Uranium Deposits of the World
Asia
Franz J. Dahlkamp

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Asia

With 192 Figures and 28 Tables
The author wishes to acknowledge the contributions of his many associates in the uranium industry, national and international institutions, and universities whose ideas, observations, and data through the years have directly or indirectly become a part of this report. Many of them are included in the list of selected references, but there are additional many more who contributed during discussions, field trips, and mine visits.

More specifically, the author is deeply indebted to those who gave freely of their time in the compilation and translation of data, and preparing and editing the manuscript, particularly A.V. Boitsov, Zhou Weixun, and T.C. Pool. Without the generous support by Alexander V. Boitsov and Zhou Weixun who spent their time over many years in selecting and translating literature on uranium deposits in Russia and all other CIS countries, and China, respectively, it would not have been possible to compile a presentation as comprehensive as given in this volume. Thomas C. Pool deserves my particular gratitude for undertaking the laborious and irksome endeavor to read, revise, and improve the entire text.

The author also is highly appreciative to the following individuals for discussions, providing information, reviewing and improving descriptions of individual deposits or districts: F. Barthel, J.R. Blaise, V.E. Boitsov, P. Bruneton, V.I. Kazansky, G. Ruhrmann, and M. Tauchid. Alexander V. Boitsov, Patrice Bruneton, Warren Finch, Jay McMurray, and Zhou Weixun critically assisted in refining the classification scheme or parts thereof for which they deserve my sincere gratitude. The contributions and comments of all these colleagues substantially improved the report, but may not necessarily endorse its contents.

A. Stasch and S. Kirchhofer skillfully prepared most figures of the manuscript.
An important prerequisite to the long-term use of nuclear energy is information on uranium ore deposits from which uranium can be economically exploited. Hence the basic purpose of this book is to present an overview of uranium geology, data characteristic for uranium districts and deposits in Asia, and a synthesis of these and additional data from uranium deposits worldwide in the form of a typological classification of uranium deposits. An additional goal is to provide access for the interested reader to the voluminous literature on uranium geology. Therefore a register of bibliography as global as possible, extending beyond the immediate need for this book, is provided.

The original concept of this work, which was to provide an encyclopedia of uranium deposits of the world in a single publication was soon doomed. The material grew out of all feasible proportions for a book of acceptable size and price as a wealth of data on uranium geology and related geosciences too vast for one volume became available during the past decades. So the original idea had to be abandoned in favor of a four- or five-volume publication covering the five continents. Each volume contains presentations of individual uranium districts, deposits and noteworthy occurrences organized by countries. For the sake of the comprehensiveness, not all the information could be distributed without some repetition.

These volumes were not originally designed as a product for its own sake. They evolved as a by-product during decades of active uranium exploration and were compiled thanks to a request by the Springer Publishing Company. Numerous publications as well as routine research work on identifying characteristic features and recognition criteria of uranium deposits, combined with associated modelling of types of deposits for reapplication in exploration, provided the data bank.

Finally, it was not so much the author's intention to present data and his own views on uranium geology and metallogenesis, but theories and models of other geoscientists who worked on any given deposit, in order to stimulate and encourage further research to achieve continuous progress in the understanding of uranium deposits and their metallogenesis.

Franz J. Dahlkamp
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Organization of the Volume

The focus of this volume is on the characterization of uranium deposits in Asia presented in Part II. In spite of this emphasis, an abbreviated typology of uranium deposits on a worldwide basis was included as Part I, which describes the principal geological features, recognition criteria, and dimensions of identified types of deposits. This amendment was considered justified insofar as numerous publications and knowledge have become available since the publication of “Uranium Ore Deposits” (Dahlkamp 1993), which required a modification of some former views and hence an updating of the previous typology scheme.

Part II contains synoptic descriptions of uranium districts and deposits in Asian countries including metallogenetic concepts based on data and views of geoscientists who have actually worked on these deposits, which are not necessarily congruent with interpretations and definitions presented in Part I. Graphic presentations and tables had to be limited to the extent considered necessary to illustrate the principles of geological setting and configuration of deposits. However, quantity and quality of illustrations are variable depending on the availability and reliability of data in the source material.

