Evidence for a Brackish to Hypersaline Paleodepositional Environment, San Elijo Lagoon, California

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Abstract

Pore-water chemistry data were obtained from continuous cores of the upper 37 meters (m) of sediment beneath the San Elijo Lagoon near San Diego, California. These cores were collected during installation of a deep test well and pore-water samples were extracted from the bottom end of each core using a hydraulic press. The analytical protocol for the pore-water samples included major ions and stable isotopes of hydrogen, oxygen, and strontium. These data were combined with lithologic information collected during drilling and with 19th-century United States Coastal Survey maps of the Southern California coast to gain a better understanding of the natural environment of the San Elijo Lagoon over geologic time.

Pore-water samples were highly saline throughout the Quaternary lagoonal deposits with chloride concentrations ranging from about 8,000 mg/L to over 73,000 mg/L. δ^2H and $\delta^{18}O$ isotopic values in the pore-water samples ranged from –34.9 per mil to –1.37 per mil and from –4.73 per mil to 1.01 per mil, respectively, with the most enriched δ^2H and $\delta^{18}O$ isotopic values coincident with the depth of the highest chloride concentration. $^{87}Sr/^{86}Sr$ isotope ratios ranged from about 0.70862 to 0.70954. Highly-saline pore-water samples with enriched δ^2H and $\delta^{18}O$ isotopic values and $^{87}Sr/^{86}Sr$ isotope ratios close to seawater provide evidence for brackish to hypersaline conditions beneath the San Elijo Lagoon. The Coastal Survey maps for the San Elijo Lagoon show the natural environment for this area during the 19th century consisted of seasonally-flooded salt flats without deep or permanent open water. These maps, along with the pore-water chemistry data and lithologic information from the continuous cores, suggest that the San Elijo Lagoon functioned as a seasonally-recharged shallow-water estuary for at least the last few thousand years.

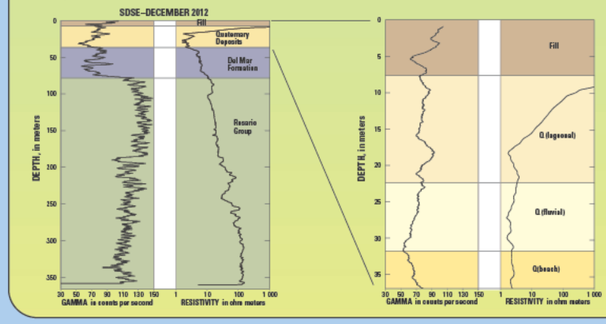
Background

Over the past decade the U.S. Geological Survey (USGS) has been conducting a regional assessment of the groundwater resources in the San Diego area. The regional assessment of groundwater resources in the San Diego area was designed to gain a better understanding of the source, quantity, and flowpaths of groundwater in the coastal aquifer system so local public agencies have the necessary information to evaluate whether, or how, to develop additional groundwater supplies Since the inception of the regional assessment, the USGS, in cooperation with four local water agencies, has installed 15 multiple-depth monitoring-well sites for the collection of groundwater samples from discrete intervals to depths of more than 600 meters (m), has mapped subsurface geologic information, and is creating a mathematical, three-dimensional geologic framework model of the coastal San Diego County A more complete description of the San Diego Hydrogeology project, including data and publications, is available on the project website —*http://ca.water.usgs.gov/sandiego.*

Recently the USGS conducted an investigation, in cooperation with the Olivenhain Municipal Water District (OMWD), to improve the geologic and hydrogeologic understanding of the San Elijo Lagoon area Such an understanding provided the OMWD with the necessary information to evaluate the technical and financial feasibility of using the brackish groundwater that underlies the San Elijo Lagoon to increase municipal supplies and flexibility An integral part of the investigation was the installation of a test well to a depth of about 400 m Data collected during the installation included geologic and geophysical logs, continuous cores of the upper 37 m, flow logs under pumped and unpumped conditions, and water-quality samples analyzed for a broad range of constituents

Geologic Framework

Lithologic information was compiled from descriptions of drill cuttings and from observations recorded during drilling. Additional data were collected from downhole geophysical logs after the borehole was drilled to its targeted depth The lithologic information and geophysical logs were compared to the regional stratigraphic section to delineate the formational geologic boundaries of the subsurface beneath the San Elijo Lagoon This comparison indicated the stratigraphic units in the area of San Elijo Lagoon consist of a relatively thin section of Quaternary deposits (lagoonal, fluvial, and beach) unconformably overlying the Tertiary Del Mar Formation The majority of the borehole penetrated the Rosario Group, a Cretaceous package of largely marine turbiditic mudstones to conglomerate rocks (Nilsen and Abbott, 1984)



