The Use of Spring Deposits in Paleoclimate Reconstruction in the Atacama Desert

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In semi-arid regions, lake deposits traditionally have been the main source of evidence of paleohydrologic change. In the most arid regions of the world where the climate is too dry for lakes to develop, spring deposits constitute one of the chief paleohydologic expressions of changes in effective moisture attending climate change. Spring deposits are widespread and often conspicuous in arid regions, and can be very reliable indicators of past changes in effective moisture in recharge areas, provided certain conditions are met.

The main sedimentologic expression of the spring deposits are diatomites, due to the very high silica content of spring waters. The diatomites are commonly interbedded with organic layers containing vascular plant material and were deposited in wetlands bordering the spring-fed channels. Little alluvial (overbank) clastic material is present in these facies. Thin layers of travertine and sinter can be locally intercalated with diatomite. Aquatic mollusks are present but uncommon. Channel deposits consist of sub-rounded gravels and poorly sorted sands that typically lie at the base of fill sequences, which fine upwards into diatomite or diatomaceous silt.

Changes in discharge (and hence recharge) are reflected in (1) changes in water-table elevation inferred from the height of fossil spring deposits, and (2) in changes in their areal extent. Some localities have witnessed dramatic paleohydrologic changes, such as Quebrada de la Higuera, where no surface discharge occurs today but in the past an extensive wetlands was present that required >5 m of water table rise. In other areas such as Tilomonte, the modern springs still flow along one channel, whereas in the past spring deposits are both higher (>5m) and perennial flow invaded many adjacent, now dry washes.

Modern springs and spring-fed wetlands under study in the Atacama are fed by recharge in the adjacent High Andes. Local recharge is nil today due to hyperaridity but may have been much larger in the past when local climate was wetter and plants extended to much lower elevations. Thus we view our fossil spring deposits as recorders of changes in recharge in the High Andes, as well as along their Pacific slope. The High Andean portion of this system is the same as that which would have controlled moisture inputs to paleo-lakes on the adjacent Altiplano.

A key advantage of the use of spring deposits is ease of carbon-14 dating, in strong contrast to many lake systems where carbon-14 reservoir effects are often present. Spring systems in the modern Atacama host a variety of vascular plants on bank sides, within spring-fed channels, and in shallow marshes. These plants draw all their CO_2 from the atmosphere, and are readily preserved in fossil spring deposits as carbonized wood, charcoal, or in some cases mummified, *in situ* roots and plant stems. Dating of this material constitutes the chief basis of our geochronologic control on the deposits.

Organic-rich layers containing fine particulate organics are also common, but when carbon-14 dated, they must be approached with caution. Some of this material may contain the remains of aquatic algae that draws its carbon from dissolved HCO_3 in water. Carbon species dissolved in many Atacaman springs are greatly out of equilibrium with the atmosphere, probably due to (1) long travel times for some water, and (2) solvation of volcanic CO_2, which is carbon-14 dead. In general, fine-organic layers yield carbon-14 dates that are consistent with dates from vascular plant remains in the same sequence. Another caution with carbon-14 dating of fine organic layers is contamination by modern rootlets and secondary humic acids. Dating humin/humic acid pairs assists in identifying these types of contamination.

Two important uncertainties surround the use of spring deposits in paleo-recharge reconstruction: (1) reconstructing the magnitude of events, and (2) potential lag times of discharge (water level) response to changes in recharge. A key limitation of spring records is that the magnitude of hydrologic changes can only be semi-quantitatively estimated. Spring and wetland deposits are produced in a complex mosaic of aquatic environments including wet meadows, seeps, flowing springs, streams, and wetlands. The aquatic environments responsible for the deposits do not leave bathtub rings as lakes do**.** Thus, they offer no means of quantifying the precipitation/evaporation (P/E) balance related only to climate. In contrast to lake hydrologic budgets, flow-dominated environments such as springs only provide insights into the limiting hydrologic conditions necessary for their genesis.

A second issue is the time required to transfer a pressure pulse (shift in recharge) from the recharge area to the discharge area. This is not the same as ground-water travel times, which may be much longer and represent travel times of individual molecules of water, not transfer times of pressure pulses. In confined aquifers, a pressure pulse will be transmitted quickly, as demonstrated from study of modern hydrologic systems. In unconfined systems, changes will came more slowly and depend on aquifer volume and transmissivity, among other things. The degree of confinement of aquifers in the Atacama varies and has not been extensively studied. Another approach to this issue is to examine a number of spring records across the region on the expectation that differences in the records reflect variable lag-times of response, whereas similarities support short response times. Thus far we see more similarity than difference in our records, but up-coming additions to this data set will provide many more tests of the lag-time issue.

Our spring deposits are not alone is these potentially confounding issues. For example, Salar de Atacama, fed by some of the springs we have studied, is also essentially a ground-water fed system, as probably are others on the Altiplano. Interpretations of core records from these systems must explicitly address the lag-time issue, as well as the effect of inflow of ground-water with high carbon-14 deficiencies.