smith, 1981). Both uranium deposits near the coasts and oxidized and other deposits farther inland contained oxidized deposits that are now mostly mined out. The oxidized ore occurred near the surface. The unoxidized ore occurs to depths of 600 m and more. The unoxidized ore deposits, located downdip and southeast of the area of oxidized deposits, occur in upper parts of upturned units. These are larger deposits of generally lower grade ore that is more nearly in equilibrium than is the oxidized ore (Kagel and MacKallor, 1973). Much of the oxidized ore in the Karnes County area is in C-shaped ore rolls similar to those in Wyoming (Harshman and Adas, 1980; Fischer, 1974). The uranium in the deposits is thought to have been leached from the volcanic ash in the host beds and in beds associated with them by ground water that moved downdip along permeable facies to a reducing environment where the ore minerals precipitated. U<sub>2</sub>S that rose along faults from gas fields is thought to be the active reducing agent (Sarge and others, 1971; Egan, 1964a; 1964b; Goldhaber and others, 1970, 1974; Goldhaber and Reynolds, 1977, 1979). The uranium mined ranges from 0.05 percent to 0.5 percent in the Oakville Sandstone. Recovery by in situ leaching to depths of 170 m and extracted 113 metric tons of UO<sub>2</sub> from sandstone by January 1, 1975 (Crawford, 1975; White, 1975). Of the U.S. total production and reserves, as of January 1, 1976, the Texas coastal region accounted for 5.6 percent (table 2). Mines active in 1975 are listed in table 3.

In the northwest part of the Cordilleran Belt, in northeast Washington, important uranium deposits occur in Stevens and Spokane Counties, map province no. 4, which accounted for 2 percent of the U.S. total production plus reserves as of January 1, 1976 (table 2). The largest and most productive deposit is at the Midnite-(Boyd) mine, Stevens County. Production during 14 years of operation was about 3,600 metric tons UO<sub>2</sub> from oxidized and reduced ores averaging 0.23 percent UO<sub>2</sub> (Nash and Lehrman, 1975). High content of iron and sulfur, or pyrite, chiefly sulfo-silicate and silicate rocks, appears to be a characteristic feature of favorable host rocks (Nash and Lehrman, 1975). At the Midnite mine uranium occurs in discordant tabular bodies 50 m or less thick, as much as 210 m wide, and as much as 380 m long, in metamorphosed steeply dipping Precambrian pelitic and calcareous rocks. These metasediments form a rock roof in a Cretaceous to Eocene porphyritic quartz monzonite pluton named the Loom Lake Batholith. The ore bodies, which are best developed in the sheared carbonaceous and pyritic pelitic and argillite, occur predominantly in the upper part of the rock with granite. The thickest ore zones invariably coincide with depressions in the metasediments-granite contact, and the margins of the ore zones generally terminate against steep granite contacts.

At the Peters lease (in map province no. 4), also known as the Northwest Uranium mine or Sherwood mine, Stevens County, Wash., uranium is disseminated in a low-grade orebody in gently dipping Oligocene conglomerate beds (Weis and others, 1976). The beds are poorly sorted and very poorly cemented, and, except for the large boulders that must be broken to be moved, the rock can be mined in open pit without blasting. The ore consists of uraninite intimately associated with carbonaceous material making up 20 percent of the basal unit of the Eocene Sanpoil Volcanics (formerly known as Gombe Andesite) in the mine area. The Sherwood open-pit mine was estimated to contain 5,440 metric tons UO<sub>2</sub> in 1966 (Engineering and Mining Journal, 1975, v. 176, no. 9, p. 206).

