SHALLOW SEISMIC DATA ACQUISITION, PROCESSING, AND INTERPRETATION AT PLAYA 5, CARSON COUNTY, TEXAS

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ABSTRACT

Seismic methods were used to determine the physical properties and geological development of Playa 5, a playa basin located on the U. S. Department of Defense's former Pantex Ordnance Plant, for comparison with results from other basins (Sevenmile Basin, Pantex Playa 3, and Pantex Lake) as well as with results from seismic data collected in interplaya areas. These studies have led to a better understanding of stratigraphic differences between playa basins, which serve as preferential recharge points for the Ogallala aquifer, and between playa and unaltered interplaya areas, where little Ogallala recharge is thought to occur.

Playa 5 is a nearly circular playa that is 0.7 to 0.9 km across. It is enclosed by a basin that is about 2 km across and has 5 m of relief between the highest and lowest closed elevation contours. Refraction surveys show that the surface layer at Playa 5 is a few meters thick and has typical seismic velocities of 420 to 440 m/s. This layer is underlain by a layer with higher seismic velocities of 808 to 910 m/s that has similar texture but more pedogenic carbonate. Refraction methods also detected a layer at more than 60-m depth with significantly higher seismic velocities of about 2000 m/s. This layer probably represents a competent horizon above the modern Ogallala water table that has been cemented by either pedogenic or hydrologic processes.

Reflection data collected across Playa 5 show that relief on seismic horizons increases with age. Modern surface relief is 6 m, which increases to 30 m on a horizon that is interpreted to be correlative to a fine-grained zone that perches ground water beneath parts of the Pantex Plant. Relief increases to 50 m on a horizon that is interpreted to be the top of Permian or Triassic bedrock. Internal bedrock reflectors dip toward the basin center beneath the playa, suggesting that subsidence related to dissolution of underlying Permian salt has contributed to the development of the Playa 5 basin. Playa 5 subsidence has occurred at average rates of 0.33 to 0.42 m per meter of deposition, rates that are similar to those at Playa 3 and Pantex Lake and are less than half those inferred for Sevenmile Basin.

INTRODUCTION

Work described in this report is part of a larger effort to use noninvasive geophysical methods (principally shallow seismic reflection profiling) to help understand the hydrogeological framework of the Pantex Plant and surrounding areas, including the City of Amarillo water supply field north of the Pantex Plant. Subsurface targets of interest include the top of the Ogallala Formation (the "caprock"), internal Ogallala stratigraphy (particularly units that may retard the flow of ground water from the surface to the main Ogallala aquifer), and the surface of the underlying Permian or Triassic bedrock. Specifically, the purpose of this study is to examine the stratigraphy beneath Playa 5, a playa basin located just southwest of the Pantex Plant (fig. 1) on the U. S. Department of Defense's former Pantex Ordnance Plant, for comparison with results from other basins (Sevenmile Basin, Pantex Playa 3, and Pantex Lake) as well as with results from seismic data collected in interplaya areas.

Between 1991 and 1994, the Bureau of Economic Geology (BEG) collected 50 km of shallow seismic reflection data in interplaya and playa basin settings (fig. 1 and table 1). Regional interplaya data (lines PRL1, 2, 3, 4, and 5) were collected in 1991 on the Pantex Plant, on the perimeter of the plant, and in the Amarillo well field north of the plant (Paine, 1992). These lines show that (a) major reflecting horizons include the top of bedrock, a lower Ogallala reflector, and a persistent upper Ogallala reflector that correlates with a perching horizon composed of a sequence of water-saturated interbedded clays and fine sands detected in well logs; and (b) elevation of the interpreted perching horizon remains relatively constant across the area whereas the bedrock and lower Ogallala reflectors dip to the northeast.

In 1992, data collection in playa basin settings began with a reflection line across Sevenmile Basin, a large playa basin located just south of the Pantex Plant (Paine, 1993, 1994a). Subsurface images across this basin showed that all major reflecting horizons dip into the basin and that relief on these surfaces increases with age, indicating a strong subsidence influence in the formation of the basin. Playa basin studies were expanded in 1993 with two lines across Playa 3 (Paine, 1994b) and one long line across Pantex Lake (Paine, 1994c).

