Appendix A

Dating procedures

Establishing a chronology – sampling strategy

Breccia material can often prove problematic for dating, therefore to establish a chronology for the fossil material in the Badak Cave C and Batu Caves systems required the use of more than one dating technique. Multiple techniques provide independent age estimates and a greater confidence in the final result. Luminescence dating techniques were employed to provide a chronology for the sand-sized quartz grains within the matrix of the breccia deposits, while U-series dating of the overlying flowstones provides a minimum age for the deposition and cementation of the breccia. Despite evidence of erosion in many of these cave sites, with evidence of former cave floor surfaces, the cemented nature of the breccia and the presence of overlying flowstones have preserved the integrity of the remaining deposits and the associated fossils, with little or no evidence of post-depositional modifications. These depositional circumstances are ideal for the application of luminescence and U-series dating techniques. Luminescence dating is the most appropriate and useful sediment-based dating technique for establishing the time since the quartz grains were last exposed to sunlight, thus a range of luminescence techniques were employed. Due to the local geology, the derived quartz is of granitic origin, and therefore produces both red and blue emissions (Rink *et al*., 1993, Kuhn *et al*., 2000; Tan *et al*., 2009; Götze, 2009). Both of these emissions can be employed via a dual signal approach whereby both red TL dating of the red emissions and UV OSL dating of single-aliquots and single-grains can be analysed as an internal test of D_e consistency (Westaway and Prescott, under review b).

The results of the geochronological techniques are presented in (Tables A1 and A2) with examples of the optically-stimulated luminescence (OSL) and red thermoluminescence (TL) data presented in Figure A1. The OSL, red TL and U-series results are all internally and stratigraphically consistent and are comparable within their minimum/maximum age confines. Minimum ages of breccia deposition were obtained from three U-series ages of 1.4 ± 0.1, 19 ± 1 and 61 ± 1 ka for the Batu Caves samples. The deposition of the sediments and the fossils occurred between 33 ± 3, 48 ± 5 and 66 ± 16 ka from Villa, Swamp and Cistern caves, respectively. In contrast the Badak Cave C breccias were deposited before 500 ka according to both the U-series ages of the flowstones and red TL ages of the samples. Duplicate U/Th isotopic analyses of the two overlying flowstone samples by both a VG Sector 54 thermal ionization mass spectrometer (TIMS) and later a Nu Plasma multi-collector inductively coupled plasma mass spectrometer (MC-ICP-MS) suggest that the ^{238}U-^{234}U-^{230}Th decay chain has approached secular equilibrium, implying the samples are likely older than 500 ka. The two samples have rather high Th/U ratios despite their high-purity crystalline appearance (possibly siderite rather than calcite). However, the four duplicate analyses define a good ($^{238}U/^{232}Th$)-($^{230}Th/^{232}Th$) isochron, corresponding to an initial ($^{230}Th/^{232}Th$) ratio of nearly zero (implying the presence of initial ^{230}Th is negligible) with a slope of 1.02±0.12 (which is the initial ^{230}Th-corrected $^{230}Th/^{238}U$ activity ratio for the two samples), confirming both samples are analytically indistinguishable from secular equilibrium conditions (i.e. activity ratio = 1). The U-series age uncertainties are quoted at 2 σ, yielding relative errors of between 1-7% at the 95% confidence interval, while the OSL and red TL age estimated are quoted at 1 σ yielding relative errors of 9-10% and 29-30%.