In the Mount Spokane area (in map province no. 4), Spokane County, Wash., the uranium deposits are entirely within the Cretaceous to Eocene Loon Lake Batholith, which consists of two provinces: the Eocene and the Cretaceous. The volcanic rocks make up 25 percent or more of the rock. Uranium in the form of autunite or meta-autunite, which is accompanied only by clay as a gangue mineral, fills crevices, joints, shear zones, and other open spaces in the Eocene and Cretaceous rocks. The highest UO<sub>2</sub> content of iron and sulfur, contained chiefly in FeS<sub>2</sub>, that rose along faults from gas fields is thought to be the active reducing agent (Eargle and others, 1968; Klohn and Plckens, 1970, 1974; Weissenborn and Moen, 1974; Weissenborn and Weis, 1976). The Eocene deposits make up 25 percent of the ore rock. Uranium in the deposits is thought to have been leached from the volcanic ash in the host beds and in beds associated with them by ground water that moved downdip along permeable facies to a reducing environment where the ore minerals precipitated. U<sub>2</sub>S that rose along faults from gas fields is thought to be the active reducing agent (Eargle and others, 1968; Weissenborn and Weis, 1976). Of the U.S. total production and reserves, as of January 1, 1976, the Texas coastal region accounted for 5.6 percent (table 2). Mines active in 1975 are listed in table 3.
North and east of the Colorado Plateau within the Cordilleran Belt lies the large, narrow, poorly defined province of the Colorado Front Range and Northern and Southern Rockies, map province no. 5. This province is defined for the most part by vein-type deposits in Proterozoic strata and partly overlaps an area of sedimentary deposits in the Phosphoria basin (province no. 9) in the north and an extension of the Tertiary basin province of Wyoming (province no. 2) into Colorado and northern New Mexico in the south. Production plus reserves as of January 1, 1976 for province 5 totalled about 1.7 percent of the U.S. total (table 2).

In the Front Range of Colorado a number of vein-type deposits occur in Precambrian host rocks at the eastern edge of the Colorado mineral belt (Rich and others, 1977; Walker and others, 1983). In this area there are three classes of uranium veins: those with minor sulfides, which are economically the most important; those with moderate to abundant sulfides; and those with abundant to minor fluorite. At the Schwartzwalder mine (Young and Lahr, 1975), active in 1975 (table 2) and the largest in the area, the veins contain pitchblende and coffinite with minor amounts of iron, lead, zinc and copper sulfides. The deposit is in Precambrian metamorphic rocks in a complexly branched southeastward extension of the Rogers breccia reef fault near the edge of the Front Range (Sheridan and others, 1967; Sims and Sheridan 1964). The main faults and fault breccias and subsidiary, less steeply dipping faults are mineralized where they cut brittle, competent limestone and rock and garnetiferous quartz-biotite gneiss.

Vein-type deposits are found at the Marshall Pass locality (in map province no. 5), in the southern part of the Sawatch Range in the Southern Rockies of Colorado, along the foot-wall of a reverse fault in brecciated, steeply dipping country rocks of Paleozoic age. A major deposit in the area is at the Pitch mine which contains a reserve of 3,245,000 Kg U₃O₈ (7,140,000 lbs) in ore with an average grade of 0.17 percent U₃O₈ (Nash, 1981), and there is a potential for considerable more in the same major structure as well as even more in other structures (J. T. Nash, oral communications, 1983).

The Cocheta district (in map province no. 5) includes the Los Ochos mine and others, Saguache County, Colorado. The Los Ochos deposit consists of secondary uranium minerals, pitchblende, and marcasite in fractured and silicified sandstone and mudstone of the Jurassic Morrison Formation or the Middle Jurassic Junction Creek Sandstone and adjacent underlying shist and gneiss of Precambrian age where the rocks have been broken by east-trending fractures (Dempsey, 1956; Olson, 1976a, 1976b; Wright and Everhart, 1960). Although the crystalline rocks are mineralized, most of the workable part of the deposit, which is now largely mined out, was in sedimentary rocks (Butler, 1964).

