RECENT AND NOT-SO-RECENT DEVELOPMENTS IN URANIUM DEPOSITS AND IMPLICATIONS FOR EXPLORATION

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Cover photograph: outcrop of the Turkey Creek roll-front uranium deposit, near Denver, Colorado, showing a sandstone layer with roll front between the oxidized and reduced zone enhanced by bleaching. Photo courtesy K. Kyser and G. Drever
### TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preface</td>
<td>xii</td>
</tr>
<tr>
<td>1. Introduction</td>
<td>1</td>
</tr>
<tr>
<td>2. The Effect of Economic and Research Factors in Understanding Uranium Exploration and Discovery of Deposits</td>
<td>15</td>
</tr>
<tr>
<td>3. Geochemical Characteristics of Uranium and Analytical Methodologies</td>
<td>23</td>
</tr>
<tr>
<td>4. Deposits Related to Magmatic Differentiation</td>
<td>57</td>
</tr>
<tr>
<td>5. Deposits Related to Partial Melting</td>
<td>79</td>
</tr>
<tr>
<td>6. Deposits Related to Na-Metasomatism and High-Grade Metamorphism</td>
<td>97</td>
</tr>
<tr>
<td>7. Hydrothermal Uranium Deposits Related to Igneous Rocks</td>
<td>117</td>
</tr>
<tr>
<td>8. Unconformity-Related Uranium Deposits</td>
<td>161</td>
</tr>
<tr>
<td>9. Sandstone-Hosted Uranium Deposits</td>
<td>221</td>
</tr>
<tr>
<td>10. Other Types of Uranium Deposits</td>
<td>241</td>
</tr>
<tr>
<td>11. Implication for exploration strategies</td>
<td>253</td>
</tr>
</tbody>
</table>
# DETAILED LIST OF CONTENTS

## 1. INTRODUCTION
- Nuclear Power 2
  - The nuclear fuel cycle 2
  - Concerns about nuclear power 4
- Major Deposit Types 5
  - Unconformity-relate deposits 5
  - Sandstone uranium deposits 8
  - Vein deposits 8
  - Metasomatic deposits 8
  - Breccia complex deposits 8
  - Intrusive deposits 9
  - Volcanic associated deposits 9
  - Quartz-pebble conglomerate deposits 9
  - Surficial uranium deposits 9
  - Collapse breccia pipe deposits 9
  - Phosphorite deposits 9
  - Black shale and seawater 10
- Thorium 10
- Distribution of Mines and Resources 10
- Mining and Processing Methods for Uranium 11
  - Open pit 11
  - Underground 12
  - In situ leaching 12
- Synopsis 12
- References 12

## 2. THE EFFECT OF ECONOMIC AND RESEARCH FACTORS IN UNDERSTANDING URANIUM EXPLORATION AND DISCOVERY OF DEPOSITS
- Economic Factors 15
- Research in Exploration and Deposit Studies of Uranium 19
- References 22

## 3. GEOCHEMICAL CHARACTERISTICS OF URANIUM AND ANALYTICAL METHODOLOGIES
- Uranium in Rocks and Minerals 23
- Uranium Solubility in Aqueous Fluids 24
  - Low temperature uranium geochemistry 25
  - High temperature uranium geochemistry 27
- Uranium Solubility in Silicate Melts and Magmatic Fluids 28
  - Uranium in fluids from granite 29
  - Application to natural examples 29
- Alteration of Uranium Minerals 29
  - Mobility of uranium in groundwaters 31
- Biogeochemistry of Uranium 32
  - Uranium and human health 33
- Analytical Methodologies 33
  - Radiogenic isotopes and uranium ore deposits 33
Decay schemes 34
The age equation 35
U-Pb systems 38
Sm-Nd systems 40
K-Ar and Ar-Ar systems 41
Radiogenic isotopes as tracers 42
Stable isotope geochemistry 43
Application of stable isotope geochemistry to uranium 46
Fluid inclusion studies 47
REFERENCES 49

