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Use of Groundwater Tracers to Assess Climate Change in North-Central New Mexico during the Holocene Epoch

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Abstract

The groundwater system at Los Alamos, New Mexico encompasses a complex shallow mountain-block and mountain-front zone; intermediate-depth perched zones located east of the mountain front; and an extensive regional aquifer occupying the Rio Grande rift. In the study area, groundwater-flow paths in the regional aquifer are generally from the northwest to southeast that laterally extend 17 km before discharging to the Rio Grande. This system is unconfined and variable mixing occurs at greater distances east of the primary recharge zones. Since 1943, the regional aquifer has been mined for industrial processes and residential use and consumption at Los Alamos. A large data set for groundwater-age and inorganic solutes has been assembled for the intermediate-depth perched zones and regional aquifer, which provides a potential archive record of paleoclimate-change occurring during the past 10,000 years. Groundwater ages range from modern groundwater to approximately 9,700 years before present. Unadjusted radiocarbon-age results for groundwater samples collected from 58 background-monitoring wells and 10 springs correlate well with natural chloride and perchlorate concentrations and $\delta^{18}O$ values. Background concentrations of dissolved perchlorate and chloride increase with increasing groundwater age and residence time. Values of $\delta^{18}O$ are slightly heavier in groundwater samples having increasing age, suggesting that warmer climatic conditions occurred 10,000 years before present. Perchlorate and $\delta^{18}O$ datasets correlate the strongest with average groundwater age, showing Pearson correlations of 0.81 and 0.71, respectively. The Pearson correlations for chloride to age and perchlorate to chloride are 0.62 and 0.81, respectively. Overall, this dataset suggests that climatic cooling has gradually occurred in north-central New Mexico during the Holocene, and does corroborate previous Holocene climate-change studies conducted in the southwestern United States.

Regional setting of Los Alamos National Laboratory

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DATA SOURCES: (1) New Mexico Environment Department, (2) LANL Earth and Environmental Sciences Geology and Geochemistry Research Lab (EES-14 GGRL), (3) Intellus New Mexico Database: http://www.intellusnmdata.com/

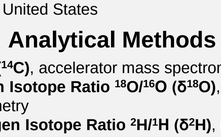
Objective

The purpose of this study is to evaluate evidence for local climate change by examining physicochemical relationships between temperature- and age-sensitive solutes in an extensive groundwater data set for the Pajarito Plateau. Based on radiocarbon age-dating, groundwater samples collected along flow paths within the local unconfined aquifer system span the Holocene Epoch. The constituents assessed include Cl^-, ClO_4^-, SO_4^{2-}, ^{14}C, and the stable isotope ratios, δ^2H, $\delta^{18}O$, and $\delta^{13}C$. The investigation determined whether these chemical and isotopic groundwater data support the findings of other investigations showing a general cooling trend from early Holocene to present day in the southwestern United States

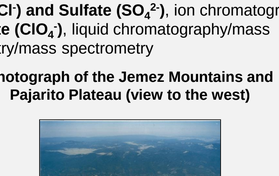
Analytical Methods

Radiocarbon (^{14}C), accelerator mass spectrometry
Stable Oxygen Isotope Ratio $^{18}O/^{16}O$ ($\delta^{18}O$), isotope ratio mass spectrometry
Stable Hydrogen Isotope Ratio $^2H/^1H$ (δ^2H), isotope ratio mass spectrometry
Chloride (Cl^-) and Sulfate (SO_4^{2-}), ion chromatography
Perchlorate (ClO_4^-), liquid chromatography/mass spectrometry/mass spectrometry

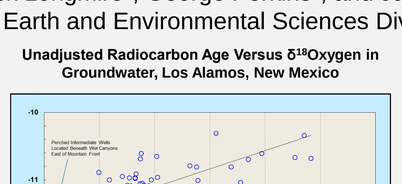
Photograph of the Jemez Mountains and Pajarito Plateau (view to the west)



Sampling locations for climate change study

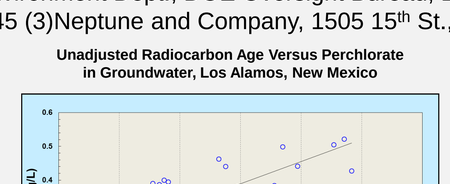


Unadjusted Radiocarbon Age Versus δ^{18}Oxygen in Groundwater, Los Alamos, New Mexico

