A Review of Uranium Deposits in the Karoo Supergroup of South Africa*

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Abstract

Uranium is present in the form of fluvially-deposited, sandstone-hosted peneconcordant tabular deposits in the Late Permian lower Beaufort Group (Adelaide Subgroup) and Late Triassic Molteno and Elliot formations within the main Karoo Basin and Late Permian coal-hosted deposits in the Springbok Flats Basin. The sandstone-hosted deposits generally contain less than 1000 t U in situ, the largest deposit having 6791 t U. Average recoverable grades are 0.76 kg U/t. Metallogenesis is thought to have been dependent upon uranium source, palaeoclimate and availability of a reductant. Basement granite and volcanic ash have been proposed as possible uranium sources for the Adelaide Subgroup and granite for the Molteno and Elliot formations.

The warm, semi-arid palaeoclimate of all these stratigraphic units implies an oxidising environment, which was a prerequisite for the leaching and mobilisation of uranium from the above sources. Uranium-bearing solutions moved through the sand bodies with precipitation occurring in relatively sparse reduced zones that contained carbonaceous debris. Coffinite and less abundant uraninite are the principal ore minerals. Molybdenite, which is confined to ore in the Adelaide Subgroup in the southwestern part of the main Karoo Basin, forms a secondary economic commodity. The coal-hosted deposits have grades of between 0.16 and 1 kg U/t over 1 m width. Uranium is disseminated in the form of organo-metallic compounds, coffinite, oyamalite and auerlite. It was mobilised from basement granite by oxidised groundwater and was absorbed by the coal several million years after peat accumulation associated with a lacustrine environment. The sandstone-hosted deposits have an estimated resource of 31,000 t U and the coal-hosted deposits 55,000 t U.

Introduction

Two types of uranium deposits are present in strata of the Karoo Supergroup in South Africa. These are: (1) fluvially-deposited, sandstone-hosted, peneconcordant, tabular deposits in the Late Permian lower Beaufort Group (Adelaide Subgroup) and Late Triassic Molteno and Elliot Formations within the main Karoo Basin, and (2) coal-hosted deposits in the Late Permian uppermost part of the Hammanskraal Formation within the Springbok Flats Basin (Figure 1). The sandstone-hosted deposits were discovered in 1969 and the coal-hosted deposits in 1976 with extensive exploration occurring up until 1981, which coincided with the preceding period of relatively high uranium prices.

Sandstone-hosted Uranium

The sandstone-hosted deposits cluster into a province, the Karoo Uranium Province, which lies between Laingsburg, Cradock and Bloemfontein over parts of the Adelaide Subgroup, and also includes a smaller, crescent-shaped satellite region between Clocolan and Harrismith over the Molteno and Elliot formations (Figure 1). The ore bodies are normally about 1 m thick, but attain 7 m in places and, where vertically stacked, have a combined thickness of 20 m (Cole, 1998). They are several hundred metres long, up to 200 m in width and are elongated along the palaeochannel thalweg within the lower portion of the enclosing fluvial sandstone body. The thickest sandstones host the larger ore bodies and these composite sandstones are up to 70 m thick in the Adelaide Subgroup and up to 40 m thick in the Molteno and Elliot Formations. The sandstone bodies represent meandering river and sheet flood deposits in the case of the Adelaide Subgroup, and braided and meandering deposits in the case of the Molteno Formation, and meandering and sheet flood deposits in the case of the Elliot Formation (Le Roux, 1990; Cole and Wipplinger, 2001).

