Near Surface 2: Shallow Seismic Applications

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Delineation of near-surface paleochannel using shallow seismic reflection techniques

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Summary

Shallow seismic reflection techniques were successful in delineating stratigraphic units and bedding geometries significant to the hydrologic modeling of unconsolidated sediments less than 60 m deep at Cherry Point Marine Air Base near Havelock, North Carolina. Discontinuous confining units beneath an industrialized portion of this major aircraft overhaul facility were thought to be due the erosion by a river that had cm through this area. Land shallow seismic reflection techniques provided images of alternating sand and clay sequences with average thicknesses on the order of 6 to 9 m. The land data have a dominant frequency of about 200 Hz, providing a minimum vertical bed resolution of about 2 m. Continuous seismic reflection data collected in the Neuse River directly north of the base have a dominant frequency around 600 Hz, providing a resolution potential of less than 1 m. Well defined cut and fill features that appear to have removed portions of the confining units are evident on the processed marine data. Correlation of the land CDP stacked seismic section with the drillhole-defined lithology was enhanced by incorporating electric logs and VSPs acquired in three strategically placed monitor wells. Some processed VSPs have interpretable reflections from within the upper 70 m that are consistent with the geologic section as inferred from drilling and electric logs. Subtle stratigraphic contacts, such as shell layers within sand or changes in the grain size of sand, were not easily interpretable on the CDP stacked sections. The land seismic reflection data provided the very high horizontal and vertical resolution necessary for determining continuity of confining units and stratigraphic variations between 10 and 60 m at this site.

Introduction

Transport and fate of contaminants associated with the 50-year history of aircraft refitting and manufacturing at Cherry Point Marine Air Station near Havelock, North Carolina is critical to current groundwater management and future remediation efforts. Base-wide horizontal extension of borehole information necessary far the generation of groundwater flow models cannot be confidently done due to the documented localized absence of both the Yorktown and Upper Castle Hayne confining units (Lloyd and Daniel, 1988). The missing confining units are interpreted to be associated with an ancient river channel (paleochannel) underlying a large portion of the industrial area of the base. Contamination introduced at the ground surface during storage, disposal, and use has migrated into and resulted in the closing of several high volume domestic and industrial water wells pumping from the 60 m deep Upper Castle Hayne aquifer. Water withdrawal from wells located new the proposed paleochannel could change both the velocity and direction of contaminant transport

Shallow high resolution seismic reflection techniques possess the necessary resolution to confirm the presence of the paleochannel as inferred from drill data as well as correlate stratigraphy from well to well across the base. Shallow land reflection surveys have successfully imaged shallow bedrock (< 100 m) as well as overlying unconsolidated sequences (Miller et al.. 1989; Pullan and Hunter. 1990; Miller et al., 1986; Birkelo et al., 1987; Jongerius and Helbig. 1988: Goforth and Hayward, 1992). The success of continuous marine seismic profiling methods are site dependent but have the potential to produce high resolution records in shallow water (Haeni, 1986; Haeni, 1988; Cardinell et al., 1990). Incorporation of VSPs, borehole geophysical logs, and lithologic logs with water and land seismic data provide an accurate and horizontally continuous representation of the unconsolidated lithology at this site.