Playa 5, the subject of this report, is a nearly circular playa that is 0.9 km across in an east-west direction and 0.7 km across in a north-south direction (fig. 2). It occupies a larger basin enclosed by the 3515-ft (1071-m) elevation contour. The longest dimension of the basin, 2.0 km, is northwest-southeast; the basin is

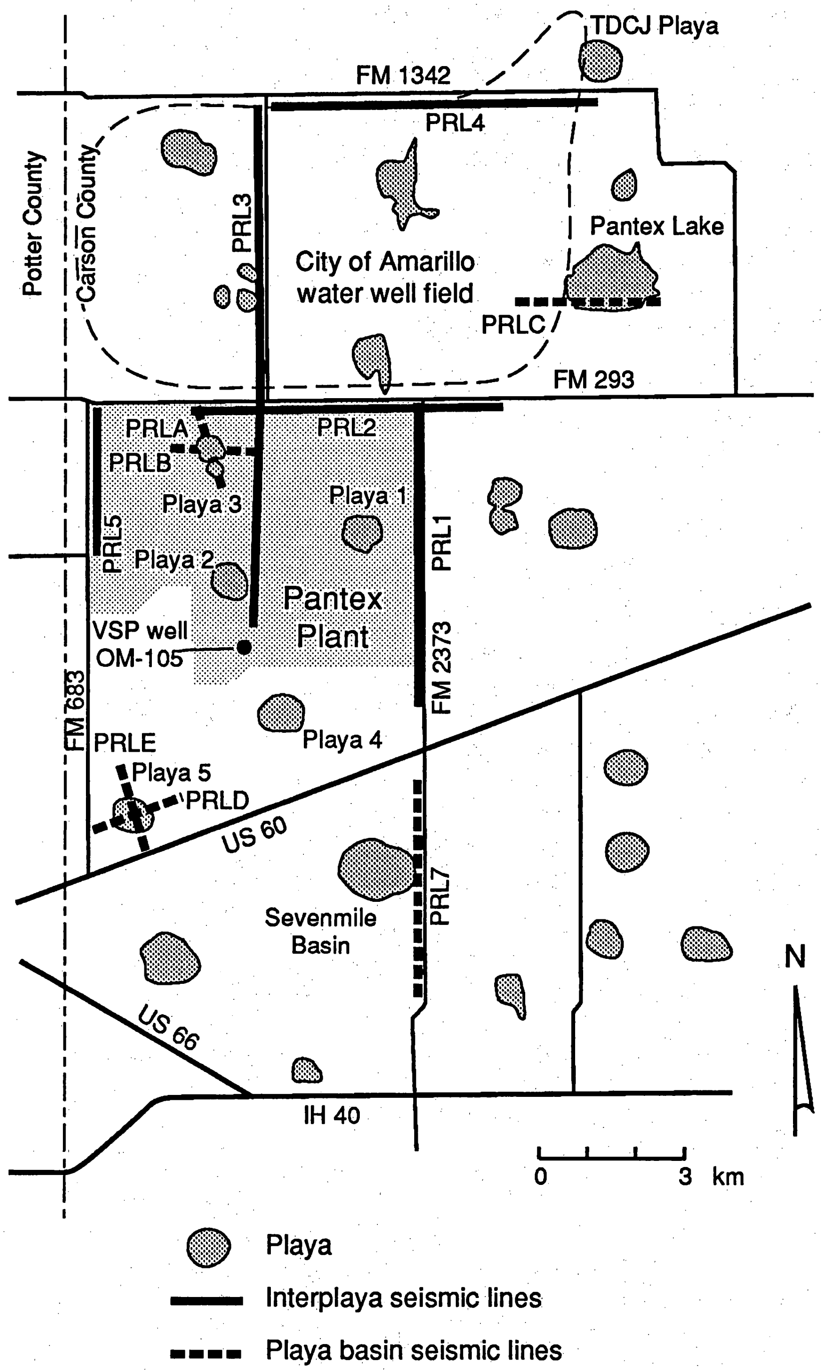

Figure 1. Locations of Bureau of Economic Geology playa and interplaya seismic lines.

Table 1. Line lengths for shallow seismic reflection data collected in the vicinity of the Pantex Plant in 1991, 1992, 1993, and 1994. Line locations shown in fig. 1.

