Ore Geology Reviews 80 (2017) 716–753

Contents lists available at ScienceDirect

Ore Geology Reviews

journal homepage: www.elsevier.com/locate/oregeorev

Genetic and grade and tonnage models for sandstone-hosted roll-type uranium deposits, Texas Coastal Plain, USA

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ARTICLE INFO

Article history:
Received 1 September 2015
Accepted 16 June 2016
Available online 12 July 2016

Keywords:
Uranium
Texas
Resources
Deposits
Genetic
Model

ABSTRACT

The coincidence of a number of geologic and climatic factors combined to create conditions favorable for the development of mineable concentrations of uranium hosted by Eocene through Pliocene sandstones in the Texas Coastal Plain. Here 254 uranium occurrences, including 169 deposits, 73 prospects, 6 showings and 4 anomalies, have been identified. About 80 million pounds of U_3O_8 have been produced and about 60 million pounds of identified producible U_3O_8 remain in place. The development of economic roll-type uranium deposits requires a source, large-scale transport of uranium in groundwater, and deposition in reducing zones within a sedimentary sequence. The weight of the evidence supports a source from thick sequences of volcanic ash and volcaniclastic sediment derived mostly from the Trans-Pecos volcanic field and Sierra Madre Occidental that lie west of the region. The thickest accumulations of source material were deposited and preserved south and west of the San Marcos arch in the Catahoula Formation. By the early Oligocene, a formerly uniformly subtropical climate along the Gulf Coast transitioned to a zoned climate in which the southwestern portion of Texas Coastal Plain was dry, and the eastern portion humid. The more arid climate in the southwestern area supported weathering of volcanic ash source rocks during pedogenesis and early diagenesis, concentration of uranium in groundwater and movement through host sediments. During the middle Tertiary Era, abundant clastic sediments were deposited in thick sequences by bed-load dominated fluvial systems in long-lived channel complexes that provided transmissive conduits favoring transport of uranium-rich groundwater. Groundwater transported uranium through permeable sandstones that were hydrologically connected with source rocks, commonly across formation boundaries driven by isostatic loading and eustatic sea level changes. Uranium roll fronts formed as a result of the interaction of uranium-rich groundwater with either (1) organic-rich debris adjacent to large long-lived fluvial channels and barrier–bar sequences or (2) extrinsic reductants entrained in formation water or discrete gas that migrated into host units via faults and along the flanks of salt domes and shale diapirs. The southwestern portion of the region, the Rio Grande embayment, contains all the necessary factors required for roll-type uranium deposits. However, the eastern portion of the region, the Houston embayment, is challenged by a humid environment and a lack of source rock and transmissive units, which may combine to preclude the deposition of economic deposits. A grade and tonnage model for the Texas Coastal Plain shows that the Texas deposits represent a lower tonnage subset of roll-type deposits that occur around the world, and required aggregation of production centers into deposits based on geologic interpretation for the purpose of conducting a quantitative mineral resource assessment.

Published by Elsevier B.V.

1. Introduction

Sandstone-hosted uranium deposits are the most significant type in the United States (U.S.). They are responsible for all current uranium production and estimated to contain 85 percent of reasonably assured resources (RAR) (NEA/OECD-IAEA, 2010). In 1980, just over half of the estimated uranium in potential (undiscovered) resources in the U.S. were assessed from sandstone-type deposits (DOE, 1980). There are three major sandstone-hosted uranium regions in the U.S.; the Colorado Plateau, the Wyoming basins and the Texas Coastal Plain (Fig. 1). Approximately 200 million pounds of U_3O_8 have been mined from the Wyoming basins, 340 million pounds of U_3O_8 from that portion of the Colorado Plateau region in New Mexico, and about 80 million pounds of U_3O_8 from deposits mined from the Coastal Plain of south Texas (Boberg, 2010; Hall, 2013; McLemore, 2011) (Appendix 1).The

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http://dx.doi.org/10.1016/j.oregeorev.2016.06.013
0169-1368/Published by Elsevier B.V.

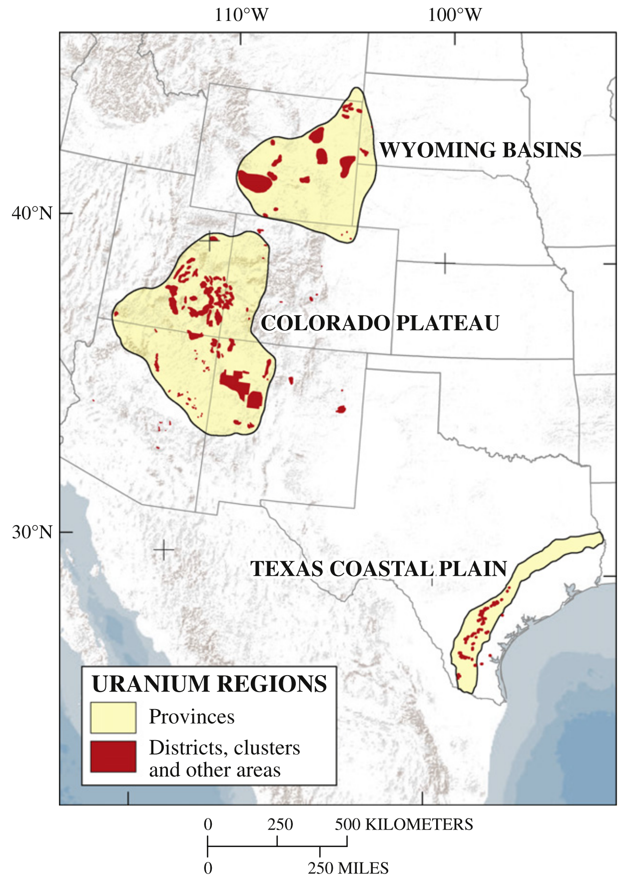

Fig. 1. Principal sandstone-hosted uranium regions of the United States.