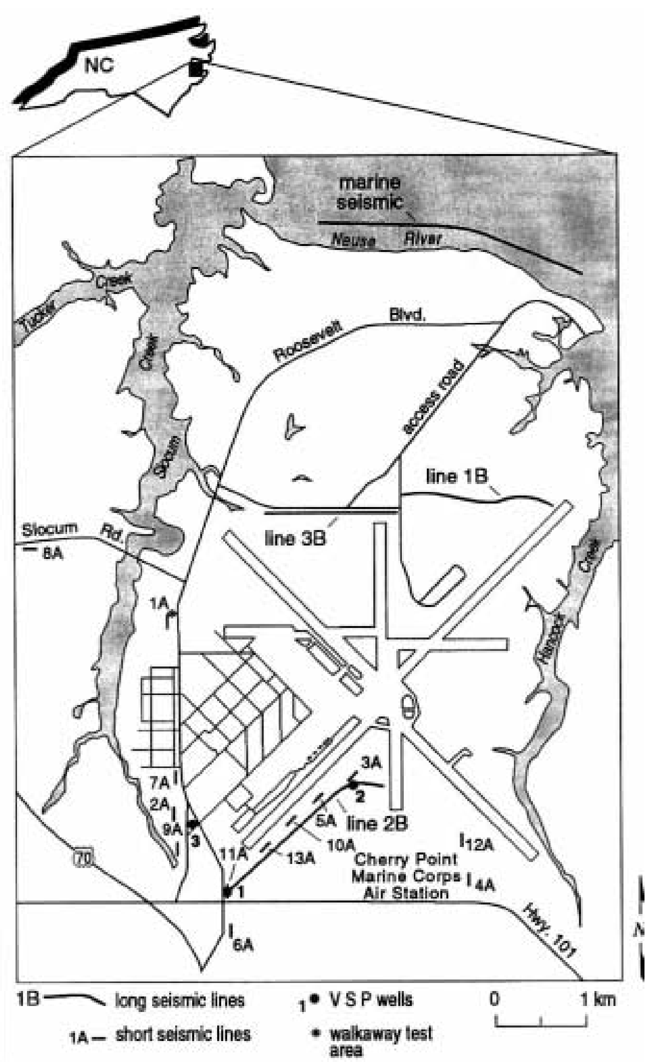

Figure 1. Site map of Cherry Point Marine Air Station indicating the major roads, rivers, runways, seismic lines, and VSP wells.

Geology/Hydrology

The air base is located an an approximately 1000 m thick sequence of Coastal Plain sediments overlaying crystalline basement rock (LeGrande, 1960). The upper 60 m or so of unconsolidated material that overlies the Castle Hayne limestone (bedrock) at the air station represents the focus of this study (Eimers et al., 1994). The unconsolidated marine sediments above bedrock predominantly consist of alternating sands and clays with occasional shell beds and phospheric sands. Of the nine aquifers present beneath the air station, only the shallowest four (Surficial, Yorktown, Pungo River, and Upper Castle Hayne) are significant to this study and the hydrologic characterization as it relates to transport and fate of surface introduced contaminant. The piezometric surface or water table at this site is generally consistent with mean sea level which along the land survey lines ranges between 5 and 10 m below ground surface. The major clay/silt units (regionally thicker than a few meters) are generally considered and referred to as confining units while the more porous sands and limestones are the aquifers. Sand lenses and shell beds are occasionally present within confining units and clay stringers are routinely present within the aquifers. The Castle Hayne aquifer is a regionally consistent porous limestone that provides fresh water for many domestic, municipal, and industrial users in eastern North Carolina (Lloyd and Daniel, 1988).

Development of a meaningful groundwater flow model is critical to the management of groundwater resources and to the formulation of accurate contaminant isolation and extraction programs. Inadequate determination of the spatial variability and hydraulic characteristics of aquifers and confining units in this area would severely limit the usefulness of numerical groundwater flow models. The importance of compensating for localized discontinuities in the confining unit at this site is evident when considering the hydraulic conductivity (a principle input parameter for hydrologic modeling) of the four upper confining units ranges from .003 to .0003 m/d (meters/day) while the hydraulic conductivity of the aquifers ranges from 3 to 97 m/d (Eimers et al., 1994).

Data Acquisition

Three different types of acoustical surveys were conducted and incorporated into this study (Figure 1). A total of sixteen multi-fold land CDP lines were acquired, primarily designed to image acoustic interfaces between 10 and 100 m deep. The 20 km of single-fold marine data focused on acoustic contrasts from a couple meters to several hundred meters deep along the rivers. The three VSPs (acquired in PVC-cased monitor wells) were primarily intended to allow accurate time-to-depth conversion of reflections interpreted on the stacked sections.

The 24-fold land CDP seismic reflection data were acquired with a 48-channel Geometrics StrataView seismograph, single 100 Hz Mark Products L40A geophones, and a downhole 30.06 firing rod. Preliminary equipment and parameter testing was instrumental in optimizing the acquired data. The very site-dependent nature of acoustic source characteristics (Miller et al., 1994) prompted the comparison of three types of compressional wave sources, including: the 30.06 downhole rifle (projectile), 12-gauge auger gun (downhole explosive), and 5.5 and 9 kg sledge hammers (weight drop). Based on the signal-to-noise ratio, resolution potential (bandwidth, dominant frequency, and corner frequency), and power spectrum, the 30.06 downhole rifle was chosen as the optimum source for this study. Single 100 Hz and triple 40 Hz geophones were compared and evaluated, with the single 100 Hz geophone being selected for the study. The seismograph was selected based on its dynamic range at faster sampling rates (l/4 msec), real time wiggle trace noise monitoring (local air traffic was a problem), and speed of both data transfer and "on-board" processing. The shear wave reflection technique was evaluated and determined not to possess acceptable signal-to-noise or bandwidth at this site. Guided by the results of walkaway testing, compressional wave data were recorded using an asymmetric split spread source/receiver geometry with a source to nearest receiver distance of 3 m and farthest receiver distance of 46 m.