	Length (km)
Interplaya lines	
PRL1	6.5
PRL2	7.3
PRL3	11.3
PRL4	6.5
PRL5	3.2
Total interplaya lines	34.8
Playa basin lines	
PRL7 (Sevenmile Basin)	4.5
PRLA (Playa 3)	1.8
PRLB (Playa 3)	1.8
PRLC (Pantex Lake)	3.2
PRLD (Playa 5)	1.9
PRLE (Playa 5)	1.9
Total playa basin lines	15.1
Total interplaya and playa basin lines	49.9

1.7 km across in an east-west direction. Elevation on the playa floor is as much as 10 m below that of the upland surrounding the playa, but relief between the highest and lowest closed elevation contours is about 5 m. The basin falls in the middle range of playa basins sizes (fig. 3) determined for 221 basins in 20 nearby quadrangles (Gustavson and others, 1980).

METHODS

Shallow seismic refraction and reflection techniques provided new information on the stratigraphy, structure, and physical properties of the upper two or three hundred meters beneath Playa 5. Conductivity, gamma, and drillers' logs from three monitoring wells drilled at Playa 5 by Ebasco Services (Ebasco, 1994) were combined with surface seismic data to support interpretations of features on the seismic reflection section.

Well Logs

Monitor wells FPOP-MW-04, FPOP-MW-05, and FPOP-MW-06 (fig. 2) were drilled between

