HYDROGEOLOGIC CHARACTERIZATION USING A SHALLOW SEISMIC REFLECTION SURVEY AT FORT ORD, CALIFORNIA

Carlene Merey, Harding Lawson Associates, 200 Rush Landing Road, Novato, CA 94945
Richard D. Miller, Kansas Geological Survey, 1930 Constant Avenue, Lawrence, KS 66047
Edward J. Ticken, Harding Lawson Associates, 200 Rush Landing Road, Novato, CA 94945
J. Scott Lewis, Harding Lawson Associates, 200 Rush Landing Road, Novato, CA 94945

SUMMARY

Shallow seismic reflection profiling was successful in delineating a shallow impermeable layer acting to perch fluids at depths ranging from 125 to 175 ft. The near-surface material was dry dune sands with varying grades of sands and gravels within the upper 20 ft. The seismic data possessed dominant frequencies in excess of 150 Hz resulting in bed resolution on the order of 3 ft at depths less than 150 ft. Several key hydrogeologic features were identified and their significance more completely ascertained using the reflection data.

INTRODUCTION

Fort Ord is an active military facility serving primarily as a training and staging area for light infantry troops. The base comprises approximately 44 square miles of coastal plain in northwestern Monterey County, California. (Figure 1). Fort Ord has been targeted for closure by a congressional committee studying military facilities. Small-scale industrial operations have been ongoing at the fort since it was established in 1917. The most environmentally significant operations have been related to vehicle maintenance and operation at military motor pools and fueling centers as well as commercial gasoline stations.

Verification and detailed analysis of several key hydrogeologic features interpreted from drill data were necessary as part of the large-scale environmental studies being conducted at Ford Ord by the Corps of Engineers, Sacramento District. The primary goals of the seismic survey were to detect the edge of a shallow confining clay layer, locate and describe a previously mapped east-west trending fault, and evaluate the potential hydrologic, stratigraphic, and structural significance of a suspected bedrock high. Shallow high-resolution seismic reflection profiling represented the most viable technique, potentially possessing sufficient vertical and horizontal resolution to significantly reduce the amount of drilling necessary to evaluate and analyze these hydrogeologic features.

HYDROGEOLOGIC SETTING

The Salinas and Seaside basins represent the two main hydrogeological systems under Fort Ord (Figure 1). Early work (DWR, 1973) suggested the Gabilan fault marked the boundary between the two basins at Fort Ord. More recent investigations suggest that the boundary lies along the Welch and Grant Ewing ridges (SGD, 1990) where the barrier for groundwater flow might be an elevated geologic structure of impervious Miocene marine sediments of the Monterey formation.

Potential water-bearing formations in the area consist of the Miocene/Pliocene Santa Margarita formation, the Pliocene Paso Robles formation, the Pleistocene Aromas formation, and

