Feasibility of high resolution seismic reflection to improve accuracy of hydrogeologic models in a culturally noisy part of Ventura County, CA, USA

Richard Miller, Kansas Geological Survey; William Black, Norcal Geophysical Consultants;*
Martin Miele and Tony Morgan, United Water Conservation District;
Julian Ivanov, Jianghai Xia, and Shelby Peterie, Kansas Geological Survey

Summary

A high-resolution seismic reflection investigation mapped reflectors and identified characteristics potentially influencing the interpretation of the hydrogeology underlying a portion of the Oxnard Plain in Ventura County, California. Design and implementation of this study was heavily influenced by high levels of cultural noise from vehicles, power lines, roads, manufacturing facilities, and underground utilities/vaults. Acquisition and processing flows were tailored to this noisy environment and relatively shallow target interval. Layering within both upper and lower aquifer systems was delineated at a vertical resolution potential of around 2.5 m at 350 m depth.

Introduction

Hydrologically, the Oxnard area is plagued by the intrusion of seawater, first observed in the 1930s and escalating to a serious problem in the mid-1950s. Subsurface inflow of brine has been credited as the source of high chlorides in wells located behind the seawater front (Izbicki, 1991; Stamos and others, 1992). Conflicting interpretations of geophysical logs and well cuttings as to the structural orientation of Plio-Pleistocene sediments that include critical aquifer systems hindered the design and construction of a barrier intended to impede the encroachment of the seawater front.

A 480-channel distributed seismograph was used to record uncorrelated vibroseis data from triple 28 Hz geophone groupings evenly spaced at 325 per km. A total of around 10 km of full-fold data on four lines was recorded along roads and trails within and around a suspected structural high (Figure 1).

General Hydrogeology

The Oxnard Plain encompasses an area of 312 km^2 located 90 km northwest of downtown Los Angeles, CA. The area is underlain by a Plio-Pleistocene complex of stacked aquifers more than 430 m thick differentiated into two aquifer systems simply referred to as the upper aquifer system and the lower aquifer systems.

Regionally, the upper aquifer system is composed of relatively flat-lying alluvial deposits about 125 m thick and is the principal potable water supply for the area. The upper aquifer system is divided into the Oxnard Aquifer and the Mugu Aquifer.

The lower aquifer system consists of the Hueneme Aquifer zone, the Fox Canyon Aquifer, and the Grimes Canyon Aquifer. Alternating layers of folded and faulted alluvial sand and clay about 1.5 to 15 m thick make up the lower aquifer system. Underlying the lower aquifer system are partly consolidated marine and volcanic rocks containing saline water. The unconformity at the base of the lower aquifer system is distinctive.

All of these aquifers are made up of both permeable and non-permeable zones with shallow marine depositional origins. Additionally, the upper aquifer is locally overlain by what is referred to as the “Semiperched Aquifer Zone.”

Borehole data (including electric logs and driller’s logs) from deep water wells and oil wells in the area present a hydrostratigraphic picture featuring a variable thickness of relatively impermeable marine clays and silts separating the mostly permeable portions of the upper aquifer system and lower aquifer system (Mukae and Turner, 1975). Two wells within a mile of the four seismic lines constrain the hydrostratigraphic interpretation and allow correlation of reflections with likely reflectors.

Structurally, the depositional layers comprising the lower aquifer system were folded and then, as a result of sea level drop, the entire Oxnard Plain was eroded by the Santa Clara River. This meandering erosional pattern left localized and isolated cut-and-fill features with tens to hundreds of meters of relief. Subsequently, the sea level rose and the impermeable interval and upper aquifer system layers were deposited on the erosionally sculpted plain. Extrapolating from borehole correlations, the layers comprising the upper aquifer system are flat lying while the lower aquifer layers dip to the northwest at about 1.25 degrees. The unconformity that forms the boundary between the upper and lower aquifer systems occurs at a depth of about 140 m near the intersection of lines 1, 2, and 3.

