Assessment of Electrical Resistivity Anomalies Caused by Fresh Water Discharge Offshore: Analysis of Data Collected off North Carolina and California

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Award Number N00014-99-1-0809

LONG-TERM GOALS

To determine the impact that fresh water discharge across the continental shelf has on the electrical resistivity structure of bottom sediments and, by so doing, to use electrical measurements to constrain the regional hydrology and the exchange of continentally derived groundwater with the ocean. The strength and spatial distribution of resistivity anomalies caused by fresh water will be used to assess the likelihood of false target identification in mine counter measures, and the degree to which bottom conditions might be misclassified.

OBJECTIVES

- Measuring and quantifying anomalous resistivity structures in a region of continental shelf known to be discharging fresh water into the ocean.

- Relating seismically determined stratigraphic framework and electrical resistivity structure to processes of groundwater exchange with the ocean.

APPROACH

The role of groundwater discharge on margin processes is one that is only beginning to be understood. Estimates of the amount of fresh water discharged from the continent through bedrock and into the ocean vary widely, and while some have suggested it is of a similar magnitude to riverine discharge, this remains a controversial issue. Most work to quantify the distribution and fluxes of fresh water across continental margins has been geochemical: there are few geophysical techniques that are sensitive to the presence of fresh pore water. However, electromagnetic techniques might respond to regions containing fresh water, as the electrical resistivity of the bulk sediment would be increased if the freshening were pervasive. We have seen off northern California regions of several hundred square meters which have extremely high electrical resistivities (for example, whereas normal sediments have resistivities of around 1 ohm-m near the seafloor, we saw values as high as several hundred ohm-m within 1-2m of the seafloor). Although we do not know at this time whether fresh water is responsible

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2001**	2. REPORT TYPE	3. DATES COVERED **00-00-2001 to 00-00-2001**

4. TITLE AND SUBTITLE **Assessment of Electrical Resistivity Anomalies Caused by Fresh Water Discharge Offshore: Analysis of Data Collected off North Carolina and California**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Department of Geology and Geophysics,,Woods Hole Oceanographic Institution,,Woods Hole,,MA, 02543**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
To determine the impact that fresh water discharge across the continental shelf has on the electrical resistivity structure of bottom sediments and, by so doing, to use electrical measurements to constrain the regional hydrology and the exchange of continentally derived groundwater with the ocean. The strength and spatial distribution of resistivity anomalies caused by fresh water will be used to assess the likelihood of false target identification in mine counter measures, and the degree to which bottom conditions might be misclassified.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a REPORT **unclassified**	b ABSTRACT **unclassified**	c THIS PAGE **unclassified**	**Same as Report (SAR)**	**4**	

for these resistivities, we have carried out modeling based on observations of fresh water beneath the seafloor to show that this explanation is plausible (Hoefel and Evans, 2001).

We used the same Canadian towed EM system that we have used in two successful ONR funded cruises, in three areas off North Carolina. The system, which is towed along bottom, provides more or less continuous resistivity-depth profiles along a tow line and so is ideal for providing spatial maps of resistivity variation, whether they are caused by changes in facies conditions or by the influence of groundwater. This is in contrast to other EM techniques which place a remote receiver on the seafloor and transmit to it with a towed source: local heterogeneity in resistivity structure at the length scale we are interested in will act as a source of noise in this kind of survey and will be hard to resolve.

The EM system measures the electrical resistivity of the seafloor which we convert to apparent porosity using empirical relationships and the assumption that the pore water has the same salinity as the near-bottom seawater. If this assumption is not valid, because the pore water is in fact fresher than seawater, then we will underpredict the porosity. In a survey off California, we predicted porosities of less than 15% in a few places close to shore. We know that these locations are immediately north of a shallow anticline system, and so one explanation for our observations has been that the pore water is fresh groundwater that is being channeled to the seafloor through faults associated with the anticline system. In the Californian case we have not been able to prove this model. In order to help determine that any observed anomalies in this survey are caused by fresh water and to place our measurements in the context of regional hydrology, we sampled fluids and took CTD measurements above areas of anomalous resistivity.

Chirp seismic profiles were also run in concert with the EM system. Seismic reflection profiling defines the geometry of sediment bedding, allowing any anomalous EM responses to be placed in a geological context.

WORK COMPLETED

During a five day cruise on the R/V Cape Hatteras, we ran a series of EM and chirp seismic profiles off North Carolina. Our survey focused on areas in Onslow Bay and Long Bay offshore North Carolina. We focused on three areas, all of which were in water depths on the order of 15m.The seafloor off Carolina is typically referred to as ``hard-bottom'' with abundant limestone outcrops.

(1) *Offshore Wrightsville Beach, N.C.*

Several paleo-river channels cut across the shelf in this area. These channels incise an Oligocene sequence which overlies the Castle Hayne limestone aquifer. In some places, we suspect that the higher permeability of the sediments within the channels allow groundwater to escape the limestone aquifer and seep out of the seafloor.

(2) *Long Bay Well Sites*

Several shallow wells have been established in Long Bay by Dr. W. Moore's group at East Carolina University. In some of these wells, a high porosity unit, at a depth of about 2-4m below the seafloor has been penetrated. Long term temperature logs within these wells show the tidally influenced pumping of groundwater within what is inferred to be a limestone cavern of unknown dimensions. While porewaters within the high porosity unit are saline, our expectation is that such a unit would have a large electrical signature. However, because the wells are occupied, we were unable to tow the EM system directly overhead. We ran within about 100m of the wells, but also ran chirp lines directly over the well sites.