The single channel continuous water-seismic-reflection profiling system consisted of a capacitor power supply, amplifier/filter unit, graphic recorder, digital audio tape recorder, broad bandwidth electromechanical plate sound source, and a hydrophone array consisting of 12 elements connected in parallel and separated by 0.6 m. The sound source and the first line receiver on the hydrophone array were separated by 2 m and towed approximately 15 m behind a 7 m boat. The average water depth during recording was less than 2 m. Data were acquired at a rate of about 2 shotpoints/second at a nominal 0.7 m station spacing.

Two walkaway VSPs (one with a hydrophone and the other with a hole lock geophone) were recorded at each of three holes.

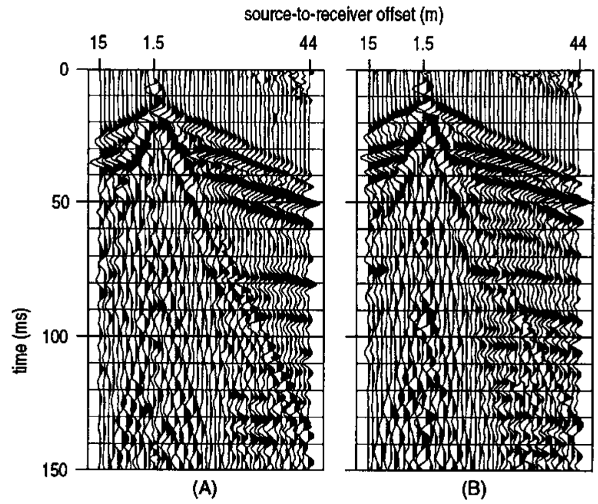

Figure 2. AGC scaled field files from two different places on line 1A. The reflection arrivals are evident on both records. Evident from comparison of A and B are the change in subtle reflection between 50 and 70 msec.

The two profiles recorded in each hole allowed interval velocities in the saturated as well as the unsaturated zones to be determined. To insure that several hundred shots could be recorded at the same location without appreciable deterioration in time zero or wavelet characteristics, a 5.5 kg sledge hammer was used to stack 3 to 5 shots per downhole location. A single surface geophone recorded data simultaneously with each downhole receiver to allow visual inspection of time break and wavelet consistency from shot station to shot station as well as shot to shot. Hydrophone recording stations began approximately 3 m below static water level while the hole lock geophone was recorded in an air filled portion of the hole. To increase overlap between hydrophone and geophone data, a portion of the water was removed from the borehole. Surface source stations were evenly spaced at 3 m and extended away from the borehole to about 50 m. Borehole receiver locations were separated by 1.5 m from as near the ground elevation as possible to the bottom of the hole (hydrophone) or top of the water column (hole lock geophone).

Data Processing

For most basic shallow high-resolution seismic reflection data the processing steps are a simple scaling down of established petroleum-based processing techniques and methods (Yilmaz, 1987; Steeples and Miller, 1990). Data from this study were processed on an Intel 80486-based microcomputer using a set of commercially available algorithms. The processing flow was similar to that used for routine petroleum exploration. A very low (by conventional standards) allowable NMO stretch (< 20%) was extremely critical in minimizing contributions from the very shallow reflected energy at offsets significantly beyond the critical angle. Limiting wavelet stretch through muting maximizes resolution potential and minimizes distortion in the stacked wavelets (Miller, 1992). Variability in depth of the first refracting horizon was as much as 10 msec across a single CDP stacked section. This depth variability was very effectively compensated for with refraction statics. Processing/processes used on this data have been carefully executed with no ***a priori*** assumptions. Extreme care was taken to enhance through processing only what can be identified on raw data and not to create coherency on stacked sections.