The sandstone bodies are interbedded with dark greenish grey, dark greyish red and maroon mudstone and subordinate siltstone, which is volumetrically more abundant in the Adelaide Subgroup and Elliot Formation and approximately equally abundant to sandstone in the Molteno Formation. Calcareous nodules and layers are common in the mudstone and sparse sandstone-filled desiccation cracks are present. The mudstone represents deposition in a flood-basin environment with suspension-settling of mud taking place in slowly moving or ponded waters remote from the fluvial channels. The reddish colours indicate oxidation of the mud during subaerial exposure and the calcareous nodules and layers have been interpreted as pedogenic calcrete that formed in a semi-arid environment (Smith, 1990a). The subordinate siltstone represents higher energy deposits such as crevasse splays, which were laid down in more proximal areas of the flood basin closer to the fluvial channels. The ore-bearing sandstone bodies generally form multi-storey broad sheets with width to height ratios exceeding 100:1. In the Adelaide Subgroup and Molteno Formation, the sandstone bodies cluster into packages up to 350 m thick with the laterally-extensive units defining lithostratigraphic members (Cole and

Wipplinger, 2001). Within the Adelaide Subgroup, one member, the Poortjie Member, hosts 80 per cent of the identified uranium resources and the entire resources of the Molteno Formation are contained within the Indwe Member.

Uranium in the ore bodies is hosted by the minerals coffinite and less abundant uraninite. The sulphides molybdenite, pyrite, arsenopyrite and chalcopyrite are commonly present with concentrations of the former being sufficiently high in the Adelaide Subgroup in the southwestern part of the main Karoo Basin (Figure 1) to warrant possible exploitation as a by-product of uranium (Cole and Wipplinger, 2001). Gangue minerals comprise quartz and feldspar with calcite being common in the Adelaide Subgroup. Fossilised carbonaceous plant fragments are ubiquitous. Metallogenesis is thought to have been dependent upon three factors: 1) uranium source; 2) palaeoclimate; and 3) availability of a reductant. In the Adelaide Subgroup, uranium was probably sourced from granitic terranes located west, southwest and south of the main Karoo Basin and a minor intrabasinal provenance, the Clocolan Dome, located near Clocolan (Figure 1).

Volcanic ash derived from a magmatic arc situated in southern South America, inboard of a subduction zone descending beneath southwestern Gondwanaland, also provided a source of uranium. The restriction of molybdenum to the southwestern part of the main Karoo Basin indicates a source confined to granitic terranes west, southwest and south of the basin (Cole and Wipplinger, 2001). Uranium in the Molteno and Elliot formations in the north-central part of the main Karoo Basin is thought to have been derived from granitic terranes located southeast of the basin centred on the Maurice Ewing Bank microplate within the Triassic reconstruction of Gondwanaland (Turner, 1999). Clastic material containing uranium was transported into the basin by entrainment within fluvial sediments. Some volcanic ash may have been similarly transported, but the bulk would have been directly windblown onto the alluvial plain. The inflowing rivers could have transported a proportion of the metals either in solution and/or adsorbed by clay minerals and organic detritus. The metals were dispersed in both flood basin mud and fluvial sand before being later mobilised and transported in slightly oxidised and alkaline solutions (Cole and Wipplinger, 2001).

Early diagenetic processes are inferred from uranium minerals filling undeformed cell structures in fossilised wood fragments and a matrix-supported fabric of calcite-cemented ore, which is explained by expansive growth of calcite cement in unconsolidated sand. The presence of calcite suggests that the uranium was transported in solution as uranyl carbonate complexes. These solutions moved from the flood basin mud into the sandstone bodies, following the thalwegs. Precipitation of metals occurred in relatively sparse, reduced zones that contained carbonaceous debris in the basal part of the sandstone below a low palaeo-water table (Cole and Wipplinger, 2001). Oxidising conditions were prevalent given the warm, semi-arid palaeoclimate in the main Karoo Basin during Late Permian to Late Triassic times (Smith, 1990b). Uranium was initially adsorbed by organic matter and then reduced by hydrogen sulphide or the sorbent itself. The scarcity of calcite in the Molteno and Elliot formation ores suggests that the mineralising solutions were acidic to neutral and slightly oxidised and were probably generated within the sandstone bodies where primary calcium carbonate would have been almost absent. The presence of the largest ore bodies within thick composite sandstones is due to differential compaction of the lower portion of the sand body relative to the flood basin muds on either side. This resulted in a relatively high water table within the sands and consequently a larger reducing zone for precipitation and preservation of uranium (Cole and Wipplinger, 2001).

