CHARACTERISTICS OF URANIUM DEPOSITS, USA

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Summary

Uranium deposits in the United States occur mainly in well-defined mineral provinces that roughly coincide with physiographic provinces in the western States. The provinces are closely related to the development of the western margin of the North American plate from Late Paleozoic through Tertiary time. The most productive deposits are of the sandstone type.

Introduction

Uranium deposits were discovered in the United States in 1896 and were exploited in three episodes, starting in the early 1900's for radium, in the 1930's for vanadium, and finally for uranium starting in the mid-1940's and extending to the present. U.S. uranium deposits have been studied since the early 1900's, and their characteristics have been well-documented, particularly during extensive government research begun by the Manhattan Project in 1943 (Chenoweth, 1997) and continued by the U.S. Atomic Energy Commission (AEC), the U.S. Geological Survey and the U.S. Department of Energy 1949 through 1983 (U.S. Department of Energy (DOE), 1980). A federal database, developed by AEC/DOE under the uranium procurement program, 1947-1970, and updated continuously to the present time, is comprised of data on over 5,000 economic uranium properties. A property is a specific land area named in the data sets that consists of reserves, mine production, grades, deposit type, mine type, metallurgical type, host rock name and age, and depth. A property may cover part or all of one or more natural uranium deposits, whose boundaries are commonly poorly known. Computed statistics for natural uranium deposits based on property data for reserves, grades, and other "deposit" parameters are believed to be reasonable estimates.

The purpose here is to describe the deposits' geologic characteristics and their distribution in the well-defined uranium provinces and to relate various factors in the database to the geology of the deposits. As the prime example, the current uranium reserves and cumulated production as of January 1, 1998 for each uranium province are shown by deposit and mine types in Table 1. The reserves are presented in two forward-cost categories that include only operating and capital costs still to be incurred in mining and milling to produce uranium concentrate from the in-place ores. Various costs of prior expenditures for exploration and development are excluded. Annual reports on the uranium industry are published by the Energy Information Administration (U.S. Energy Information Administration, 1999).

Geology of uranium deposits

The principal type of uranium deposit in the United States is the sandstone uranium deposit (Finch, 1967). These deposits yielded about 95 percent of the cumulated production (Table 1) and occur mostly in sandstone formations in the western States; a few small deposits were discovered in Pennsylvania.

Solution-collapse breccia-pipe uranium deposits occur in Pennsylvanian-Permian sandstone formations in the Grand Canyon region of Arizona. The remainder of economic deposits occur in veins and volcanic structures in igneous, marine sedimentary, and metamorphic rocks. By-product uranium production from Florida phosphorite has been significant in recent years.

Sandstone uranium deposits occur mainly in quartzitic to arkosic fluvial sandstone lenses and channel-fills in the lower parts of host formations. The host units are overlain regionally by thick volcanoclastic sequences. Sandstone uranium deposits are of two forms: tabular and roll-front. Tabular deposits are generally in irregular discontinuous layers peneconcordant to bedding, most commonly in Permian, Triassic, and Jurassic rocks on the Colorado Plateau and in Cretaceous rocks in the Black Hills in South Dakota and Wyoming. The thickness of layers varies from tens of centimeters to several meters. Layers may be stacked, such as in the San Juan Basin, New Mexico. Clusters of deposits in districts range in size from 500-20,000 metric tons U and their grade ranges from 0.05-0.60 percent U (Finch, 1996). The uranium minerals, and in many places either vanadium or copper minerals as well as pyrite, impregnate the sandstone and replace organic material, commonly fossilized wood or disseminated humic matter. Uraninite and coffinite are the primary uranium minerals (Burns and Finch, 1999). Reduced alteration of surrounding rocks is prevalent. The uranium ores most likely precipitated by reduction from uranium-bearing groundwater at great depths.

Roll-front uranium deposits were formed at a oxidation/reduction interface of uranium-bearing groundwater that moved down dip from the ground surface, most commonly in Tertiary sandstone in Wyoming, Nebraska, and Texas, resulting in a deposit of uranium minerals in the shape of a roll. Some ore bodies consist of large single rolls measuring several meters high, but many are a complex of smaller rolls. Clusters of roll-front ores range from 500-10,000 metric tons U and their grades range from 0.04-0.30 percent U (Finch, 1996). The mineralogy is similar to that of tabular deposits, and the vanadium and copper contents are very low.

Vein uranium deposits are those deposits localized along steeply dipping structures, commonly in hard and brittle rocks, such as at the Schwartzwalder deposit, Colorado. Their mineralogy is commonly more complex than in sandstone deposits. Clusters of vein ores range from 500-5,000 metric tons U and their grades range from 0.15-1.0 percent U (Finch, 1996). The Schwartzwalder vein ores formed during the inception of the Laramide orogeny by sulphur species that reduced uranyl ions derived from the enclosing metamorphic rocks (Wallace and Whelan, 1986).

