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Mineralogical and petrographical controls on Uranium-Thorium in-equilibrium dating of cave carbonates: Insights from speleothems of Northeastern and Central India

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Uranium-Thorium (U-Th) dating of cave carbonate has proved to be exceptionally useful in explaining late Quaternary paleoenvironmental events. Aragonitic speleothems provide more reliable U-Th dating than calcitic ones. As UO^{2+} the dominant mobile uranium species in near-surface waters, adopts less stable structural arrangement in calcite than in aragonite. Aragonitic speleothems generally contain 5–10 times more U^{238} than calcitic ones, as seen in U-Th chronological records from the Indian karst system. However, anomalies from Mawmluh cave, northeastern India (NEI) and Sahiya cave, northwestern Himalaya show elevated U^{238} in calcitic speleothems, likely due to uranium-enriched drip water from epikarst soils. The precision of U-Th dating in speleothems primarily depends on the concentrations of radioactive U^{238}, radiogenic Th^{230}, and detrital Th^{232}. These isotopic abundances are further influenced by factors such as epikarst lithology, drip rate and type within the cave, external detrital inputs in the system and speleothem mineralogy and fabric. This study presents U-Th chronology, mineralogy, and microfabric analyses of two speleothems: SYN-2 from Syndai Cave in NEI and KC-1 from Kailash Cave in central India. The SYN-2 exhibits mixed mineralogy, with primary columnar calcite (Cc) at the basal part transitioning to primary acicular (Aca) and ray aragonite, and late-stage vein-filling calcite at the younger part. The older Cc layers show high dissolution with several layers of micrite deposition. Among U-Th dating of 15 layers two dates affected by high detrital Th^{232}, two by uranium loss due to inter-crystalline porosity in Aca, and one by uranium loss from aragonite-to-calcite transformation. The KC-1 consists entirely of calcite and contains 40-50 times less U^{238} in compare to SYN-2, the latter being aragonite rich. The KC-1 exhibits Cc at the basal part transitioning to diagenetic dendritic and mosaic calcite fabrics in younger layers. The U-Th dating of five layers indicates uranium loss in all except the oldest sample, likely due to diagenetic alteration and high micro-porosity, leading to stratigraphic age reversals. This study highlights that while aragonitic speleothems yield more precise U-Th dates than calcitic samples, both can exhibit open-system behaviour at any stage of deposition, as evidenced by the $(^{234}U/^{238}U)_{Activity}$ vs. $(^{230}Th/^{234}U)_{Activity}$ plot.