Data Acquisition Phase

Acquisition parameters were finalized based on experience and walkaway tests at the west end of line 1. The recording system included triple Sensor 28 Hz geophones and twenty 24-channel Geodes and one 8-channel DZ seismographs by Geometrics. The seismographs were networked to simultaneously transmit and store 25MB of data from 480 receiver stations and 8 auxiliary feeds in 4 seconds. The geophones were planted at 3.1 m intervals in approximate 0.5 m arrays

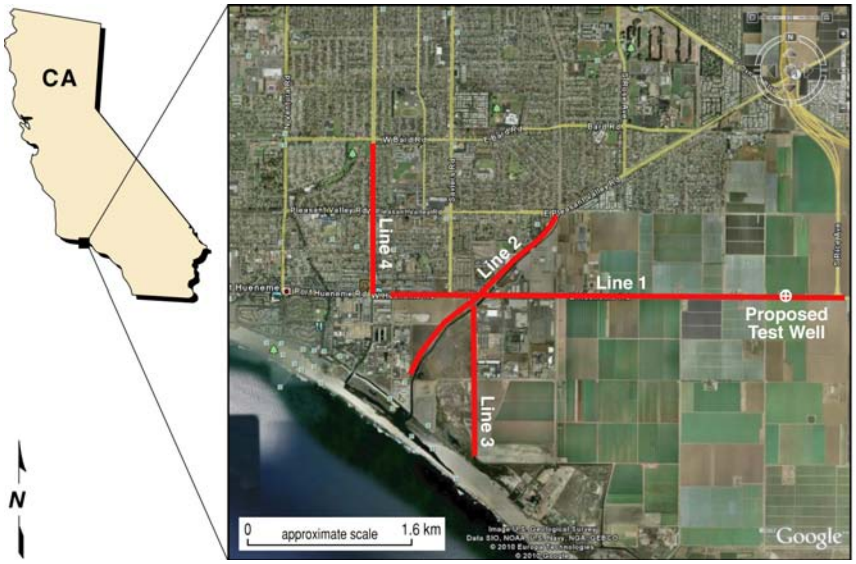

Figure 1. Site map with four seismic lines highlighted in red. Line 4 was acquired in a dry cement drainage canal.

and seated in small divots into firm to hard soil. Custom rock plates were used where invasive inserting of geophone spikes was not possible or resulted in substandard coupling.

An IVI minivib2 delivered three 10-second, 20-200 Hz upsweeps at each shot location (shot interval was 6.2 m) (Figure 2). Each sweep was recorded individually and stored in an uncorrelated, unstacked format. The ground force for each sweep was telemetried from the vibrator to the seismograph and recorded as the aux trace of each 12-second, 480-trace shot record. The telemetried ground force was used for on-site QC only. An independent 8-channel DZ seismograph was mounted in the IVI minivib and dedicated to recording the additional baseplate and mass accelerometers used for post-acquisition calculation of the ground force. The IVI minivib's controller computer recorded an independent pair of mass and baseplate accelerometers for drive feedback.

Data Processing

Special emphasis was placed on analysis steps and noise suppression prior to CMP stacking. With almost 1500 m of receiver spread active for most shots, significant reduction in fold was necessary to optimize stacked reflection wavelets. Therefore, approximately half the recorded traces outside the optimum window were deleted during processing. The nominal fold for reflections from 125 to 250 m below ground surface was around 80 with symmetric azimuthal distributions.

Enhancing the signal-to-noise ratio prior to correlation and vertical stacking was instrumental in the overall quality of these data. Key pre-correlation processing techniques included vibroseis whitening, spectral shaping, editing of coherent noise (a variation of diversity stack), and clip wavelet suppression. Post-correlation and pre-vertical stack processing included coherent noise muting, spectral balancing, and high grading gathers (pruning based on quality standards and consistency of wavelets). Post vertical stacked data signal-to-noise ratio and resolution were improved with the application of severe inside and first arrival mutes (ensuring shallow, coherent events on CMP stacked sections were reflections), < ½ wavelength surface consistent and residual static corrections based on a 400 ms correlation window, fk filter targeting near-surface guided wave, and migration/migration filtering.

Traffic noise was a factor on all the data (Figure 2). Pre-correlation and pre-vertical stack processing proved beneficial in producing shot gathers with interpretable reflections separated from coherent noise and with a high-resolution reflection bandwidth throughout the first one second (Figure 3). Other dominant noise sources requiring special attention included high voltage power lines, repetitive high-energy industrial noise, military aircraft, trains, pedestrians, agricultural activities, and underground utilities.