Processing of the single-channel marine data was limited to digital filtering and variations in display parameters (Sylwester, 1983). The 300 Hz to 1500 Hz bandpass filter provided the clearest picture of the channel in the subsurface.

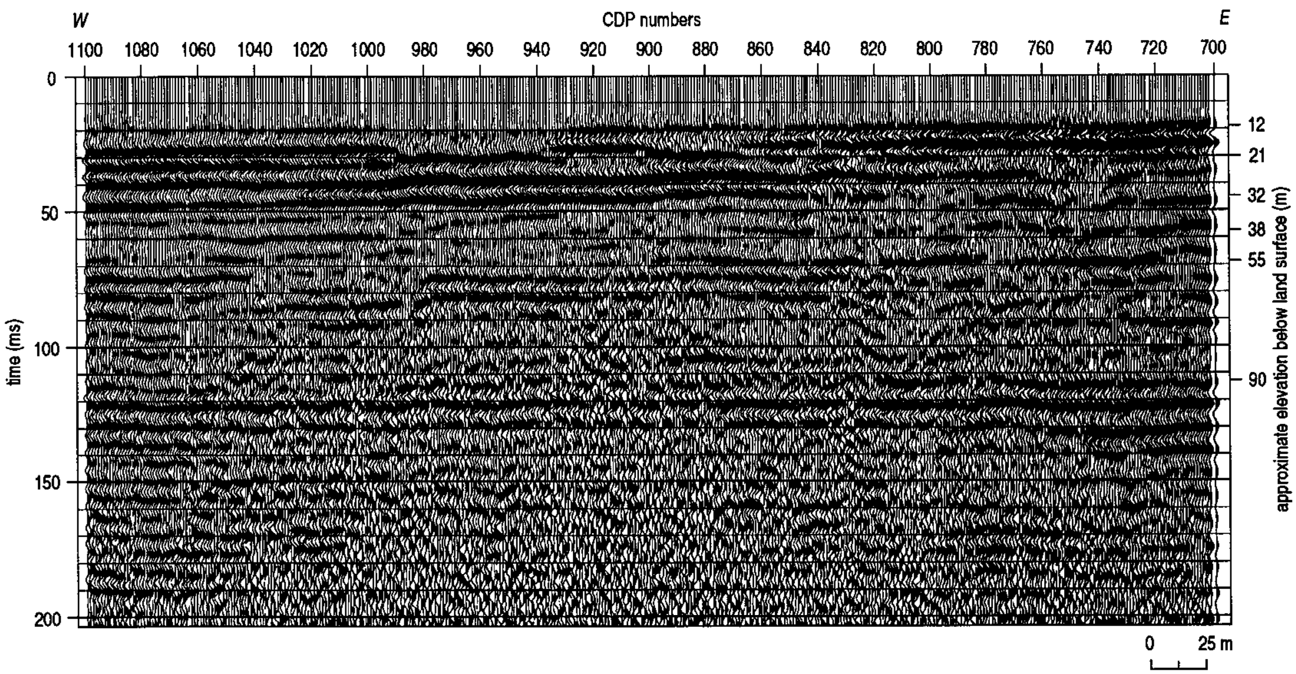

Figure 3. 24-fold CDP stack of a portion of line 1A. The prominent reflections are interpreted as the various unique geologic/hydrogeologic units. Several cut-and-fill as well as dipping features are interpretable on the stacked section.