Volcanic uranium deposits most commonly occur in late Tertiary calderas and their associated sedimentary basins, such as the McDermitt deposit, Nevada/Oregon, but a few occur in

Table 1. United States Uranium Reserves and Production by Uranium Province

Uranium Province, Deposit and Mine Characteristics	$80/Kg U Forward Cost, 1998			$130/Kg U Forward Cost, 1998			Cumulative Production, 1947-1998		
	Metric Tons Ore (1 000)	Grade [a]	Kilograms U (1 000)	Metric Tons Ore (1 000)	Grade [a]	Kilograms U (1 000)	Metric Tons Ore (1 000)	Grade [a]	Kilograms U (1 000)
Colorado Plateau	**20,530**	**0.236**	**48,520**	**122,660**	**0.134**	**164,460**	**120,060**	**0.178**	**214,090**
Deposit Type									
Sandstone-tabular	17,280	0.229	39,530	94,230	0.135	127,000	96,060	0.168	161,630
Sandstone-roll front	0	--	0	90	0.110	100	W		W
Limestone	10	0.208	30	270	0.141	380	1,610	0.158	2,540
Co-product	0	--	0	0	--	0	180	0.230	410
Vein	0	--	0	0	--	0	510	0.369	1,890
Other	3,240	0.277	8,960	28,070	0.132	36,970	21,700	0.219	47,620
Mine Type									
Open-pit	560	0.166	940	3,540	0.101	3,590	24,490	0.165	40,400
Underground	18,910	0.240	45,330	105,840	0.145	153,120	85,900	0.183	156,960
In Situ Leach	1,010	0.212	2,150	2,130	0.145	3,070	7,940	0.153	12,180
Other	50	0.226	110	11,160	0.042	4,680	1,730	0.263	4,560
Rocky Mountains and Intermontane Basins, Crawford Basin	**45,130**	**0.120**	**54,260**	**250,390**	**0.069**	**173,750**	**77,390**	**0.136**	**105,600**
Deposit Type									
Sandstone-tabular	28,420	0.116	32,980	77,010	0.076	58,560	18,330	0.114	20,800
Sandstone-roll front	14,700	0.126	18,510	124,560	0.063	78,820	35,950	0.142	50,900
Vein	640	0.206	1,320	9,400	0.061	5,690	4,320	0.258	11,150
Other	1,370	0.105	1,440	39,420	0.078	30,680	18,790	0.121	22,750
Mine Type									
Open-pit	7,920	0.120	9,490	129,200	0.067	86,930	64,850	0.127	82,320
Underground	3,640	0.196	7,140	21,740	0.108	23,530	3,630	0.358	12,990
In Situ Leach	33,570	0.112	37,620	96,870	0.064	62,230	7,850	0.116	9,140
Other	0	--	0	2,570	0.041	1,060	1,060	0.108	1,150
Basin and Range	**20**	**0.180**	**30**	**6,820**	**0.071**	**4,830**	**10,420**	**0.014**	**2,020**
Deposit Type									
Sandstone-roll front	0	--	0	0	--	0	W		W
Vein	0	--	0	10	0.138	10	30	0.182	50
Other	20	0.180	30	6,820	0.000	4,820	10,400	0.014	1,970
Mine Type									
Open-pit	10	0.201	20	6,780	0.070	4,770	150	0.145	210
Underground	10	0.145	10	50	0.116	50	480	0.175	840
In Situ Leach	0	--	0	0	--	0	W		W
Other	0	--	0	0	--	0	9,800	0.004	970
South Texas Coastal Plain	**3,990**	**0.068**	**2,700**	**17,250**	**0.055**	**9,320**	**43,570**	**0.062**	**26,820**
Deposit Type									
Sandstone-roll front	3,990	0.068	2,700	17,250	0.055	9,320	43,570	0.062	26,820
Mine Type									
Open-pit	400	0.117	460	4,130	0.066	2,730	16,080	0.089	14,380
In Situ Leach	3,420	0.060	2,050	12,550	0.050	6,310	26,250	0.047	12,350
Other	180	0.105	190	570	0.085	270	1,240	0.007	90
Others	**880**	**0.094**	**830**	**5,430**	**0.050**	**2,720**	**1,340**	**0.475**	**6,360**
Deposit Type									
All deposit types	880	0.094	830	5,430	0.050	2,720	1,340	0.475	6,360
Mine Type									
Open-pit	560	0.044	250	3,870	0.021	810	150	0.055	80
Underground	290	0.176	510	1,210	0.132	1,600	830	0.350	2,890
In Situ Leach	20	0.224	50	300	0.087	260	120	0.142	160
Other	10	0.203	10	50	0.094	50	250	1.299	3,220
Totals:	**70,550**	**0.151**	**106,330**	**402,550**	**0.088**	**355,080**	**252,790**	**0.140**	**354,890**

[a] Weighted average percent U3O8 per ton of ore. "--" = Not applicable. "W" = Data withheld to avoid disclosure: values are included in respective totals for Other.

