

1. Introduction

Strontium ($^{87}\text{Sr}/^{86}\text{Sr}$) and uranium ($^{234}\text{U}/^{238}\text{U}$) isotopes are effective tools to track and quantify mixtures of modern water sources in arid wetlands, where lighter isotopic tracers are strongly influenced by evaporation and transpiration. In the spring-fed Pahrnagat National Wildlife Refuge (PNWR) of southern Nevada (Fig 1), these isotopes were used to understand the modern water supply. Paces and Wurster (2014) found that modern surface waters in the PNWR are comprised of a 65:25:10 mixture of three primary spring sources, with 90% ultimately coming from a deep regional aquifer in Paleozoic carbonates, and the remaining 10% from a local aquifer in shallow Tertiary volcanics. Between 2012–2016 several sediment cores were collected from Lower Pahrnagat Lake (LPAH) at the southern end of the PNWR (Hickson et al., 2018). The composite core record from LPAH spans ~ 5800 ^{14}C cal yr BP (Theissen et al., in review). In this investigation, we found evidence that Sr and U isotopes from LPAH sediments are useful in tracking the changing source contributions from the primary spring sources to the PNWR through time.

2. Study Site

LPAH is a small (1.2 km²), shallow (avg. depth <1 m, max. depth 1.5 m), alkaline lake in The PNWR, a 17.7 km long, 21.8 km² area of marshes, impoundments, and shallow lakes that lies at the southern end of the Pahrnagat Valley in southern Nevada (Fig. 1A and B). LPAH is spring-fed, receiving water from a number of springs that discharge north of the lake, then flowing south through the Pahrnagat Valley (Fig. 1A). The deep regional carbonate aquifer extends north to Great Basin National Park, east into Utah, and south to Death Valley and Lake Mead (Eakin 1963). U.S. Geological Survey stream-gages for the two highest discharge springs, Crystal, and Ash discharged at 340 l s⁻¹ and 510 l s⁻¹ between 2004–09 with discharge at a relatively constant rate throughout the year (Paces and Wurster, 2014). The Pahrnagat Valley is in a region with some of the highest evaporation rates in the U.S. Wurster (2010) calculated that open water evaporation approaches 1676 mm yr⁻¹, greater than 10 times the average annual precipitation.