4. DEPOSITS RELATED TO MAGMATIC DIFFERENTIATION

MAGMATIC DIFFERENTIATION 57
Ilimaussaq (South Greenland) 58
Regional geology 58
Geochemistry 59
Uranium mineralization 61
Resource estimations 64
Bokan Mountain (USA) 64
Regional geology 64
Geology of the pluton 65
Geochemistry 65
Uranium mineralization 66
Genetic model 69
Other occurrences of albitic episyenite 70
Other world occurrences of mineralized peralkaline granite 70
Poços de Caldas U-Mo-Zr mineralization (Brazil) 70
Thor Lake (Canada) 73
Palabora carbonatite (South Africa) 74
REFERENCES 74

5. DEPOSITS RELATED TO PARTIAL MELTING

INTRODUCTION 79
THE RÖSSING DEPOSIT, NAMIBIA 79
General geology 79
General characteristics of the U mineralization 84
Alaskite Geochemistry 85
Parameters controlling the location of the ore bodies at Rössing 87
Origin of mineralized alaskite 89
OTHER WORLD OCCURRENCES OF RÖSSING-TYPE MINERALIZATION 90
Archean occurrences 90
“Hudsonian” S.L. occurrences 90
The Wollaston and Mudjatik domains 90
Steward Lake, Quebec 91
Northern Quebec, Ungava Bay and Baffin Island 91
Litsk district, Kola Peninsula 91
Mineralized pegmatoid bodies in the Wheeler Basin, Colorado 91
The Orrefjell mineralized pegmatite 91
The late orogenic potassic granite of Southern Finland 91
6. Deposits related to Na-metasomatism and High-Grade Metamorphism

INTRODUCTION

Na-metasomatism-related deposits of Ukraine
Regional geology
The Krivoy-Rog district
The Michurinskoye deposit
Resources
Genetic model
Lagoa Real (Bahia, Brazil)
Regional geology
The Lagoa Real granite
Na-metasomatism
Uranium mineralization
Geochemistry
Genetic model
Other world occurrences of uranium deposits associated with Na-metasomatism
Valhall (NW Queensland, Australia)
Skuppesavon (northern Sweden)
Uranium deposits related very high temperature metasomatism, Tranomaro, Madagascar
Regional geology
Metasomatic skarns
Th-U mineralization
Genetic model
REFERENCES

