UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Organic Matter and Sandstone-type Uranium Deposits: A Primer

By

Joel S. Leventhal

Open File Report 79-1310

1979

Organic Matter and Sandstone-type Uranium Deposits: A Primer

by Joel S. Leventhal

Abstract

Organic material is intimately associated with sandstone-type uranium deposits in the western United States. This report gives details of the types of organic matter and their possible role in producing a uranium deposit. These steps include mobilization of uranium from igneous rocks, transportation from the surface, concentration by organic matter, reduction by organic matter, and preservation of the uranium deposit.

Introduction

Organic matter is present in most sandstone-type uranium deposits. This common association has led many uranium geologists to comment on the importance of organic matter; for example, Granger and others (1961), Fischer (1974), Rackley and others (1968), Motica (1968), and Squires (1972). Considerable work has been done on organic matter by Breger and his co-workers (summarized in Breger, 1974), Manskaya and Drozdova (1968), and Schmidt-Collerus (1969).

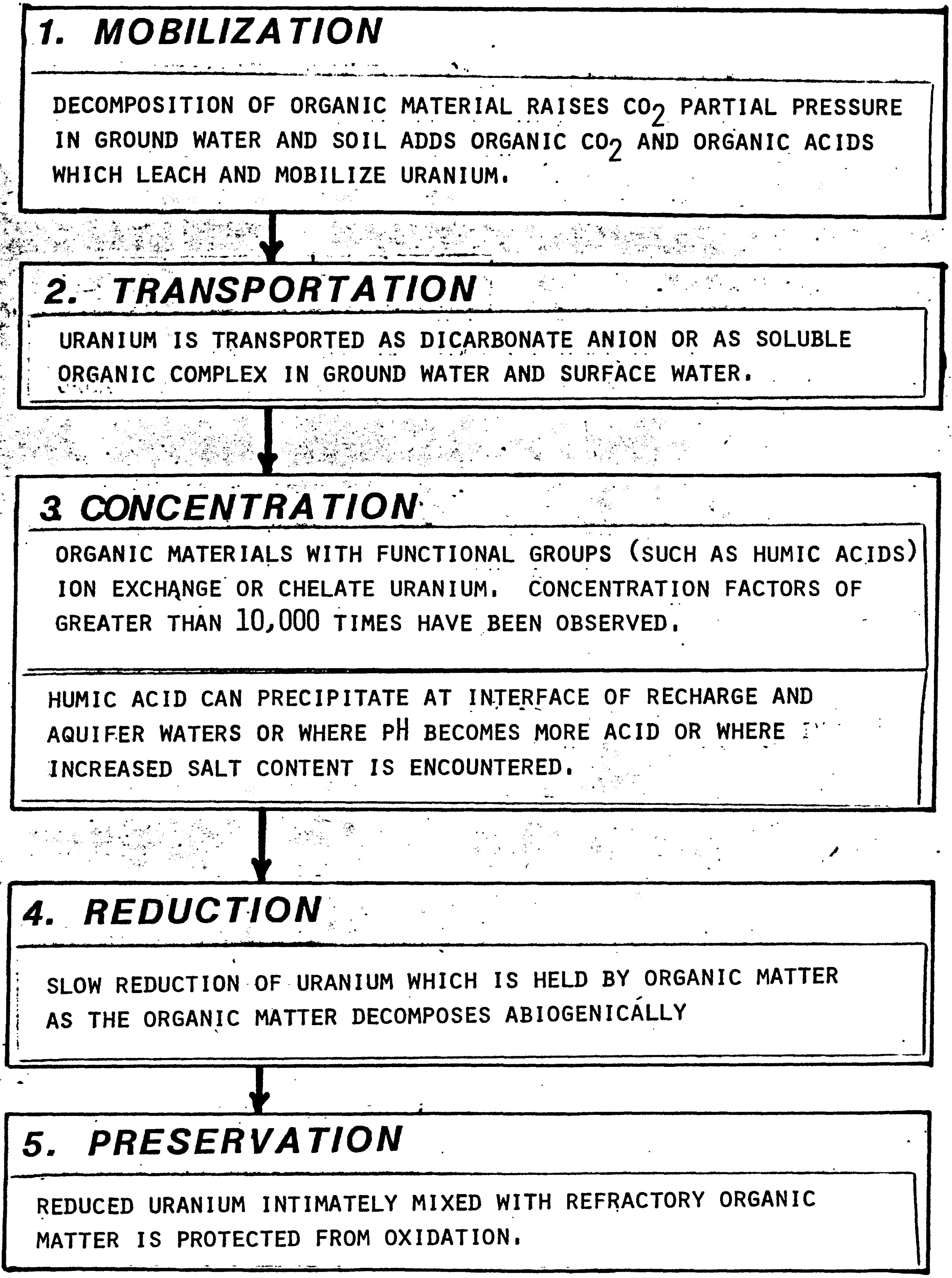
This report is meant to be a general outline of the role of organic matter in forming and preserving uranium deposits (Leventhal, 1976); organic matter will first be classified and then the relationships of organic matter to uranium will be discussed.