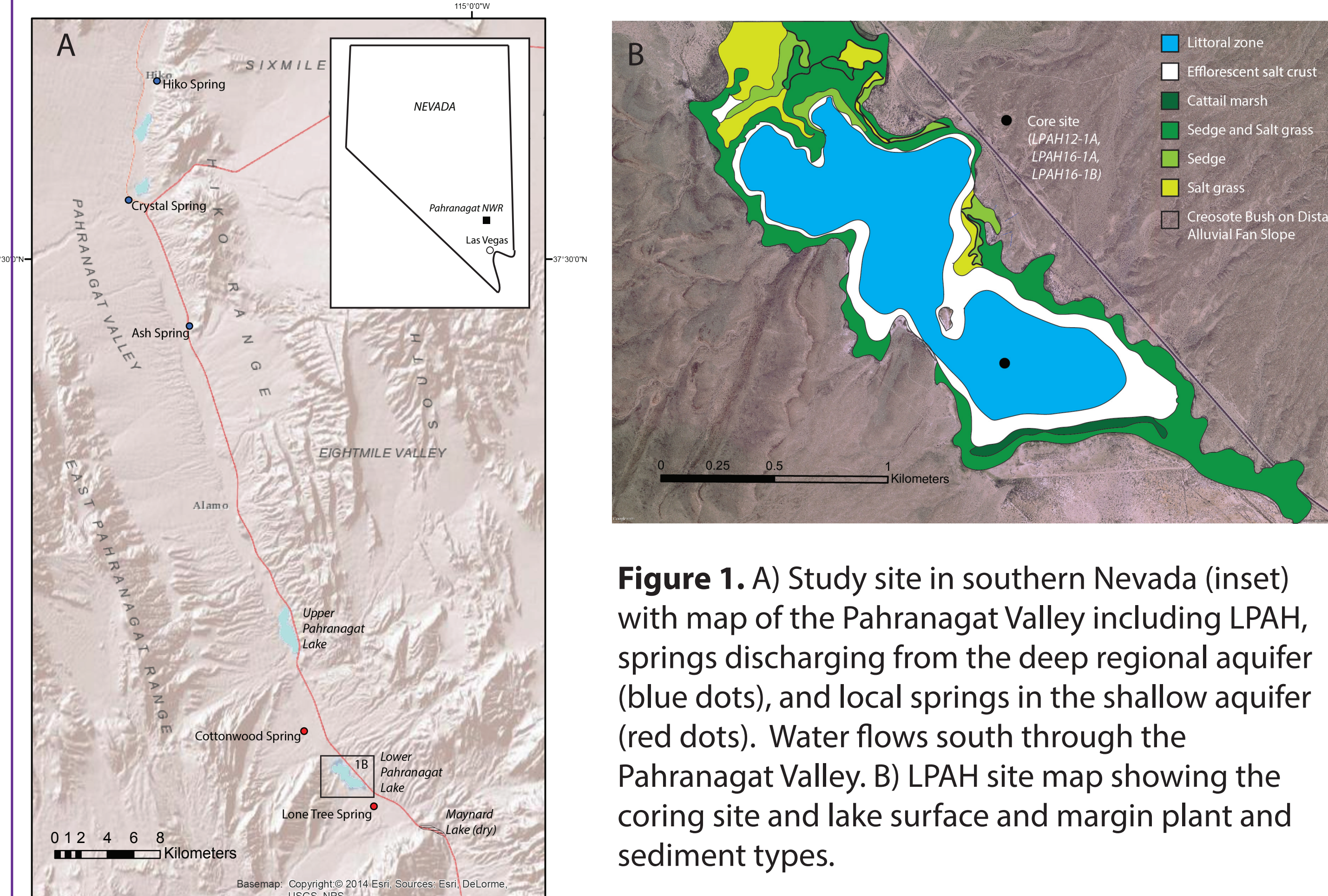


Figure 1. A) Study site in southern Nevada (inset) with map of the Pahrnagat Valley including LPAH, springs discharging from the deep regional aquifer (blue dots), and local springs in the shallow aquifer (red dots). Water flows south through the Pahrnagat Valley. B) LPAH site map showing the coring site and lake surface and margin plant and sediment types.

3. Materials and Methods

1. Downcore samples of carbonate used for Sr- and U-isotope analysis were obtained from LPAH cores spanning the ~ 5800 yr composite record and consisted of mollusk shells, plant petioles, and bulk carbonate cement. Materials were cleaned by hand picking under liquid to avoid detritus and organic matter as much as possible.
2. Carbonate fractions were leached overnight at room temperature in 5% acetic acid. Supernatant liquid was extracted after centrifugation at 10,000 rpm. Sr and U were purified by ion chromatography using Sr SpecTM resin for Sr and AG 1 \times 8 anion resin for U.
3. $^{87}\text{Sr}/^{86}\text{Sr}$ and $^{234}\text{U}/^{238}\text{U}$ (square brackets denote activity ratios) compositions were determined by thermal ionization mass spectrometry (TIMS) at the USGS Denver Radiogenic Isotope Lab.

4. Results and Interpretation

Source Waters and Mixing: Combined Sr and U isotope ratios in Holocene LPAH carbonates fall within the range defined by the 3 primary spring sources and reflect varying mixtures of those sources supplying LPAH from mid-Holocene to modern time. Modern LPAH waters fall along a distinct mixing line reflecting proportions of their composition from Crystal and Ash springs, discharging from the regional aquifer, and Cottonwood Spring, discharging from the local aquifer (Fig 2A). A second local spring, Lone Tree, likely had a more important role in the past, with the oldest of the core samples appearing to be exclusively derived from this source. LPAH core sample compositions are perhaps best represented by 3-part mixtures with that spring as the key local source (Fig 2B).