Confidence of Data

Not all deposits are well researched and, on some, research data were not available. Some data are vague, if not biased or wrong. Other data are presented ambiguously, being easily misinterpreted. Interpretation of certain criteria may likewise be conflicting. Descriptions of the same district or deposit or specific features thereof by different authors are not necessarily unanimous and sometimes confusing, which, in some instances, may be due to the translation quality of the original text. Due to former and partly still existing secrecy conditions, in some former East Block countries (e.g. China and some CIS countries) published data particularly of resource and grade figures are not always congruent. In a number of cases resource figures do not coincide with independent calculations or are only given in a general way.

Concerning uranium metallogenesis, its principles are at present sufficiently well understood only for some types of deposits, whereas other types are understood to a lesser extent and in varying degrees and therefore permit space for speculation or geofantasy.

The attempt was made to reconcile conflicting data and deviating hypotheses as far as possible in order to give at least an idea of the overall geological situation and size of a district or deposit. It has to be admitted, however, that this demanding task was not always satisfactorily achieved. In any event, the various views are presented and in case the reader requires more precise information, the original literature should be reviewed or the original author(s) should be contacted for additional data.

Citing of Authors

All the country chapters include a reference list of authors whose data have been used directly or indirectly or who have contributed work to the country, district or deposit described in that particular chapter. This scheme was selected

a to serve as a reference index on literature pertaining to the respective country, district or deposit. The list is restricted to respective principal uranium papers and to contributions to general geology with relevant or possible implications on uranium geology. Special publications not directly related to uranium geology, e.g., age dating of rocks, are cited in the text (titles of the papers can be found listed according to the author’s name in the Bibliography);

b to credit authors who have worked on the given district or deposit;

c to reduce the immense repetition of authors’ names to a bearable minimum within the text. In this kind of synoptically presentation, often using numerous papers on one single district or deposit, a complete citation of all authors would in many instances have required a list of names after a couple of sentences or a short section. Alternatively, numbers referring to authors and their papers could have been used. My preference is, however, to see the name of an author and not a colorless number, which, in addition, requires searching in the bibliography for the numbered individual. Although the selected system may not satisfy all authors who wish to see their names precisely repeated, they may forgive me for the sake of easier reading.

Bibliography

This section is organized in alphabetical order of authors and provides complete coverage of papers cited in the text and reference lists. Papers published since the final revision of the manuscript have been added in the bibliography but, for technical reasons, could be incorporated into the standing manuscript only in exceptional cases.
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The attempt was made to provide a bibliography as complete as possible, but some papers will still be missing. This deficiency does not reflect my disregard of the respective contribution, but should rather be excused as an imperfection on my side. Proceedings of workshops, symposia, etc. were in many instances not published until several years later. Meanwhile, some authors had published the workshop data elsewhere or the data had been disseminated otherwise and hence the material may have had influenced and may have found access to publications of other workers prior to the printing of the original presentation. Consequently, publication years of reference data do not necessarily reflect the first presentation of results.

Geological, Mineralogical, Mining, and Related Terms

Connotation and spelling of geological and mineralogical terms are, in principle, understood as and based on those given by: Thrush and the Staff of the Bureau of Mines (eds), 1968, in "A Dictionary of Mining, Mineral, and Related Terms", U.S. Dept. of the Interior Washington, DC. Exceptions or additions to this are:

**Clarke value (= background value):** Mean content of a chemical element in the Earth's crust as a whole or in its particular segments and specific rocks (e.g. for granite).

**Costs, expenditures:** In U.S.$ unless otherwise stated.

**Deposit:** This term is not restricted to economic U deposits but used in a broader sense to signify all U concentrations with U tenors distinctly elevated above common background U values of a corresponding (host) rock type.

**Granite/granitoid, pegmatite/pegmatoid, etc.:** The terms are used synonymously and not in their strict genetic sense. Various authors apply both words differently and the connotation is not always clear.

**Mineralization, alteration, etc.:** These terms are used in both connotations, to denote the process implied and the product of the process.

**Monometallic mineralization/mineralogy (simple mineralization/ mineralogy):** Denotes ore containing U only as recoverable element, although many other metals may be present but in trace or subeconomic quantities.

**Polymetallic mineralization/polymetallic mineralogy (corresponds to complex mineralization/mineralogy of some authors):** Denotes ore containing at least two different metals including U in economic or potentially economic amounts.