Interpretations

Shot Gathers

Many of the signal characteristics in this area are evident on shot gathers along line 1 (Figure 3). The dominant frequency through most of the section is over 100 Hz and, in the interval between 50 and 400 ms, useable frequencies over 150 Hz were recorded. Vertical resolution is around 2 m. As much as 10 ms of trace-to-trace reflection wavelet mismatch is evident along the profiles (Figure 3). Much of this trace-to-trace "chatter" (static) is indicative of localized changes in material velocities and therefore elastic moduli.

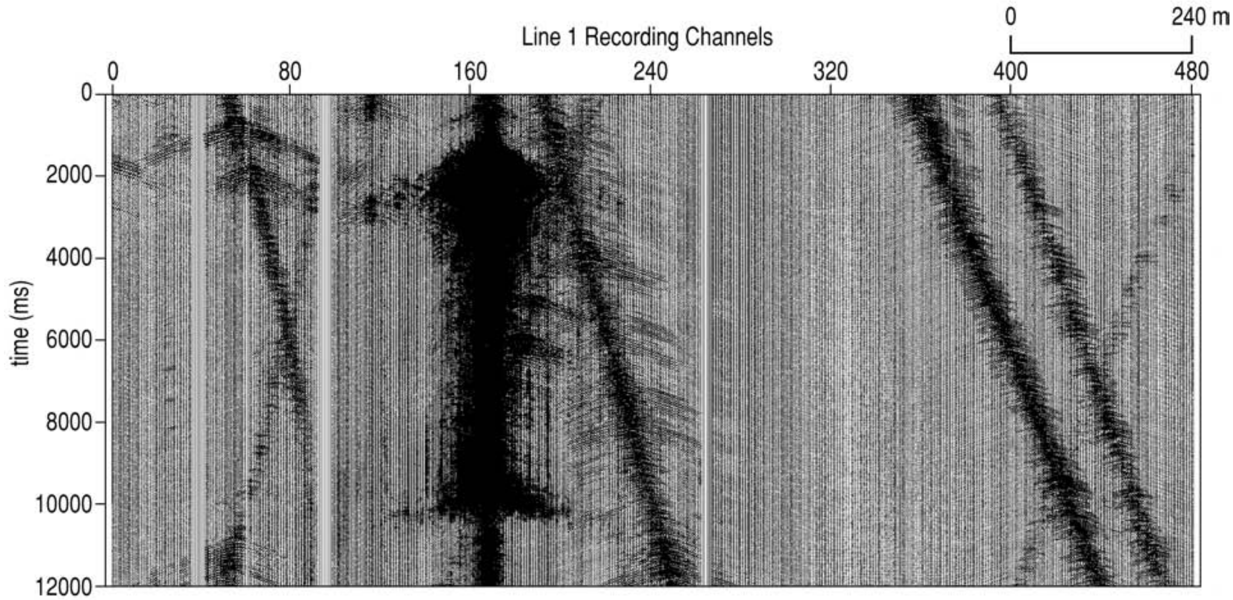

Figure 2. Uncorrelated 12-second sweep with traffic noise obvious. Power lines cross the profile near channel 300. All dead traces are the result of road crossings. Recording channel 160 correlates to station 1300 on CMP stacked section (Figure 4).

