Uranium and Vanadium Resources of Utah: an Update in the Era of Critical Minerals and Carbon Neutrality

by

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Suggested citation:

Mills, S.E. and Jordan, B., 2021, Uranium and vanadium resources of Utah—an update in the era of critical minerals and carbon neutrality: Utah Geological Survey Open-File Report 735, 26 p., 1 appendix, https://doi.org/10.34191/OFR-735.

UTAH DNR GEOLOGICAL SURVEY

OPEN-FILE REPORT 735
UTAH GEOLOGICAL SURVEY
a division of
UTAH DEPARTMENT OF NATURAL RESOURCES
2021

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INTRODUCTION

Utah is the second largest vanadium producing state and the third largest uranium producing state in the United States (Krahulec, 2018). Carnotite, a primary ore mineral for both vanadium and uranium, was first discovered and used by Native Americans as a source of pigment in the Colorado Plateau physiographic province of eastern Utah (Chenoweth, 1985; figure 1). Radioactive deposits have been commercially mined in Utah since about 1900, starting with radium, followed by vanadium, and then uranium. In 1952, the discovery of the Mi Vida mine in Utah's Lisbon Valley mining district in San Juan County kicked off a uranium exploration rush across the Colorado Plateau. As a result, the United States dominated the global uranium market from the early 1950s to late 1970s. In the modern mining era, Utah is an important contributor to the domestic uranium and vanadium markets with the only operating conventional uranium-vanadium mill in the country, multiple uranium-vanadium mines on standby, and active uranium-vanadium exploration. Overall, Utah has produced an estimated 122 million lbs U_3O_8 and 136 million lbs V_2O_5 since 1904 (table 1). Most of this production has been from the sandstone-hosted deposits of the Paradox Basin (figure 1), with minor production from volcanogenic deposits and as byproducts from other operations across the state.

Given the legacy of uranium and vanadium mining in Utah, much has been written about the production, exploration, and geology of these deposits. One of the most comprehensive summaries of the U.S. Atomic Energy Commission (AEC) purchasing era is Doelling's (1974) publication summarizing Utah's uranium and vanadium occurrences and subsequent bibliography of uranium publications (Doelling, 1982). William Chenoweth, largely regarded as a leading expert on the Colorado Plateau uranium and vanadium industry, published a summary of Utah's historical uranium and vanadium production in 1990 (Chenoweth, 1990a). Gloyn and others (2005) published the first modern mining district boundaries for uranium and vanadium deposits and Krahulec (2018) expanded the scope of Gloyn's work to include all of Utah's metallic mineral mining districts, thus capturing districts outside of the Colorado Plateau. In addition to these statewide summaries, numerous county- or district-focused publications have provided extensive detail on the geology and production of uranium and vanadium (e.g., Hawley and others, 1966; Doelling, 1969, 1975; Trimble and Doelling, 1978; Doelling and others, 1980, 1989; Thamm and others, 1981; Chenoweth, 1990b, 1993; Gloyn and others, 1995, 2003).

A comprehensive and consistent review of production data has proven difficult to quantify despite the volume of information that has been published on Utah's uranium and vanadium deposits. Variations and discrepancies between records of production are due to multiple factors. First, production is often reported by mining district, but the boundaries of mining districts have evolved significantly since the advent of uranium and vanadium production (figure 2). As a result, early production numbers from certain mining districts do not necessarily align with later mining districts of the same name. One effort to combat this discrepancy is to report production by county, but the issue remains that geology and hence mineralization often crosses geographic boundaries. Therefore, counties do not adequately capture the geologic aspect of production. Reporting standards have also changed through time, both in terms of reporting ore versus grade versus tonnage and in terms of units (e.g., short ton versus tonne). Depending on the information provided, it is not always possible to reconcile information reported in different publications.

The most significant issue complicating consistent production data is the difference between uranium and vanadium mined in Utah versus uranium and vanadium milled in Utah. During the peak of the AEC purchasing period, Utah had several active mills and six AEC purchasing stations that frequently procured ore from neighboring states like Arizona. At the same time, Utah sent ore out of state to nearby stations (e.g., Rifle, Colorado). Vanadium production in particular is poorly constrained because it was considered less valuable than uranium and often not closely recorded, if it was recovered at all.

This report focuses on the mined production in Utah, which is the best representation of Utah's historical uranium and vanadium activity. The information in this report provides a synthesis of the existing historical uranium and vanadium mined production data, including data from unpublished Utah Geological Survey records, AEC procurement data, and published production figures. A summary of annual Utah production from the onset of mining in 1904 to modern time is provided, as well as totals by modern mining district as defined by Krahulec (2018). The data presented here also serve to set the stage for discussion of the potential future of uranium and vanadium mining in Utah as a new era of critical minerals and carbon-neutral energy sources unfolds. Additional publications on the geology of uranium and vanadium mineralization in Utah are given in the appendix.

GEOLOGIC OVERVIEW

The geologic distribution of uranium and vanadium mineralization has been detailed from deposit to terrane scale multiple times over the years, with notable descriptions in Doelling (1974), Gloyn and others (1995, 2003), and Krahulec (2018). As such, only a brief overview is presented here. More than 90% of Utah's uranium production came from sandstone-hosted ura-

Table 1. *Annual production of uranium and vanadium in Utah.*

Year	U_3O_8 (lbs)	Uranium Price (2020$/lb U_3O_8)	V_2O_5 (lbs)	Vanadium Price (2020$/lb V_2O_5)
1904-1943	550,000	na	4,000,000	$15.94
1944	0	na	514,138	$17.93
1945	100,000	na	174,950	$17.60
1946	115,000	na	114,253	$15.51
1947	0	na	85,690	$13.58
1948	101,596	$69.65	121,394	$13.09
1949	169,980	$79.40	271,350	$12.72
1950	369,368	$83.58	503,426	$11.24
1951	509,599	$79.12	992,571	$11.82
1952	583,382	$132.10	346,329	$12.39
1953	571,378	$139.07	689,087	$12.27
1954	1,702,302	$125.53	1,028,275	$12.31
1955	2,219,000	$129.47	1,778,059	$12.31
1956	5,919,000	$93.37	5,712,640	$12.10
1957	7,511,000	$82.35	5,688,254	$12.47
1958	8,914,000	$79.56	6,783,760	$11.41
1959	8,600,000	$80.33	5,989,989	$12.43
1960	6,539,000	$79.24	5,163,013	$12.23
1961	6,160,000	$75.31	5,744,131	$12.19
1962	5,492,000	$70.34	5,867,060	$11.16
1963	5,526,000	$67.97	4,268,984	$11.00
1964	6,029,000	$66.79	4,526,018	$9.77
1965	2,160,000	$66.15	1,381,745	$9.64
1966	1,254,000	$55.72	1,260,351	$10.13
1967	1,287,000	$52.93	1,681,658	$9.85
1968	1,712,000	$50.15	2,010,135	$8.74
1969	1,140,000	$44.57	1,585,258	$10.83
1970	1,635,000	$34.82	917,593	$8.49
1971	1,445,000	$39.00	806,910	$18.51
1972	1,496,000	$36.00	671,235	$11.65
1973	1,961,000	$32.00	506,997	$10.96
1974	1,860,000	$73.00	3,034,840	$11.12
1975	2,020,000	$168.00	2,549,266	$10.46
1976	2,410,000	$173.00	3,570,400	$15.63
1977	2,460,000	$170.00	3,713,216	$15.10
1978	3,000,000	$161.00	4,284,480	$14.07
1979	3,200,000	$142.00	6,426,720	$12.88
1980	4,200,000	$83.00	4,998,560	$9.81
1981	2,900,000	$63.00	5,712,640	$9.11
1982	2,890,000	$53.00	5,027,123	$7.47
1983	2,500,000	$51.00	2,764,918	$9.27
1984	2,400,000	$39.00	497,685	$8.90
1985	1,560,000	$30.00	0	$8.58
1986	1,600,000	$41.00	892,600	$8.41

Table 1 continued. *Annual production of uranium and vanadium in Utah.*

Year	U_3O_8 (lbs)	Uranium Price (2020$/lb U_3O_8)	V_2O_5 (lbs)	Vanadium Price (2020$/lb V_2O_5)
1987	1,500,000	$38.00	839,044	$8.12
1988	1,200,000	$32.62	1,071,120	$7.59
1989	1,000,000	$21.28	1,249,640	$13.09
1990	900,000	$19.78	1,160,380	$8.49
1991	0	$16.73	0	$5.50
1992	0	$15.97	0	$4.27
1993	0	$18.18	0	$2.64
1994	0	$16.48	0	$5.25
1995	0	$19.67	0	$4.84
1996	0	$26.06	0	$5.38
1997	0	$19.51	0	$6.36
1998	0	$16.39	0	$8.82
1999	0	$16.08	0	$3.14
2000	0	$12.50	0	$2.78
2001	0	$12.99	0	$2.04
2002	0	$14.39	0	$1.96
2003	0	$16.40	0	$3.16
2004	0	$25.91	0	$8.33
2005	0	$38.78	0	$21.95
2006	0	$64.54	0	$10.26
2007	201,000	$153.50	1,078,261	$9.40
2008	621,000	$79.07	3,327,613	$15.80
2009	576,000	$57.11	3,084,826	$6.65
2010	612,000	$55.65	3,277,627	$7.80
2011	508,000	$66.61	3,216,930	$7.92
2012	553,000	$55.43	3,213,360	$7.43
2013	55,000	$43.07	321,336	$6.81
2014	0	$37.00	0	$6.24
2015	0	$40.71	0	$4.64
2016	0	$28.69	0	$3.71
2017	0	$23.52	0	$8.17
2018	0	$25.68	0	$17.23
2019	0	$26.52	0	$12.20
2020	0	$29.59	0	$6.70
Total:	**122,497,605**		**136,497,837**	

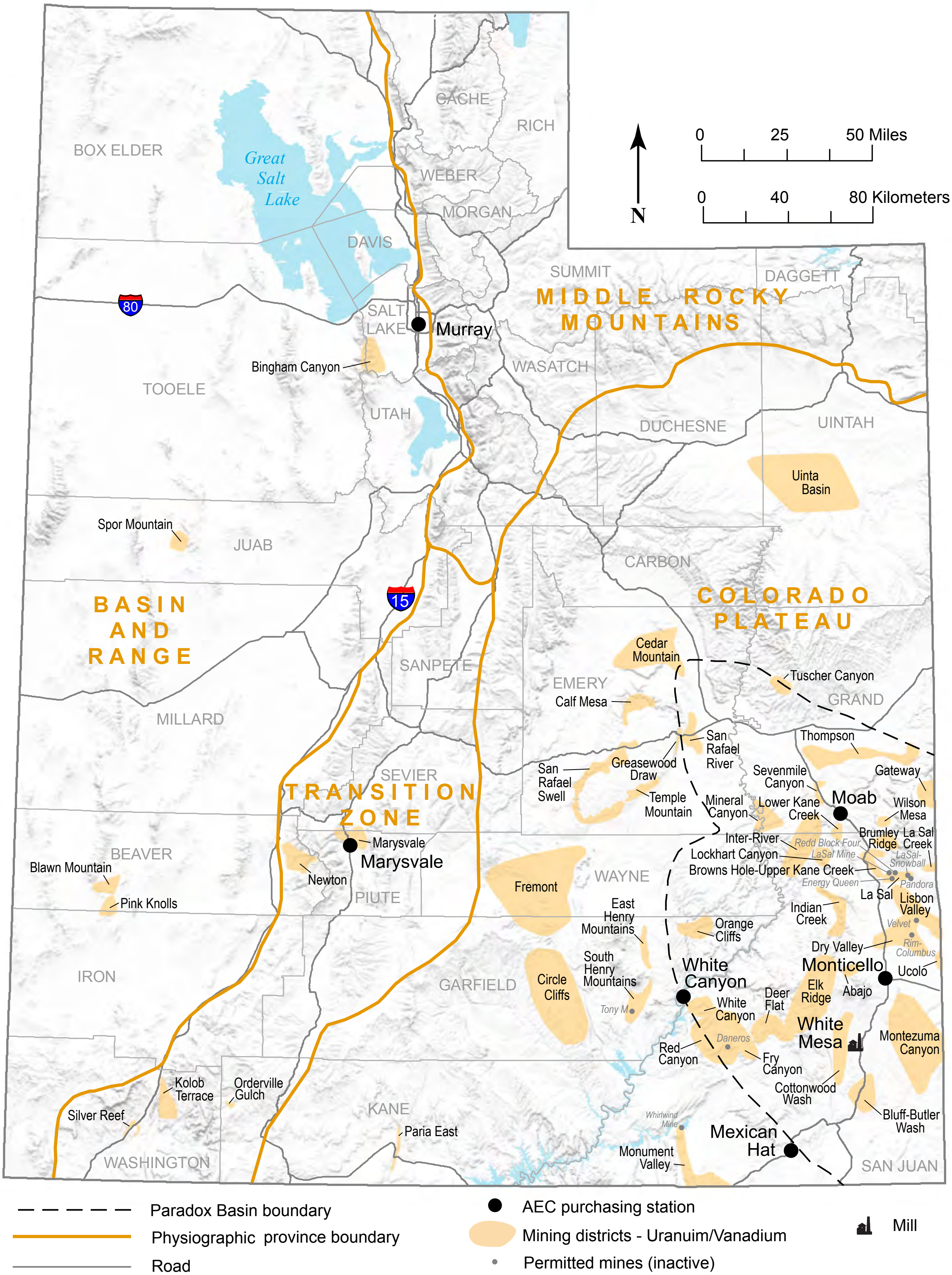

Figure 1. *Overview of the modern mining districts that contain uranium and vanadium. The Paradox Basin is the major source of uranium and vanadium deposits within Utah and contains most of the permitted but inactive mines.*