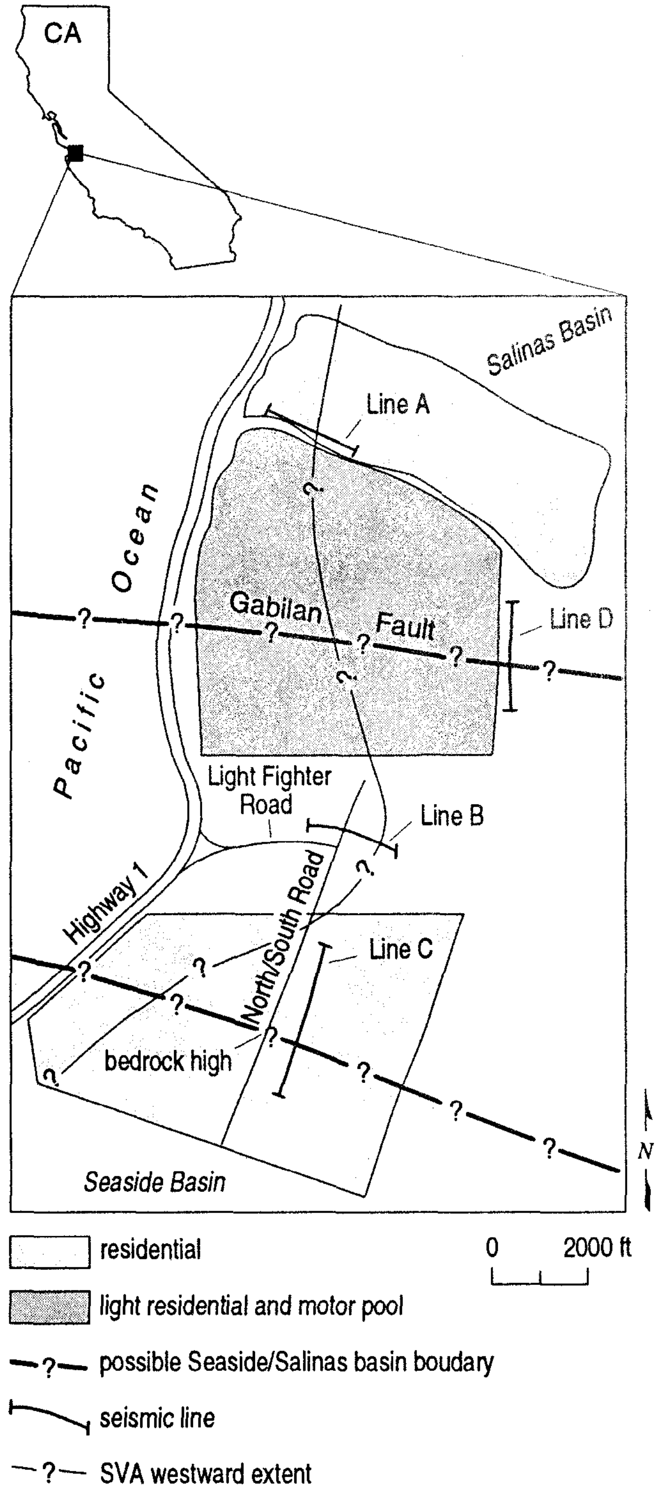

Figure 1 Site Map. The Salinas and Seaside basins as well as the locations of the four seismic lines.

Pleistocene and Holocene age alluvial deposits. The non-water-bearing rocks in the area consist of Mesozoic granodiorite, as well as Miocene and older marine sediments.

Fort Ord occupies an area of the Salinas subbasin known as the Salinas Valley Pressure Area (Muir, 1977). In general, the Salinas Valley Pressure Area consists of four aquifer zones that extend offshore into Monterey Bay, known as the uppermost (unconfined), 180-foot, 400-foot, and 900-foot aquifers, each defined by a confining or semi-confining layer.

The uppermost aquifer comprises permeable dune sand deposits with a maximum thickness of 300 feet, which are only partially saturated and are underlain by an extensive confining layer known regionally as the Salinas Valley Aquiclude (SVA). The aquiclude can be as thick as 100 feet though it averages about 50-75 feet, and appears to be laterally continuous in most areas of Fort Ord. In the central (north-south) portion of Fort Ord, the SVA pinches out to the west along a line roughly parallel to the coast (HLA, 1990; DM, 1990). West of this line, the uppermost aquifer and the 180-foot aquifer are hydraulically connected. Dames and Moore (1990) suggest that the uppermost aquifer, which generally flows oceanward, probably discharges into the 180-foot aquifer at the pinch-out and follows the eastward flow of the deeper aquifer.

The exact extent of the SVA to the south is difficult to define because of sparse data in this area. The top of the SVA undergoes a steep rise just south of the inferred Gabilan fault trace and may possibly continue further south into the Seaside Basin, where it is known as the Seaside Clay. Alternatively, it may extend only to the Gabilan Fault while the Seaside clay may be a separate stratigraphic unit belonging strictly to the Seaside Basin.

The eastern portion of the Gabilan fault is considered a hydraulic barrier for the deeper aquifers. Offset in the fault decreases to the west possibly to the point where similar formations come into contact.