Several types of plants and animals from terrestrial or aquatic environments provide a variety of organic matter for sediments. Most of it comes from plants and microorganisms. More than 99 percent of the living material is oxidized by biological or inorganic processes. Less than 1 percent of organic matter has been preserved by sedimentary burial.

If the preserved organic material is buried less than 3000 m or not heated over 100°C, it retains its cellular structure and can be recognized as leaves, twigs, or other forms and it will contain some of its original chemicals. Soluble, nonstructured organic material is also present in recent sediments as humic material. Humic material can be carried, dissolved in water, but most of it is decomposed or ends up in the ocean; some of it may coat mineral grains.

If the organic material is deeply buried and heated, it will be transformed into gas (CO_2, CH_4), petroleum, amorphous carbon, and graphite. The gas and oil may migrate back to the surface environment or accumulate in a suitable trap.

Solid insoluble organic matter is termed "kerogen," regardless of origin (Tissot and Welte, 1978). Humic material is low-temperature organic matter that is soluble in weakly basic aqueous solutions. Petroleum is high-temperature organic matter that is insoluble in water but will dissolve in organic solvents--such as a mixture of benzene-methanol-chloroform-hexane. Lab or field tests can be made on organic material to classify it as kerogen, humic material or petroleum by mixing a 1-gram finely ground sample of organic material or sediment in 10 grams of water or organic solvent. A colored solution above the solid indicates solubility and type of organic matter. Fig.1, which is a schematic of the five steps of the role of organic matter in uranium ore formation: mobilization, transportation, concentration, reduction, and preservation. Step 1 illustrates the possible role of organic matter in mobilization of uranium from igneous rocks, where decomposition of biological material raises the partial pressure of CO_2 and forms organic acids both of which may leach and complex uranium. Step 2 shows the possible role of organic decomposition products as transporting agents for oxidized uranium species. These organic materials, such as fulvic and humic acids as well as smaller organic molecules, are capable of complexing and transporting oxidized uranium species.



1. MOBILIZATION

DECOMPOSITION OF ORGANIC MATERIAL RAISES CO_2 PARTIAL PRESSURE IN GROUND WATER AND SOIL ADDS ORGANIC CO_2 AND ORGANIC ACIDS WHICH LEACH AND MOBILIZE URANIUM.

2. TRANSPORTATION

URANIUM IS TRANSPORTED AS DICARBONATE ANION OR AS SOLUBLE ORGANIC COMPLEX IN GROUND WATER AND SURFACE WATER.

3 CONCENTRATION

ORGANIC MATERIALS WITH FUNCTIONAL GROUPS (SUCH AS HUMIC ACIDS) ION EXCHANGE OR CHELATE URANIUM. CONCENTRATION FACTORS OF GREATER THAN 10,000 TIMES HAVE BEEN OBSERVED.

HUMIC ACID CAN PRECIPITATE AT INTERFACE OF RECHARGE AND AQUIFER WATERS OR WHERE pH BECOMES MORE ACID OR WHERE INCREASED SALT CONTENT IS ENCOUNTERED.