Notes: Colorado Plateau: Deposit Type "Other" reserves and production include undisclosed. Sandstone-roll front production is included under sandstone-tabular. Mine Type "Other" reserves can include heap leach, open pit-underground undivided, and undisclosed, and "Other" production can include mine water, heap leach, mine dumps, protore, open pit-underground undivided, and undisclosed. **Rocky Mountain and Intermontane Basins, and Crawford Basin:** Deposit Type, "Sandstone-roll front" and Mine Type "In situ leach" include totals for Crawford Basin, Nebraska, to avoid disclosure of company specific data. **Basin and Range:** Deposit Type "Other" can include sandstone-roll front, hydroallogenic, and undisclosed. Mine Type "Other" can include in situ leach, open pit-underground undivided, dumps, and undisclosed. **South Texas Coastal Plain:** Mine Type "Other" reserves and production include underground, heap leach of low grade ores, and undisclosed. **Others:** "All deposit types" can include sandstone-tabular and -roll front, vein, hydroallogenic, and undisclosed. Values shown are rounded to nearest ten thousand units for tons ore and kilograms uranium. Totals may not equal sum of components because of independent rounding.

Sources: Estimated by the Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, based on historical U.S. Department of Energy data and on Form EIA-858, "Uranium Industry Annual Survey," (1998).

shallow intrusive rocks, such as at Marysvale, Utah. The forms of the ore bodies may be those of sandstone deposits or veins. Clusters of deposits range from 500-20,000 metric tons U, and their grades range from 0.05-0.25 percent U (Finch, 1996). Minerals are uraninite and coffinite, commonly associated with jordisite, molybdenite, flourite, and cinnabar. McDermitt deposits formed from hydrothermal fluids and hotspring and meteoric waters, whereas the Marysvale deposits formed from hydrothermal magmatic fluids.

Distribution of uranium provinces

The major uranium deposits are clustered in four, large, well-defined tectonic elements that are part of the North American plate. They are 1) Colorado Plateau uranium province (CPUP), 2) Rocky Mountain and Intermontane Basins uranium province (RMIBUP), 3) Basin and Range uranium province(BRUP), and 4) Gulf Coastal uranium province (GCUP) (Finch, 1996). The latter two provinces extend into Mexico. The CPUP occupies the Colorado Plateau physiographic province; a block of the Proterozoic crust isolated since late Paleozoic time. Production from this province totaled 214,100 metric tons U (Table 1). The RMIBUP is a modification of the Rocky Mountains structural province and is essentially defined by the Cenozoic Laramide uplifts and basins. Roll-front sandstone deposits formed in the basins, mainly in Wyoming, and large vein uranium deposits occur in Colorado. Production from this province totaled 105,600 metric tons U (Table 1). The BRUP borders the CPUP and the western edge of RMIBUP and extends into the Mexican Cordillera. Production in BRUP totals 2,000 metric tons U from volcanic uranium deposits (Table 1). The GCUP is a narrow band of Tertiary formations along the coastal plain parallel to the Gulf of Mexico in Texas and extending into Mexico. Production in the GCUP totals 26,800 metric tons U (Table 1). East of the Rockies only a few major economic uranium deposits occur on the High Plains and in northeastern United States. A single large vein uranium deposit, Swanson, occurs in Virginia. Over 25,000 metric tons U has been produced as a by-product during the manufacture of phosphoric acid in Florida and Louisiana from phosphorite rock mined in Florida (compiled by W. Chenoweth from DOE, NUEXCO, and International Nuclear Inc. data, 1999).

Development of uranium provinces

The evolution of the U.S. uranium provinces was associated with volcanic activity related to the development of the western margins of the North American plate from Late Paleozoic through Tertiary time (Finch, 1996). Volcanic arcs to the west, and mainly outside a province itself, resulted in air-fall sediments that later became the source of the uranium. In the Wyoming basins, weathering of Precambrian granite may also have been a source of uranium as well as Tertiary tuffaceous sediments. Thus, the ultimate source of uranium in various provinces was igneous activities and rocks (Plant and others, 1999).

Future exploitation and uranium research

The remaining uranium reserves in the United States (table 1) are mostly deeply buried and of lower grade than the currently mined very high-grade uranium ores in Canada and Australia. Thus, prices of uranium will have to increase markedly for most United States ores to be economic. At the present, in situ leach solution mining of Tertiary sandstone in Wyoming, Nebraska, and Texas are the only viable operations in the United States.

Future research on uranium geology and environmental problems related to the nuclear fuel cycle in producing electricity will be based on new technology developed since the late 1980s. Most important are technology and theoretical advances in analytical methods that have revolutionized research on distribution and quality of uranium and other trace elements in uranium ores and host rocks reported in Burns and Finch (1999), especially for radioactive-waste disposal. New sequence stratigraphy and sediment depositional methods will be useful in updating favorability of potential uranium host formations for exploration.

Because of discoveries of new deposits, new and improved assessment methodologies, and new geoscience research results since the original assessment in 1980 (U.S. Department of Energy, 1980), a new national assessment is urgently needed (Finch, 1997).

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