Total identified resources in the Karoo Uranium Province are presently 32,832 metric tons U with 95 per cent being hosted by the Adelaide Subgroup (OECD/IAEA, 2008). Ore bodies generally contain less than 1000 t U *in situ*, but in the Adelaide Subgroup in the southwestern part of the main Karoo Basin, eight deposits contain between 1659 and 6791 t U. Average recoverable grades are 0.76 kg U/t. In this part of the basin, a total of 28,000 metric tons Mo *in situ* has been calculated with an average grade of 0.8 kg Mo/t (Cole and Wipplinger, 2001). Renewed exploration is currently taking place, as well as feasibility studies on the largest deposit, Ryst Kuil, some 45 km southeast of Beaufort West (Figure 1), where reasonably assured resources of 6791 t U and 7420 t Mo have been calculated.

Coal-hosted Uranium

Uranium is hosted by coal in the Late Permian, uppermost part of the Hammanskraal Formation within the Springbok Flats Basin (Figure 1). This basin is essentially a northeast-trending half-graben 200 km long and 60 km wide, being fault-bounded on the northwestern side. Here, an ancient structure named the Thabazimbi-Murchison Lineament was episodically active during accumulation of the Karoo Supergroup sediments and lavas between the Early Permian and Early Jurassic (Good and de Wit, 1997). The uppermost part of the Hammanskraal Formation consists of interbedded carbonaceous shale and coal and is informally known as the Coal Zone. It has a maximum thickness of 12 m, but averages 5 to 8 m (Christie, 1989). Individual seams have a maximum thickness of 4 m thick. The Coal Zone conformably overlies a succession of fine- to very coarse-grained sandstone beds and less abundant carbonaceous shale, rhythmite, conglomerate and coal, which are non-uraniferous. These form the greater part of the Hammanskraal Formation, are up to 110 m thick and occur in west- and southwest-trending palaeovalleys excavated into the basin floor. They represent deltaic, fluvial, lacustrine and peat deposits. Locally, in the deepest parts of the palaeovalleys, this succession overlies a sequence of shale containing sparse exotic pebbles, fine- to coarse-grained sandstone, conglomerate and minor diamictite. This sequence is up to 90 m thick and forms the glaciogenic Dwyka Group with deposition of the original sediments occurring in proglacial, subaqueous and subaerial environments in front of a slowly melting glacier. The glaciers were probably responsible for the excavation of the palaeovalleys.

A lacustrine environment prevailed during deposition of the Coal Zone with suspension-transported mud in low-energy fluvial systems and windblown dust being the main sources of clastic sediment within the Coal Zone (Christie, 1989). A predominance of vitrinite in the coal has been ascribed to peat accumulation in a permanently waterlogged swamp, a characteristic of lacustrine settings (Falcon, 1986). The Coal Zone is conformably overlaid by up to 65 m of grey and red variegated mudstone and sparse fine-grained sandstone of the Beaufort Group, which represent a Late Permian alluvial plain environment. This unit, as well as the underlying units, are truncated unconformably by conglomerate and medium- to coarse-grained sandstone of the Late Triassic Molteno Formation (maximum thickness 43 m), which oversteps onto Precambrian bedrock on the shoulders of palaeovalleys and onto horst blocks that were uplifted during the Early to Middle Triassic. A fluvial, possibly braided river palaeoenvironment is indicated (Roberts, 1992). The Molteno Formation is overlaid by the Late Triassic to Early Jurassic Elliot, Clarens and Letaba formations, which respectively comprise red mudstone with subordinate fine- to coarse-grained sandstone (alluvial plain), fine-grained, well-sorted quartzose sandstone (desert) and amygdaloidal basaltic lava (volcanic flood basalt). These units combined have a maximum thickness of 800 m (Roberts, 1992).

