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

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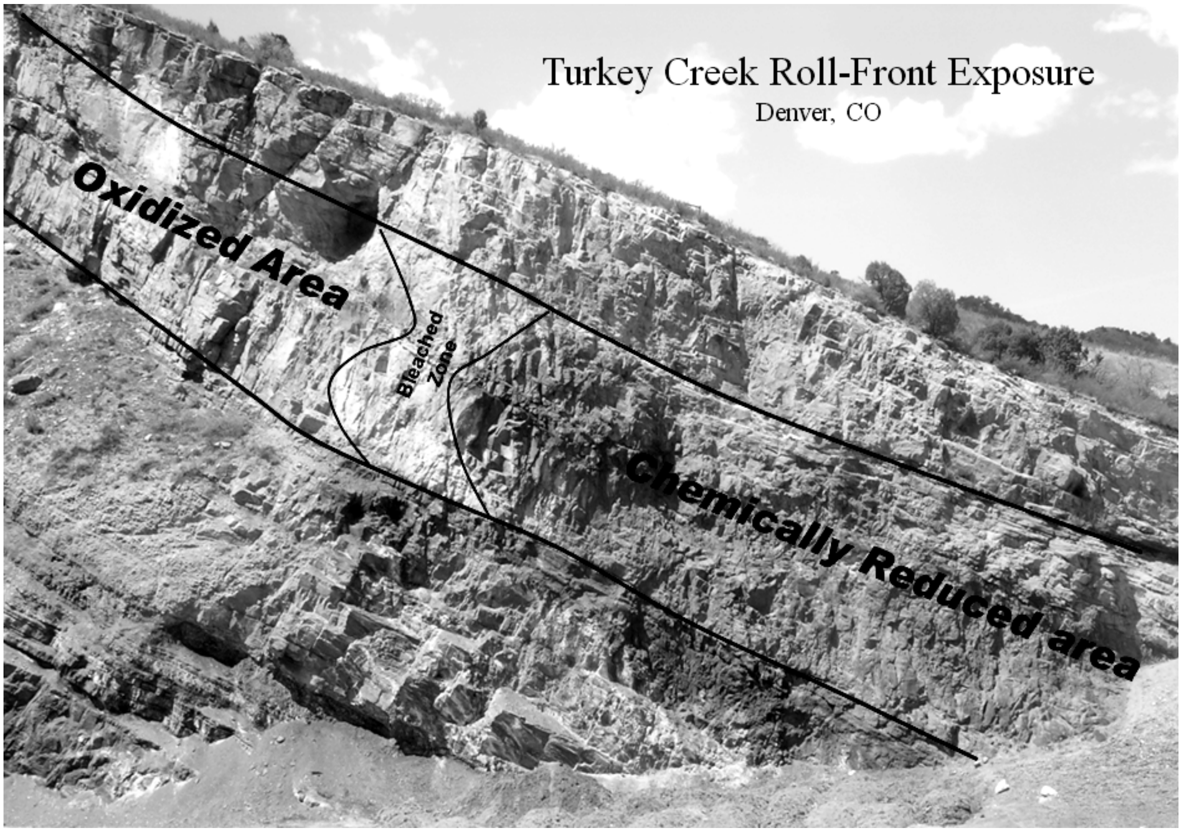

Cover photograph: outcrop of the Turkey Creek roll-front uranium deposit, near Denver, Colorado, showing a sandstone layer with roll front between the oxidized and reduced zone enhanced by bleaching.
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PREFACE

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. <u>Introduction</u> 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. <u>Economics and Research</u> 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. <u>Geochemistry of Uranium</u> 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 migmatitic 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 paleoaquifers 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.

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