7. Hydrothermal Uranium Deposits related to Igneous Rocks

IGNEOUS ROCK TYPES AND URANIUM METALLOGENESIS
Peraluminous leucogranite and volcanic rocks
Highly fractured calc-alkaline granite
S-type granite bodies
Guéret-type biotite-cordierite granite (G-type)
Two-mica leucogranite
Peralkaline granite, syenite and volcanic rocks
High K calc-alkaline granite
INTRA- AND NON-GRANITIC URANIUM DEPOSITS
Relations between Variscan granite types and U mineralization
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radioelement distribution in the Variscan crust</td>
<td>124</td>
</tr>
<tr>
<td>Characterization of the protoliths of U-enriched peraluminous leucogranite</td>
<td>124</td>
</tr>
<tr>
<td>Successive fractionation in the Saint Sylvestre granite complex</td>
<td>125</td>
</tr>
<tr>
<td>Relations between magmatic U enrichment and hydrothermal deposits</td>
<td>130</td>
</tr>
<tr>
<td>Alteration and uranium mobility</td>
<td>131</td>
</tr>
<tr>
<td>Characteristics of vein uranium deposits</td>
<td>132</td>
</tr>
<tr>
<td>OTHER VEIN-TYPE URANIUM DEPOSITS</td>
<td>133</td>
</tr>
<tr>
<td>METALLOGENETIC MODELS FOR THE VARISCAN GRANITE-RELATED URANIUM DEPOSITS</td>
<td>133</td>
</tr>
<tr>
<td>VOLCANIC-RELATED URANIUM DEPOSITS</td>
<td>134</td>
</tr>
<tr>
<td>Streltsovskoye caldera (Transbaikalia, Russia)</td>
<td>136</td>
</tr>
<tr>
<td>Uranium distribution in the granite</td>
<td>138</td>
</tr>
<tr>
<td>Uranium deposits</td>
<td>138</td>
</tr>
<tr>
<td>Uranium sources</td>
<td>142</td>
</tr>
<tr>
<td>Other volcanic-related uranium districts of Asia</td>
<td>143</td>
</tr>
<tr>
<td>Dornot (northeastern Mongolia)</td>
<td>143</td>
</tr>
<tr>
<td>Other volcanic-related uranium districts of the world</td>
<td>144</td>
</tr>
<tr>
<td>U-Mo Kitts-Michelin deposit</td>
<td>144</td>
</tr>
<tr>
<td>Th-U-REE Rexpar deposits</td>
<td>145</td>
</tr>
<tr>
<td>U-Zr-F Moonlight and U-Hg Aurora deposits</td>
<td>145</td>
</tr>
<tr>
<td>U-Mo-F Marysvale deposit</td>
<td>145</td>
</tr>
<tr>
<td>The Lakeview district</td>
<td>145</td>
</tr>
<tr>
<td>U-Be-Li-F Spor Mountain mineralization</td>
<td>145</td>
</tr>
<tr>
<td>U-Mo mineralizaion of the Sierra Peña Blanca</td>
<td>145</td>
</tr>
<tr>
<td>U-Mo Ben Lomond deposit</td>
<td>145</td>
</tr>
<tr>
<td>U-Mo-Sn-F Maureen uranium deposit</td>
<td>145</td>
</tr>
<tr>
<td>Arjeplog-Arvidsjour U province</td>
<td>146</td>
</tr>
<tr>
<td>Duobblon deposit</td>
<td>146</td>
</tr>
<tr>
<td>Skuppesavon uranium district</td>
<td>146</td>
</tr>
<tr>
<td>Macusani mineralization</td>
<td>146</td>
</tr>
<tr>
<td>The Los Frailes U occurrences</td>
<td>146</td>
</tr>
<tr>
<td>La Puna uranium mineralization</td>
<td>146</td>
</tr>
<tr>
<td>Novazza (U-Mo-Zn) and Val Vedello (U, Cu, Pb, Zn, Sb, As and Hg) deposits</td>
<td>147</td>
</tr>
<tr>
<td>Very recent (0.4 to 0.06 Ma) Vulsini fissures and calderas and the Vico caldera (Italy)</td>
<td>147</td>
</tr>
<tr>
<td>Uranium deposits related to volcanic units in Bulgaria</td>
<td>147</td>
</tr>
<tr>
<td>MODEL FOR URANIUM DEPOSITS ASSOCIATED WITH VOLCANISM</td>
<td>147</td>
</tr>
<tr>
<td>Nature of the magmatism</td>
<td>147</td>
</tr>
<tr>
<td>Melt chemistry recorded by magmatic inclusions</td>
<td>148</td>
</tr>
<tr>
<td>Nature of the volcanic system</td>
<td>148</td>
</tr>
<tr>
<td>Olympic Dam</td>
<td>149</td>
</tr>
<tr>
<td>Geological setting</td>
<td>149</td>
</tr>
<tr>
<td>The Roxby Downs Granite</td>
<td>149</td>
</tr>
<tr>
<td>The Gawler Range Volcanic Complex</td>
<td>149</td>
</tr>
<tr>
<td>The IOCG mineralization</td>
<td>149</td>
</tr>
<tr>
<td>Uranium mineralization</td>
<td>150</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>151</td>
</tr>
</tbody>
</table>

8. UNCONFORMITY-RELATED URANIUM DEPOSITS

UNCONFORMITY-RELATED DEPOSITS                                        161
  Proterozoic Basins – why so much uranium?                             162
THE ATHABASCA BASIN                                                    166
  General geology                                                       166
9. **Sandstone-Hosted Uranium Deposits**

### INTRODUCTION

- Basal type 223
- Tabular type 223
  - Uravan Mineral Belt & Colorado Plateau 228
  - Monument Valley-White Canyon Districts 229
  - Powder River Basin, Wyoming 230
  - Asia 230
- Roll-front type 230
- Franceville Basin, Gabon 232
- Tectonic/lithologic type 232
  - Solution collapse breccia-type deposits, Arizona, USA 232