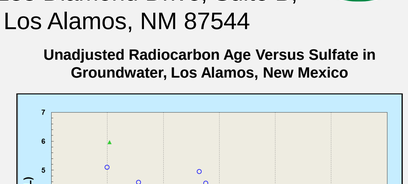


Unadjusted Radiocarbon Age Versus Chloride in Groundwater, Los Alamos, New Mexico

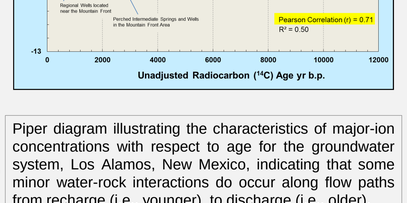
Unadjusted Radiocarbon Age Versus Perchlorate in Groundwater, Los Alamos, New Mexico



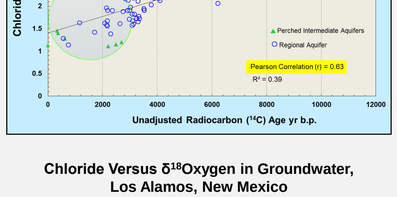
Unadjusted Radiocarbon Age Versus Sulfate in Groundwater, Los Alamos, New Mexico



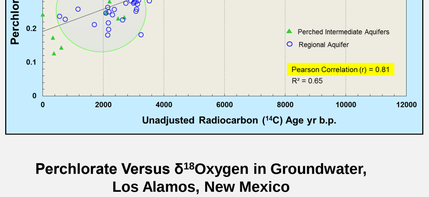
Piper diagram illustrating the characteristics of major-ion concentrations with respect to age for the groundwater system, Los Alamos, New Mexico, indicating that some minor water-rock interactions do occur along flow paths from recharge (i.e., younger) to discharge (i.e., older).



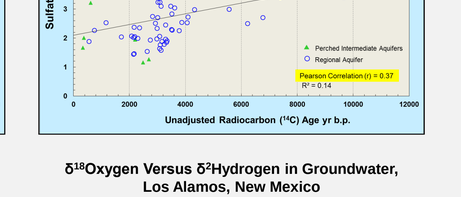
Chloride Versus δ^{18}Oxygen in Groundwater, Los Alamos, New Mexico



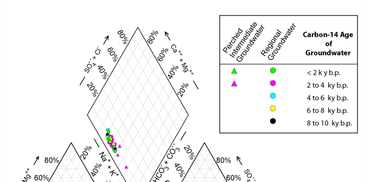
Perchlorate Versus δ^{18}Oxygen in Groundwater, Los Alamos, New Mexico



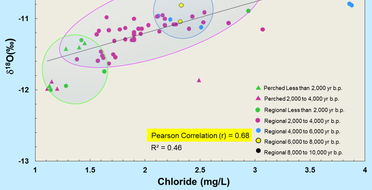
δ^{18}Oxygen Versus δ^2Hydrogen in Groundwater, Los Alamos, New Mexico



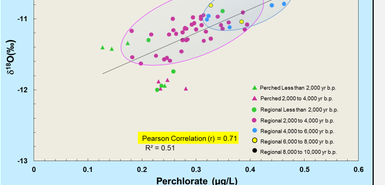
Recharge – mountain front and mountain block



Discharge – White Rock Canyon, Rio Grande



Inferred average atmospheric temperature deviation in °C calculated from shift in $\delta^{18}O$ relative to a local reference temperature containing 100% modern recharge water with a mixed composite age of ~ 5 yr. $\delta^{18}O$ temperature dependence taken from Phillips et al., 1986 using the local meteoric water line from Vuataz and Goff, 1986.



Conclusions

- Chloride and perchlorate concentrations and δ^2H and $\delta^{18}O$ ratios are variably correlated with the average radiocarbon age of groundwater beneath the Pajarito Plateau of the Jemez Mountains.
- From early to late Holocene, concentrations of chloride and perchlorate have decreased from approximately 3 to 1.5 mg/L and approximately 0.5 to 0.2 µg/L, respectively. $\delta^{18}O$ ratios have become lighter by approximately 1 permil.
- The degree of scatter in groundwater age versus solute concentration and differences in temperature is most likely due to
  1. variations in groundwater mixing occurring within the unconfined aquifer,
  2. short duration (0 to 500 years) micro-climate fluctuations occurring during the Holocene, and
  3. instrument analytical error.
- Results of this investigation are consistent with previous climate studies showing an atmospheric cooling trend in the southwestern United States from early to late Holocene.

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