Mesozoic sedimentary rocks on the flanks of the Black Hills region, S. Dakota and Wyoming, map province no. 6, contain productive peneconcordant uranium deposits and reserves that, together with the North and South Dakota uraniumiferous lignite and overlying nonlignite deposits, represent less than 3 percent of the U.S. total production and reserves as of January 1, 1976. The deposits are in gently dipping rocks of the Lakota and Fall River Formations of the Lower Cretaceous Inyan Kara Group on the southwest flank and around the northern nose of the Black Hills Uplift, a broad domal uplift of Laramide age (Gott and others, 1974). The Dakota and Fall River Formations are composed predominantly of mudstone and lenticular sandstone, in part conglomeratic. Coalesced plant fossils are common in the sandstone. The environment of sedimentation was mainly fluviatile and lacustrine, and partly marginal marine. Overlying sediments of Tertiary age, since largely removed by erosion, contained abundant volcanic ash. The ore bodies in the Inyan Kara are chiefly irregularly tabular or pod-shaped masses, and some are crescent-shaped rolls (Hart, 1968; Ramey, 1968; Marshman and Adams, 1980).

The Basin and Range, map province no. 7, is a geographic province dominated by fault-block mountains separated by broad alluvium-filled basins. It was a geosyncline during most of Paleozoic and Mesozoic eras and great thicknesses of sedimentary rocks accumulated. During the Cretaceous and Tertiary time, folding and thrusting of the Laramide orogeny deformed the sediments in a southward-trending zone that extends from Canada to Mexico. High-angle normal faulting during the mid- to late-Tertiary extension determined the present topography of long, graben valleys partially filled with alluvial debris from the intervening mountains. The uranium deposits occurring in this uranium province include sedimentary, vein, and other types. Total production plus reserves for the Basin and Range province was estimated as 0.3 percent of total U.S. (U.S. ERDA, 1975, 1976) (see table 2).

In the Marysvale district of central Utah, at the eastern edge of the Basin and Range province where it adjoins the Colorado Plateau, (Kerr and others, 1957; Kerr, 1968; Cunningham and Stevens, 1978; Cunningham and others, 1980) uranium occurs in veins where Tertiary volcanics have been intruded by subvolcanic acidic plutons.

Contact-type deposits near Austin, Lander County, Nevada, in the Rhyolite River district occur in intensely fractured zones peripheral to the contact of a Jurassic quartz monzonite intrusive and Precambrian or Cambrian quartzite or argillite (Sharp and Hetland, 1954; Thurlow, 1956; Chenoweth and Malan, 1969).

In the northern part of Basin and Range province, uranium occurs in veins in rhyolite breccia in the Kings River and McDermitt area, Humboldt County, Nevada and adjoining Oregon; in Lassen and Kern Counties, California; and in Esmeralda, Lincoln, and Washoe Counties, Nevada (Chapman, 1979). Active in 1975 (table 2) uranium occurs in veins in rhyolite breccia of Tertiary age. At McDermitt the uranium deposits occur along the ring fracture of a nonresurgent caldera (Ryuba and Glanzman, 1979). The Moonlight mine is a uranium vein deposit along the ring fracture (or basin-range faults) on the west side of the caldera complex. The Aurora deposit, on the other hand, occurs with abundant pyrite and leucoxene in altered mafic flows beneath mostly-filled sediments south of the northern rim of the McDermitt complex (Roper and Winters, 1969). Uranium occurred during intense alteration by hydrothermal fluids moving upward along pre-existing fractures (J. K. Otton, 1983, oral communication) and thus is not a vein deposit but a replacement-type orebody. The Aurora deposit has reserves of 7,700 metric tons U₃O₈ contained in rock that averages 0.05 percent U₃O₈.

Uranium occurs in Tertiary lake sediments and water-laid tuffs at widely separated areas in Nevada and California of the Basin and Range province (Davis and Hetland, 1956). Intensive search for large low-grade deposits in these Tertiary lake beds and associated rocks, such as in the Date Creek basin, Arizona (Otton, 1981a, b), is needed, but many deposits may prove uneconomic to mine. Otton (1961c, oral communication, 1983) has identified resources of 580,000 metric tons U₃O₈ in rock with an average grade of 0.023 percent for the Date Creek basin deposits and about 1.2 million metric tons of potential resources in the unexplored parts of Date Creek basin and two additional western Arizona Tertiary basins. At Lakeview, Oregon, deposits occur in the contact zone between a rhyolite intrusive of late Tertiary age and pyroclastic and lacustrine sediments of Miocene age (Cohenour, 1960; Walker and others, 1963).