### REFERENCES

10. **Other Types of Uranium Deposits**

### Quartz-Pebble Conglomerate Uranium Deposits

- Blind River-Elliot Lake district 242
- The Witwatersand Basin 244
- Koli 246

### REFERENCES
11. IMPLICATIONS FOR EXPLORATION STRATEGIES

COMMON DENOMINATORS

Timing is everything 253
Knowledge of the nature of fluids 253
Gradients in redox environments 254
The source of uranium 254
Carbon is an effective reductant for fixing U 254
Uranium deposits are geochemical anomalies 254
Specific tectonic environments, structural settings and lithologies required, but are not definitive indicators of mineralization 254
Exploration for uranium deposits requires the integration of geology, geophysics and geochemistry 255

EXPLORATION STRATEGIES

Geology 255
Geophysics 255
Geochemistry 255

REFERENCES 257
**TABLE OF CONTENTS OF SHORT COURSE 3**  
**URANIUM DEPOSITS: THEIR MINERALOGY AND ORIGIN (1978)**  
*(located on DVD)*

<table>
<thead>
<tr>
<th>Introduction</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Uranium Solution – Mineral Equilibria at Low Temperatures with Applications to Sedimentary Ore Deposits</td>
<td>17</td>
</tr>
<tr>
<td>D. Langmir</td>
<td></td>
</tr>
<tr>
<td>2. The Mobility and Concentration of Uranium and its Decay Products in Temperate Surficial Environments</td>
<td>57</td>
</tr>
<tr>
<td>W. Dyck</td>
<td></td>
</tr>
<tr>
<td>3. High Temperature Uranium Geochemistry</td>
<td>101</td>
</tr>
<tr>
<td>M.M. Kimberley</td>
<td></td>
</tr>
<tr>
<td>4. Uranium Minerals in Canada: Their Description, Identification and Field Guides</td>
<td>107</td>
</tr>
<tr>
<td>H.R. Steacy and S. Kaiman</td>
<td></td>
</tr>
<tr>
<td>5. The Identification of Uraniferous Minerals</td>
<td>141</td>
</tr>
<tr>
<td>R.D. Morton</td>
<td></td>
</tr>
<tr>
<td>6. Genetic Aspects and Classification of Important Canadian Uranium Deposits</td>
<td>187</td>
</tr>
<tr>
<td>R.H. McMillan</td>
<td></td>
</tr>
<tr>
<td>7. Uranium Deposits in Australia</td>
<td>205</td>
</tr>
<tr>
<td>F.F. Langford</td>
<td></td>
</tr>
<tr>
<td>8. Phanerozoic Uranium Deposits and Occurrences in Europe and Eastern North America</td>
<td>217</td>
</tr>
<tr>
<td>V. Ruzicka</td>
<td></td>
</tr>
<tr>
<td>9. Uranium Deposits in Ontario</td>
<td>229</td>
</tr>
<tr>
<td>J.A. Robertson</td>
<td></td>
</tr>
<tr>
<td>10. Uranium Mineralization in Shallow Intrusive Environments</td>
<td>281</td>
</tr>
<tr>
<td>J.E. Tilsley</td>
<td></td>
</tr>
<tr>
<td>11. Uranium in Phanerozoic Sandstone and Volcanic Rocks</td>
<td>293</td>
</tr>
<tr>
<td>R.W. DeVoto</td>
<td></td>
</tr>
<tr>
<td>12. Uranium in Black Shales – a Review</td>
<td>307</td>
</tr>
<tr>
<td>R.T. Bell</td>
<td></td>
</tr>
<tr>
<td>13. Mineralogy and Setting of Elliot Lake Deposits</td>
<td>331</td>
</tr>
<tr>
<td>N.J. Theis</td>
<td></td>
</tr>
<tr>
<td>M.M. Kimberley</td>
<td></td>
</tr>
<tr>
<td>15. Mobility and Concentration of Uranium in Arid Surficial Environments</td>
<td>383</td>
</tr>
<tr>
<td>F.F. Langford</td>
<td></td>
</tr>
<tr>
<td>16. Classification of Uranium Deposits in Northern Saskatchewan</td>
<td>397</td>
</tr>
<tr>
<td>J. Hoeve</td>
<td></td>
</tr>
<tr>
<td>17. Application of Mineralogy to the Study of Multistage Uranium Mineralization in Remobilized Uranium Deposits, Saskatchewan</td>
<td>403</td>
</tr>
<tr>
<td>J. Rimsaite</td>
<td></td>
</tr>
</tbody>
</table>
18. Geologic Setting of the Beaverlodge-type of Vein-Uranium Deposit and its Comparison to That of the Unconformity-type
   L.P. Tremblay
   431