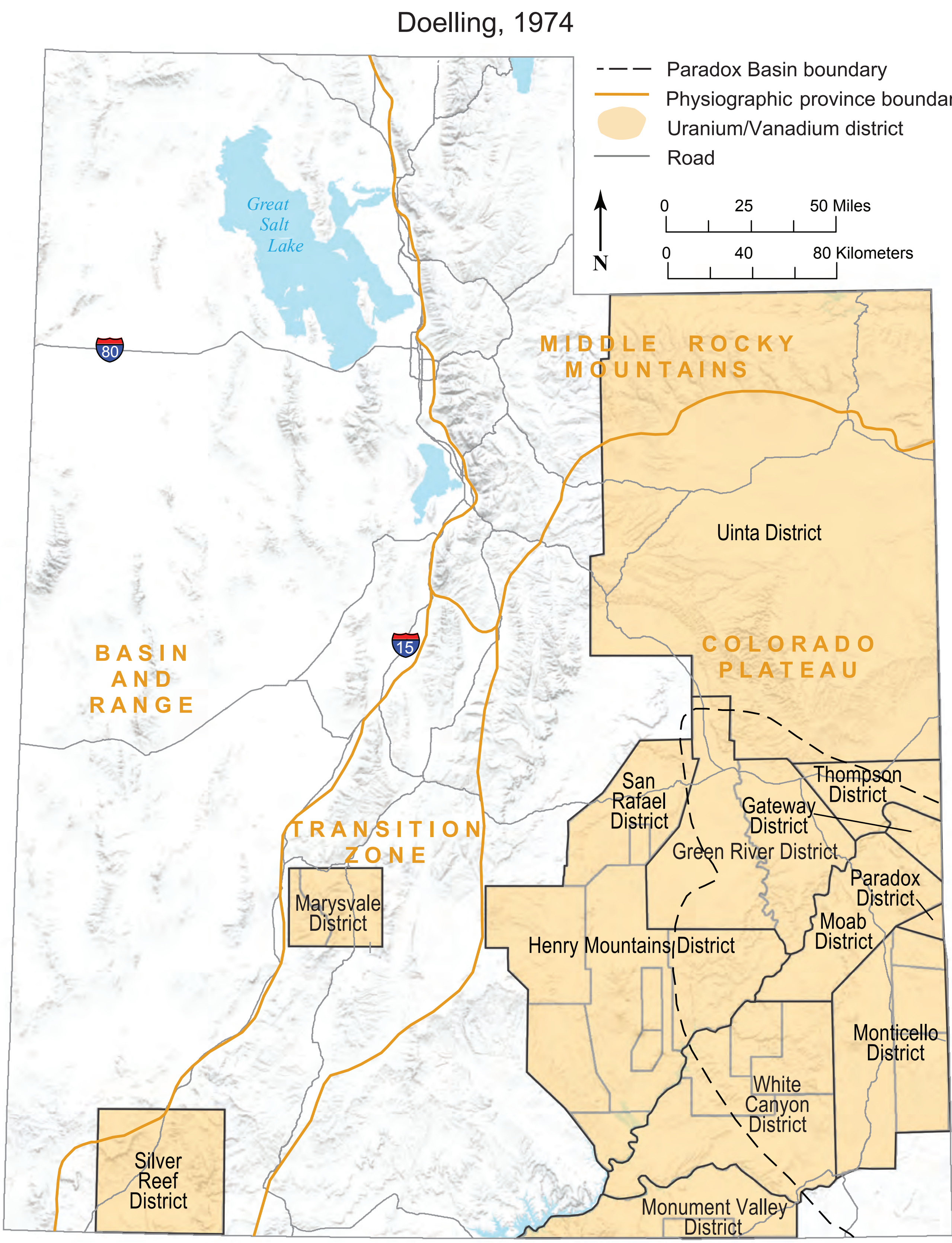

Figure 2. *Changes to uranium/vanadium mining districts through time.*

Chenoweth, 1990

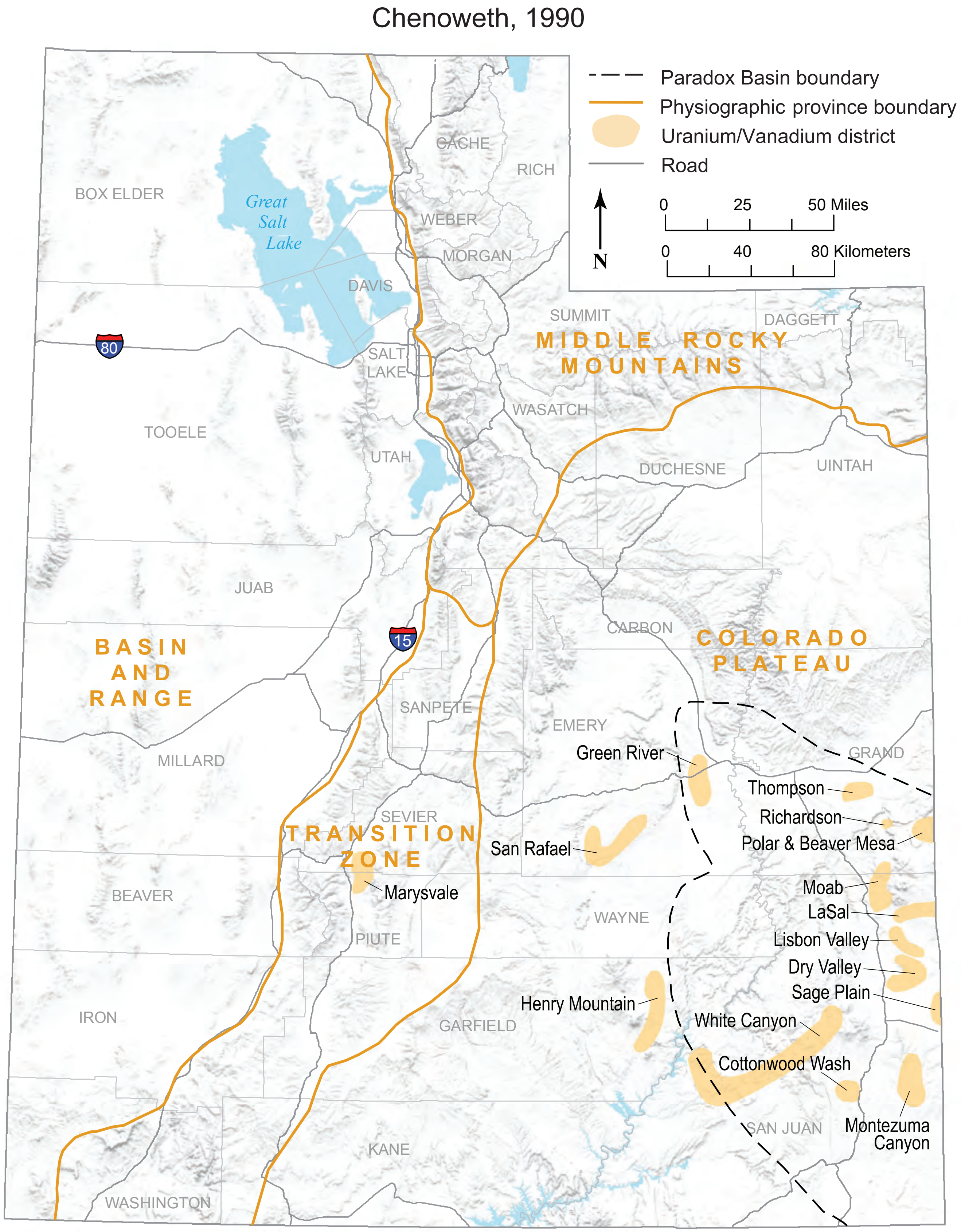

Figure 2 continued. *Changes to uranium/vanadium mining districts through time.*

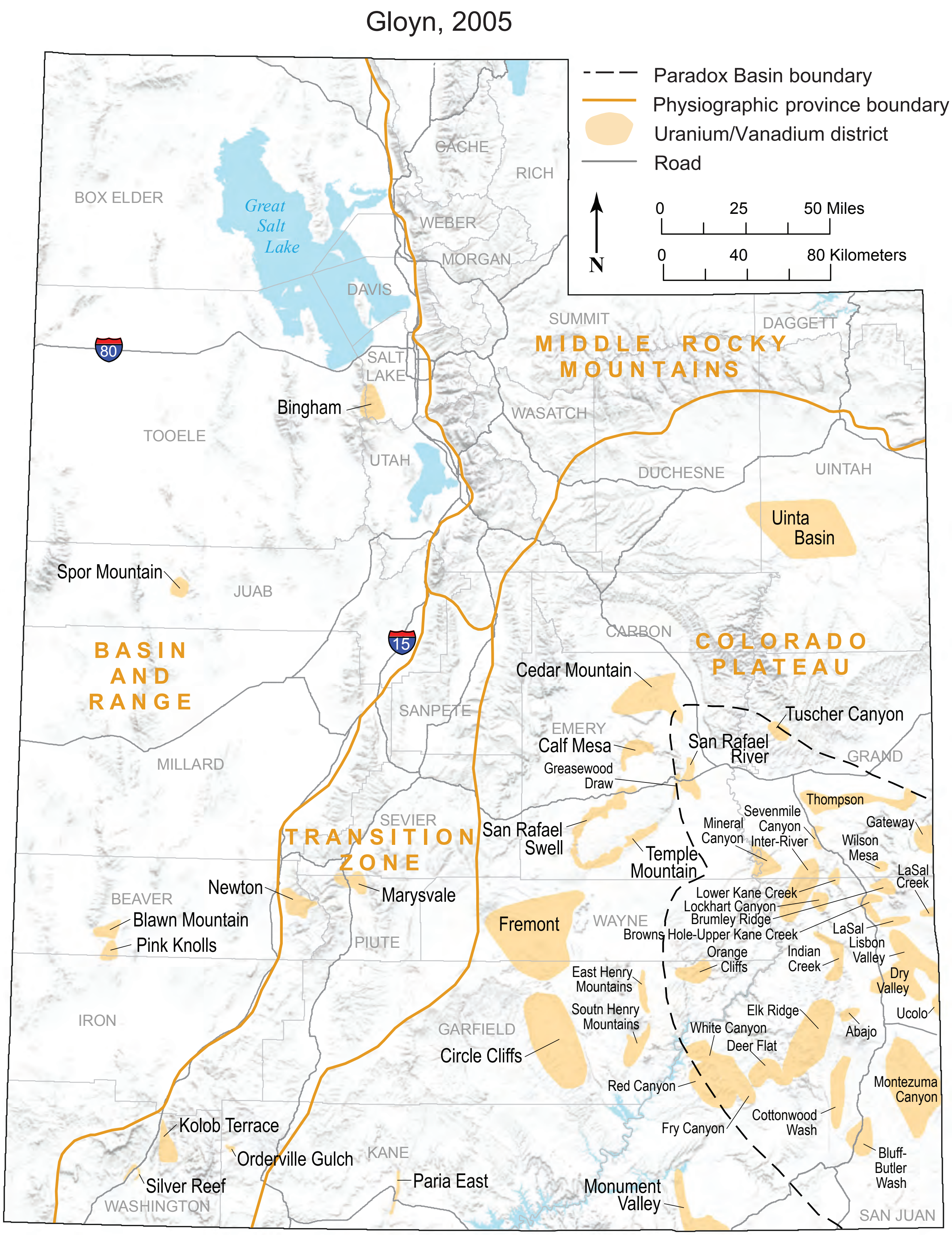

Figure 2 continued. *Changes to uranium/vanadium mining districts through time.*

nium and vanadium deposits in the Paradox Basin of the Colorado Plateau. The remaining 10% of uranium production was from collapse breccia features in the San Rafael Swell, volcanogenic deposits in the Basin and Range Province and the Basin and Range–Colorado Plateau Transition Zone, and the Bingham Canyon porphyry deposit (figure 1).

