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Comparison between the uranium deposits in the Alligator River Uranium Field and the Westmoreland area (Northern Territory and Queensland, Australia)

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INTRODUCTION

The Northern Territory (Australia) hosts about 30% of Australia's low-cost uranium sources with 361 uranium occurrences [1]. The production of U3O8 concentrates in Northern Territory to 2012 was 128 017 t. The uranium deposits of the Northern Territory can be subdivided into five main types [2]. The two on which this study is focused are the "unconformity-related"and the "Westmoreland-Murphy"types. The Alligator River Uranium Field (ARUF) hosts numerous unconformity-related deposits such as Ranger, Nabarlek, Jabiluka and Koongarra. They are located exclusively in basement rocks, near the unconformity between an Archean to Paleoproterozoic basement complex (˜2670-1818 Ma) and the Paleo- to Mesoproterozoic McArthur Basin (1815-1492 Ma) and mostly grade above 0.1% U3O8 [1, 3, 4]. In the Westmoreland area, on the southern margin of the McArthur Basin, former uranium mines and current prospects belong to the Westmoreland-Murphy type (e.g. Eva in Northern Territory and Redtree and Junnagunna in Queensland). They are located within the Westmoreland Conglomerate and Seigal Volcanics that are part of the McArthur Basin, near the unconformity with the Paleoproterozoic Murphy Inlier (1855-1830 Ma) and grade 0.07-0.1% U3O8 [1]. As the two types of deposits share similar settings and are associated with the same basin (McArthur Basin), it is critical to establish detailed comparison of their timing, mineralogy and geochemistry in order to determine if they could be linked to the same ore-forming event or ore-forming processes. While unconformity-related deposits have been extensively studied [5–9], much less is known about the Westmoreland-Murphy-type deposits [10, 11]. In this work, we complement the existing data on ore mineralogy, geochemistry, geothermometry, age dating and fluid inclusions on Westmoreland-Murphy-type deposits and compare them with published data from unconformity-related deposits.

METHODS AND RESULTS

The new data obtained on U deposits from the Westmoreland area is based on mineralized samples collected in the Westmoreland conglomerate from Junnagunna and Redtree deposits.

Petrographic investigation was carried out using optical microscope and SEM at GeoRessources laboratory (Vandœuvre-lès Nancy, France). Early diagenesis is represented by hematite and quartz overgrowth over detrital quartz grains. This was followed by an episode of quartz dissolution that corresponds to the beginning of peak diagenesis [10]. Quartz precipitates after this episode, and hematite, chlorite and then apatite, clays minerals and uraninite (10-50μm) (hereafter referred to as "intergranular uraninite") take turns, filling intergranular voids between quartz grains in the sandstone. Intergranular uraninite is texturally associated with clays minerals and hematite and also occurs as micron-sized grains within hematite grains [10] Apatite is older than the intergranular uraninite because small fractures within apatite grains are filled with uraninite, which also surrounds the apatite grains. After these diagenetic events, veins containing quartz, uraninite (hereafter referred to as "vein uraninite"), pyrite and chalcopyrite develop. In this study, we focused on both intergranular and vein uraninite. By comparison, the main stage of uranium mineralization in the ARUF consists of very fine grained (10–50 μm diameter) euhedral uraninite (U1) disseminated within chlorite and intergrown with tourmaline. A second generation of uraninite (U2) is represented by fine-grained uraninite inclusions within

veinlets of disordered graphitic carbon. The final stage of uranium mineralization is represented by veinlets of massive uraninite (U3) [6].

Intergranular and vein uraninite were dated by U-Pb using SIMS at CRPG laboratory (Vandœuvre-lès Nancy, France). The average age for both generations yielded by the analysis is 559 ±33 Ma, which is consistent with the youngest age already obtained for these deposits [10]. The oldest published ages (1606 ± 80 and 1655 ± 83 Ma) in Westmoreland area are 207Pb/206Pb ages from two analyses obtained by LA-HR-ICPMS on very fine-grained intergranular uraninites inclusions in hematite (6-8μm) [10]. This very fine uraninite has not been dated yet in this study. U-Pb dating of a thin layer (1mm) of euhedral apatite grains has also been carried out by SIMS. Apatite shows abnormally high U content probably due to the vicinity of uraninites or to tiny UO2 inclusions. As a consequence, on 31 spot analyses, only 9 could be used to constrain an age of 1685 ±65 Ma, consistent with the diagenesis processes dated on illite [10]. According to the analytical uncertainties, the oldest published age for small intergranular uraninite is compatible with that of the apatite dated here [10]. By comparison, the ages obtained on uraninites in the ARUF show a first mineralizing stage around 1720-1680 Ma [6, 7, 9]. Lots of uraninite ages are younger than 1400 Ma and this wide range of ages doesn't allow any relevant comparison between the two areas [6, 8–10]. Significant amounts of illite have K-Ar ages that indicate crystallization between ~1680 and 1520 Ma in the ARUF [12]. This corresponds to the initiation of the diagenetic/hydrothermal fluid circulations. Illite from Westmoreland Conglomerate has a plateau 40Ar/39Ar age at 1680 ± 18 Ma that confirms basinal-brine migration in the Westmoreland Conglomerate at this period [10].