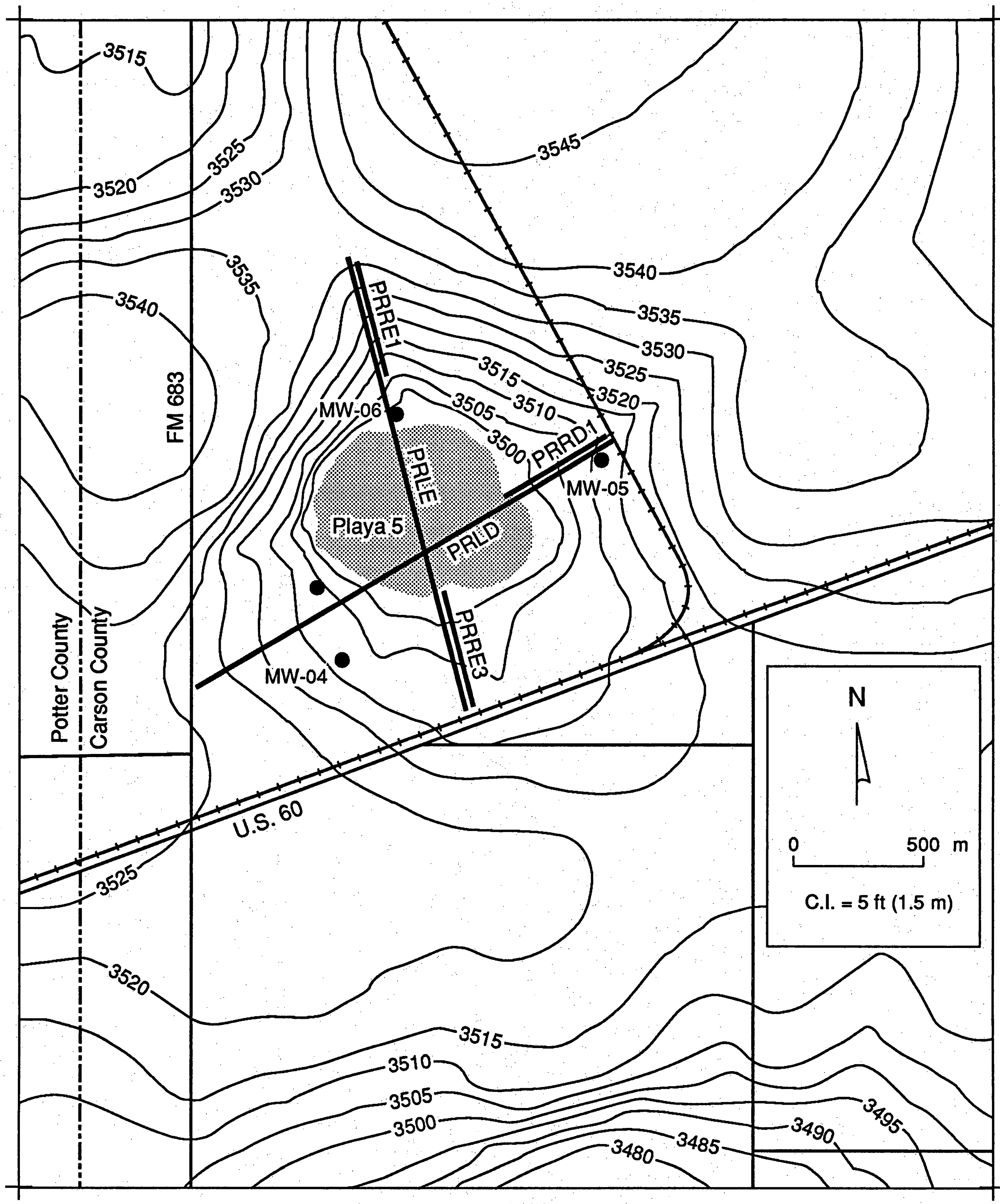

Figure 2. Location of seismic reflection lines PRLD and PRLE, refraction spreads PRRD1, PRRE1, and PRRE3, and monitor wells FPOP-MW-04, FPOP-MW-05, and FPOP-MW-06.

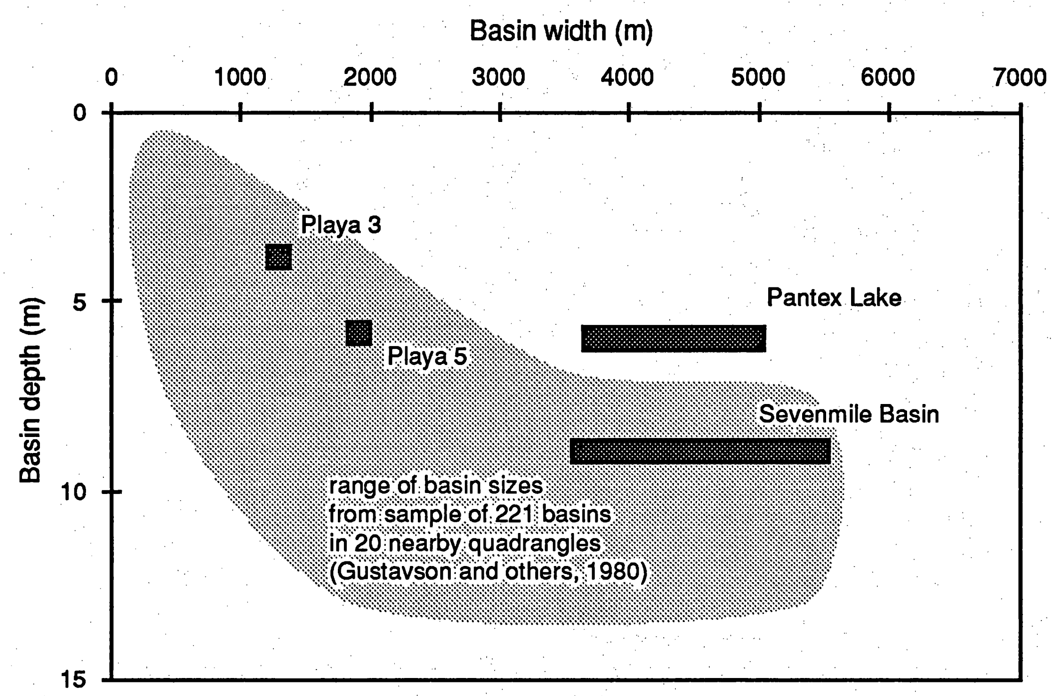

Figure 3. Depth and width of Pantex area playa basins superimposed on range of playa basin sizes.