**Uraninite/pitchblende:** In this book *uraninite* is used for the macrocrystalline, more or less euhedral variety of UO$_2$, which typically occurs in rocks of higher P-T metamorphic grades (amphibolite grade and higher, contact-metamorphic), igneous rocks such as granite and pegmatite but also in vein and veinlike-type deposits.

*Pitchblende* is used for UO$_2$ varieties of micro- or crypto-crystalline, colloform (collomorphic, botryoidal, spherulitic) habit, which typically occur in low grade metamorphic and non-metamorphic rocks such as greenschist facies metasediments and more or less arenaceous sediments, and in most vein- and veinlike-type uranium deposits. It is understood that both varieties crystallize in the same crystallographic system, the cubic system, but have certain discriminating physico-chemical properties (for details see Fritsche et al. 1988, 2001 and Ramdohr 1980).

The term pitchblende was the first name used for black uranium oxide minerals back in 1565 and is widely used, particularly in Europe. Uraninite is a term commonly used for all kinds of uranium oxides in American literature. Worldwide, both terms are applied by a number of authors variably and in an overlapping way. The criteria used by various geoscientists to differentiate between uraninite and pitchblende are sometimes conflicting and can lead to confusion.

**Secondary uranium minerals:** This term, commonly referring to colored U minerals, was abandoned in favor of hexavalent U (U$^{6+}$) minerals to avoid confusion. "Secondary U minerals" are of primary origin in several deposits, e.g., in surficial deposits. Both terms, primary and secondary, have been restricted in this book to their strict genetic sense denoting primary or secondary origin of a given mineral.

**Ore:** Synonymous with (potentially) minable mineralization.

**Regolith:** refers to saprolite/paleosol. It is not used in the sense often applied in Canada, where weathered rocks are also called regolith. Herein, the term regolithic rock is preferred.
Resource/reserves, production, and grade figures are calculated in metric tons (t or tonnes) U and percent (%) U (respectively in ppm U for low grade values) and represent published data or best estimates based on published data and personal communication.

Terms Commonly Used in Russian Literature

**Beresite**: A metasomatic rock composed of quartz, sericite, carbonate, and pyrite.

**Beresitization**: A variety of phyllic alteration. This term as well as beresite originated from the Berezovskoye Au deposit in the Urals, Russia.

**Geochemical specialization of rocks**: Refers to a given rock or complex that contains a systematically higher content of one or more elements relative to other rocks or to the same rock occurring elsewhere.

**Nenadkevite**: Hydrous U, Th, REE silicate.

**Rare metals**: This term does not seem to be strictly defined. In a general way, a rare metal does not belong to ferrous, noble, base, or radioactive metals. In Russian publications Mo, Sn, W, Nb, Li, and other elements are commonly attributed to rare metals although they are not necessarily rare in nature.

Terminology of U Resources

OECD-NEA/IAEA replaced several of the category terms of resources in the 2005 Red Book, which they had used in their biannual Red Books through 2003. In this volume, the former terms were maintained in order to avoid a complete revision of the manuscript. For comparison, Table 0.1 provides a listing of the former and new resources terminology of OECD-NEA/IAEA combined with more or less equivalent categories used in several countries.

Resource/reserve definitions with respect to confidence classes and cost categories of an ore deposit cannot be achieved from purely geological parameters. Economic considerations have to be included. Demand for the commodity and related price/cost factors dictate whether a localized metal concentration is a deposit that can be profitably exploited presently or in the future, or whether it is a mineral occurrence of only scientific or academic interest. OECD-NEA/IAEA have accordingly established a cost category system that subdivides the various confidence resource classes into resources recoverable at <U.S.$130 per kg U, <U.S.$80 per kg U, and <U.S.$40 per kg U, which was used as far as data were available.

Table 0.1.