(3) *Long Bay, Castle Haynes Outcrop*.

Several lines were run to the north east of the well sites, where vibra-cores sampled the Castle Haynes aquifer unit outcropping on the seafloor. The Castle Haynes is one of the larger and more regionally important aquifer units supplying fresh water to south-eastern North Carolina.

We have now processed chirp seismic profiles, removing noise associated with motion of the ship. We have merged navigation files for all chirp seismic and EM lines and have produced co-incident resistivity and seismic profiles.

At Wrightsville Beach, we are interested in understanding the role played by fluvial channels in local hydrology. We hypothesize that these channels allow leakage of groundwater from the underlying Castle-Hayne limestone upwards to the seafloor. To test this idea, we have begun a modeling exercise with Dr. Ann Mulligan at WHOI, who has constructed a hydrologic model of the Wrightsville Beach area. We first of all constructed a regional model to constrain head boundary conditions and then have used these in a more detailed local 2D model including a fluvial channel to look at groundwater discharge patterns.

In Long Bay, we have begun examining the geological structure seen in seismic and EM profiles and are developing a model that can explain the down-well temperature data seen by Dr. W. Moore.

IMPACT

The loss of continental groundwater to the oceans is a potentially important area of research both from an oceanographic and from a societal viewpoint. Thus, the use of EM surveys to identify groundwater discharge will be of fundamental importance, not only to the Navy in its mine counter measures efforts, but also to a large geological and hydrological community seeking to understand the exchange of groundwater with the oceans. To date, there is a lack of geophysical constraint on this process, since few methods have direct sensitivity to the presence of fresh pore water. If our survey is successful, it will open up a new avenue of exploration.

RELATED PROJECTS

I have been funded by NSF to develop a towed EM capability at WHOI, and work is underway on the construction of a similar instrument to that operated by the geological survey of Canada.
Additional support was provided by the Rhinehart Coastal Research Center at WHOI to carry out a series of land-based resistivity profiles along Wrightsville Beach in an effort to tie channel sequences seen offshore to onshore creek systems. A series of EM profiles were collected along Wrightsville Beach, measuring electrical resistivity to depths of about 30m. These data show evidence for saltwater intrusion into the main aquifer unit beneath the town of Wrightsville Beach.
In addition, a boat based resistivity profile was obtained along the intra-coastal waterway using a commercially contracted system operated by Zonge Corporation. Work is underway to invert these data and examine them for evidence of inshore channel features related to present day creek systems.

PUBLICATIONS

Hoefel, F and R.L. Evans, Impact of low salinity porewater on seafloor electromagnetic data: a means of detecting submarine groundwater discharge ? Estuarine, Coastal and Shelf Science, 52, 179-189

Evans, R.L., Measuring the shallow porosity structure of sediments on the continental shelf: A comparison of an electromagnetic approach with cores and acoustic backscatter, J. Geophys. Res. (oceans), in press.

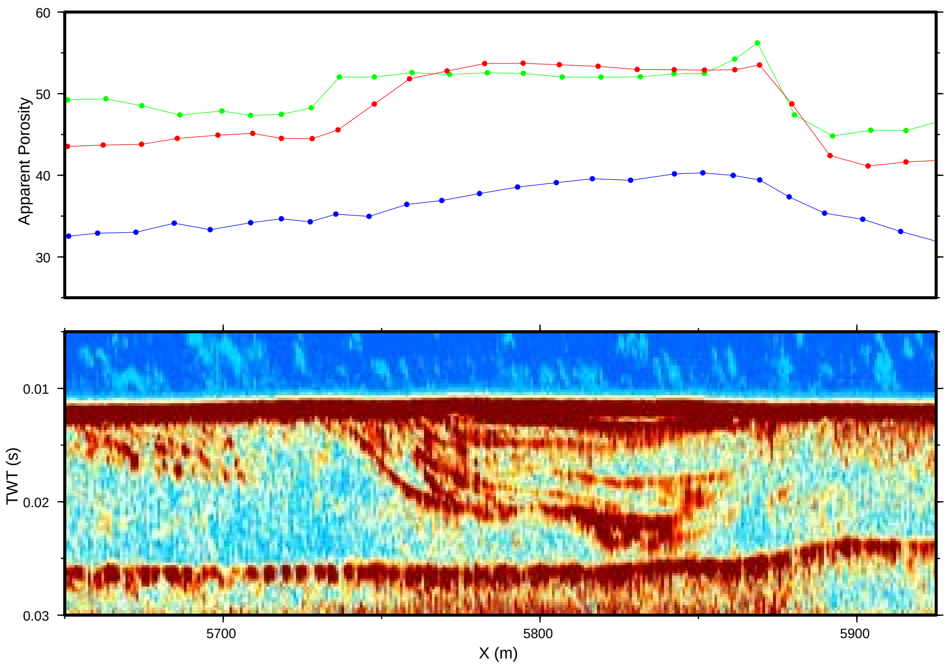

Figure 1. An example of a channel sequence seen of Wrightsville Beach using a combination of EM (top) and chirp seismic (bottom) techniques. The EM system returns three measurements of apparent porosity with the green an average over about 2m of seafloor, the red averaging over about 7m depth and the blue sensing as deep as 20m below the seafloor. The channel fill has a higher porosity than the surrounding oligocence sequence. In places, the channels incise down almost to the underlying Castle Hayne limestone, which is a regional aquifer and which appears as a bright seismic reflector.