December 1993 and February 1994 by Ebasco Services for the U.S. Army Corps of Engineers. These wells were drilled to depths of between 80 and 91 m on the periphery of the playa (fig. 2), and samples from each well were described. One of these wells, MW-06, was logged using induction and gamma ray probes. Induction logs indicate the conductivity in the subsurface adjacent to the borehole. Induction logging measures conductivity indirectly by creating an alternating electromagnetic field around a transmitting coil. This varying field induces current to flow in the formation, which in turn creates a secondary magnetic field that induces a current to flow in a receiver coil. The strength of the secondary field and the strength of the receiver current are proportional to the conductivity of the formation. Conductivity in the subsurface is typically a function of water content, the conductivity of the water, and the pore structure (Schlumberger, 1989). Because clay, sand, and gravel have differing porosities and pore structures, they can be differentiated on resistivity and induction logs. Clay and clay-rich deposits typically have lower resistivities (higher conductivities) than do sand and sand-rich deposits.

The gamma logger responds to textural changes only, allowing a better understanding of textural changes with depth and reducing the ambiguity of electromagnetic data. Nearly all naturally occurring gamma radiation is emitted by an isotope of potassium (K^{40}) and isotopes in the uranium (U^{238}) and thorium (Th^{232})

decay series. Gamma probe response is proportional to weight concentrations of these radioactive isotopes in the logged material and is practically proportional to K_2O content, which is generally higher in clays than in siliceous sands (Schlumberger, 1989).

Seismic Methods

The seismic source chosen for the seismic reflection and refraction work at Playa 5 is the Bison EWG-III, a noninvasive, stackable 500-lb (230-kg) accelerated weight drop unit (table 2). Data were acquired on a 48 channel Bison 9048 seismograph, transferred to a computer, and processed. Acquisition personnel included a survey crew of two who operated an optical theodolite and metric staff and surveyed shotpoint and geophone locations and a seismic crew of three who operated the seismograph, moved the source from shotpoint to shotpoint, fired the source, and moved and installed cables and geophones. Crew members were supplied by the Bureau of Economic Geology (BEG). All data were acquired in December 1994. Because the acquisition system uses metric units, discussion of acquisition parameters and geophysical properties is in metric units. Metric system units are also used in discussions of calculated depths, elevations, and on-the-ground distances.

Seismic Refraction

Refraction data were collected at three sites (PRRD1, PRRE1, and PRRE3, fig. 2) along reflection lines PRLD and PRLE at Playa 5. The geophone spread at each site consisted of 48 40-Hz geophones spaced at 5-m intervals along a surveyed line 235 m long (table 2). The weight-drop source was fired at five sites spaced 117.5 m apart: one at the center of the geophone spread, one at each end of the spread, and one 117.5 m beyond each end of the spread. Source to receiver offsets ranged from 2.5 to 352.5 m. The number of shots at each shotpoint increased from 1 to 3 at the center of the geophone spread to a maximum of 12 when the source was farthest from the geophones. Data were recorded on the seismograph with a 1-millisecond (ms) sample interval, a 1-s record length, and a 4-Hz low-cut filter, the lowest possible setting (table 2).

After the refraction data were transferred to a computer, first arrivals were picked using SPW and then exported to a spreadsheet program in which layer assignments and apparent velocity measurements were made and zero-offset intercept times were calculated for critically refracted arrivals. True velocities, layer

Table 2. Equipment, acquisition geometry, recording parameters, and field statistics for seismic refraction and reflection surveys at Playa 5, Pantex Plant.

	Refraction			Reflection	
	PRRD1	PRRE1	PRRE3	PRLD	PRLE
Equipment					
Seismic source	Bison EWG III	Bison EWG III	Bison EWG III	Bison EWG III	Bison EWG III
Geophones	40 Hz	40 Hz	40 Hz	40 Hz	40 Hz
Seismograph	Bison 9048	Bison 9048	Bison 9048	Bison 9048	Bison 9048
Geometry					
Source offset	2.5 to 352.5 m	2.5 to 352.5 m	2.5 to 352.5 m	25 m	25 m
Source spacing	117.5 m	117.5 m	117.5 m	5 m	5 m
Spread length	235 m	235 m	235 m	235 m	235 m
Source-receiver geometry	-	-	-	End on	End on
Geophones in array	1	1	1	1	1
Geophone spacing	5 m	5 m	5 m	5 m	5 m
Recording parameters					
Recording channels	48	48	48	48	48
Sample interval	0.001 s	0.001 s	0.001 s	0.001 s	0.001 s
Record length	1 s	1 s	1 s	1 s	1 s
Analog low-cut filter	4 Hz	4 Hz	4 Hz	16 Hz	16 Hz
Analog high-cut filter	500 Hz	250 Hz	250 Hz	250 Hz	250 Hz
Statistics					
Line length	-	-	-	1900 m	1855 m
Orientation	ENE-WSW	NNW-SSE	NNW-SSE	ENE-WSW	NNW-SSE
Shots per shotpoint	1 to 12	3 to 12	3 to 12	4	4
Date acquired	12/1/94	12/2/94	12/3/94	12/1 to 12/2/94	12/2 to 12/3/94

thicknesses, and apparent dip angles were calculated using the slope-intercept method (Palmer, 1986; Milsom, 1989).