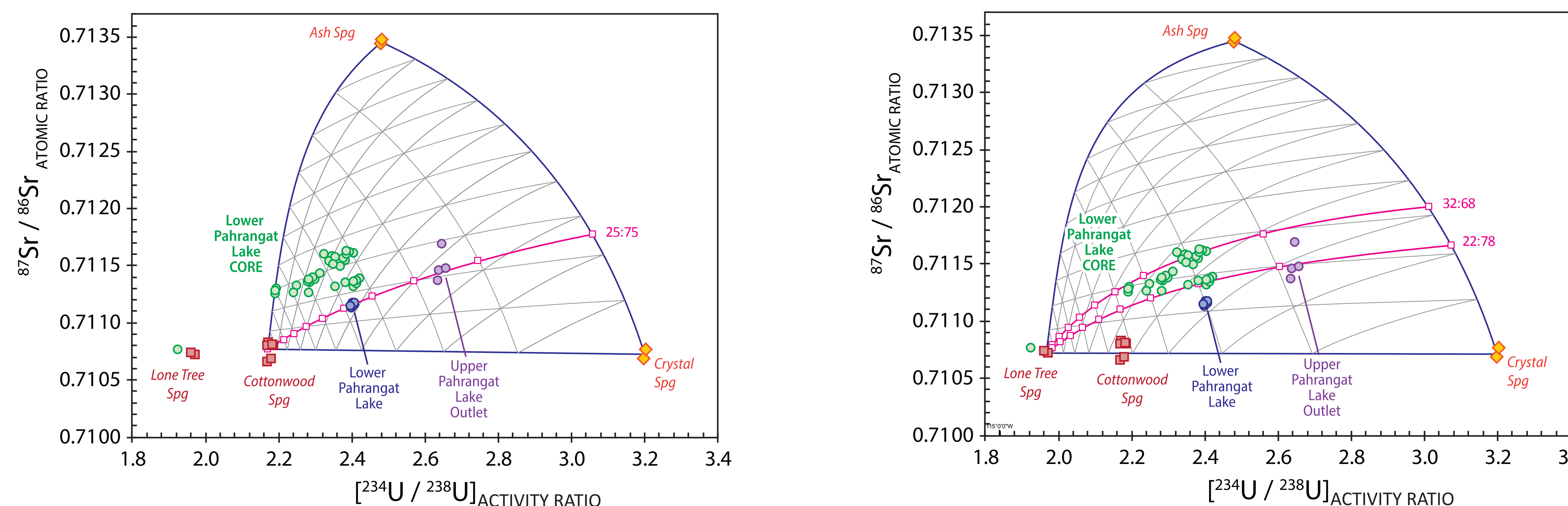


Figure 2. Crossplots of Sr and U isotopes showing 3-component mixing webs of modern waters from regional and local spring sources. A) Surface water samples in the PNWR form a 2-component mixing line (pink line with 10% mixing intervals) between compositions of the 25:75 mixtures of Ash Spring and Crystal Spring flowing southward into the PNWR. LPAH water samples fall at a position on this mixing line that suggest a nearly 40% component from Cottonwood Spring, the primary local component in the modern system. B) Crossplot showing Lone Tree spring as the most important local spring source. Two possible mixing lines (pink lines) for PNWR water compositions in the past, are shown. Water data for the spring end members and for Upper Pahrnagat Lake are from Paces and Wurster, 2014.

Paleohydrology: Values in the oldest LPAH samples (~ 5800 ^{14}C cal yr BP) have distinct $^{87}\text{Sr}/^{86}\text{Sr}$ and $^{234}\text{U}/^{238}\text{U}$ values that nearly match the local spring end member (Lone Tree), suggesting that LPAH water at that time was dominated by proximal volcanic aquifer sources. By ~ 5300 – 5200 ^{14}C cal yr BP, LPAH water was comprised of a nearly equal mixture of the three spring sources, marking a dramatic shift in hydrologic conditions that allowed contributions of surface flow from distal carbonate springs to the north. Values in samples from $\sim 1,000$ – $4,000$ ^{14}C cal yr BP indicate that discharge from the local volcanic aquifer constituted a greater proportion of LPAH water (up to $\sim 35\%$ of the total) relative to flow from distal carbonate springs during that period. By 730 ^{14}C cal yr BP, contributions of surface flow originating from the carbonate springs returned to proportions similar to those observed earlier ($>80\%$ of the total) with slightly more water originating from Crystal Spring.