SEISMIC ACQUISITION PROCEDURES

The feasibility portion of the project included an extensive series of tests conducted at three geologically unique locations around the fort. The sequence of tests performed at each site was focused on the geologic target(s) unique to that site. Testing included a series of walkaway noise tests and a 200 ft CDP line at each site. A variety of analog low cut filters, receiver intervals, and sources (Betsy firing rod {12 and 8 gauge} and 16 pound sledge hammer) were tested during the walkaways. The short CDP test data were collected in an attempt to determine the actual resolution and data quality potential that could be expected on a larger survey in each of the three areas. The feasibility testing was critical to the efficient design and implementation of the production portion of this study.

The production phase of the project was initiated after thorough analysis and evaluation of all test data. Locations of the four production lines were based on access, potential cultural interference, topographic relief, maximum geologic significance, and quality, quantity, and proximity of well control points. The four lines comprised approximately 10,000 linear feet of full fold CDP coverage. The western most and northern most CDP production lines targeted the west edge of the SVA at a depth of approximately 125 to 175 ft. The eastern most CDP line was located to maximize the probability of crossing the Gabilan Fault. The fourth line focused on the bedrock high. Surface conditions required some slight bending of the lines to accommodate street intersections, topographic obstacles, and patches of relatively thick vegetation. The CDP data possesses a nominal fold of 12 with increased fold associated with the undershooting of roads and decreased fold associated with both underground and surface obstacles.

The data were acquired using a standard CDP roll-along method. The source for the majority of the data was a 12-gauge auger gun (Healey et al., 1991). The auger gun is uniquely suited for downhole detonation of small shotgun shell explosives. The hollow stem design allows a shotgun shell to be placed to a depth of just over 2 ft through the inner portion of the same auger used to drill the hole and thereby maintain hole integrity. The source station spacing was 8 ft. The receivers were three L28E 40 Hz geophones configured in a 3 ft in-line array with station spacings of 8 ft. The array was designed to reduce recorded cultural and source-generated noise travelling approximately parallel to the line. All four lines were acquired with an end-on source to receiver configuration. The source-to-nearest receiver distance was 8 ft and the source-to-furthest receiver distance was 192 ft on all four lines. The geometries and receiver spacings were designed to optimize the potential of recording reflections from the target interface.

A 24-channel EG&G Geometrics model 2401 seismograph was used to record the data. The record length was 512 ms with a sampling interval of 0.5 ms. Floating point amplification followed by analog-to-digital (A/D) conversion of the signal resulted in 15 bit digital words. Pre-A/D low cut filters with an 18 dB/octave roll-off and a -3 dB point of between 35 to 70 Hz (actual low-cut filter value was site dependent) were used to reduce the effects of low-frequency noise.

SEISMIC DATA PROCESSING

The processing flow was very similar to that used in routine petroleum exploration, except for the severity and precision of the surgical muting processes and precision of velocity analysis. Rarely is shallow reflection data enhanced by deconvolution and this data set was no exception. Testing with deconvolution on this data set resulted in a significant reduction in the signal-to-noise ratio of the data as a whole and coherency of individual reflections. For some operations shallow reflection processing is simply a scaled down version of deep petroleum processing. Attention to detail and exact parameter designations are critical to producing a meaningful shallow section.

RESULTS

Identification of reflections on raw field files is important for quality control, optimization of acquisition parameters, and establishing direction and priorities for the processing flow. Several reflections from less than 200 ft can be clearly identified on field files (Figure 2). The event at approximately 140 msec is the SVA and represents one of the primary targets. Two reflections shallower than the SVA can be identified at about 80 and 110 msec. These reflections are probably from contacts between the predominantly sandy near-surface material and occasional interbedded clays. The dominant frequency of the shallow clay reflection (80 and 110 msec) is over 150 Hz. The reflection from the SVA is just over 125 Hz. With an average velocity in this area of around 1600 ft/sec in the upper 150 ft the resolution potential of the shallower reflections is on the order of 3 ft using the 1/4 wavelength criteria (Widess, 1973).

