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Geochemical characteristics of accessory minerals in sandstone as indicator of the source for uranium and rare earth elements in unconformity-related uranium deposits in the Athabasca Basin, Canada

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The Proterozoic Athabasca Basin (Canada) is endowed with many world-class, high-grade uranium (U) deposits. These deposits are located near the basal unconformity of the basin and are referred to as unconformity-related uranium (URU) deposits. Many of the URU deposits are also enriched in rare earth elements (REE). The source of the U and REEs has been a subject of scientific debate for more than four decades, particularly regarding whether they were derived from the basin, basement, or both. The basin-wide development of U- and REE-rich fluid inclusions in quartz overgrowths in the sandstone suggests that the sediments in the basin are possibly the major source of U and REE in the URU deposits. However, it remains unclear which minerals in the sediments are the main contributors of these metals, whether the amounts of metals released from these minerals are sufficient to account for those found in the URU deposits, and whether the geochemical characteristics of these minerals are consistent with those found in the URU ores. This study addresses these questions through petrographic examination of the sandstones and geochemical analysis of targeted minerals, including zircon, Ti-oxide, iron oxide/hydroxide (IOH), and aluminium phosphate sulfate (APS) minerals. Multiple analytical methods were used in the study, including Raman spectroscopy, scanning electron microscope – energy dispersive spectroscopy (SEM-EDS), TESCAN integrated mineral analyzer (TIMA), and Laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS). The results suggest that detrital zircon and rutile, characterized by REE patterns showing variable degree of relative enrichment of heavy rare earth elements (HREE), similar to those of uraninite in the URU ores, are the most likely source of U and REE released into the diagenetic fluids (brines). Mass balance calculations suggest that the amounts of U and REE released from detrital zircon and rutile are much higher than the amounts required to form the URU deposits, even if certain amounts of the metals were retained in diagenetic zircon, anatase, IOH and APS minerals. The results of this study therefore support the hypothesis that the U and REE in the URU deposits were mainly derived from the sediments in the Athabasca Basin.