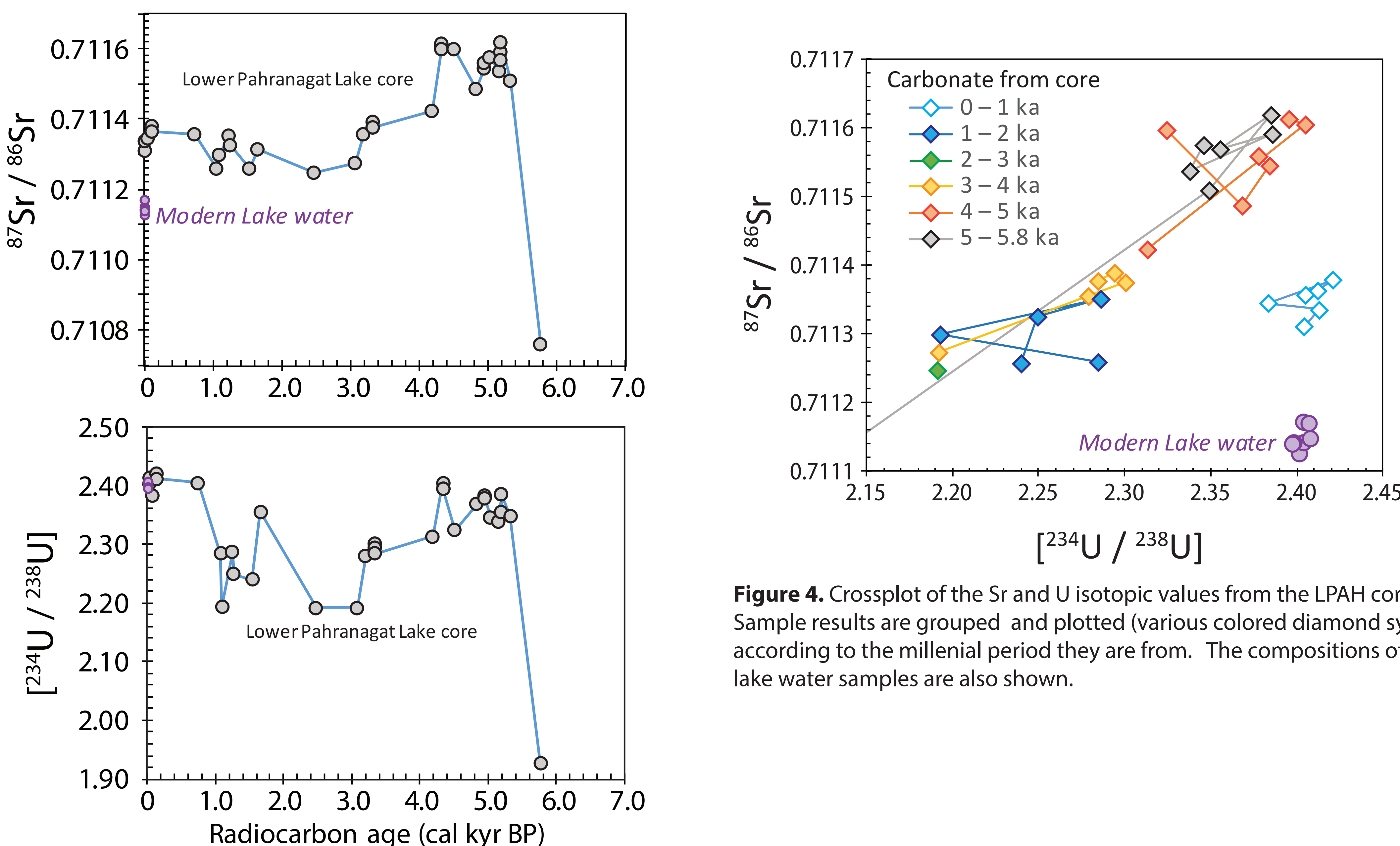


Figure 3. Plots of Sr and U stable isotopic ratios (upper and lower panels respectively) over the 5800 yr core record for LPAH. Modern lake waters (purple circles) are indicated for reference.

5. Discussion

The Sr and U isotope values in a single sample dated at 5800 ^{14}C cal yr BP suggest that LPAH lake water was almost exclusively supplied by local volcanic aquifer sources at that time. Given the disproportionate supply of water from the regional carbonate aquifer today, this shift represents an important difference in the paleohydrology of the Pahrnagat Valley. This period of distinct locally-sourced water appears to have ended abruptly, perhaps due to large regional changes in climate. Another possible explanation for a rapid change might lie in tectonic activity on one or more strike-slip faults in the valley. A near-surface rupture on one of these faults, which are important conduits for groundwater, could account for a sudden change in groundwater supply. There is some evidence of Holocene activity on these faults, although dates are entirely lacking. Smaller, but still notable reductions in the supply from regional sources appear to have occurred between ~ 3000 – 2000 ^{14}C cal yr BP, a period of maximum aridity for the Pahrnagat based on $\delta^{18}\text{O}$ values measured from the LPAH core (Fig. 5). During that period, dry conditions may have influenced the northern recharge areas to the regional springs more significantly than the local recharge areas within the PNWR.