4. REDUCTION

SLOW REDUCTION OF URANIUM WHICH IS HELD BY ORGANIC MATTER AS THE ORGANIC MATTER DECOMPOSES ABIOGENICALLY

5. PRESERVATION

REDUCED URANIUM INTIMATELY MIXED WITH REFRACTORY ORGANIC MATTER IS PROTECTED FROM OXIDATION.

FIGURE 1. THE ROLE OF ORGANIC MATTER IN THE URANIUM GEOCHEMICAL CYCLE.

Step 3 depicts the most important step, in which organic matter is shown to be essential in forming high-grade uranium deposits. Organic matter will concentrate uranium 10,000 times from water according to Szalay, (1964). On the basis of this ratio, water containing 50 ppb uranium passing over organic matter would result in organic matter with 500 ppm uranium. A 1-to-1 ratio, by weight, of organic matter to uranium is found in the Grants district (Granger and others, 1961). Rocks containing 0.7 percent organic matter also contain approximately 0.7 percent uranium, and, likewise, rocks containing 4 percent organic matter also contain approximately 4 percent uranium. Concentration factors as high as 10^7 have been shown for fulvic acid, a naturally occurring organic material similar to humic acid, by Jennings (1976) and Jennings and Leventhal (1976). A structural model (fig. 2) for humic acid, a type of organic matter that is known to concentrate other organic matter, has been presented by Jennings and Leventhal (1977). Humic material is made up of water and base (carbonate or hydroxide)-soluble fulvic acid and humic acid. It is a complex macromolecule having molecular weight of 500 to 20,000. Its solubility is due to the many oxygen-containing polar functional groups. Humic material has the approximate chemical formula $(C_{15} H_{16} O_8 N S)_n$, where n is an integer from 1 to 3 for fulvic acid and n=4-50 for humic acid. Fulvic and humic materials can be formed in water or soil from decomposition of organic materials such as plants, animals, and micro-organisms or by reoxidation of coal, petroleum, or kerogen.

Not all organic material is capable of directly concentrating uranium. For example, the uranium content of petroleum is generally in the range of only a few parts per million (Erickson and others, 1954). It should also be mentioned that even the "proper" type of organic matter is not sufficient;