Sandstone-Hosted

The sandstone-hosted uranium and vanadium deposits in the Colorado Plateau are generally tabular bodies of varying size that formed in Triassic to Jurassic fluvio-lacustrine channel sandstones. Mineralization is thought to be peneconcordant, indicating they formed closely in time to the host strata. Most uranium deposits are associated with vanadium mineralization, and copper is a common secondary metal.

The two most important host rocks for sandstone-hosted uranium are the Upper Triassic Chinle Formation and the Upper Jurassic Morrison Formation, particularly the Salt Wash Member of the Morrison Formation (figure 3). Most of the historical uranium production comes from the Salt Wash Member of the Morrison Formation (57%) whereas a minority comes from the Chinle Formation (34%) (figure 4a). The deposits in the Chinle Formation are nearly evenly split between the Moss Back and Shinarump Members. The remaining production (8%) comes from various sedimentary and volcanic deposits. The distribution for vanadium deposits is even more skewed towards the Salt Wash Member, which hosts 74% of major and minor vanadium deposits having past production (figure 4b). The Moss Back and Shinarump Members host 14% and 4%, respectively. Although the Salt Wash and Chinle are the most common host rocks in the most prolific uranium producing areas, other units (like the Springdale Sandstone Member of the Moenave Formation) contain sandstone-hosted uranium and vanadium farther west, including in the Silver Reef district near Cedar City.

The formation of uranium and vanadium mineralization is believed to be the result of oxidizing meteoric fluids and/or locally derived diagenetic brines (Northrop and others, 1990). These fluids interact with organic material in a redox reaction that causes precipitation of uranium and vanadium minerals in the reducing organic material. The requirement of a porous host rock to promote circulation of meteoric fluids and brines, as well as the required redox reaction with indigenous reductants (carbon trash, plant fragments) or introduced reductants (dead oil, hydrocarbons), demonstrates why the fluvio-sedimentary sandstone channels of the Colorado Plateau are ideal for hosting uranium mineralization. However, this also demonstrates why uranium deposits in the plateau tend to be smaller than other types of uranium deposits in the world, such as unconformity or pebble conglomerate deposits, as they are confined to fluvial channels (IAEA, 2020). Mineralization is thought to have occurred soon after deposition of the host rock, generally from the Triassic to Jurassic, with sporadic mineralization into the Cretaceous. However, uranium mineralization is notoriously difficult to date, and as yet there is no comprehensive study for the exact age of mineralization across specific deposits in Utah.

Collapse Breccia

A secondary style of mineralization in the Colorado Plateau is the collapse breccia pipes of the Temple Mountain and San Rafael Swell districts. These deposits differ from the traditional sandstone-channel deposits in that they form in passive collapse breccias, tend to have unique metallic assemblages, and have a strong association with hydrocarbons such as asphaltite. The collapse breccias form around a central core of down-dropped sedimentary strata due to the dissolution of underlying carbonate units (like the Permian Black Box Dolomite, the Triassic Sinbad Limestone Member of the Moenkopi Formation, and the Mississippian Leadville Limestone). The central breccia core is surrounded by a sag zone of inward-dipping sedimentary rocks. Collapse breccias are a common feature in many deposit types, including the famous Carlin gold deposits of the Basin and Range Province. In the Temple Mountain and San Rafael Swell areas, the collapse breccias range from 100 to 2500 ft in diameter and have a vertical extent of up to 800 ft, with sedimentary units down dropped by as much as 400 ft (Gloyn and others, 2003). Although the deposit description implies a direct analog to the breccia pipe uranium deposits found in northern Arizona, significant differences keep the Utah deposits from falling under that classification. The Arizona pipes contain more sulfides, including a massive sulfide pyrite “cap” above the uranium, and the hydrocarbons are thought to have been introduced after, rather than prior, to brecciation (Krewedl and Carisey, 1986; Wenrich and others, 1989).

Volcanogenic

Volcanogenic uranium (± vanadium) deposits are associated with highly evolved alkali volcanics such as topaz rhyolites, which form in rift settings associated with bimodal volcanism. The volcanic suites involved in volcanogenic uranium deposits tend to be enriched in Be, F, Li, and Th. Sandstone-hosted and collapse breccia deposits are associated with meteoric fluids and

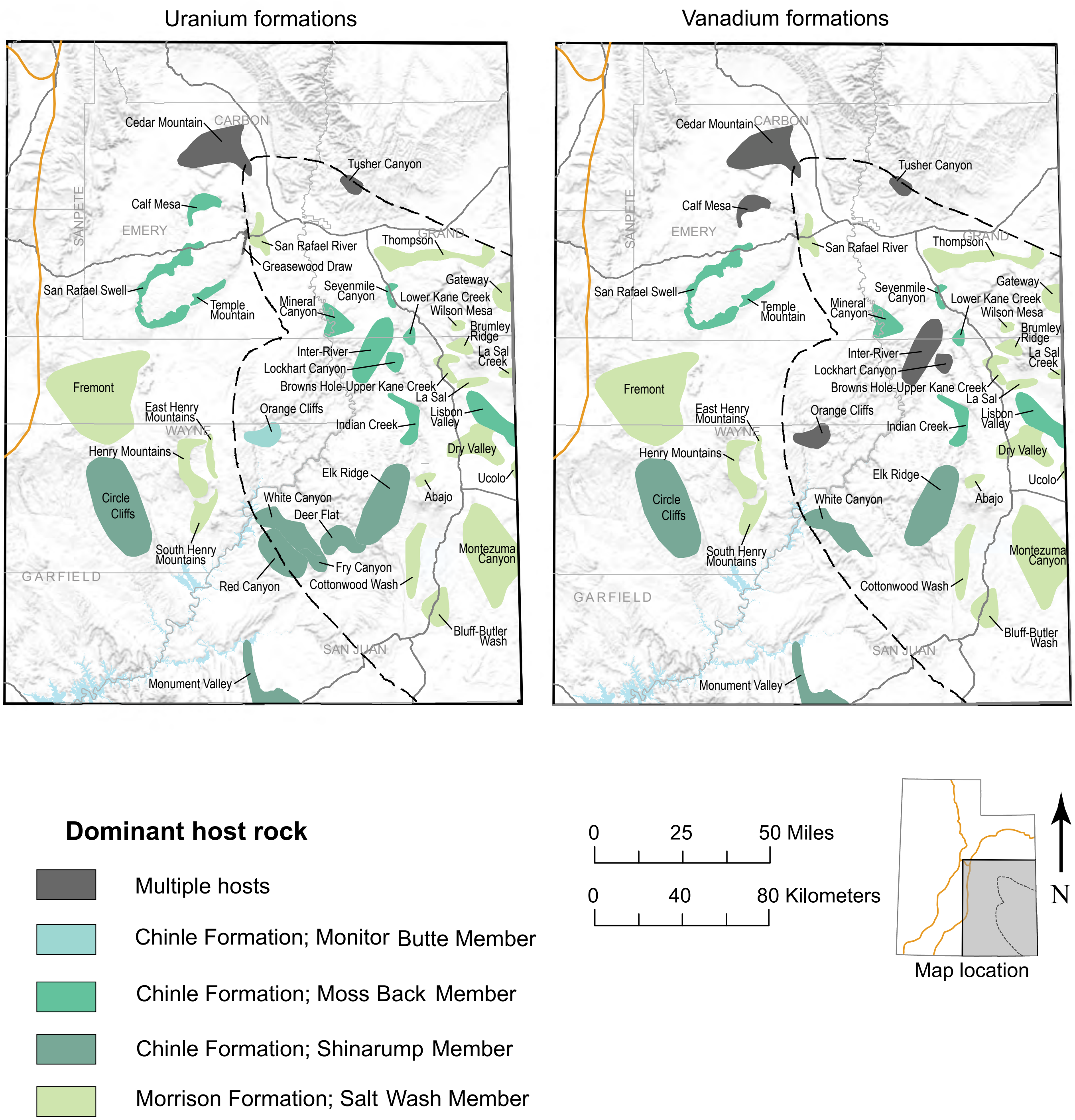

Figure 3. *Uranium and vanadium host formations, grade, and production by mining district in the Colorado Plateau.*

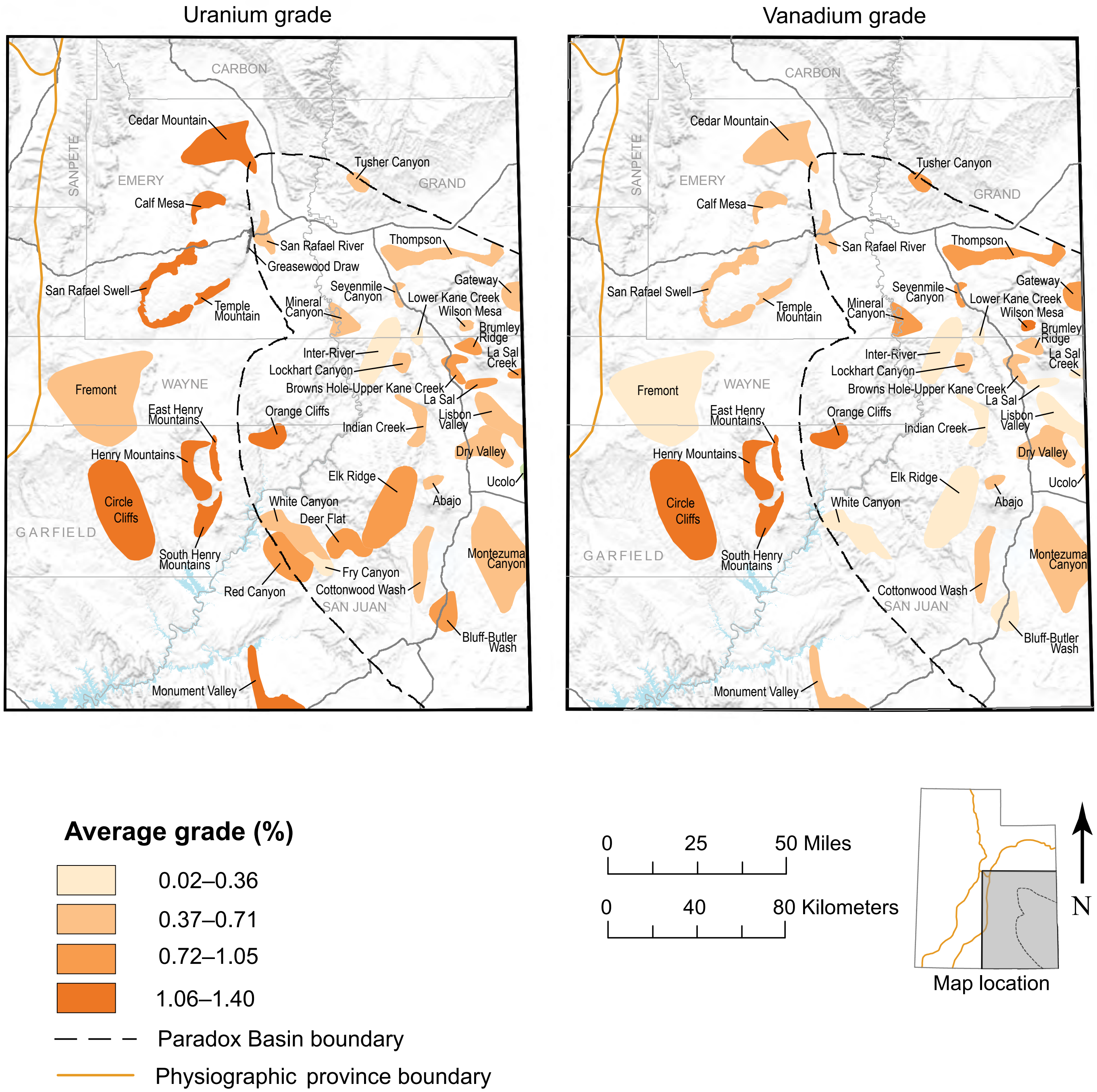

Figure 3 continued. *Uranium and vanadium host formations, grade, and production by mining district in the Colorado Plateau.*