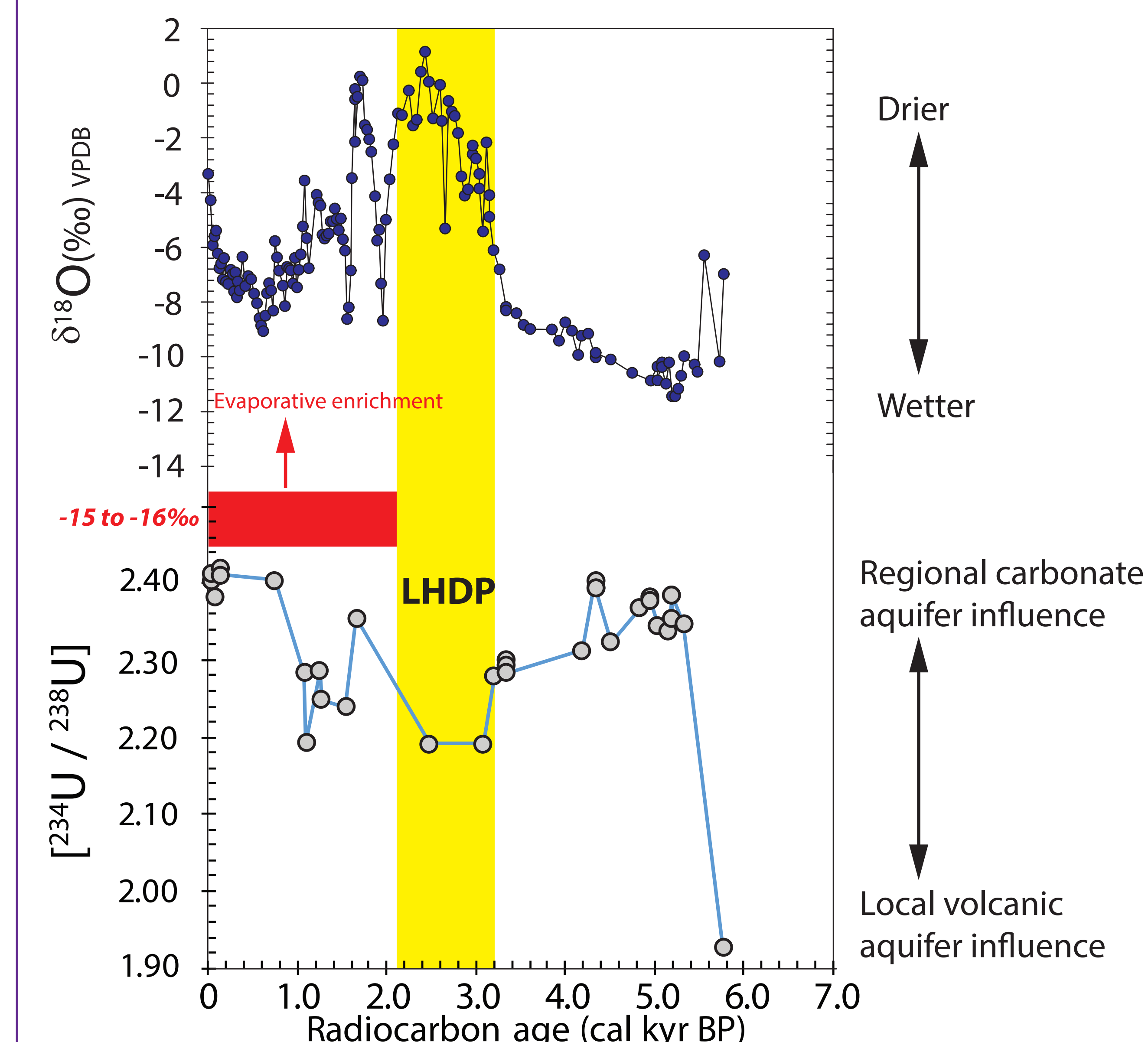


Figure 5. Comparison of O and U isotopic values from the LPAH core record. A prolonged drought, The Late Holocene Dry Period (LHDP), is indicated in yellow. Modern spring water in the local volcanic aquifer (Cottonwood and Maynard Springs) has measured values of -12.0 to -12.9 ‰ (VSMOW). Regional carbonate aquifer water (Crystal and Ash Springs) is -14.0 to -14.4 ‰. Red bar indicates $\delta^{18}\text{O}$ range of calcite in equilibrium with the volcanic water source at 20°C.

6. Conclusions

Combined Sr and U isotopic results reveal changing mixtures of regional and local spring sources supplying LPAH from mid-Holocene to recent time. Throughout the record, these mixtures show that discharge from the regional carbonate aquifer was important. However, a period of known drought (~ 3000 – 2000 ^{14}C cal yr BP) correlates with a reduction in supply from regional aquifer sources, and our oldest sample (~ 5800 ^{14}C cal yr BP) implies that the lake was entirely fed from a local spring source. The causes for these paleohydrological shifts are likely related to climate-driven changes in recharge in different source areas, or to hydraulic changes caused by Holocene faulting.

References

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