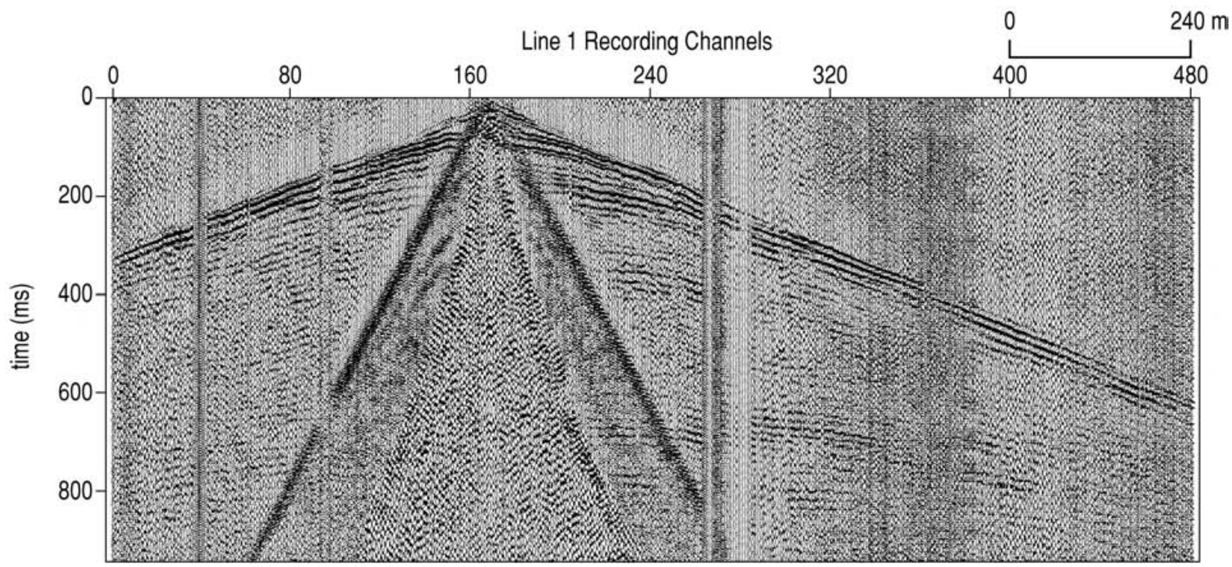

Figure 3. Correlated shot gather from line 1 (Figure 2) with dead traces from road intersections obvious. Most vehicle and power line noise suppressed near background levels. Recording channel 160 correlates to CMP station 1300 on CMP stacked section (Figure 4).

CMP Stacked Sections

Confident interpretation of reflections on CMP stacked sections, and correlating those reflections to reflectors, is only possible on shallow high-resolution CMP stacked sections if sufficient noise (coherent and random) has been removed or attenuated for reflections to be the dominant coherent energy on shot gathers.

A relatively thin and uniform sequence of reflections is interpretable within the upper aquifer system (Figure 4). A locally consistent reflection possibly defining the division between the Oxnard and Mugu aquifers is evident within the upper aquifer system on all the seismic sections. The wedge of more chaotic appearing events on the seismic section between the green and yellow events from station 1300 to the west end of