REE-patterns on dated intergranular and vein uraninites from Westmoreland have been established by LA-ICP-MS at GeoRessources laboratory (Vandœuvre-lès Nancy, France). The uraninite REE-patterns in Westmoreland do not exhibit the "bell-shape"(i.e. high concentrations of Tb and Dy) typical of unconformity-related U deposits [13]. The REE-patterns on intergranular UO2 is enriched in LREE in comparison with patterns from unconformity-related, basement-hosted deposits from ARUF (Nabarlek and Koongarra) [13]. For vein uraninite, the patterns show some similarities with vein-type deposits worldwide although the latter are generally considered to be formed at higher temperature in the presence of magmatic and/or metamorphic fluids. Even if some post crystallization modification of the REE patterns may have contributed to the LREE enrichment, such phenomenon is not sufficient to explain the differences of the REE patterns between the two zones. Therefore, the REE-patterns of UO2 differ between the North and the South of the McArthur Basin, which indicates different modes of U transport and deposition.

The major element composition of chlorite associated with intergranular UO2 was determined using EPMA at GeoRessources laboratory (Vandœuvre-lès Nancy, France). Major element (Si, Al, Fe and Mg) composition was used to determine the chlorite species which turn out to be chamosite and to calculate crystallization temperatures [14]. A lot of compositions give temperatures in excess of 300℃ according to the model used [14]. Previously-published data on chlorite from the Seigal Volcanics and the Westmoreland Conglomerate indicate that chlorite formed at 230° ± 30℃ [10]. However, the composition of some chlorites from the conglomerate indicate high temperatures of crystallization (364℃) that was explained by the vicinity of the Seigal Volcanics which could have provided excess of Fe leading to high calculated temperature. The reason explaining these high calculated temperatures in both previously-published and new data are under investigation but could also be linked to the emplacement of the Seigal Volcanics just above the Westmoreland Conglomerate that might have brought additional heat to the system. In the ARUF, chlorite gives temperatures between 200℃ and 310℃ [8]. Temperature estimates on syn-ore illite were calculated based on illite crystallinity. They compare well between the Westmoreland area (200 ±30℃) [10] and the ARUF 180-230℃ [8, 9].

Previously published data on the salinity, temperature and pressure of the fluid inclusions hosted in diagenetic quartz overgrowth and quartz veins have also been investigated. The compilation of all the available primary or pseudo-secondary fluid inclusion data have been plotted in a homogenization temperature (Th) vs salinity diagram. In both areas, the data lie into a triangle-shape pattern defined by a low-temperature (100-150 ℃) and high-salinity (35 wt% eq. NaCl) end-member and two low-salinity end-members, one at high temperature (until 350℃) and one at low temperature (100℃). In the ARUF, mineralizing events occur in a small range of temperature (100 to 175℃) [8, 9, 15–18]. In Westmoreland area, at least two stages of fluid mixing associated with the mineralization (U-Cu) occurred. Firstly, there was mixing between a CaCl2 ± LiCl-rich brine and a NaCl-rich brine to produce a fluid of intermediate composition. This fluid then mixed with a low salinity fluid [11, 19]. In the ARUF, Cl/Br and cation ratios indicate that the high-salinity brine is probably a primary brine, resulting from the evaporation of seawater [16]. Reconstructed isotopic (O, H) compositions based on the composition of quartz veins and associated alteration minerals have been also compiled. In Westmoreland, compositions are the followings: δ18O = 4 ± 1‰ and δD = −31 ± 6‰ [10], whereas in the ARUF δ18O = 3.5 ± 2‰ and δD = −25 ± 15‰ [5, 8, 9]. According to isotopic compositions, the brines are evolved basinal brines with comparable δ18O and δD values in the two regions.

DISCUSSION AND CONCLUSION

From the previously-published and newly-acquired data presented here it appears that Australian unconformity related U deposits from the ARUF and Westmoreland-Murphy-type U deposits share some striking

similarities in terms of alteration and ore mineralogy, temperature, fluid composition but also noticeable differences.

Age dating suggests that uranium mineralization might have started about 65 Ma earlier in the ARUF compared to Westmoreland area. However, the measured errors are sometimes substantial and some crystallization stages could be synchronous. A common ore-forming event is recorded around 1680-1600 Ma, which corresponds to the primary mineralization in Westmoreland and Pine Creek region. Both deposit types have undergone successive episodes of U remobilization/recrystallization since then which significantly disturbed the isotopic and chemical compositions of the uranium oxides.

REE patterns of UO2, which are diagnostic features of deposit types, differ significantly between the two zones. It seems that the oldest UO2 generation in both areas have distinct REE patterns. Therefore, probable contemporaneous ore-forming events at both localities were related to distinct ore-forming processes.

Further work is planned to compare the composition of the Na-Ca-Cl brines which appear to be involved in both areas. A comparison of fluid inclusions characteristics (pressure, temperature, composition) show that the mixing between low-salinity fluids and brines is a key process for ore deposition in both areas. Raman spectrometry of fluid inclusions will allow identifying trace gases in the mineralizing brines (CO2, CH4, N2, H2, O2), which may provide information on the redox state of the brines, the mechanisms for UO2 deposition and fluid-rock interaction. LA-ICPMS analysis of fluid inclusions will allow determining the major and trace element (including U) content of the brines, which will provide crucial information on their origin, the fluid-rock interaction they underwent and their metal-transporting capacities. Finally, noble gas and halogen analysis of fluid inclusions will provide invaluable information on the origin of the salinity and the interaction of the fluids with various surficial and crustal reservoirs (atmosphere, sediments, basement rocks etc···).

From an exploration point of view, it seems that defining the pathways for the Na-Ca-Cl brines along and both sides of the unconformity could be critical for discovering new U deposits in the Westmoreland area. This could be carried out, for example, by careful lithogeochemistry and mapping of alteration minerals in basal conglomerates and sandstones as well as along the unconformity and major structures cutting across [20]. However, conceptual models for the brine origin and potential pathways based on detailed fluid inclusion analysis, as planned in this project, will be an important prerequisite for more efficient exploration targeting.

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