Seismic Reflection

Acquisition Geometry

Two shallow seismic reflection lines were acquired across Playa 5 (fig. 2) using the common depth point method adapted to the shallow subsurface (Mayne, 1962; Steeples and Miller, 1990). Acquisition geometry was similar to that used for most other playa and interplaya seismic lines (Paine, 1992, 1993, 1994b,c): 5-m source and receiver intervals, 25-m minimum source to receiver distance, 260-m maximum source to receiver distance, and 24-fold data acquisition (table 2). Source-receiver geometries were asymmetric (end on), with the weight-drop source trailing a 48-geophone spread. Single 40-Hz geophones were used at each geophone location for both lines.

Seismic Tests

Seismic tests performed in the Pantex area included noise, filter, and stacking tests. For these tests, the seismograph was connected to a spread of 48 geophones spaced at 5-m intervals. For the noise test, the seismograph recorded background seismic noise with no source activated. This test and observations made during the remainder of the survey revealed that only wind was an important source of noise. Wind noise was severe at times and was largely unavoidable.

The optimum source-receiver offset range for the reflection survey was determined during previous seismic surveys with walkaway tests. In these tests, the source was fired at successively greater distances from the geophone spread with the low-cut filter at its lowest setting. The optimum offset range begins as close to the source as possible, but not so close that the nearest geophones are saturated with high-amplitude surface waves or source-related noise. The farthest offset should be equal to or greater than the depth of the deepest target. Based on these tests, a 25-m minimum source-receiver offset and a 5-m geophone spacing were chosen. Maximum source-receiver offset was thus 260 m.

Filter tests were conducted to determine the optimum setting for the analog low-cut filter. The intent was to raise the filter as high as possible to reduce unwanted surface wave noise, but low enough to allow the deepest events of interest to be recorded. Tests using the chosen acquisition geometry showed that the optimum filter setting was 16 Hz (table 2).

Stacking tests were also conducted using the source-receiver geometry selected for the reflection lines. The source was fired repeatedly into the geophone spread in an attempt to increase the signal to noise ratio by partly canceling random noise. Four source stacks per shotpoint were chosen as a compromise between improvement in data quality and the pace of the survey.

Other acquisition parameters chosen based on these tests included a seismograph sampling interval of 1 ms, a record length of 1 s, and an anti-alias (high cut) filter setting of 250 Hz (table 2).

Processing

Seismic reflection data acquired at Playa 5 were transferred each evening to a Macintosh Quadra 700 computer and stored on 8 mm digital tape. After the field work was completed, the data were processed at

BEG using the software Seismic Processing Workshop (SPW). Processing procedures (table 3) were those common to many types of reflection processing (Yilmaz, 1987).

At BEG, the first processing step was to convert the data files from seismograph format to SPW format. Next, trace headers were created that combined the seismic data with acquisition geometry information recorded by the seismograph operator and the surveyor. Dead or excessively noisy traces were then deleted from the data set, which was resampled to a 2-ms sample interval to reduce the size of the data set. Automatic gain control was applied to amplify weak arrivals at late times or distant offsets. A mute function was designed to delete the first arrivals from each shot gather to prevent them from stacking as a false reflector. Another mute function was designed to remove the air wave, or the sound of the source weight striking the ground plate, from each shot gather. Datum corrections were then made to each trace that shifted them to a common elevation. A low-pass filter was then applied to remove high-frequency wind noise. A dip filter was applied in the frequency-wave number domain to attenuate high-amplitude, slow-moving surface waves. This step was followed by shot deconvolution, which collapses the long and reverberatory source wavelet into a sharper wavelet that is easier to interpret on a stacked section. Velocity analysis was conducted by fitting reflection hyperbolas to events on common midpoint (CMP) gathers, or gathers of all traces that have the same source-receiver midpoint. For 24-fold data, there are 24 traces in a CMP gather. A bandpass filter was then applied to remove unwanted low- and high- frequency noise.