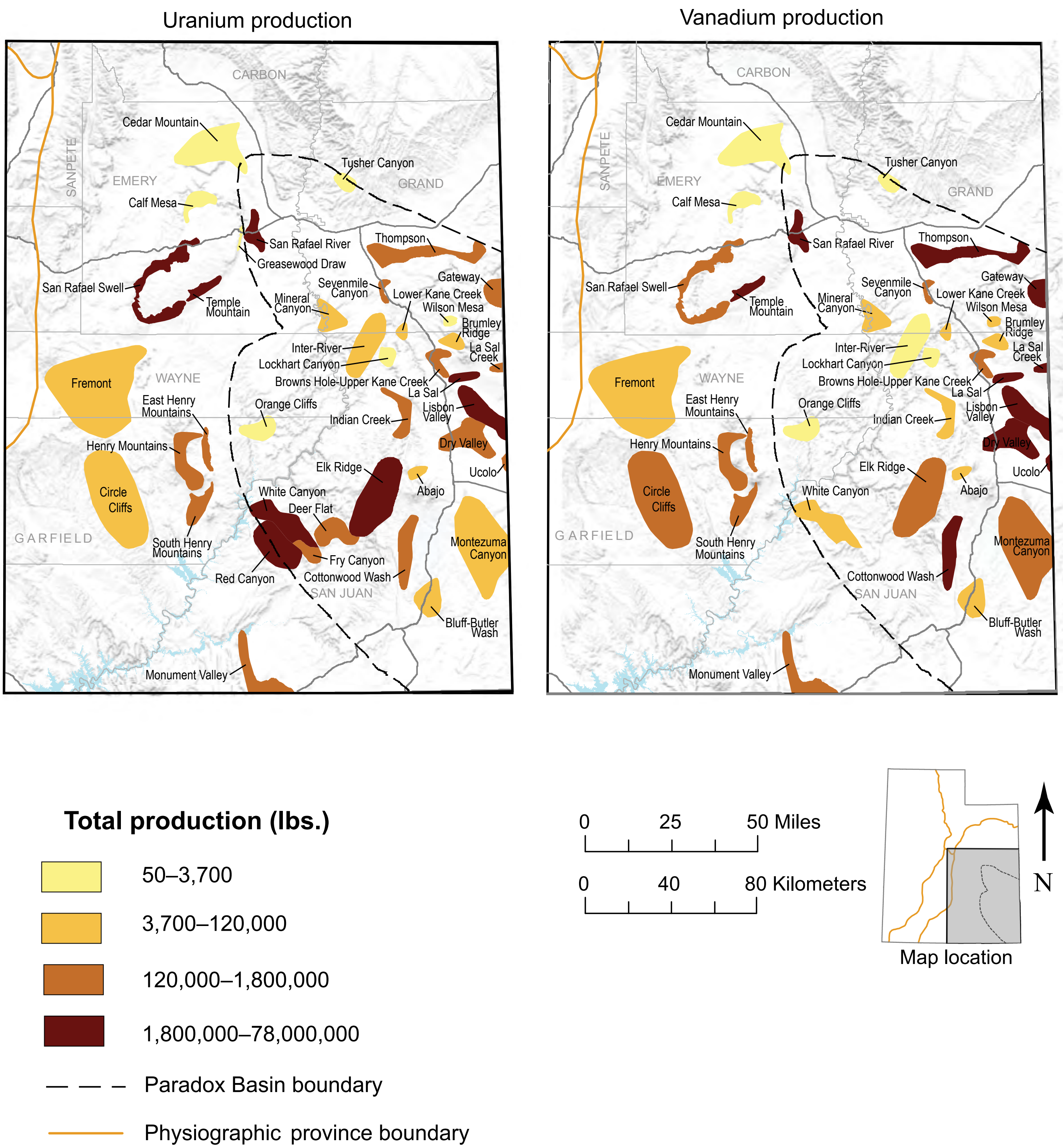

Figure 3 continued. *Uranium and vanadium host formations, grade, and production by mining district in the Colorado Plateau.*

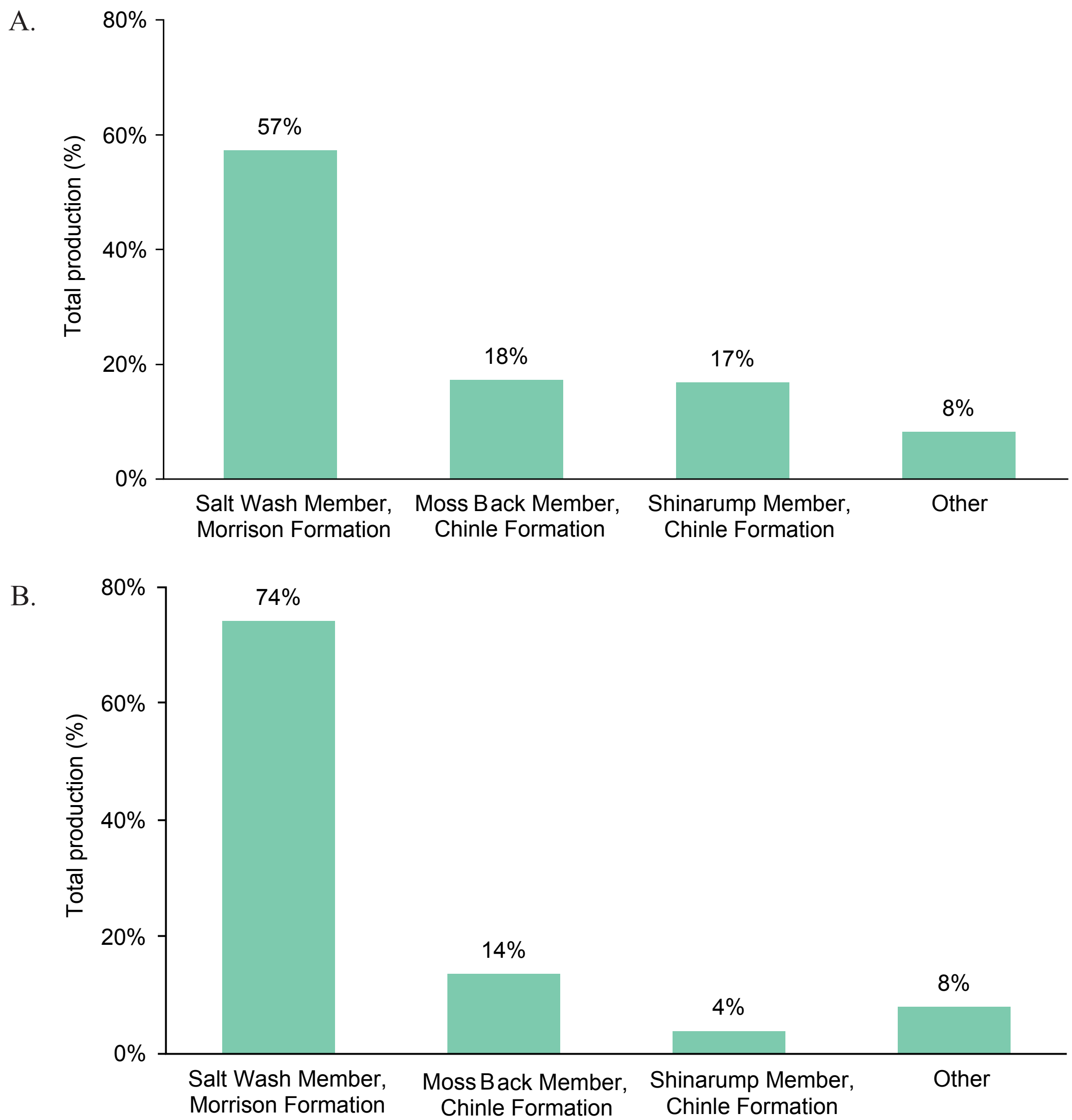

***Figure 4. A)** Percent of total production of uranium in Utah by host formation. **B)** Percent of total production of vanadium in Utah by host formation.*

basin brines, whereas volcanogenic deposits involve magmatic fluids. In Utah, the most notable volcanogenic uranium deposits are found in the Marysvale and Spor Mountain districts, with minor volcanogenic uranium mineralization in the Pink Knolls, Blawn Mountain, and Newton districts. These districts host alkalic rhyolite volcanics or porphyries resulting from an epoch of bimodal extension during Miocene Basin and Range extension. Overall, volcanogenic uranium deposits are smaller and lower grade than many other styles of uranium mineralization, hence are rarely targeted in modern uranium exploration. The Marysvale district in Piute County hosts volcanogenic uranium vein deposits in alkali rhyolites, and the Spor Mountain district hosts volcanogenic uranium in volcanic sandstones and conglomerates sourced from topaz rhyolites. Notably, volcanogenic uranium deposits have a distinct mineralogy from the Colorado Plateau deposits and tend to have lower vanadium concentrations.

Porphyry Byproduct

The Bingham mining district in Salt Lake County is the most prolific mining district in the United States, having been the first porphyry Cu mine in the world and operating continuously for over a century and a half. Through its history, the Bingham district has produced copper, gold, molybdenum, silver, lead, and zinc as major commodities, as well as byproducts such as tellurium, bismuth, selenium, platinum, palladium, and uranium. Economic rather than geologic factors drove uranium extraction in the Bingham district, where the recovery of uranium was made possible due to the sheer volume of mineralized rock being processed as opposed to geologic events that created an abnormal concentration of uranium. Pilot studies on extraction of uranium from copper leach solutions (i.e., the solutions resulting from leaching the waste ore dumps to recover copper) began in the mid-1960s and utilized a combination of ion exchange and solvent extraction or liquid ion exchange techniques (George and others, 1968). Development of this method in 1965 showed U_3O_8 contents in leach solutions at 14 copper porphyry mines in Arizona, Utah, and Nevada were between 2 and 15 ppm. Despite this early work, the extraction of uranium was not implemented commercially at Bingham Canyon until 1978. After implementation, over 1.5 million lbs U_3O_8 were recovered from copper leach solutions until the idling of the extraction facility in 1989.

ERAS OF PRODUCTION

The uranium and vanadium mining history in Utah can be split into four time periods: the pre-nuclear era, the AEC purchasing era, the nuclear energy era, and the modern era (figure 5). Historical events greatly influenced the uranium industry and caused irrevocable changes to the economics and politics surrounding uranium. Inevitably, significant shifts in the uranium market also affected vanadium. These historical events, and their influence on exploration and production of uranium and vanadium resources, provide natural boundaries for each era. An overview of the major defining factors for each era is outlined below.

Pre-Nuclear (1900 to 1946)

Uranium was identified as an element in 1789, and its radioactive properties have been known since 1896. Vanadium was discovered in 1801, though was not isolated in its pure form until 1867. Despite knowledge of both elements, the earliest mining to take place in the Colorado Plateau in the late 19th to early 20th century was focused on radium. The Colorado Plateau gained notoriety as an area of mining interest with the discovery of carnotite in 1899 from a sample found in Colorado. The presence of uranium in carnotite ore made it the primary global source for radium from 1913 to 1922, with vanadium and uranium either produced as byproducts or discarded. Utah produced an estimated total of 0.5 oz of radium during this period (one gram of radium could be extracted from 200 to 300 tons of ore containing over 2% U_3O_8) (Chenoweth, 1990a). Vanadium became increasingly important with the onset of WWI and the recognition of vanadium's metallurgical properties, particularly once the United States entered the conflict in 1917. Radium also saw an increased demand in WWI, moving away from the traditional medical uses for cancer reduction once it was realized that when mixed with zinc oxide radium was luminous. The luminosity became desirable for nighttime dials in aircraft and on watches, eliminating the need for lights that could give away one's position. The end of WWI caused a drop in demand for vanadium, and Colorado Plateau ores were no longer a competitive source of radium with the discovery and development of high-grade pitchblende deposits in modern-day Democratic Republic of the Congo in the early 1920s. As a result, mining for uranium and vanadium in the Colorado Plateau ceased around 1923.

However, by the mid-1930s demand for vanadium as a metallurgical agent in the alloy-steel industry renewed interest in the Colorado Plateau deposits, and the U.S. entry into WWII in 1942 gave the vanadium market an additional boost. Given the strategic importance of vanadium to the war effort, the federal government formed the Metals Reserve Company to establish an ore purchasing program and stockpile vanadium ore—a move that would be mirrored in just a few years with the establishment of the Atomic Energy Commission. The Metals Reserve program ended in 1944, after which vanadium mining slumped significantly.

As WWII progressed and the Manhattan Project (1942–1946) gained traction, the need for more uranium led to reprocessing vanadium tailings, where uranium had previously been discarded as a waste product. Approximately 265,000 lbs U_3O_8 were extracted from tailings at vanadium mills in Monticello and Moab between 1943 and 1946 (Chenoweth, 1990a). The deployment of the first nuclear bombs against Japan in 1945 marked a stark end to the pre-nuclear era and shortly after in 1946, the Manhattan Project was disbanded. The age of nuclear fission had officially arrived and domestic uranium mining was rapidly becoming front and center.