Colorado Plateau has the highest estimated amount of in situ uranium resources, the Wyoming basins and the Coastal Plain region, of which the south Texas portion contains the bulk of resources, are second and third, respectively (Table 1) (DOE, 1980; DOE/EIA, 2010). In each of these areas, a unique combination of uranium source, transport and trap formed geologically distinct world-class uranium regions. In the Wyoming basins and Coastal Plain regions, uranium is principally identified as roll-type uranium deposits, whereas Colorado Plateau deposits are dominated by tabular-sandstone deposits. The Wyoming basins and Colorado Plateau regions have been the focus of recent comprehensive analysis and genetic deposit studies, but a comprehensive analysis of uranium deposits in the Texas Coastal Plain has not been published since 1981 (Adams and Smith, 1981; Boberg, 2010; Goldhaber et al., 1990; McLemore, 2011; Northrop et al., 1990; Peterson and Turner-Peterson, 1980; Sanford, 1992; Turner-Peterson and Hodges, 1992).

Uranium has been produced continuously from deposits in south Texas since its discovery in the mid-1950s. Since comprehensive studies describing uranium deposits in this region were published in the early 1980s, exploration and development of deposits have continued to provide information about the location and geology of deposits; focused theses and research papers have been completed; and a more complete understanding of paleogeography, paleoenvironment and basin evolution has been achieved. A new compilation of occurrences, and a refined genetic model for sandstone-hosted deposits in the Coastal Plain of south Texas have been completed and are presented here. The enhancement of georeferenced databases since the last comprehensive work also provides new analytic methods and a deeper level of analysis of spatial relationships critical for a complete understanding of uranium deposits. All have added a depth of knowledge not available when earlier regional genetic interpretations of these deposits were developed, and form the basis for a refined genetic deposit model for sandstone-hosted uranium deposits in the Coastal Plain of Texas that is presented here.

2. Exploration and mining history

The first uranium mines in Texas were developed within the outcropping Whitsett Formation of the Jackson Group in the Tordilla Hill area in Karnes County. These deposits were identified by airborne radiometric surveys conducted in 1954 by independent oil companies who incorrectly believed oil was associated with anomalous radioactivity (Eargle and Weeks, 1961). Shallow, surface oxidized deposits were mined using open pit methods beginning in 1960, and deeper deposits mostly found at the boundary between reduced and oxidized sediments began to be developed in the mid-1960s. The first in situ recovery (ISR) mine in Texas was developed in 1975, one of the earliest ISR mines developed worldwide. Currently all uranium in Texas is produced using ISR mining.

Many roll-type uranium deposits were initially identified as downhole gamma anomalies coincident to oil and gas drilling in the region, and this type of reconnaissance exploration method is still used. Regional groundwater sampling from preexisting wells has also been used as a reconnaissance exploration technique to target roll-type deposits in Texas. Modern exploration methods are focused on identifying mineralizing "trends" such as permeable paleochannels, structural domes and lineament features that would channel groundwater flow and/or reducing solutions into host units. Once prospective terrain is delineated, follow-up drilling is used to identify the location of potentially mineralized reduction-oxidation fronts that are defined by subtle changes in the color of subsurface sediments. Geophysical logging of these drill holes with Prompt Fission Neutron technology to directly measure U^{235} content is further used to delineate deposits within roll front systems (Humphreys, 1983).

3. Production and Resources

Between 1955 and 2013, just over 80 million pounds of U_3O_8 were produced from an estimated 92 mines and 1 tailings facility in Texas (Appendix 1). This is about 8% of total U.S. production (DOE, 2009;

Table 1
Mean tons of U_3O_8 reserves and potential resources in the $100/lb. U_3O_8 cost category within the major sandstone-hosted uranium regions of the U.S.

Region	Reserves[a] (metric tons U_3O_8) (DOE, 1980)	Reserves[b] (metric tons U_3O_8) (DOE/EIA, 2010)	Probable potential resources (metric tons U_3O_8) (DOE, 1980)
Colorado Plateau	542,300	294,000	753,761
Wyoming Basins	407,800	223,000	480,500
Coastal Plain[c]	61,000	20,000	324,400

For a definition of resource categories and NURE resource regions, see DOE (1980).
[a] Reserves are not differentiated by deposit type but are predominantly from sandstone-hosted deposits with minor contributions from other deposit types and are reported in cost categories based in 1980 prices and dollars.
[b] Reserves are sandstone-hosted deposits and are reported in cost categories using 2010 dollars.
[c] The NURE Coastal Plain region includes the Texas Coastal Plain as well as areas of the Atlantic Coastal Plain.