The velocity function derived from the CMP gathers was used to correct each trace in the CMP gather for normal moveout (the delay in arrival time caused by increasing source-receiver offset) and to simulate zero offset for all traces. Each velocity-corrected trace in a CMP gather was summed to produce a single composite trace. A stacked seismic section is a display of these composite traces. The final step was to shift each trace in the stacked section by a constant time interval to move the stacked section to the final datum elevation.

RESULTS

Seismic data collected at Playa 5 included both refracted and reflected seismic energy. The three refraction surveys PRRD1, PRRE1, and PRRE3 revealed information on the seismic velocity structure of the upper 50 to 100 m of the subsurface, whereas seismic reflection lines PRRD and PRRE showed the configuration of prominent subsurface reflecting horizons beneath the playa and adjacent interplaya areas.

Table 3. Processing steps, parameters, and purpose of each step used to convert seismic reflection data collected at Playa 5 to final seismic sections. Data processed using Seismic Processing Workshop (Parallel Geoscience Corporation).

Processing step	Parameters	Purpose
SEG-2 input	1 ms sample rate, 1 s record length	Convert seismic data from Bison format to processing format
Create trace headers	Seismic data, surveyor and observer notes	Combine acquisition geometry and shot records
Trace edit		Remove bad traces
Resample	2 ms sample rate	Reduce size of data set
Automatic gain control	400 ms window	Amplify weak arrivals at late times or far offsets
Early and surgical mute		Mute first break and air wave
Datum correction	800 m/s velocity	Adjust all traces to preliminary surface datum
Low pass filter	100 Hz, 18dB/octave rolloff	Attenuate high-frequency wind noise
Dip filter	Reject 10 to 500 m/s, < 200 Hz	Attenuate surface waves
Shot deconvolution	Predictive, 1 % whitening 100 ms inverse filter length 0 ms design window start 500 ms design window length 20 ms prediction length	Shrink wavelet
Common midpoint sort		Collect all traces with same source-receiver midpoint (CMP)
Velocity analysis	Semblance plot, 400 to 1900 m/s Hyperbola picking	Pick stacking velocities for moveout correction
Bandpass filter	Pass 20 to 70 Hz	Remove unwanted low- and high-frequency noise
Normal moveout correction	Velocity function every 20 CMPs (50 m)	Simulate zero offset for all traces
Common midpoint stack	All traces	Stack all traces with same source-receiver midpoint (CMP)
Apply static shifts	800 m/s; 1093 m elevation	Move all traces to final datum (1093 m)

Refraction Data

Refraction Spread PRRD1

Refraction spread PRRD1 was located on the upland east of Playa 5 along reflection line PRLD (fig. 2). Forward (shots east of receivers) and reverse (shots west of receivers) data show three groups of first arrivals (fig. 4a). The first group is nearest the souce and represents a compressional wave that travels directly from the source to the receiver without appreciable refraction. This wave is the first arrival out to between 10 and 15 m from the source; its velocity is estimated to be 392 m/s for the forward shots and 465 m/s for the reverse shots. The relatively large difference in calculated velocity for the direct arrival is caused by the narrow offset range over which it is observed.

At slightly longer offset distances, the first critically refracted wave is the first arrival (fig. 4a). This wave is a compressional wave that travels from the source to a subsurface seismic boundary, is critically refracted along that boundary, and returns to the surface. The first critically refracted wave is the first arrival at offset distances greater than 10 to 15 m for forward shots and 15 to 20 m for reverse shots. It has an apparent velocity of 788 m/s in the forward (westward) direction and 857 m/s in the reverse (eastward) direction. Beyond offset distances of 165 m for forward shots and 120 m for reverse shots, a second critically refracted wave is the first arrival. This wave was critically refracted at a deeper and faster subsurface horizon than the first refraction. It has apparent velocities of 2029 m/s in the forward direction and 1864 m/s in the reverse direction.