U.S. Atomic Energy Commission Purchasing (1947 to 1970)

With the advent of the nuclear arms race, the AEC was formed in 1947 and in 1948 began a purchasing program for uranium ore. Like the short-lived Mineral Reserve Company precursor, the AEC set guaranteed prices for uranium purchases to ensure the United States had adequate stockpiles for nuclear applications. The purchasing program was intended to stimulate the growth and development of a domestic mining industry. Private companies explored, mined, and processed ores with support from the AEC in the form of a guaranteed market, geologic surveys, and testing and assay services (Chenoweth, 1990a). With prices guaranteed and the discovery of the Mi Vida uranium mine in Utah in 1952, a new era of uranium exploration and mining began in the Colorado Plateau. Although uranium was the focus of the AEC's program, a \$0.31 bonus (roughly \$3.15 in 2020 dollars) was also given per pound V_2O_5.

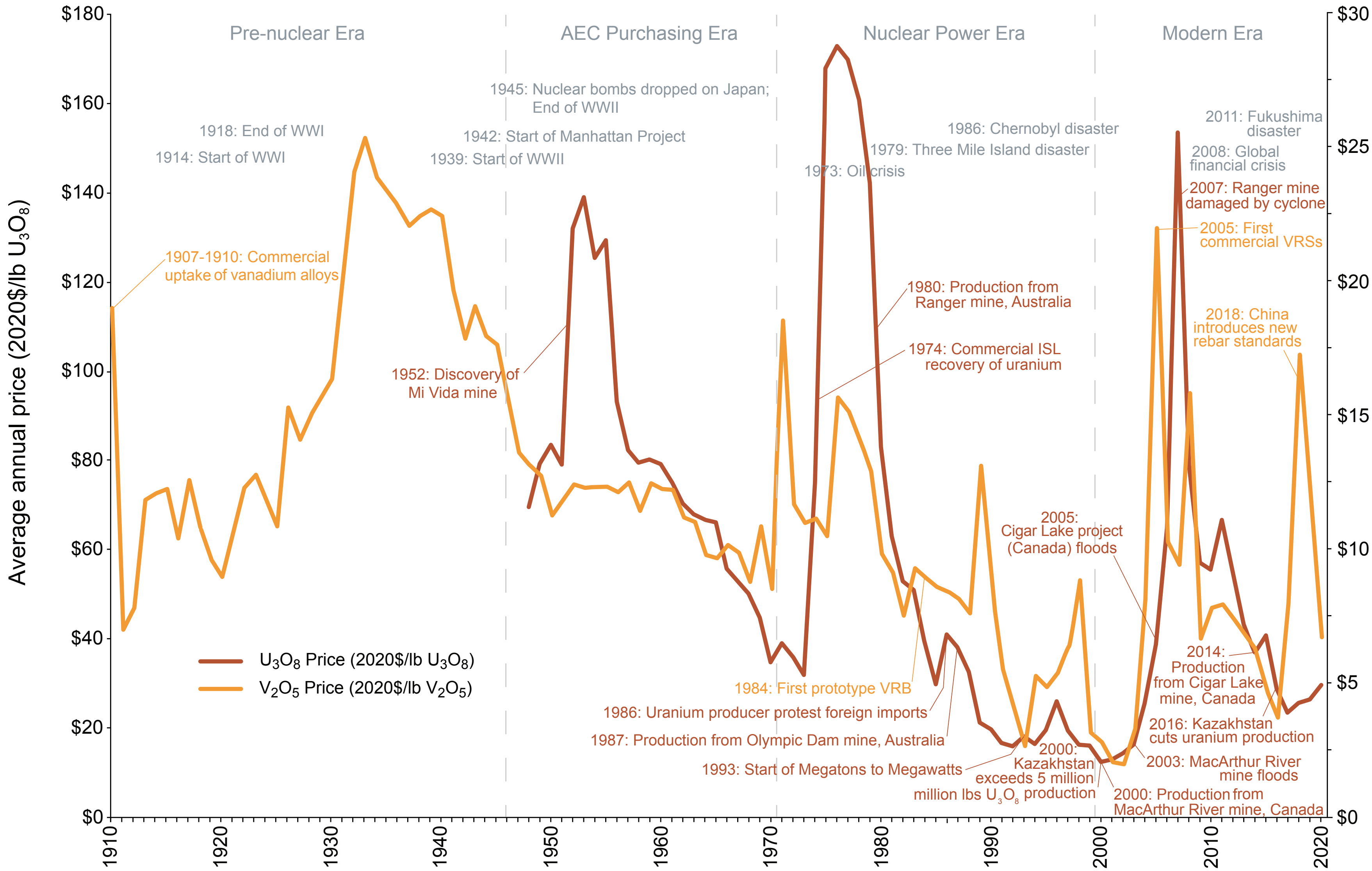

Figure 5. *Uranium and vanadium prices through time, annotated with relevant events and time periods.*

During the procurement period, the AEC set up six uranium ore-buying stations in Utah, as well as several in surrounding states like Colorado and New Mexico. Two of the six purchasing stations were outside the Colorado Plateau to accept ore from smaller volcanogenic deposits and from byproduct production at Bingham Canyon (see Geologic Overview section for more detail). The AEC purchasing program led to rapid growth in Utah's uranium production into the 1950s, with peak production in 1958 that waned into the 1960s and 70s. The AEC changed the set purchase price as needed to jump-start the uranium industry during lulls while avoiding an oversupply. However, price adjustments did not necessarily have instantaneous results. On a national scale, the lag between peak price and peak production was 7 years, and in Utah, the lag between peak price and peak production was approximately 5 years (figure 6). This lag was despite mining in a period of comparatively little regulation or oversight when deposits were near surface and easy to discover in comparison to modern times. By the 1960s, uranium was only being produced from the Colorado Plateau, and by the time the AEC procurement program ended in 1973, Utah had a handful of operating mines producing a fraction of its past production capacity. During the AEC procurement program, an estimated 13 million tons of ore was mined producing 81 million pounds U_3O_8 and 66 million lbs V_2O_5 from over 500 individual mines in Utah (table 1).

The AEC purchasing program overlapped with the start of uranium purchases for civilian nuclear energy purposes. The first significant orders for civilian plants began in the late 1960s. By the end of the AEC period enough civilian reactor orders provided the incentive needed for operators to continue production, despite the loss of a guaranteed market.

Nuclear Power (1971 to 1999)

The AEC purchasing program ended in the early 1970s and the nuclear power era began. The price of uranium, no longer guaranteed by the government, went through wild fluctuations due to speculation on the uptake of nuclear energy during the 1970s and 1980s (figure 6). In 1976, the newly reported spot uranium price shot upward to a high of \$173/lb U_3O_8 (2020 dollars), even though production expansion was outpacing near-term demand. Peak production lagged peak price by 4 years in Utah, with Utah hitting a post-AEC production high of over 4 million lbs U_3O_8 produced in 1980. Unfortunately, by late 1980, the uranium price had fallen to half the 1976 level as oversupply began to saturate the market. The Three Mile Island accident in 1979 and multiple reactor cancellations also tempered expectations about the growth of nuclear energy. The low uranium price was particularly burdensome for Utah and other conventional underground mining operations as the more economical in situ leach (ISL) mining method was implemented in many of Wyoming's uranium deposits. A compounding effect to increased domestic competition was the discovery of large, high-grade ore bodies internationally in the early 1980s. Notably, this included the Olympic Dam and Ranger mines in Australia, both high-grade high-tonnage deposits in a country with strong trade ties. Given the availability of uranium supply from ally countries, the U.S. government eliminated existing trade embargos to allow for the import of uranium. As a result, by 1985 domestic production had decreased to a quarter of 1980 production. Domestic

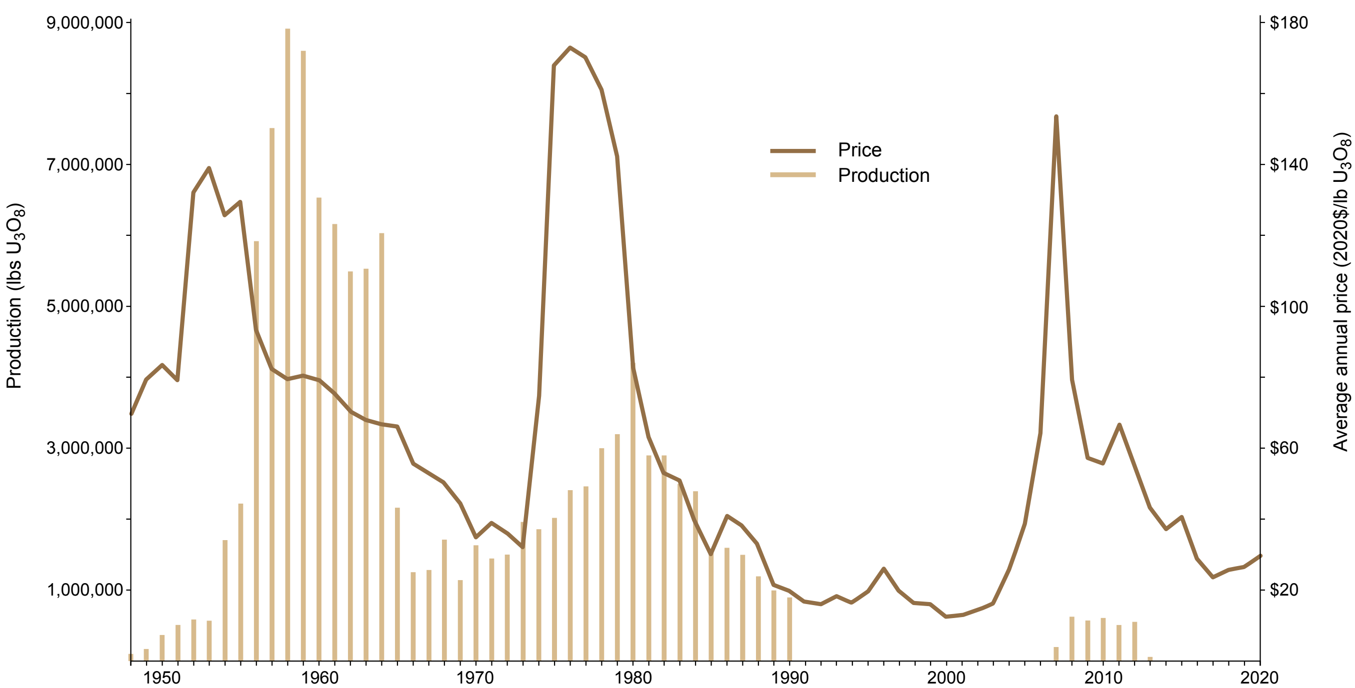

Figure 6. *Uranium spot prices (in 2020 dollars) and Utah production, 1948–2020. Notably, spikes in uranium production lag behind spikes in uranium pricing.*

producers, now struggling to remain operational, filed a protest in 1986 against imported uranium from other countries under the Atomic Energy Security Act of 1963, though no action was taken by the federal government (Burgin, 1988).

Vanadium prices and production broadly mirrored that of uranium throughout the nuclear power era, though price spikes were less extreme and shorter in duration. Both uranium and vanadium prices decreased by over 75% throughout the nuclear power era (figure 7). However, the nuclear power era marked a shifting dynamic between uranium and vanadium where vanadium overtook uranium in terms of overall production (figure 8). Domestic and international competition also had a less drastic effect on vanadium; although there was more competition for production, the market for vanadium and its versatile metallurgical applications was expanding.

By 1990 all of Utah's uranium production had ceased, and only minor production continued in the Colorado Plateau region. From 1971 to 1990, Utah produced approximately 43 million lbs U_3O_8 and nearly 50 million lbs V_2O_5. Production continued to languish as the competition from imports increased and was exacerbated by slackening enthusiasm for new nuclear power stations, particularly following the 1986 Chernobyl disaster. Foreign competition became particularly stark in 1993 with the initiation of the "Megatons to Megawatts" program, during which the United States purchased ex-weapons grade uranium from Russia. The trade agreement with Russia marks the decline in the nuclear power era, where uranium use in the United States was no longer largely from domestic production or imported from close allies. The cutoff of the nuclear power era is considered to be 2000, the first year that Kazakhstan exceeded 10 million lbs U_3O_8 production in its journey to becoming the largest uranium producer globally, as it is today. The increasing globalization of the uranium and vanadium markets, both in consumption and trade, marks the shift into the modern era.

Modern Era (2000 to Present)

The modern era of uranium production is marked by a continued increase in commodity market globalization, as well as shifting geopolitical relationships. In addition to major uranium discoveries in Canada (MacArthur River and Cigar Lake) and continued trade allyship with Australia, Kazakhstan became a major player in the uranium market from 2000 to present day, as it is the largest uranium producing country globally. Enthusiasm for developing significant new nuclear power capacity in America remains ambivalent due to factors like awareness of health impacts from past uranium mining, concerns over nuclear plant safety, and a lack of storage solutions for nuclear waste.