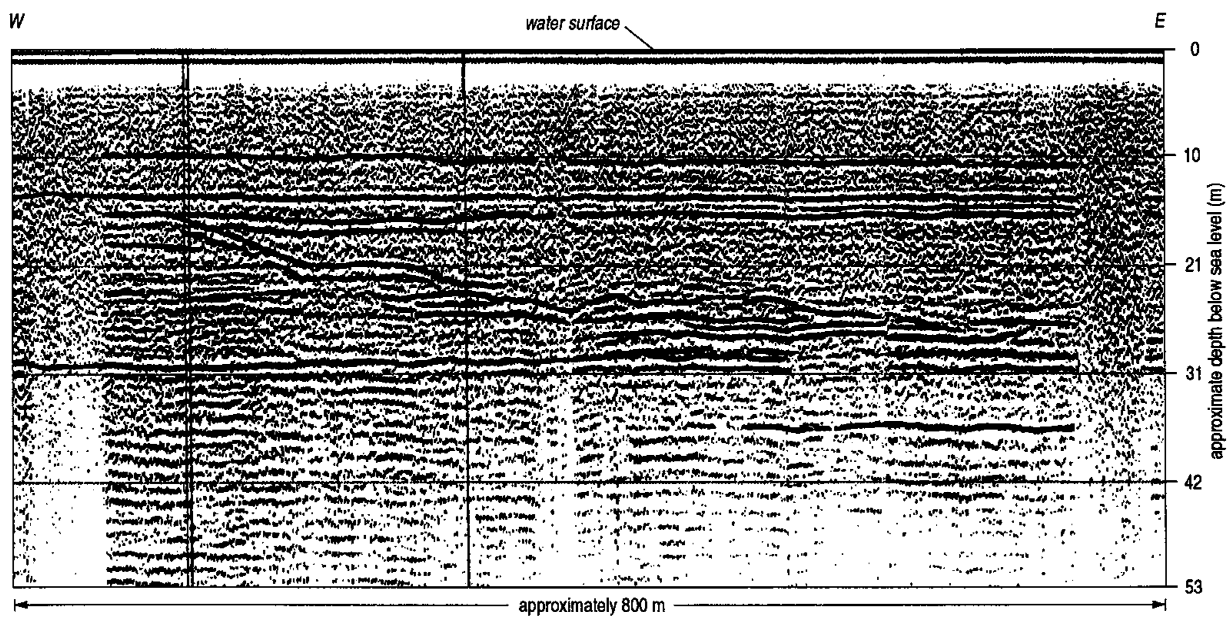

Figure 4. Single-fold marine data interpreted to trace the expression of the paleochannel.

Results

Correlating of coherent events on CDP stacked sections with any borehole defined geologic feature or unit cannot be confidently made without an irrefutable tie between reflection hyperbola interpreted on field files and coherent events on CDP stacked sections. AGC scaled field files from this site possess several high quality reflection hyperbola (Figure 2). The shallowest event (zero offset time of about 26 msec) clearly separates from the refraction arrival at close offsets. At longer offsets the 26 msec event becomes asymptotic to and interferes with the refraction wavetrain. The bedrock is easily identified at about 70 msec and correlates extremely well with both the VSP derived time/depth conversions and the electric logs. The variability of the sediments within each formation is evident when comparing reflected energy between 50 and 70 msec on the two selected field files (Figure 2). At least six unique reflection events as well as direct wave, refractions, air coupled wave, and ground roll can be identified on the majority of field files from this survey.

Interpretations of reflections on CDP stacked sections suggests that horizontal correlation of these shallow unconsolidated units from well to well is possible in this part of the Coastal Plain (Figure 3). The four hydrogeologic units identified on geologist and electric logs from local boreholes correlate extremely well to stacked reflections. Within individual aquifer and confining units subtle variations in reflection geometries are evident. Erosional features such as the one at CDP 970 in the 12 m clay and CDP 1010 in the 55 m bedrock are evident across most of the CDP stacked sections. A series of dipping reflections within what is interpreted as the Pungo River aquifer could be representative of a series of thin shell layers noted on geologists logs from a nearby borehole. The reflections evident on the CDP stacked section very closely matches potential reflectors identified from borehole geology.

The marine sections clearly show the characteristic curved geometries of classic cut-and-fill or channel features (Figure 4). From the marine data there appear to be at least two channel features, each approximately 3/4 to 1 km wide with one slightly offset yet superimposed on part of the other. Based on time-to-depth conversions from VSP interval velocities, both channel features cut into the Pungo River confining unit at about 30 m. It is not clear if one or both have completely replaced the Yorktown confining unit. The marine data dramatically improves the overall picture of the paleochannel geomorphology with respect to subtle interbed sequences and characteristic bed variability.

Conclusions

Shallow seismic reflection was extremely successful in delineating hydrologically significant changes in hydrogeologic units on Cherry Point Marine Air Station. The incorporation of land and marine seismic reflection data with VSP data, geophysical logs, and geologist stratigraphic borehole logs greatly enhances both the confidence and the overall understanding of the geology and hydrogeology of any area. This data set allows for a reasonable inference as to the possible subsurface expression of the paleochannel speculated from sporadic drill data.

Acknowledgments

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