Approximate correlation of terms used in resources classification systems of OECD-NEA/IAEA until 2003 and in 2005, and selected countries. (Note: The terms listed are not strictly comparable as the criteria used in the various systems are not identical. “Grey zones” in correlation are therefore unavoidable, particularly as the resources become less assured. Nonetheless, the chart presents a reasonable approximation of the comparability of terms.) (After OECD-NEA/IAEA 2005) (CIS: Russian Federation, Kazakhstan, Ukraine, Uzbekistan, etc., UNFC: United Nations International Framework Classification for Reserves/Resources-Solid Fuels and Mineral Commodities)

<table>
<thead>
<tr>
<th>OECD-NEA/IAEA 2005 (OECD-NEA/IAEA &lt;2003)</th>
<th>Identified resources (known conventional resources)</th>
<th>Undiscovered resources (Undiscovered conventional resources)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reasonably assured</strong> (RAR)</td>
<td><strong>Inferred</strong> (EAR-I)</td>
<td><strong>Prognosticated</strong> (EAR-II)</td>
</tr>
<tr>
<td><strong>Speculative</strong> (speculative)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Australia</td>
<td>Demonstrated</td>
<td>Inferred</td>
</tr>
<tr>
<td></td>
<td>Measured</td>
<td>Undiscovered</td>
</tr>
<tr>
<td></td>
<td>Indicated</td>
<td></td>
</tr>
<tr>
<td>Canada (NRCan)</td>
<td>Measured</td>
<td>Inferred</td>
</tr>
<tr>
<td></td>
<td>Indicated</td>
<td>Prognosticated</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Speculative</td>
</tr>
<tr>
<td>United States (DOE)</td>
<td>Reasonably assured</td>
<td>Estimated additional</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Speculative</td>
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<tr>
<td>CIS</td>
<td>A + B</td>
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<td>UNFC</td>
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<td>G4</td>
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</table>
National Resource Data

In this book, national resource data were taken from the biannual OECD-NEA/IAEA Red Books. It should be noted, however, that national resource figures published in the Red Books are provided by government agencies. Some of these national authorities occasionally underestimate the real recovery costs. Therefore some of the national resource figures appear in, and consequently inflate to a certain extent, lower cost resource categories of the Red Book tables. On the other hand, changes in the market price of uranium may increase or decrease the figure of established economic resource quantities.

Terminology of Resources for Individual Deposits

Available resource figures for individual deposits or districts do not necessarily correspond to the OECD-NEA/IAEA nomenclature and categories since mining companies have not necessarily applied the terminology suggested by OECD-NEA/IAEA, or their published figures are not attributed to one or the other category. Hence in many cases it remains unclear whether in situ (geological) or recoverable (mining) reserves/resources are given, i.e., whether or not mining dilution and milling losses are included, whether the numbers refer to RAR to EAR categories or to any other equivalent category of reserves/resources (e.g., proven, probable, or possible reserves). Mining dilution can reduce recoverable reserves to less than 75% of the in situ tonnage and can downgrade the ore mined to 85% or less of the in situ grade. In addition, the cutoff grade for reserve/resource calculations are not always given. Depending on the cutoff grade used, reserve/resource figures can augment or decrease.

For this reason reserve, resource, and grade figures given for individual deposits or districts are, except for verifiable figures, best estimates of, but not always, in situ tonnages and grades based on various, not necessarily published, information. Also, the terms reserves and resources are not used in this volume in their strict sense but more synonymously. This means that, independent of their status of confidence, no great distinction is made between the terms “reserves” (except for being used in rather undefined or not clearly defined cases) and “resources” [more restricted to clearly defined (potentially) economic resources].

Abbreviations

a.o. among others or and others
a.s.l. above sea level
Ba (b.y.) billion years = 1 000 Ma
EAR estimated additional resources
ISL In situ leaching method (also referred to as ISR In situ recovery method)
lb. pound (7 000 grains = 16 ounces = 451 grams)
Ma (m.y.) million years
RAR reasonably assured resources
redox reduction-oxidation (boundary)
REE rare earth elements
sh.t. short ton
t metric ton(s) (tonnes)
$ equivalent ton(s) measured by geophysics
U eq equiv. ton(s) measured by geophysics
U met. metallic or natural uranium

Conversion Factors

1 t = 1 metric ton
1 t = 1.1023 sh.t. = 2 200 lbs
1 t U = 1.18 t U3O8
1 t U = 1.30 t U3O8 = 2 600 lbs U3O8
1 t U3O8 = 0.848 t U
1 t U3O8 = 1.1 t U3O8 = 2 200 lbs U3O8
1 sh.t. U3O8 = 0.769 t U
1 sh.t. U3O8 = 2 000 lbs U3O8
1% U3O8 = 0.848% U
1 $/lb U3O8 = 2.6 $/kg U
1 $/kg U = 0.3824 $/lb
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