Concerns over the lack of long-term nuclear waste storage in the United States have been present since the 1980s but became highly politicized in the 2000s. Congress passed the Nuclear Waste Policy Act in 1982 and the Yucca Mountain site was selected as the U.S. site for a nuclear waste repository in 1986. Tunneling construction began on the site in 1994 but concerns over the

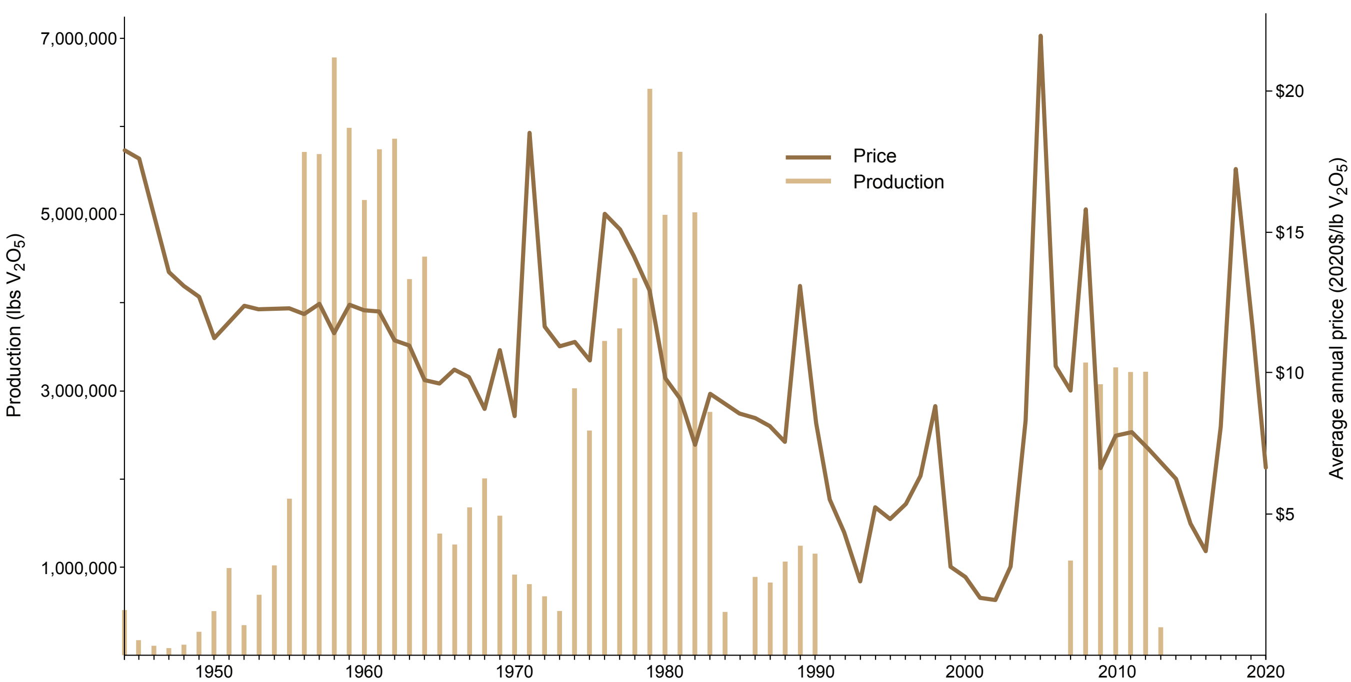

__Figure 7.__ Vanadium spot prices (in 2020 dollars) and Utah production, 1944–2020.

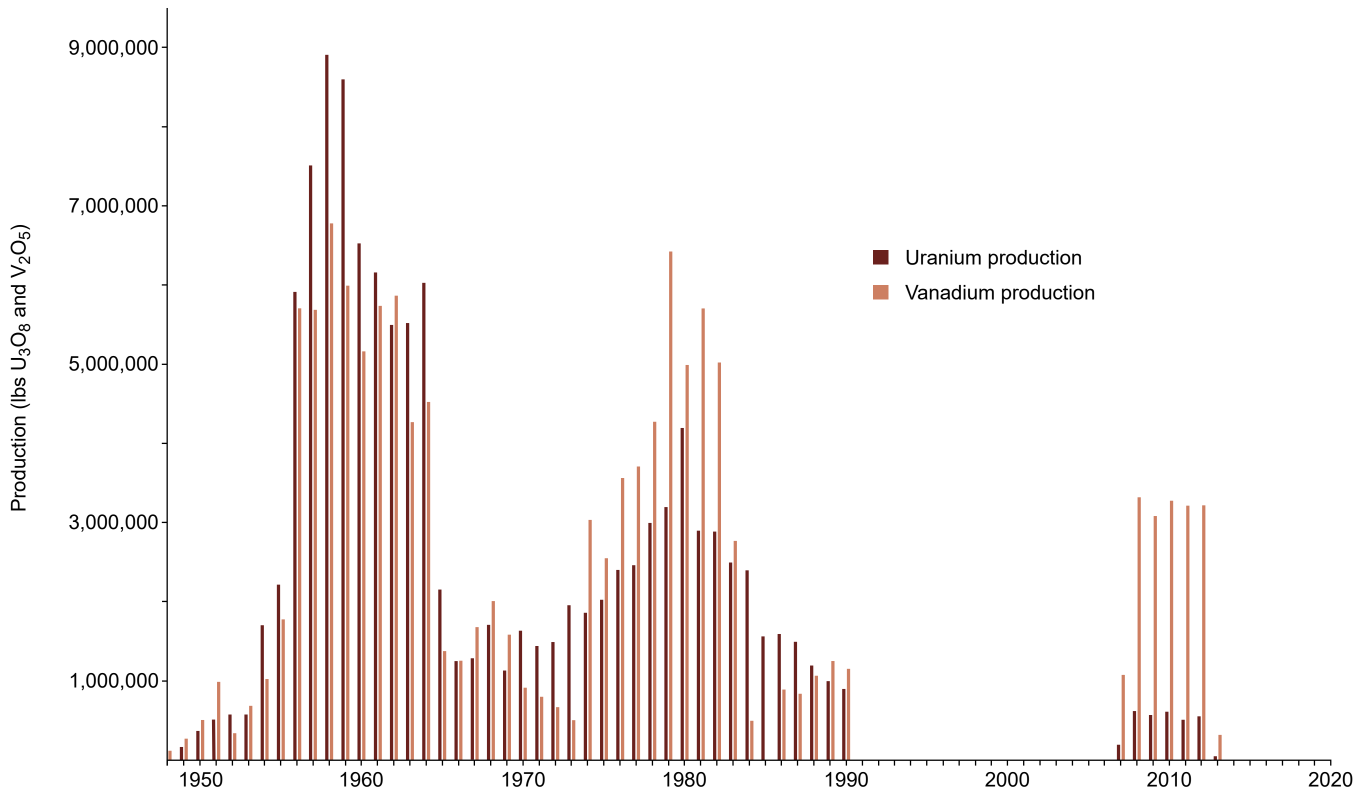

Figure 8. *Utah uranium and vanadium production, 1948–2020.*

suitability of the site were raised and the DOE missed the January 1998 deadline for waste acceptance, triggering a series of lawsuits by state and industry parties. This marked the beginning of protracted legal woes for Yucca Mountain and a series of stops and starts that have been characteristic of the modern era. As of 2016, the project was abandoned with the exploratory tunnel boarded up.

Despite the ambivalent attitude towards nuclear energy and the uranium mining industry, a slight revival in the Colorado Plateau and Utah's uranium mining industry began in 2007, peaked in 2012, and fizzled out in 2013 (figure 6). The uptick in uranium and vanadium mining was due to several factors. First was the global commodity super cycle that occurred in mineral commodities as developing countries, particularly China, supercharged their economy on an unprecedented scale. The super cycle was especially impactful for vanadium given its essential role in infrastructure development, though China's decision to promote nuclear power in the mid-2000s was a significant boost to uranium markets. Secondly, the super-deposits MacArthur River and Cigar Lake in Canada both experienced flooding in 2003 and 2005, respectively, which reduced production at MacArthur River and delayed operational start up at Cigar Lake. Operations at the Ranger mine in Australia were also impacted by a cyclone in 2007. With production from these deposits removed from the market, coupled with the super cycle, uranium prices peaked at the second highest point historically in 2007, and vanadium peaked at an all-time high in 2005 with a second peak in 2008 (figures 6 and 7). From 2007 to 2013, Utah produced more than 3 million lbs U_3O_8 and about 18 million lbs V_2O_5.

The end of the renaissance in the Colorado Plateau had multiple causes, including the global financial crisis in 2008, the abrupt end of the commodity super cycle in 2012, and for uranium in particular, the 2011 Fukushima nuclear disaster. The Fukushima disaster severely damaged perception of nuclear energy across the globe and even caused some countries such as Germany to implement plans to close all nuclear energy stations. Following the cessation of uranium and vanadium mining in Utah in 2013, mining in the Colorado Plateau has continued to remain dormant, as has almost all active uranium mining in the United States. As there is no vanadium-only mining in the United States, vanadium production has also been suspended. Utah's White Mesa mill in Blanding, San Juan County, remains the only active conventional uranium mill in the country and has been sustained by processing alternate feed, typically uranium waste from cleaning up old mining operations or historical tailings.

It remains to be seen if another era of uranium and vanadium mining will rise, but if it does, Utah has considerable established resources and ten permitted mines on standby. Of these permitted mines, all are located within the Colorado Plateau—eight in San Juan County, one in Grand County, and one in Garfield County (figure 1). The most significant of these mines is the Tony M mine with 20,880,000 lbs of indicated and inferred uranium ore at a grade of 0.26% (Roscoe Postle Associates

Incorporated, 2012). At the lower end, the Daneros mine has indicated and inferred reserves of 190,000 lbs at a grade of 0.35% (Peters Geosciences, 2018). Regardless, uranium mining in Utah is poised for a return should domestic production become profitable.

PRODUCTION

Production information in the following section is summarized as total state production through time and as total production by mining district. As a result of the difficulties discussed in the introduction with reconciling historical production, all production numbers have been rounded to give accurate implications of certainty.

State and District Production

Utah is the second largest historical vanadium producing state and the third largest uranium producer in the United States. Since the onset of uranium and vanadium mining with the discovery of carnotite in 1904, Utah has produced an estimated 122 million lbs U_3O_8 and 136 million lbs V_2O_5 (table 1).

The Lisbon Valley district is by far the most important uranium producing district in Utah, alone accounting for nearly 78 million lbs U_3O_8 production, or 64% of the state's total production (table 2, figure 3). From a historical perspective, the Lisbon Valley district is one of the most important districts in the whole of the Colorado Plateau, as it is home to the 1952 discovery of the Mi Vida mine that kicked off the uranium rush across the Colorado Plateau. The Lisbon Valley district is the main reason the Chinle Formation is considered a significant uranium and vanadium mineralization host rock, since based on deposit numbers alone many more deposits are hosted in the Salt Wash Member of the Morrison Formation (figure 4). The Moss Back Member of the Chinle Formation is the primary host of Lisbon Valley deposits, with minor mineralization in the underlying Permian Cutler Formation (the Cutler Formation represents only 8% of production). By comparison, the next largest uranium producing district is the La Sal mining district, which produced over 6 million lbs U_3O_8 and accounts for 5% of the state's total production. In addition to the Lisbon Valley and La Sal districts, an additional 48 districts across Utah are known to have produced uranium and account for the remaining 31% of the state's production: 24% from sandstone-hosted deposits, 3% from Bingham Canyon byproduct production, 2% from volcanogenic-hosted deposits, and less than 1% from collapse breccia deposits.

The average grade of uranium mineralization in sandstone-hosted deposits is 0.30% U_3O_8. Average grades within individual districts of all deposit types range from 0.43% to <0.02% U_3O_8 (figure 3). The grade of Utah's deposits is higher than in many other significant uranium provinces worldwide (e.g., Australia's Olympic Dam averages 0.05% U_3O_8, Namibia's Husab averages 0.045% U_3O_8, and Kazakhstan's Inkai averages 0.03–0.06% U_3O_8) though is far lower than Canada's world-class high-grade deposits (McArthur River averages 9.7% U_3O_8, Cigar Lake averages 15.9% U_3O_8). Between these two deposits, Cameco reports total resources (measured, indicated, and inferred) at nearly 151.4 million lbs of U_3O_8, nearly three times the resources of Utah (Cameco, 2020). However, other significant low-grade operations compensate for grade by additional metal credits and/or large tonnages. Olympic Dam, for example, has additional copper, gold, and silver production, plus the proven and probable reserves of over 550 million lbs U_3O_8 is nearly 5 times the entire historical production of Utah's uranium industry.