19. Mineralogy and Geological Settings of Unconformity-type Uranium Deposits in Northern Saskatchewan
   J. Hoeve and T.I.I. Sibbald
   457

20. Uranium Concentrations Related to the Sub-Athabasca Unconformity, Northern Saskatchewan, Canada
    J. Hoeve and T.I.I. Sibbald
    475

21. Origin of Unconformity-type Pitchblende Deposits in the Athabasca Basin of Saskatchewan
    F.F. Langford
    485

Glossary
    501
The purpose of this short course, co-sponsored by the Society for Geology Applied to Mineral Deposits (SGA) and MAC, is to highlight data and research that have developed over the past 30 years, as well as discuss new techniques and ideas that can be integrated into effective exploration strategies for uranium. A short course in 1978 sponsored by the MAC is included in this volume as a base on which to build the developments over the last thirty years.

The Mineralogical Association of Canada (MAC) was among the first organizations to support a short course on uranium, which was presented as its third short course volume in 1978 entitled *Uranium Deposits: Their Mineralogy and Origin* and edited by M.M. Kimberley. This proved to be the most popular short course volume ever for MAC, and has been used in both undergraduate and graduate courses on mineral deposits geology and by the exploration industry. Although about half of the volume was dedicated to deposits in Canada because of the discovery of unconformity-related deposits in the Athabasca Basin, this short course volume was so successful that it is currently out of print. There have been various conferences supported by international uranium concerns such as the International Atomic Energy Commission (IAEA), but MAC was among the few professional organizations that saw value in promoting a knowledge base for uranium deposits. Subsequently, other organizations, such as the International Atomic Energy Commission, Prospectors and Developers Association of Canada, Saskatchewan Energy and Resources, Mineralogical Society of America, Canadian Institute of Mining, Metallurgy, and Petroleum and CREGU have supported short courses and conferences on uranium, with most of these occurring during the last few years in response to the renewed interest in uranium as an alternative energy source. An international group of scientists (Grenthe et al. 1992) supported by the NEA and OECD published the only available compilation of selected thermodynamic data on uranium in 1992.

The lack of interest in uranium by the mining industry and subsequently by the research community was largely the result of the low spot price which began in 1987 and continued until recently. The low price of uranium had a ripple effect in that not only were expenditures in exploration for uranium depressed, but support for research in uranium deposit studies also decreased. Despite the demise in uranium exploration and support for research, some government organizations and companies that specialized in uranium such as Uranerz, Cameco and Cogema (now AREVA) continued to support research, albeit at a reduced level. The authors of this volume are among those who continued with their research on uranium through such support. During this time in the former Soviet Union and then Russia, where uranium geologists are considered critical, research continued. During the 1990s, other nations such as Japan, India and China continued their research efforts as nuclear energy was strategic in their energy policies and they were less tied to the global market. Research supported by state agencies and the IAEA continued during this time on aspects of the geochemistry of uranium in solution and in the environment (e.g., Grenthe et al. 1992). Studies of the Oklo natural reactors in Gabon (e.g., Gauthier Lafaye et al. 1996), the Cigar Lake deposit in the Athabasca Basin (e.g., Cramer & Smellie 1994), Poços de Caldas in Brazil (e.g., Chapman et al. 1991) were undertaken as natural analogs for the long term disposal of nuclear waste in geologic formations and remediation of closed uranium mines (Merkel et al. 2006).