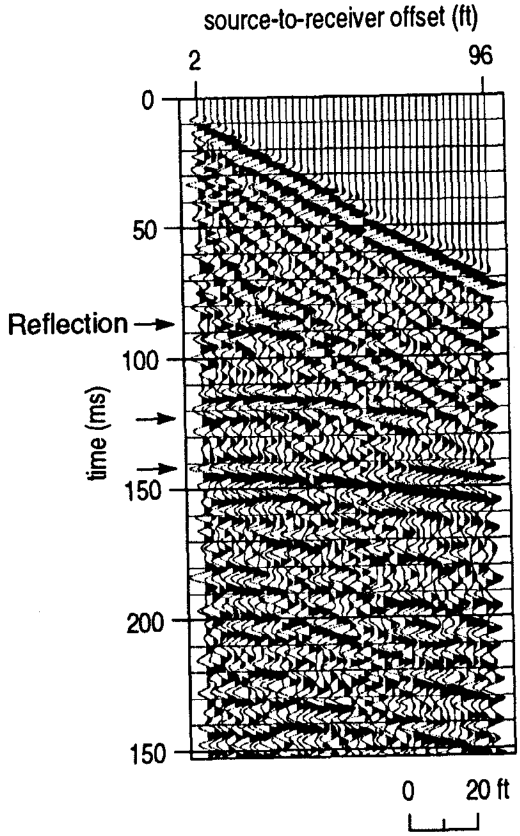

Figure 2 24 channel field file from Line B. Reflections are clearly interpretable at 80, 115 and 135 msec on this filtered and scaled file from Line B.

The near-surface in this area consists of dry sand with an occasional clay lens down to just above the SVA. The higher amplitude of the SVA reflection in comparison to shallower reflections is probably related to the presence of the water perched on top of the SVA. The saturated sand/clay at or just above the SVA represents the largest acoustic impedance contrast within the depth range of this survey.

Several coherent reflections consistent with the raw field files (Figure 2) can be interpreted across the expanse of the nominal 12 fold CDP stacked section (Figure 3). The target of this survey is the reflection at 140 msec on the east side of the stacked section. The 140 msec reflection is the SVA and is acting as an impermeable barrier to water perched above it. The termination of the SVA is obvious at about CDP 350 and is interpreted to be an erosional pinch-out. Termination of the westward dipping SVA is suspected to be the conduit for potentially contaminated water to cascade onto the eastward dipping 180 ft aquifer.

From existing drill data and hydrologic data, the 100 to 110 msec reflection does not represent an impermeable barrier but seismic data do suggest a geometry that could influence percolation of surface water. The synclinal shape of this reflection in conjunction with an apparent break in continuity at about CDP 360 could act to funnel the downward propagation of fluids.

The deeper reflection (about 200 msec) is interpreted to be the 180 ft aquifer. The decrease in apparent amplitude is directly related to the extreme acoustic impedance contrast at the SVA. The apparent pull-up beneath the SVA on the east half of the line is related to the velocity contrast across the pinch-out of the SVA. Remediation programs will benefit by the dip information the seismic data provides.

DISCUSSION

The quality of the seismic data collected at Fort Ord has allowed detailed descriptions of the structure and extent of several important hydrogeologic features. The westward extent of the SVA has been identified clearly on the seismic sections and will afford highly accurate placement of remediation systems for treatment of the uppermost aquifer. Also identified on the sections is the groundwater gradient of both the uppermost aquifer and the 180 ft aquifer.

Future studies at this site could include more east-west lines to continue mapping the westward extent of the SVA along with north-south lines to both tie the east-west lines and define three-dimensional structures more accurately.

ACKNOWLEDGEMENTS

Funding for this study and release of the data for publication provided by the Corps of Engineers, Sacramento District is greatly appreciated. We would like to thank Phil Boudreau, Tom Casebier, and Roark Smith for assistance during the acquisition of the data. We would also like to acknowledge Pat Acker for her work on graphics and generation of camera ready copy and Rex Buchanan for his editorial suggestions.