In Utah, the La Sal, Ucolo, and Dry Valley districts account for 53% of Utah's vanadium production (table 3). The La Sal district is the most significant vanadium producer, accounting for over 32 million lbs V_2O_5 of total production (figure 3). The Ucolo district, representing the Utah portion of the prolific Slick Rock district that extends into Colorado and is one of the largest vanadium producing districts in the Colorado Plateau, is the second largest producer at nearly 25 million lbs V_2O_5. The Dry Valley district is the third largest, with nearly 16 million lbs V_2O_5. Mineralization in all three districts is primarily hosted in the Salt Wash Member of the Jurassic Morrison Formation. In addition to the three largest producing districts, an additional 39 districts across Utah have recorded vanadium production and account for the remaining 47% of the state's total production: 40% from sandstone-hosted deposits, 7% from collapse breccia deposits, and less than 0.01% from volcanogenic deposits.

The average grade of vanadium mineralization in sandstone-hosted deposits is 0.8% V_2O_5, and average grades within individual districts of all deposit types range from 1.4% to <0.02% V_2O_5 (figure 3). Unlike uranium, the Colorado Plateau's vanadium grades tend to be among the highest worldwide. Most vanadium globally is produced from vanadiferous titanomagnetite deposits, which typically average <1% V_2O_5. However, like uranium, the low tonnages of Utah's deposits make it difficult for them to compete on the global stage. The Balla Balla deposit in Australia, for example, contains a resource of over 6 billion lbs V_2O_5, over 40 times the historical vanadium production from Utah.

Table 2. *Uranium production by mining district.*

Mining District	U_3O_8 produced (lbs)	Grade U_3O_8 (%)	Dominant Host Rock	U Mineralization
Lisbon Valley	77,910,000	0.30	Chinle Formation; Moss Back Member	Sandstone-hosted
La Sal	6,010,000	0.35	Morrison Formation; Salt Wash Member	Sandstone-hosted
White Canyon	4,710,000	0.27	Chinle Formation; Shinarump Member	Sandstone-hosted
San Rafael River	4,480,000	0.27	Morrison Formation; Salt Wash Member	Sandstone-hosted
Red Canyon	3,640,000	0.35	Chinle Formation; Shinarump Member	Sandstone-hosted
Elk Ridge	2,610,000	0.35	Chinle Formation; Shinarump Member	Sandstone-hosted
Temple Mountain	2,450,000	0.38	Chinle Formation; Moss Back Member	Collapse breccia
San Rafael Swell	2,360,000	0.43	Chinle Formation; Moss Back Member	Collapse breccia
Dry Valley	1,800,000	0.28	Morrison Formation; Salt Wash Member	Sandstone-hosted
Deer Flat	1,750,000	0.35	Chinle Formation; Shinarump Member	Sandstone-hosted
Sevenmile Canyon	1,710,000	0.30	Chinle Formation; Moss Back Member	Sandstone-hosted
Marysvale	1,570,000	0.22	Mount Belknap volcanics	Volcanogenic
Gateway	1,560,000	0.30	Morrison Formation; Salt Wash Member	Sandstone-hosted
Bingham	1,520,000	<0.02	Monzonite	Byproduct
Ucolo	1,470,000	0.31	Morrison Formation; Salt Wash Member	Sandstone-hosted
La Sal Creek	1,080,000	0.35	Morrison Formation; Salt Wash Member	Sandstone-hosted
Cottonwood Wash	1,060,000	0.27	Morrison Formation; Salt Wash Member	Sandstone-hosted
Henry Mountains	930,000	0.41	Morrison Formation; Salt Wash Member	Sandstone-hosted
Thompson	720,000	0.29	Morrison Formation; Salt Wash Member	Sandstone-hosted
South Henry Mountains	560,000	0.42	Morrison Formation; Salt Wash Member	Sandstone-hosted
Spor Mountain	500,000	0.20	Silurian-Ordovician dolomites	Volcanogenic
Browns Hole - Upper Kane Creek	490,000	0.33	Morrison Formation; Salt Wash Member	Sandstone-hosted
Monument Valley	380,000	0.36	Chinle Formation; Shinarump Member	Sandstone-hosted
Indian Creek	290,000	0.30	Chinle Formation; Moss Back Member	Sandstone-hosted
Fry Canyon	210,000	0.20	Chinle Formation; Shinarump Member	Sandstone-hosted
East Henry Mountains	210,000	0.42	Morrison Formation; Salt Wash Member	Sandstone-hosted
Circle Cliffs	120,000	0.42	Chinle Formation; Shinarump Member	Sandstone-hosted
Montezuma Canyon	100,000	0.28	Morrison Formation; Salt Wash Member	Sandstone-hosted
Newton	80,000	0.17	Bullion Canyon volcanics	Volcanogenic
Mineral Canyon	70,000	0.30	Chinle Formation; Moss Back Member	Sandstone-hosted
Lower Kane Creek	50,000	0.23	Chinle Formation; Moss Back Member	Sandstone-hosted
Fremont	30,000	0.29	Morrison Formation; Salt Wash Member	Sandstone-hosted
Bluff - Butler Wash	20,000	0.35	Morrison Formation; Salt Wash Member	Sandstone-hosted
Blawn Mountain	20,000	0.24	Blawn Formation volcanics	Volcanogenic
Brumley Ridge	20,000	0.33	Morrison Formation; Salt Wash Member	Sandstone-hosted
Inter-River	20,000	0.23	Chinle Formation; Moss Back Member	Sandstone-hosted
Abajo	10,000	0.27	Morrison Formation; Salt Wash Member	Sandstone-hosted
Wilson Mesa	<5000	0.30	Morrison Formation; Salt Wash Member	Sandstone-hosted
Orange Cliffs	<5000	0.42	Chinle Formation; Monitor Butte Member	Sandstone-hosted
Calf Mesa	<5000	0.43	Chinle Formation; Moss Back Member	Sandstone-hosted
Silver Reef	<5000	<0.02	Moenave Formation; Springdale Sandstone Member	Sandstone-hosted

Table 2 continued. *Uranium production by mining district.*

Mining District	U_3O_8 produced (lbs)	Grade U_3O_8 (%)	Dominant Host Rock	U Mineralization
Lockhart Canyon	<5000	0.30	Chinle Formation; Moss Back Member	Sandstone-hosted
Orderville Gulch	<1000	0.10	na	Sandstone-hosted
Uinta Basin	<1000	0.20	na	Sandstone-hosted
Kolob Terrace	<1000	0.08	na	Sandstone-hosted
Greasewood Draw	<1000	0.29	na	Sandstone-hosted
Pink Knolls	<1000	0.10	na	Volcanogenic
Tuscher Canyon	<1000	0.30	na	Sandstone-hosted
Paria East	<1000	0.10	na	Sandstone-hosted
Cedar Mountain	<1000	0.43	na	Sandstone-hosted

Production Against Price

Price information for the AEC procurement period is derived from Neff (2004) and USAEC (1970) (figures 6 and 7). Prices during the nuclear power period are derived from Nuexco spot prices and from spot prices provided by TradingEconomics.com, as are prices for the modern era. All prices have all been adjusted to 2020 dollars. Where spot prices were given on a daily or monthly basis, they were averaged for an annual value. Spot prices also are not necessarily reflective of purchase and sale prices for uranium and vanadium, much of which is done on long term contracts, though they capture shifts in attitudes, policies, and demand.

FORECAST

Established Resources

Despite the current lack of mining activity in Utah's Colorado Plateau, significant ore resources remain. Table 4 details known modern resources, which total approximately 12.6 million tons of ore containing nearly 50 million lbs U_3O_8 and over 58 million lbs V_2O_5. There are likely more resources than included in table 4 because many of Utah's resource calculations were made in the 1980s. This earlier era of resource calculation was prior to the rigor introduced by NI 43-101 (www.sedar.com) and JORC (www.jorc.org) reporting standards. The resources included below are from modern technical reports or are historical numbers that have been reviewed in the modern era.

The largest uranium resource in Utah is the Energy Fuels' Henry Mountains Complex, which includes the Tony M, Southwest, Copper Bench, and Indian Bench deposits totaling an estimated 21 million lbs of U_3O_8. Anfield Resources' Velvet-Wood deposit is the largest individual deposit, hosting an estimated 5.2 million lbs U_3O_8. The largest known vanadium resource is Energy Fuels' La Sal Complex, containing an estimated 23 million lbs V_2O_5. Energy Fuels' Sage Plain deposit is the largest single deposit, hosting nearly 14 million lbs V_2O_5. Sage Plain is in the Ucolo district, which is the Utah part of the Slick Rock area of the prolific Uravan mineral belt in Colorado. The Slick Rock area, including the Ucolo district, is known for prolific historical vanadium production.

Should economics shift to favor active uranium and vanadium mining, the initial wave of production will likely come from these known resources, as many are mines that are currently permitted and being maintained on stand-by (table 5, figure 1). Early exploration would likely focus on near mine expansion, but it is possible that with prolonged strength in either the uranium and/or vanadium market, greenfields exploration could resume. A ramp up in greenfields exploration would be likely for a prolonged vanadium bull market, and the Colorado Plateau probably contains considerably more vanadium resources than listed in table 4 due to the historical bias for uranium during exploration. A short-lived price jump in 2018 (figure 7) was related to vanadium being named a critical mineral and expectations of increased vanadium consumption in China due to new rebar standards. Even this price jump, less than a year in duration, caused junior explorers to quickly establish land positions in areas not previously viewed as favorable for mining restarts, such as the Temple Mountain district.

Table 3. *Vanadium production by mining district.*

Mining District	V_2O_5 produced (lbs)	Grade V_2O_5 (%)	Dominant Host Rock	V Mineralization
La Sal	32,510,000	0.3	Morrison Formation; Salt Wash Member	Sandstone-hosted
Ucolo	24,600,000	1.0	Morrison Formation; Salt Wash Member	Sandstone-hosted
Dry Valley	15,660,000	0.7	Morrison Formation; Salt Wash Member	Sandstone-hosted
La Sal Creek	10,400,000	0.2	Morrison Formation; Salt Wash Member	Sandstone-hosted
Lisbon Valley	10,280,000	0.3	Chinle Formation; Moss Back Member	Sandstone-hosted
Temple Mountain	9,030,000	0.8	Chinle Formation; Moss Back Member	Collapse breccia
Thompson	6,170,000	1.1	Morrison Formation; Salt Wash Member	Sandstone-hosted
Cottonwood Wash	5,660,000	0.9	Morrison Formation; Salt Wash Member	Sandstone-hosted
Gateway	4,380,000	1.1	Morrison Formation; Salt Wash Member	Sandstone-hosted
San Rafael River	3,610,000	0.6	Morrison Formation; Salt Wash Member	Sandstone-hosted
South Henry Mountains	3,020,000	1.4	Morrison Formation; Salt Wash Member	Sandstone-hosted
Browns Hole - Upper Kane Creek	2,250,000	0.9	Morrison Formation; Salt Wash Member	Sandstone-hosted
Henry Mountains	1,690,000	1.3	Morrison Formation; Salt Wash Member	Sandstone-hosted
East Henry Mountains	1,410,000	1.4	Morrison Formation; Salt Wash Member	Sandstone-hosted
Montezuma Canyon	1,380,000	0.7	Morrison Formation; Salt Wash Member	Sandstone-hosted
Monument Valley	950,000	0.7	Chinle Formation; Shinarump Member	Sandstone-hosted
Sevenmile Canyon	890,000	1.1	Chinle Formation; Moss Back Member	Sandstone-hosted
San Rafael Swell	860,000	0.8	Chinle Formation; Moss Back Member	Collapse breccia
Elk Ridge	430,000	0.2	Chinle Formation; Shinarump Member	Sandstone-hosted
Circle Cliffs	360,000	1.4	Chinle Formation; Shinarump Member	Sandstone-hosted
White Canyon	240,000	0.1	Chinle Formation; Shinarump Member	Sandstone-hosted
Abajo	160,000	0.9	Morrison Formation; Salt Wash Member	Sandstone-hosted
Indian Creek	160,000	0.3	Chinle Formation; Moss Back Member	Sandstone-hosted
Mineral Canyon	160,000	1.1	Chinle Formation; Moss Back Member	Sandstone-hosted
Brumley Ridge	120,000	0.9	Morrison Formation; Salt Wash Member	Sandstone-hosted
Fremont	70,000	0.3	Morrison Formation; Salt Wash Member	Sandstone-hosted
Silver Reef	60,000	<0.02	Moenave Formation; Springdale Sandstone Member	Sandstone-hosted
Bluff - Butler Wash	30,000	0.2	Morrison Formation; Salt Wash Member	Sandstone-hosted
Lower Kane Creek	30,000	0.4	Chinle Formation; Moss Back Member	Sandstone-hosted
Washington	30,000	1.1	Crystal Peak Dolomite	Sandstone-hosted
Wilson Mesa	30,000	1.3	Morrison Formation; Salt Wash Member	Sandstone-hosted
Calf Mesa	<3,000	0.8	na	Sandstone-hosted
Inter-River	<3,000	0.4	na	Sandstone-hosted
Marysvale	<3,000	<0.02	na	Volcanogenic
Orange Cliffs	<3,000	1.4	na	Sandstone-hosted
Orderville Gulch	<3,000	<0.02	na	Sandstone-hosted
Cedar Mountain	<1,000	0.8	na	Sandstone-hosted
Greasewood Draw	<1,000	0.8	na	Sandstone-hosted
Lockhart Canyon	<1,000	0.7	na	Sandstone-hosted
Spor Mountain	<1,000	<0.02	na	Volcanogenic
Tuscher Canyon	<1,000	1.1	na	Sandstone-hosted
Uinta Basin	<1,000	0.2	na	Sandstone-hosted