Uraniferous limestones and sandstones, which occur in the Fort Union Formation of Paleocene age in the Cave Hills-Slim Buttes and other parts of the western Williston Basin in North and South Dakota, in Dakota lignite fields, map province no. 8 (Denson and Gill, 1956; Vine, 1962; Gott and Winters, 1969) are characterized by a relatively low concentration of uranium and by a relatively large area extent. At the Flat Top Butte and other claims in Harding County, South Dakota, uranium associated with lignite occurs.
Pennsylvania, Virginia, West Virginia, Maryland, and North Carolina host rocks that range in thickness from 15 centimeters to more than 0.6 meters and are characterized by high volcanic ash content and quite high permeabilities (Denson and Gill, 1965).

Phosphorite layers in the Bone Valley Formation of Pliocene age in the land-locked Florida basins, part of the Phosphatic fields, Florida and South Carolina, map province no. 9, range in thickness from 1.8 to 2.1 meters over about 800 square kilometers and average 0.012-0.024 percent U₃O₈ and 20-30 percent P₂O₅ (Altschuler and others, 1956, 1964; Cathcart, 1963). Uranium in marine phosphorite deposits was probably deposited from sea water during sedimentation, or in some places, possibly later from downward percolating ground water. The Bone Valley Formation has bedded pebbly and clayey phosphatic sands in which alteration to aluminum phosphate has occurred. Most of the formation was deposited in a flat platform area that was gradually inundated by marine water. The region had an irregular shore line, scattered islands, a gently sloping bottom, and distinct connections with the ocean that influenced the nature of sedimentation and alteration. The Engineering and Mining Journal, 1976 (v. 177, no. 1, p. 89) reported that both U₃O₈ and fluorine were being recovered from some wet-process phosphoric acid plants and sold as by-products of phosphate production.

Uranium occurs in marine phosphorite beds on the lower Coastal Plain of South Carolina (in map province no. 9), mainly in the mineral carbonatite-fluorapatite. The uranium content of phosphorite ranges from 0.025 to 0.063 percent equivalent U₃O₈ (Southern Interstate Nuclear Board, 1969).

Marine phosphatic rocks with anomalous uranium concentration occur in the Phosphoria Formation and its stratigraphic equivalents of Permian age in an area of about 350 square kilometers in Idaho, Montana, Utah, and Wyoming (Carlson, 1964; Kay and others, 1964; Carswell, 1964). The part of the Phosphoria Formation with the highest uranium concentration (0.0012 percent U₃O₈) is outline as Phosphoria basin, map province no. 10 in eastern Idaho and adjacent parts of Montana, Wyoming, and Utah (McKelvey, 1967; McKelvey and Carswell, 1956, 1967). These phosphorite beds are more than 1 meter thick and average more than 31 percent P₂O₅ (McKelvey and Carswell, 1956, 1967). The Phosphoria consists of a sequence of phosphatic carbonaceous shale and mudstone, phosphorite, chert, carbonate rock, and sandstone. Deposition of these rocks occurred in marine geosynclines and on platforms. Thin platform facies lie to the east, and a thick geosynclinal facies occurs on the west. The richest phosphite beds occur in two geosynclinal members of the formation in the tightly folded and faulted Triassic geosynclinal sections, the Phosphoria Formation is not presently economic to mine for uranium except as a by-product of wet-process phosphoric acid production.

Subeconomic resources of U.S. phosphate deposits that contain at least 0.012 percent U₃O₈ are estimated to be 1,000,000 metric tons U₃O₈, of which 800,000 are in the Phosphoria and its equivalents in the western U.S., and 200,000 are in pebble phosphate field of Florida (in map province no. 9) (Sheldon, 1964; Davidson and Atkin, 1953).