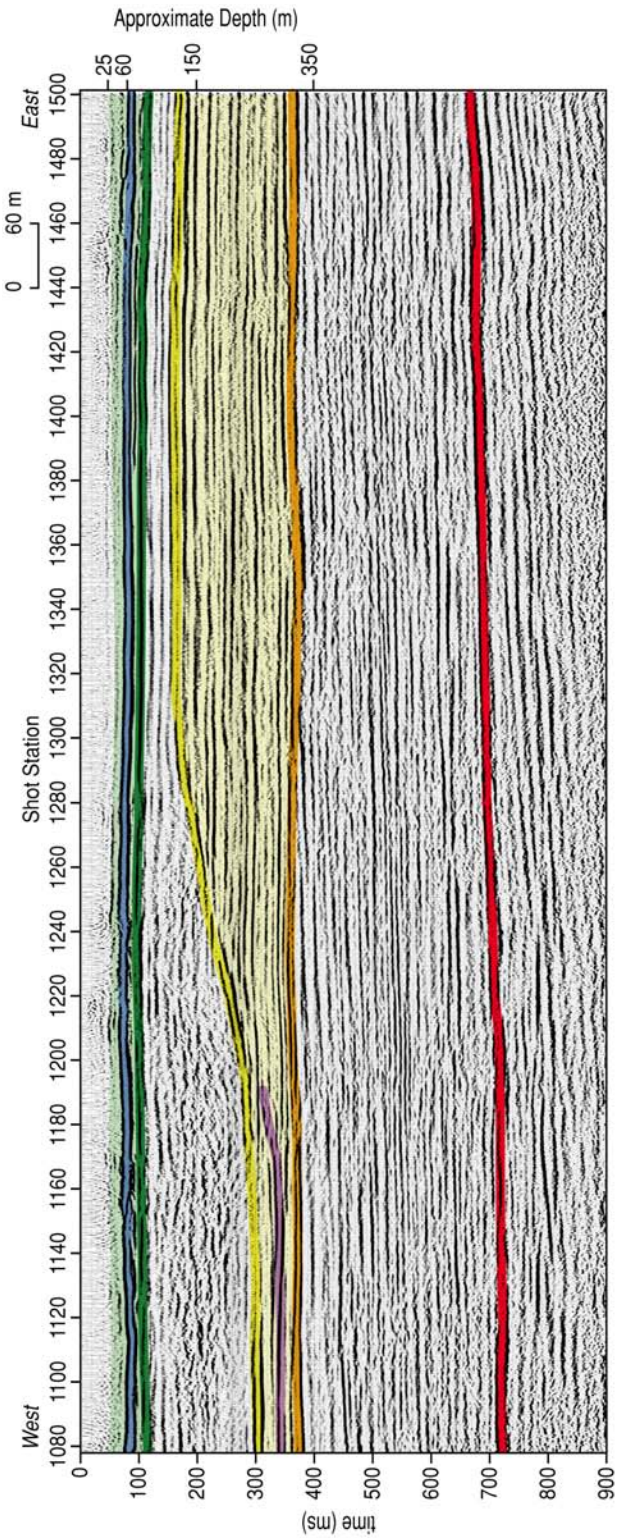

Figure 4. The erosional unconformity that marks the division between the upper and lower aquifer systems is clearly evident and interpreted as the yellow reflection on the westernmost portion of the CMP stacked section of line 1. The green line is interpreted as the base of the Mugu aquifer and the blue line separates the Oxnard and Mugu aquifers. The purple reflection is a high amplitude (abrupt change in velocity-density contrast) event that is likely a cut-and-fill feature of the ancestral Santa Clara River. The red line is an arbitrary reflector within consolidated marine sediments.

the profile could be a low permeability zone consistent with borehole data. The hydrostratigraphic interpretations should be considered preliminary, as United Water Conservation District is currently integrating additional borehole geophysical and drilling data to refine the understanding of the hydrogeology. If the yellow reflection defines the erosional unconformity that separates the upper and lower aquifer systems then the thickness of the lower aquifer increases from around 100 m at station 1160 to over 250 m at station 1300. Such a dramatic increase in the thickness of the lower aquifer system, as suggested by these seismic data, would have significant ramifications for optimized well placements.

Based on well data, reflectors at depths greater than 350 m are part of a thick sequence of partially consolidated marine sediments and volcanic rocks. An arbitrary reflection from within that sequence is interpreted to highlight the apparent westward dip. Deeper reflectors truncate against the approximate 300 m deep unconformity that defines the base of the lower aquifer. It is beyond the scope of this project to determine if this chaotic zone is more appropriately categorized as part of the upper aquifer system or lower aquifer system.

Conclusions

State-of-the-art shallow high-resolution seismic reflection techniques proved valuable in detecting, delineating, and advancing the interpretation of local variations in reflectors and structure associated with unlithified Plio-Pleistocene sediments. The value and significance of these seismic interpretations will only be fully realized when incorporated into current borehole based hydrostratigraphic interpretations. Previous hydrologic models in the Oxnard area were based on a small number of non-optimally placed wells. Even in this noisy area, seismic reflection has proven effective in delineating hydrostratigraphic sequences at a lateral and vertical resolution not possible with any other method.

Acknowledgments

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EDITED REFERENCES

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REFERENCES

Izbicki, J. A., 1991, Chloride sources in a California coastal aquifer, *in* H. Peters, ed., Groundwater in the Pacific Rim Countries: Proceedings of the American Society of Civil Engineers, IR Div/ASCE, 7177.

Mukae, M. M., and J. M. Turner, 1975, Ventura County water resources management study — Geologic formations, structures, and history in the Santa Clara-Callegus area: Ventura County Department of Public Works, Flood Control District.

Stamos, C. L., S. K. Predmore, and A. R. Zohdy, 1992, Use of D-C Resistivity to map saline ground water, *in* T. Engman, ed., Saving a threatened resource — In search of solutions: American Society of Civil Engineers, IR Div/ASCE, 80–85.