Table 4. *Modern uranium and vanadium established resources.*

District	Area	Sub-Area	County	Company	Ore resource (short tons)	Average U_3O_8 grade (%)	U_3O_8 resource (lbs)	Average V_2O_5 grade (%)	V_2O_5 resource (lbs)	Resource Confidence	Resource Source	Citation
South Henry Mountains	Henry Mountains Complex	Tony M, Southwest, Copper Bench, Indian Bench	Garfield	Energy Fuels, Inc.	4,020,000	0.26	20,880,000	na	na	Indicated and inferred	NI 43-101	Roscoe and others, 2012
San Rafael River	San Rafael	Deep Gold, Down Yonder, Jackrabbit, 4484, North	Emery	Western Uranium and Vanadium Corporation	1,210,000	0.22	5,260,000	0.3	7,110,000	Indicated and inferred	NI 43-101	Gatten, 2014
Lisbon Valley	Velvet-Wood		San Juan	Anfield Resources Inc.	900,000	0.29	5,180,000	na	na	Measured, indicated, inferred	NI 43-101	Beahm and McNulty, 2016
La Sal	La Sal Complex	Beaver, Pandora, La Sal, Energy Queen, Redd Block	San Juan	Energy Fuels, Inc.	1,330,000	0.17	4,460,000	0.9	23,430,000	Measured, indicated, inferred	NI 43-101	Peters, 2014
Gateway	Whirlwind		Grand	Energy Fuels, Inc.	610,000	0.25	3,000,000	0.8	9,770,000	Indicated and inferred	NI 43-101	Peters, 2011
La Sal	La Sal		San Juan	Laramide Resources Ltd.	440,000	0.31	2,700,000	na	na	na	Historic	Laramide Resources, 2006
South Henry Mountains	Frank M		Garfield	Anfield Resources Inc.	1,140,000	0.10	2,280,000	na	na	Indicated and inferred	NI 43-101	Beahm and Anderson, 2008
Cedar Mountain	Cedar Mountain		Emery	enCore Energy Corp.	2,000,000	0.05	2,200,000	na	na	na	Historic	Encore Energy, 2021
Ucolo	Sage Plain		San Juan	Energy Fuels, Inc.	490,000	0.17	1,650,000	1.4	13,540,000	Measured, indicated, inferred	NI 43-101	Peters, 2015
Dry Valley	Dunn		San Juan	Western Uranium and Vanadium Corporation	210,000	0.13	560,000	1.1	4,490,000	Indicated and inferred	NI 43-101	Gonzales, 2012
White Canyon	Geitus		San Juan	enCore Energy Corp.	140,000	0.14	390,000	na	na	na	Historic	Encore Energy, 2021
White Canyon	Blue Jay		San Juan	enCore Energy Corp.	10,000	0.12	260,000	na	na	na	Historic	Encore Energy, 2021
Red Canyon	Daneros		San Juan	Energy Fuels, Inc.	30,000	0.36	190,000	na	na	Indicated and inferred	NI 43-101	Peters, 2018
San Rafael River	Snow		Emery	enCore Energy Corp.	40,000	0.23	160,000	na	na	na	Historic	Encore Energy, 2021
White Canyon	Marcy Look		San Juan	enCore Energy Corp.	40,000	0.19	140,000	na	na	na	Historic	Encore Energy, 2021
San Rafael River	Probe		Emery	enCore Energy Corp.	30,000	0.25	140,000	na	na	na	Historic	Encore Energy, 2021
Total					**12,640,000**		**49,450,000**		**58,340,000**			

Table 5. *Permitted but inactive uranium and vanadium mines.*

Permit #	County	Mine	Company	Minerals	UTM Easting	UTM Northing
M0170049	Garfield	Tony M	Energy Fuels Resources (USA)	uranium, vanadium	526213	4179547
M0370006	San Juan	Rim-Columbus	Energy Fuels Resources (USA)	uranium	657350	4214490
M0370012	San Juan	Pandora	Energy Fuels Resources (USA)	uranium, vanadium	655646	4241264
M0370026	San Juan	La Sal - Snowball	Energy Fuels Resources (USA)	uranium	655792	4241916
M0370040	San Juan	Velvet	Anfield Resources Holding Corp	uranium	660438	4220241
M0370043	San Juan	Energy Queen	Energy Fuels Resources (USA)	uranium	647801	4241844
M0370046	San Juan	Redd Block Four	Energy Fuels Resources (USA)	uranium	649779	4242289
S0370121	San Juan	Daneros	Energy Fuels Resources (USA)	uranium, vanadium	570772	4160870
S0370125	San Juan	La Sal Mine	Laramide La Sal Inc	uranium	651905	4232240
S0190065	Grand	Whirlwind Mine	Energy Fuels Resources (USA)	uranium, vanadium	668929	4278103

Critical Minerals and a Carbon-Neutral Energy Transition

Over the past three years a new shift in the uranium and vanadium markets has been developing due to a renewed interest in critical minerals and the rising desire of private and government sectors to increase carbon-neutral energy solutions.

Critical Minerals

The concept of critical minerals is not new and various lists of commodities and definitions of what qualifies as critical have been developed since the early 1900s (Mills and Rupke, 2020). In fact, the Strategic and Critical Materials Stock Piling Act of 1939 was responsible for driving the WWII vanadium boom in Utah. In the most recent iteration, published in 2018, a critical mineral is a mineral or mineral material essential to the economic and national security of the United States and has a supply chain vulnerable to disruption (Fortier and others, 2018). The modern suite of 35 critical minerals reflects the spread of high-tech devices and battery technology that have become essential in everyday life and includes uranium and vanadium. However, the commodities considered critical evolve over time, taking into consideration changes in the demand for minerals, the production landscape, and updates to evaluation methodology. A recent review of the critical minerals list by the U.S. Geological Survey (Nassar and Fortier, 2021) elected not to evaluate uranium as a critical mineral, because it's primary use is as a fuel mineral (critical mineral status is reserved for non-fuel minerals). Vanadium is recommended to remain a critical mineral. The updated critical mineral list has not been published in the Federal Register as of July 2021; as such, uranium currently remains a critical mineral.

Uranium's criticality, as assessed in the 2018 critical mineral list, is based on non-fuel uses such as radiation shields, medical isotopes, and armament applications. Although the United States has domestic production capability for uranium, in 2019 less than 10% of domestic uranium nuclear power reactor needs were produced by domestic mines (U.S. EIA, 2020a and 2020b). Nearly half of the country's uranium supply is imported from Canada and Australia, with significant contributions also from Russia and Kazakhstan. However, because this high level of import reliance impacts uranium primarily in its fuel mineral use, it is unclear if the non-fuel applications are at sufficiently high risk for uranium to maintain its status as a critical mineral.

Vanadium's criticality is based on a high import reliance, despite the existence of domestic resources. In 2020, the United States imported 96% of vanadium needed to meet domestic demand. Vanadium's malleability, ductility, and corrosion resistance contribute to its importance in high-strength low-alloy steels. As a metallurgical ingredient, vanadium is a crucial element for infrastructure development, such as rebar, and other specialty alloy applications, such as aerospace titanium alloys.

Carbon-Neutral Energy

Aside from critical minerals, the other major change to the minerals landscape is the focus on the "green" energy transition, which has shifted commodity focus towards materials necessary for renewable energy generation, energy storage, and electrification of our transportation sector. The "green" energy transition, also referred to as the renewable energy transition, is a loose term referring to the transformation of the global energy landscape towards carbon-neutral energy sources. Such a transition has been a topic of discussion for decades but has recently made major advances and is becoming a hallmark of political and industry policy. Currently, significant debate surrounds what mineral commodities will be essential to this energy transition. Lithium is often cited for battery technology, though the lithium market has yet to fully stabilize around this expectation. Likewise, copper is seen as an essential commodity given its fundamental role as an energy transmitter, but like lithium has yet to see a significant market shift as a result.

Uranium's role in a carbon-neutral energy environment is as fuel for nuclear energy production. Although the energy density and land footprint of nuclear energy presents one of the best options for carbon-neutral electricity generation, concerns over the safety of uranium mining, the safety of nuclear power stations, and the lack of any long-term nuclear waste storage means that public and political opinion remains divided. As such, nuclear energy has yet to feature as a major component of carbon-neutral energy policy. Currently in the United States, only eight nuclear power stations are proposed to be built. As such, domestic production of uranium concentrate decreased by 89% in 2019 (U.S. EIA, 2020a and 2020b).

Although the national nuclear scene may be in a lull, Utah and its neighbors have experienced growing interest and exploration of nuclear options. In 2014, the Idaho National Laboratory proposed a Carbon Free Power Project in association with Utah Associated Municipal Power Systems. In the fall of 2020, the ongoing project received an additional $1.4 billion in funding to develop new small modular reactors and has cleared the initial Nuclear Regulatory Commission reviews. In addition, Wyoming recently announced a partnership with PacifiCorp's Rocky Mountain Power to convert a retired coal power plant into a nuclear plant. These two projects are encouraging for the future of the domestic uranium market—both seek to solve technical issues on scalability that would open the door for more reactors to be built in the future.

However, until demand for uranium increases, domestic producers will look towards the federal government for support. In January 2018, Energy Fuels and Ur-Energy submitted a Section 232 of the Trade Expansion Act of 1962 petition to the U.S. Department of Commerce. The petition related to uranium imports from countries such as Russia, Kazakhstan, Uzbekistan, and China, arguing that production from these countries is heavily state-subsidized and unfairly undercuts domestic production. The initial petition recommended an import quota reserving 25% of the U.S. market for domestic producers and requiring U.S. federal agencies to purchase domestically sourced uranium. Although no regulatory action was implemented, the Consolidated Appropriations Act of 2021 passed in December 2020 included $75 million to create a U.S. uranium reserve and thereby support domestic uranium miners.

Vanadium features significantly in discussion around what commodities may become essential for energy storage due to the potential of vanadium redox flow batteries (VRBs). VRBs are seen as a potential large-scale energy storage solution to help mitigate fluctuations in energy supply from renewables and ensure a constant baseload of energy for the grid, one of the largest drawbacks to many modern renewable energy sources. Japan was the first country to deploy VRBs as a commercial energy storage solution as early as 2005, but most commercial deployment of VRB arrays occurred in the mid- to late 2010s. Although gaining traction and prominence, it remains to be seen if VRBs, and hence vanadium, will be a significant feature in the move towards more carbon-neutral energy sources over the next several decades.

UTAH'S FUTURE

The advent of a new critical-mineral and carbon-neutral energy-focused era may present a new opportunity for revival of Utah's uranium and vanadium industries. As the only state with an operating conventional uranium and vanadium mill, Utah is a prime location for uranium and vanadium mines that minimize transport distance of ore. Additionally, Utah ranks high annually on the investment attractiveness index globally due to streamlined claim and permitting procedures, as well as the availability of mineral leases on state or private lands rather than federal (Yunis and Aliakbari, 2021). However, the ore bodies in the Colorado Plateau tend to be smaller than deposits in countries like Canada, where the world's two largest uranium deposits are located and with whom the United States has strong trade relationships. Despite international competition, Utah has several mines permitted and on standby and it is likely any significant economic impetus will spur the mining industry back to action.

ACKNOWLEDGMENTS

This report was funded in part by the U.S. Geological Survey National Geological and Geophysical Data Preservation Program grant G20AP00087. This report has drawn heavily from the efforts of previous Utah Geological Survey staff who have maintained geological and production records over the 70 years of our organization. In particular, we are indebted to Hellmut Doelling, Robert W. Gloyn, and Ken Krahulec for their previous work on uranium and vanadium deposit geology, mining district production through time, and resource compilations. Special recognition should also be given to William (Bill) L. Chenoweth, known throughout the Colorado Plateau as a leading expert on uranium and vanadium mining from the early 1950s to his death in 2018. This report would not have been possible without the prolific data compilations and publications by Bill.

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