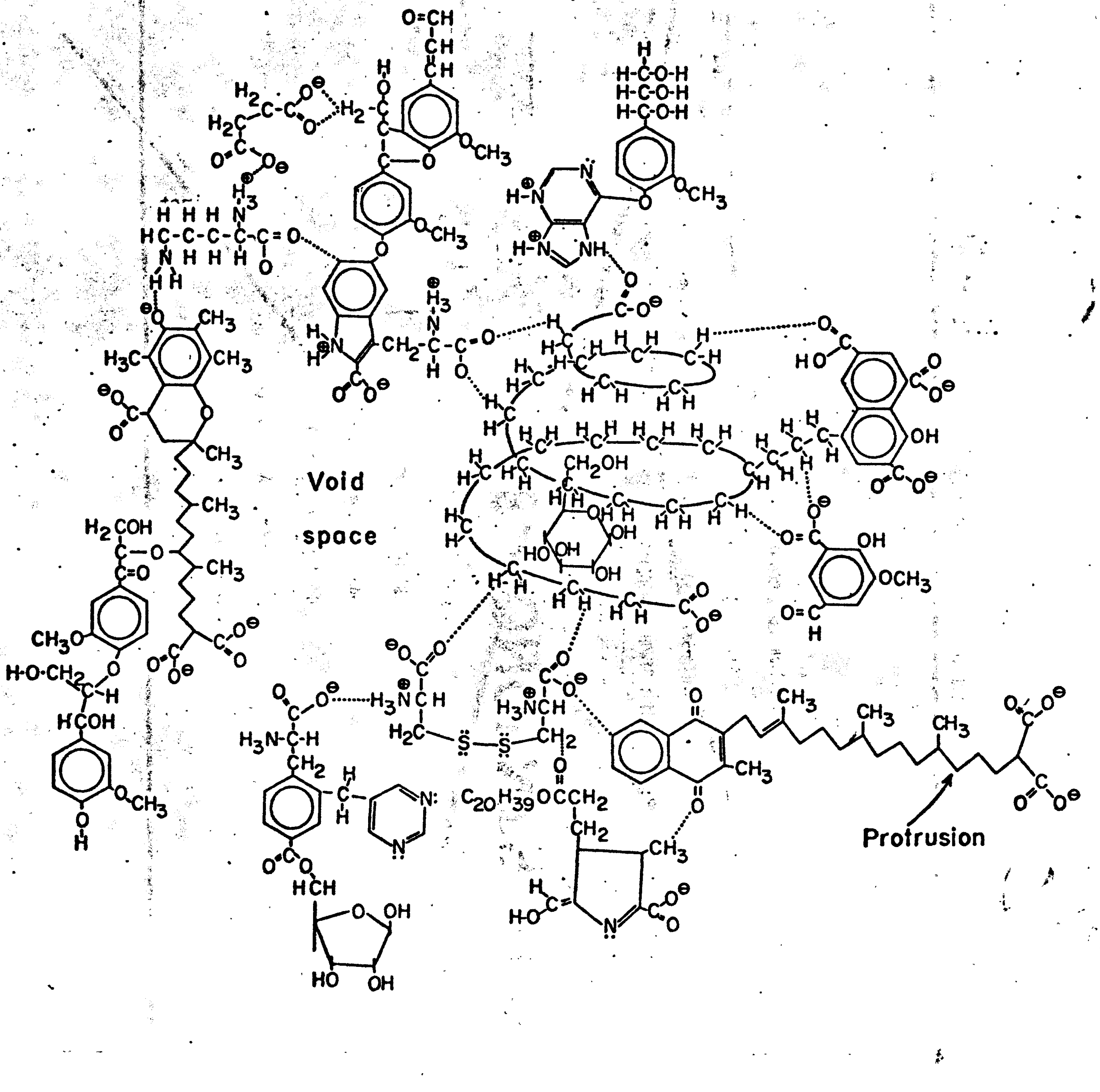


Figure 2. A suggested chemical-structural model of humic acid (Jennings and Leventhal, 1977).

uranium must also be present. This appears to be the case for the Green River Formation of Wyoming and Colorado, where even though 10-20 percent organic matter is present, only 2-4 ppm of uranium is found. Humic acid has often been used as the "model" substance of organic matter in certain uranium deposits (see, for example, Squyres, 1972). Actually the evidence that the material has a humic acid origin has not been proven, because the infra-red spectrum from organic matter in these deposits is not distinct from that of oxidized coal or oxidized petroleum fractions. The organic material is structureless, coats sand grains, and was probably water soluble, but its source and mode of precipitation are not known at this time.

The best evidence for the importance of organic matter in concentrating uranium in sandstone-type deposits is to look at deposits from which organic matter is absent. In some south Texas deposits (Eargle and others, 1975), organic matter is absent (less than 0.1 percent) (Goldhaber and Reynolds, 1977). These deposits are generally low grade (<500 ppm). The genesis can be explained by H_2S seeping up faults (Goldhaber and others, 1979). It is true, however, that the H_2S is produced by bacteria that reduce sulfate using petroleum as an energy source.

Other deposits lacking large amounts of organic matter, which seem to be associated with high amounts of vanadium, are present in certain mines of the Colorado Plateau, (for instance, the Rifle mine; Spirakis, 1977), Fischer, 1974). In such mines vanadium can act to form an insoluble mineral or perhaps even reduce uranium. Even in these cases organic matter is often present though not at a 1:1 ratio with uranium.

Step 3 concerns the close association of uranium and organic matter in the interstices between sand grains. Presumably the organic matter created a reducing environment which, after the depletion of oxygen from the uraniumbearing solution, reduces the uranium which has been concentrated by the organic matter. Thus the organic matter places a dual role of concentrating uranium from solution and also of chemically reducing it to insoluble uraninite and coffinite. It is not known whether this process is fast or slow on a geologic time scale, but the reduction is not as fast in the concentration step (fig 3).