Uranium is concentrated in the upper part of the Coal Zone over a vertical interval of 1 m, but in the vicinity of bedrock in the form of Bushveld Complex granite on the flanks and shoulders of palaeovalleys, the entire Coal Zone is uraniferous (Christie, 1989). Only the Coal Zone in the central and northeastern part of the basin is significantly mineralised (Figure 1), where several ore bodies containing between 0.16 and 1 kg U/t over 1 m width were delineated in a 1000-km^2 block in the central part and in a 600-km^2 block in the northeastern part (Cole, 1998). The uranium is disseminated throughout the coal and carbonaceous shale, with uranium phases having grain sizes of less than 20 microns. Kruger (1981) identified coffinite, oyamalite and auerlite as uranium-bearing minerals, but a high proportion of uranium is held in organo-metallic compounds. Uranium in the Coal Zone has only been detected in prospecting boreholes at depths between 20 and 650 m, with most occurrences being clustered between 100 and 200 m below surface (Cole, 1998).

The uranium was probably derived from granite of the Bushveld Complex that underlies most of the Springbok Flats Basin and is locally in contact with the Coal Zone on the flanks and shoulders of palaeovalleys (Kruger, 1981). This rock type contains relatively high uranium values (20 – 40 ppm U), in contrast to the remaining pre-Karoo bedrock. The Coal Zone is also uraniferous at sites where it is unconformably overlaid by the fluvially-deposited Molteno Formation, which contains abundant detritus including pebbles, derived locally from Bushveld Complex granite (Kruger, 1981). The uranium was probably mobilised from the granite and granite detritus in the Molteno Formation shortly after deposition of the latter during the Late Triassic. The rank or degree of metamorphism of the coal, which results from increases in temperature and pressure after burial of the original peat, was probably still in the lignitic stage given the limited thickness of the Late Permian Beaufort Group overburden. The mobilising groundwaters would have been oxidising and these transported uranium to the Coal Zone where it was adsorbed by the lignite under reducing and slightly acidic conditions, leading to the formation of organo-metallic compounds (Hambleton-Jones, 1980). The present higher rank of the coal, which is in the bituminous stage (Falcon, 1986), was attained later following burial by at least 300 m of Late Triassic to Early Jurassic sediments and lavas (Roberts, 1992). Total identified resources in the Coal Zone of the Springbok Flats Basin are 77,072 metric tons U (OECD/IAEA, 2008).

Discussion

Uranium deposits in the Karoo Supergroup are confined to fluvially-deposited sandstones in the Adelaide Subgroup, the Molteno Formation and the Elliot Formation within the main Karoo Basin, and to coals in the uppermost part of the Hammanskraal Formation within the Springbok Flats Basin. Their apparent absence from lithologies of similar disposition in terms of palaeoclimate and palaeoenvironment is probably due to the non-availability of a suitable uranium source at the time of metallogenesis. In the smaller Karoo basins in the northern region of South Africa, i.e. Tuli, Tshipise, Ellisras, Springbok Flats and Lebombo (Figure 1), prerequisite tabular sandstones interbedded with red-coloured mudstones are either absent or not well-developed.

Neither the sandstone- nor coal-hosted deposits have been mined, but given the significant increase in the price of uranium over the past five years, they could become economically-viable and this is supported by renewed exploration including feasibility studies, which are currently being conducted. A consideration of ore body thickness and overburden depth indicates that the sandstone-hosted deposits would have to be mined using opencast and *in situ* methods and the coal-hosted deposits by *in situ* methods. The sandstone-hosted uranium deposits containing the by-product molybdenum in the southwestern part of the main Karoo Basin would probably be developed first, but a viable and efficient method of recovering these metals from the ore would have to be found. The recovery of uranium from coal using *in situ* techniques presents greater problems, since pollution of the groundwater and atmosphere must be avoided.