New models developed for different deposits and the mechanisms that control their genesis are central themes in this new short course volume. This volume is divided into the following chapters:
1. *Introduction* discusses the discovery and properties of uranium, which countries have the greatest reserves and which use nuclear energy, what are the types of deposits and in which geological environments are they found.
2. *Economics and Research* describes the interplay between the market price of uranium and the exploration and research that have occurred during the past thirty years. As a commodity, interest in uranium is driven by the spot price of uranium, and *vice versa*, although the spot price serves as a guide for the value of uranium because not anyone can simply purchase it. Most of the uranium sold for use in reactors is brokered through long-term contracts.
3. *Geochemistry of Uranium* consists of a brief review of the geochemical properties of uranium...
that figure greatly in the development of uranium deposits. Our goal here is not to discuss in detail the geochemistry of uranium, which is not very well known except by those in the processing or disposal industries, but to present an overview of the characteristics of uranium in natural fluids at a variety of temperatures.

4. Magmatic Differentiation describes uranium mineralization generated by high temperature magmatic processes related to peralkaline magmas and granitoid rocks in migmatic environments such as alaskite and carbonatite bodies. Extreme fractional crystallization of peralkaline magmas can lead to the formation of very large low-grade U and Th resources because of the high solubility of U and Th in highly depolymerized magmas.

5. Partial melting discusses the effects of crustal melting processes on the production of melts that host uranium mineralization.

6. Metasomatic Deposits is concerned with high temperature hydrothermal processes associated with regional Na metasomatism and quartz dissolution, forming discontinuous occurrences of uraniferous Na metasomatized granite, metasedimentary or metavolcanic units that extend over several tens of kilometres.

7. Hydrothermal (granite-related and volcanic-related) Deposits is concerned with a diverse category of deposits generally exhibiting vein-type morphology, but also as disseminated ore in syenitic bodies. They may be hosted by granite, volcanic rocks or without any direct relation with granite. High-temperature hydrothermal deposits can also be associated with IOCG-type deposits.

8. Unconformity-related Deposits examines uranium mineralization related to a reduction front near the unconformity between Proterozoic sandstone units and underlying metamorphosed basement lithologies. The deposits are structurally hosted either in the basement or in the overlying sandstone. Models involving the source of uranium from breakdown of uranium-bearing phases in altered basement rocks along fault zones or from an oxidized basinal brine carrying uranium leached from detrital phases are also discussed, as are the role of paleoquifers in the prospectivity of a basin.

9. Sandstone-hosted Deposits discusses breccia pipes and sandstone-hosted low-temperature deposits such as roll-front, tabular and sedimentary copper associated deposits. These occur in medium to coarse-grained sandstone deposited in a continental fluvial or marginal marine sedimentary environment such that impermeable shale/mudstone units immediately above and below the mineralized sandstone confine fluid flow so that uranium can precipitate under reducing conditions within the sandstone because of carbonaceous material, sulfides, hydrocarbons and interbedded basic volcanic rocks with abundant ferromagnesian minerals.

10. Other types of deposits examines the Elliot Lake quartz pebble conglomerate deposits in Canada and the Witwatersrand gold/uranium deposits in South Africa, the latter a resource of increasing importance. Also discussed are surficial deposits that include the young near-surface uranium concentrations in sediments and soils, with those in calcrete being the largest deposits.

11. Implication for exploration strategies briefly discusses what we have learned during the past thirty years that may help us to explore for uranium deposits.

These chapters are by no means meant to be comprehensive as the knowledge base for uranium deposits is vast. Unfortunately, much of the knowledge on uranium is manifest in the literature on uranium deposits research prior to 1990, and much of this is outdated, or in the minds of those individuals associated with the last uranium boom, many of whom have long since moved on. We have learned a great deal in formulating this short course, and we hope that some of this knowledge will be useful to you. Those interested in uranium should find the list of references, particularly some of the books listed below, to be useful in expanding their knowledge base.

We are indebted to many for their support of this volume, including the Mineralogical Association of Canada and the Society for Geology Applied to Mineral Deposits for their sponsorship. In particular, Rob Raeside of the MAC is thanked for his patience and diligence in editing this volume. Several others, particularly Paul Alexandre, Don Chipley, April Vuletich and the group at the Queen’s Facility for Isotope Research, and Dr. Narelle Neumann of Geoscience Australia provided constructive criticism and editorial skills that greatly improved this volume.
REFERENCES