Step 5 points out the importance of the bulk organic matter (long after the ore-forming process)--both in physically enclosing the uranium and in chemically preventing oxidizing conditions from being established. Undoubtedly the organic matter could be oxidized, but under natural ground water chemistry and flow conditions the time for oxidation is long enough so that deposits at least 130 million years old have been preserved.

References

Breger, I. A., 1974, The role of organic matter in the accumulation of uranium: Coal uranium associations, in Proceedings of the International Conference on Formation of Uranium Ore Deposits: Vienna, International Atomic Energy Agency, p. 99-123.

Eargle, D. H., Dickinson, K. A., and David, B. O., 1975, South Texas uranium deposits: American Association of Petroleum Geologists Bulletin, v. 50, p. 766-779.

Erickson, R. L., Meyers, A. T., and Horr, C. A., 1954, Association of uranium and other metals with crude oil, asphalt and petroliferous rock: American Association of Petroleum Geologists Bulletin, v. 38, p. 2200-2218.

Fischer, R. P., 1974, Exploration guide to new uranium districts and belts. Economic Geology, v. 69, p. 362-376.

Goldhaber, M. B., and Reynolds, R. L., 1977, Geochemical and mineralogical studies of a south Texas roll-front uranium deposit: U.S. Geological Survey Open-File Report 77-821, 37 p., 7 figs.

Goldhaber, M. B., Reynolds, R. L., and Rye, R. O., 1978, Origin of a South Texas roll type deposit. II, Sulfide petrology and sulfur isotope studies: Economic Geology, v. 73, p. 1690-1705.

Granger, H. C., Santos, E. S., Dean, B. G., and Moore, F. B., 1961, Sandstone-type uranium deposits at Ambrosia Lake, New Mexico, an interim report: Economic Geology, v. 56, p. 1179-1210.

Jennings, J. K., 1976, Interaction of uranium with naturally occurring organic substances: Golden, Colorado School of Mines, M.S. thesis, 72 p.

Jennings, J. K., and Leventhal, J. S., 1976, Interaction of oxidized uranium with humic acids and ion exchange and Chelating reasons to determine conditions of fixation [abs.]: Geologic Society of America Abstracts with Programs, v. 8, p. 940.

Jennings, J. K., and Leventhal, J. S., 1977, A new structural model for humic materials and uranium, in Campbell, J. C., ed., Short papers of the U.S. Geological Survey Uranium-Thorium Symposium, 1977: U.S. Geological Survey Circular 753, p. 10-11.

Leventhal, J. S., 1976, Characterization of insoluble organic matter associated with uranium ores [abs]: American Association of Petroleum Geologists Bulletin, v. 60, p. 692.

Manskaya, S. M., and Drozdova T. V., 1968, Geochemistry of organic substances, chapter 6: New York, Pergamon Press p. 164-180.

Motica, J. E., 1968, Geology and uranium-vanadium deposits in the Uravan mineral belt, southwestern Colorado, in Redge, J. D., ed, Ore deposits of U.S. 1903-73: New York, AIME, p. 805-813.

Rackley, R. I., Shockley, P. N., and Dahill, M. P., 1968, Concepts and methods of uranium exploration: Wyoming Geological Association Guidebook, Twentieth Field Conference (September), p. 23-34.

Schmidt-Collerus, J. 1969, Investigations of the relationship between organic matter and uranium deposits: University of Denver Research Institute #2513, 192 p.

Spirakis, C. S., 1977, The role of semipermeable membranes in the formation of certain vanadium-uranium deposits: Economic Geology, v. 72, p. 1442-1448.

Squyres, J. B., 1972, Uranium deposits of the Grants region, New Mexico: Wyoming Geological Association Earth Science Bulletin, September, p. 3-12.

Szalay, A., 1964, Cation exchange properties of humic acids and their importance in geochemical enrichment of UO_2^+: Geochimica et Cosmochimica Acta, v. 28, p. 1605-1614.

Tissot, B., and Welte, D., 1978, Petroleum formation and occurrence: New York, Springer-Verlag, 538 p.