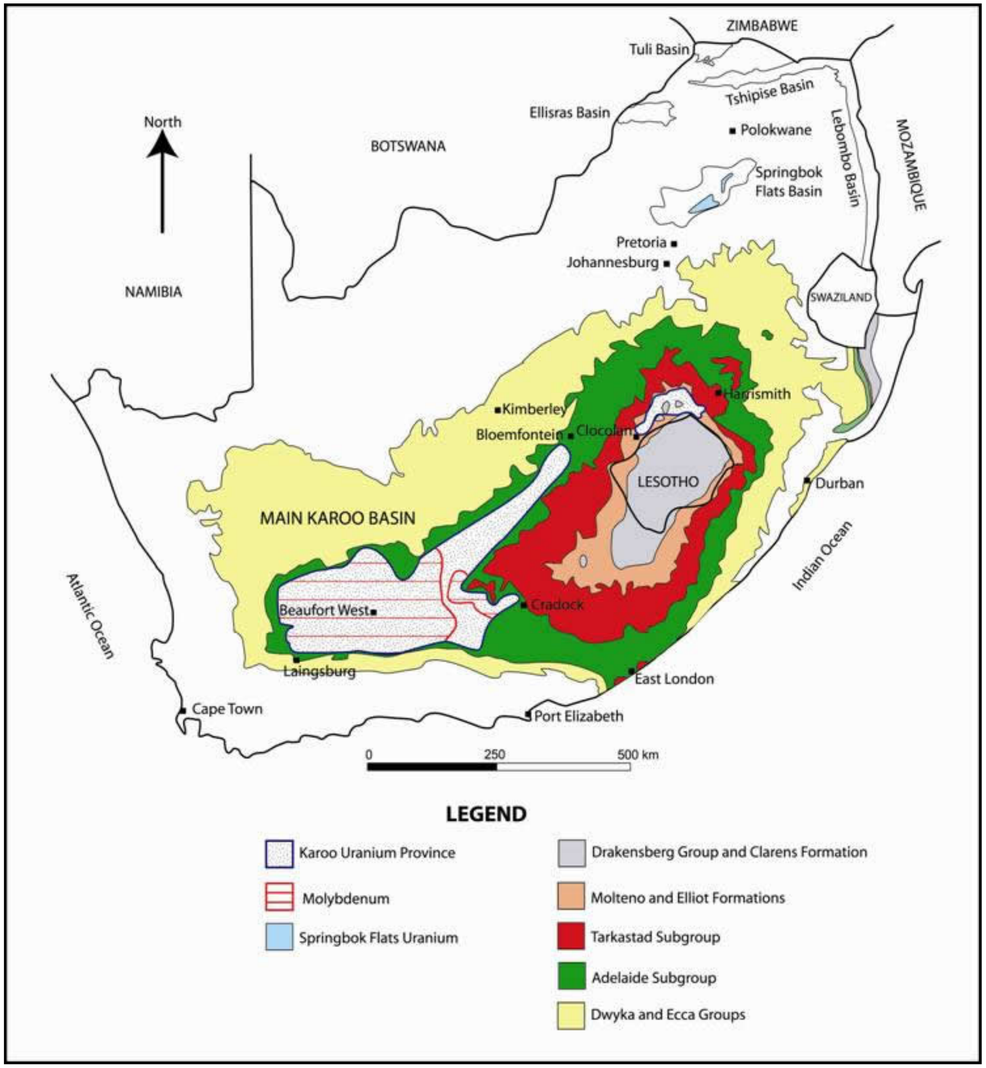

Figure 1. Map of South Africa showing distribution of Karoo basins, uranium provinces and major lithostratigraphic units in the main Karoo Basin.

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