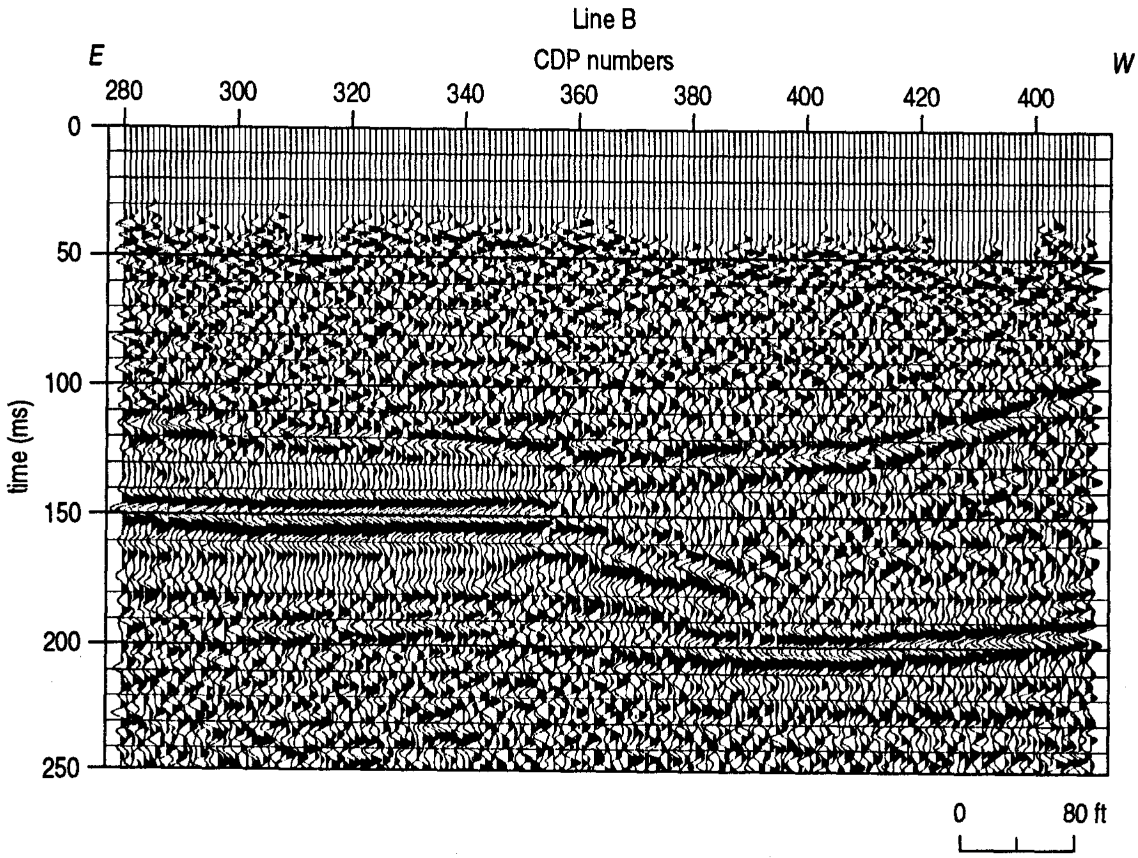

Figure 3 12 fold CDP stack of a portion of Line B.

figure 2

REFERENCES

California Department of Water Resources (DWR), 1973, Seawater Intrusion, Lower Salinas Valley, Monterey County, California.

Dames and Moore (DM), 1990, Fort Ord, California, October Quarterly Meeting Report: prepared for the U.S. Department of the Army.

Harding Lawson Associates (HLA), 1990, Groundwater Well Management Plan, Fort Ord Complex, prepared for the United States Department of the Army, Corps of Engineers, Sacramento District.

Healey, J., J. Anderson, R. D. Miller, D. Keiswetter, D.W. Steeples, and B. Bennett, 1991 Improved shallow seismic-reflection source: building a better Buffalo [Exp. Abs.]: Soc. Explor. Geophys. v. 1, p. 588-591.

Muir, K.S., 1977, Initial Assessment of the Groundwater Resources in the Monterey Bay Region, California: Water Resources Investigations 77-46, U.S. Geological Survey.

Staal, Gardner, & Dunne, Inc. (SGD), 1990, Hydrogeologic Investigation, Monterey Coastal Groundwater Basin: consultants report to Monterey Peninsula Water Management District.

Widess, M. B., 1973, How thin is a thin bed?: Geophysics, 38, 1176-1180.