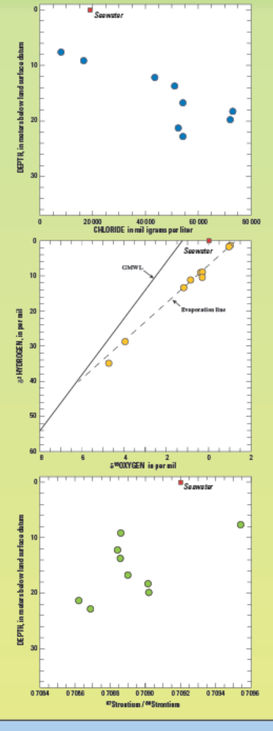
Pore-water Chemistry

Continuous cores were collected from the upper 37 m of the deep test well to provide data to document the depositional character of the San Elijo Lagoon over geologic time. Pore water was extracted from 9 core samples using a hydraulic press and stainless steel capsule system (Manheim et al , 1994) During the extraction process, between 3 to 15 mL of fluid was squeezed from about 50 grams of sediment by applying 4,000-6,000 psi to the capsule system for a period of 15 to 45 minutes The pore-water samples were then analyzed for major ions and stable isotopes of hydrogen, oxygen, and strontium

Pore-water samples were highly saline throughout the lagoonal deposits Chloride concentrations ranged from about 8,000 mg/L to over 73,000 mg/L; the highest chloride concentration occurred at a depth of about 18 m

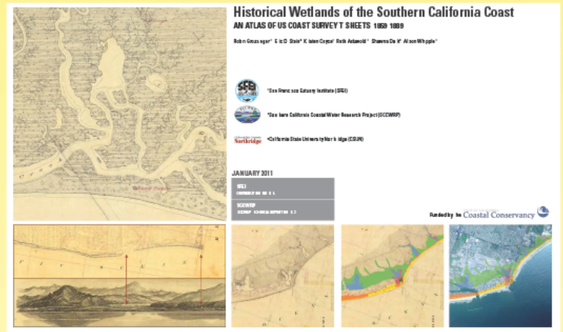
Deuterium (^2H) and oxygen-18 (^{18}O) are stable isotopes that were used in this study to identify the evaporative history of groundwater in the area of the San Elijo Lagoon δ^2H and $\delta^{18}O$ isotopic values in the pore-water samples ranged from –34 9 per mil to –1 37 per mil and from –4 73 per mil to 1 01 per mil, respectively The most enriched δ^2H and $\delta^{18}O$ isotopic values resulting from evaporation were coincident with the depth of the highest chloride concentration

$^{87}Sr/^{86}Sr$ isotope ratios are particularly useful for detecting mixing among waters of different sources, as well as in characterizing the effects of water-rock interaction $^{87}Sr/^{86}Sr$ isotope ratios in the pore-water samples ranged from about 0 70862 to 0 70954 and reflect variable amounts of mixing of modern water with ancient water



Atlas of U.S. Coast Survey T-Sheets, 1851-1889

Twenty-six detailed topographic surveys (referred to as "T-sheets") of the Southern California coast produced between 1851 and 1889 by the United States Coast Survey were acquired, georeferenced, and vectorized as part of the Southern California Historical Coastal Wetland Mapping Project (Grossinger et al , 2011) These T-sheets represent the single most important data source for understanding the physical and ecological characteristics of the coastline prior to extensive Euro-American modifications (NRC, 1990)



T-1898, San Elijo Lagoon

T-1898 was produced in 1887-88 and shows San Elijo Lagoon and the southern edge of Batiquitos Lagoon Like other T-sheets of northern San Diego County, T-1898 has certain limitations in detail and exhibits more significant modifications because this part of the coast was one of the last areas to be surveyed by the Coast Survey According to the T-sheet, the area does not appear to have had deep or permanent open water It is likely that this area may have been seasonally-flooded salt flats, i e , unvegetated flats that filled with water in the rainy season and dried out in the summer The coastal features are digitized from T-1898 and overlaid on modern aerial photography (USDA, 2005) at the same scale as the T-sheet (insert)

Significant Findings

1 Lithologic information and downhole geophysical logs collected during the installation of a test well to a depth of about 400 m indicated the stratigraphic units in the area of San Elijo Lagoon consist of Quaternary lagoonal deposits from 8 to 23 m, Quaternary fluvial deposits from 23 to 31 m, Quaternary beach deposits from 31 to 37 m, the Tertiary Del Mar Formation from 37 m to 79 m, and the Rosario Group below 79 m

2 Pore-water samples extracted from continuous coring of the upper 37 m of the deep test well provide evidence for brackish to hypersaline conditions beneath the San Elijo Lagoon over geologic time

3 Topographic surveys of the Southern California coast show the natural environment for the San Elijo Lagoon during the 19th century consisted of seasonally-flooded salt flats without deep or permanent open water

4 Lithologic information, downhole geophysical logs, and pore-water chemistry in combination with T-1898 suggest that the San Elijo Lagoon functioned as a seasonally-recharged shallow-water estuary for at least the last few thousand years

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