The Pennian and Triassic Basins of eastern New Mexico, West Texas, and the Oklahoma Panhandle and the Quachita Mountain area along the Oklahoma-Texas border in the Central Plains, map province no. 11, contain uranium deposits in continental sandstones of Triassic and Permian ages, Pennian and Triassic basins (Russell, 1958; Finch, 1972, 1975). A few of the deposits, mainly in Triassic rocks, have been mined and yielded a total of about 800 tons of ore averaging about 0.20 percent U₃O₈. This province is only moderately favorable for small deposits similar to those mined.

In the Appalachian Highlands, map province no. 12, continental sandstone sediments accumulated during Paleozoic and Triassic times in the shallow, poorly drained foreland and deep post-orogenic basins of New Jersey, New York, Pennsylvania, Virginia, West Virginia, Maryland, and North Carolina. The Devonian Catskill and Mississippian Mauch Chunk Formations and the arkose sediments of the Newark Group in the Triassic basins contain small sandstone-type deposits and are favorable for additional deposits (Klenic, 1962; Turner-Petersen, 1980).

The eastern Central Plains uraniumiferous Devonian marine black shale basins, map province no. 13, in which the Chattanooga Shale and correlatives were formed as part of a blanket of black shales in early Late Devonian (or possibly late Middle Devonian) to Early Mississippian times cover much of the interior of North America (Conant and Swanson, 1961). The Chattanooga Shale was deposited in an area of epicontinental seas. It is composed of marine, black, siliceous, lower-grade oil shale and gray claystone and has areas where it contains uranium ores such as arems, spores, and amacerated debris. The Chattanooga Shale, as a formation averages 0.007 percent U₃O₈, and is estimated to contain 7,000,000 metric tons U₃O₈ (Swanson, 1961; U.S. Dept. Energy, 1980b). Uraniferous shales correlate with the Chattanooga (Vine and Tourtelot, 1970) have been found in Indiana, Ohio, Pennsylvania, New York, West Virginia, and Kentucky (Broadhead and others, 1980; Leventhal, 1978, 1979, 1980a,b; Leventhal and Goldhaber, 1978; Leventhal and others, 1978; Wallace and others, 1977). Leventhal (1980a,b) observed that core samples from Devonian shales from the Illinois and Michigan Basins appear to show the same ranges of chemical compositions and geochemical controls as those from the Appalachian Basin. Uraniferous black shales were not considered to be viable sources for uranium in 1980.

The Precambrian Shield area, map province no. 14, contains no known economic uranium deposits, but just across the border in Canada both classical vein and quartz-pegge conglomerate types are known. Areas of the Precambrian Shield in Michigan, Minnesota, Wisconsin, and New York may have deposits similar to the large Precambrian quartz-pegge conglomerate uranium deposits of Elliot Lake-Blind River district, Ontario, Canada. In addition, vein-type uranium deposits related to the Lower to Middle Proterozoic unconformity may occur in the areas of Idaho, Montana, Wyoming, Utah, South Dakota, Iowa, Minnesota, Wisconsin, and Michigan (Kallikoski and others, 1978; F. A. Hills, oral communication, 1981). Finally, the area is possibly favorable for intermediate-grade deposits of disseminated type in crystalline rocks (F. A. Cull, oral communication, 1981; Houston and Karlstrom, 1979; Kallikoski and others, 1978; Button and Addams, 1981).

Extensive marine phosphorites of Miocene age, which are commonly radioactive, are present in a number of places in California in the southern Pacific Coast Ranges, Pacific Coast, map province no. 15, and along the west side of the San Joaquin Valley (Walker and Butler, 1966). Compared to the large economic deposits in other parts of the United States, most of the uranium deposits of the Pacific Coast area are small, and none are thought to contain large reserves of marketable uranium, or are likely to contribute appreciably to total resources in the United States.

Certain provinces (map province nos. 11, 12, 13, 14, and 15) have less potential for uranium production than others. Many of the deposits in these provinces are either small or large, very low-grade occurrences. Size alone, however, will not determine which deposits might become economic producers. Some, which may permit uranium to be recovered by bulk mining methods or as a byproduct could probably be mined before some larger and higher grade deposits. Some, because of their isolated location, may never be mined.

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