Once apparent velocities and zero offset times are calculated for the direct and refracted waves, true velocities and dips for each of the detected subsurface layers can be estimated (Palmer, 1986). For refraction spread PRRD1, layer 1 (the surface layer) is estimated to be 3.4 m thick with an average velocity of 425 m/s. Beneath this layer is layer 2, which is calculated to be 59 m thick with a seismic velocity of 821 m/s. The top of this layer has an apparent dip of 1.5° westward. Layer 3, the deepest layer recognized in the refraction data, has a velocity of 1942 m/s. Its upper surface is calculated at 62 m and has an apparent dip of 3° westward.

Seismic data and descriptions of sediment samples taken during the drilling of well FPOP-MW-05 (Ebasco, 1994), located just south of refraction spread PRRD1 (fig. 2), suggest that the low-velocity surface layer consists of sandy clay with organic matter and little soil carbonate (fig. 5). The intermediate-velocity layer below this probably represents a zone of soil carbonate accumulation in sediments having texture similar to

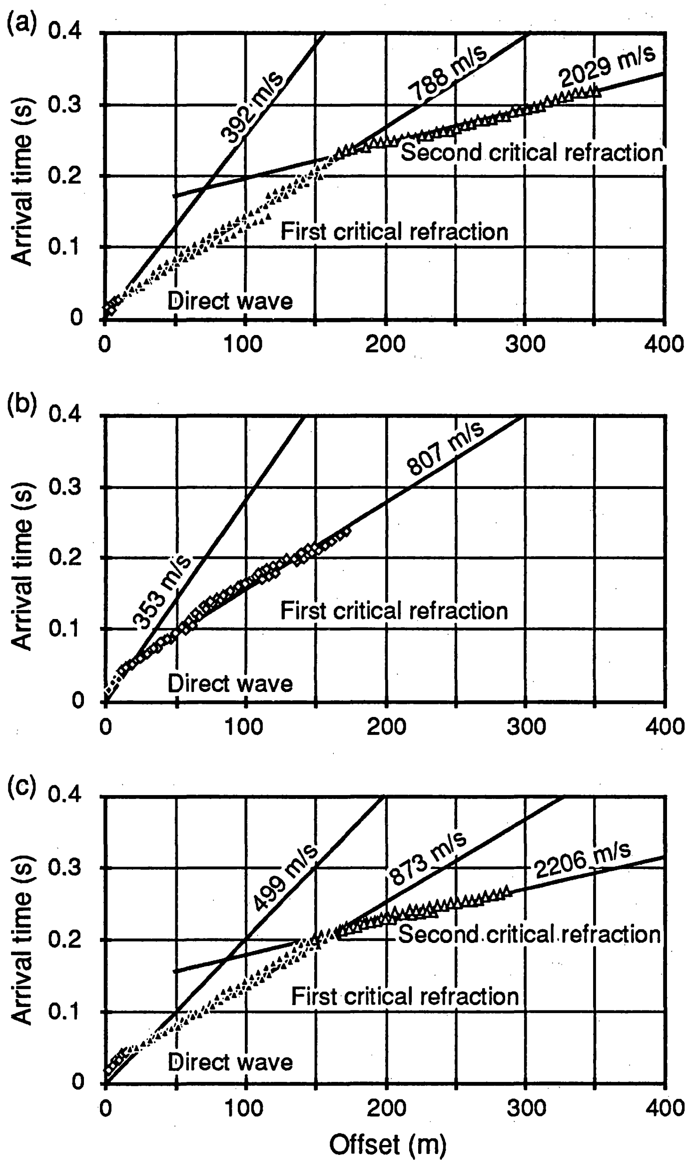

Figure 4. First arrival picks, layer assignments, and best-fit apparent velocities for refraction spreads (a) PRRD1, (b) PRRE1, and (c) PRRE3.

those in the surface layer. The basal, high-velocity layer may represent the water table at a true depth of 75 m or a carbonate-cemented horizon above it. Calculated depths to this horizon may be in error if the velocity calculated for layer 2 is not representative of the entire layer, as would be the case if it is a pedogenic carbonate horizon.

Refraction Spread PRRE1

Spread PRRE1 is located north of Playa 5 along reflection line PRLE (fig. 2). For both forward (shots north of receivers) and reverse (shots south of receivers) data, a direct wave is the first arrival from the source

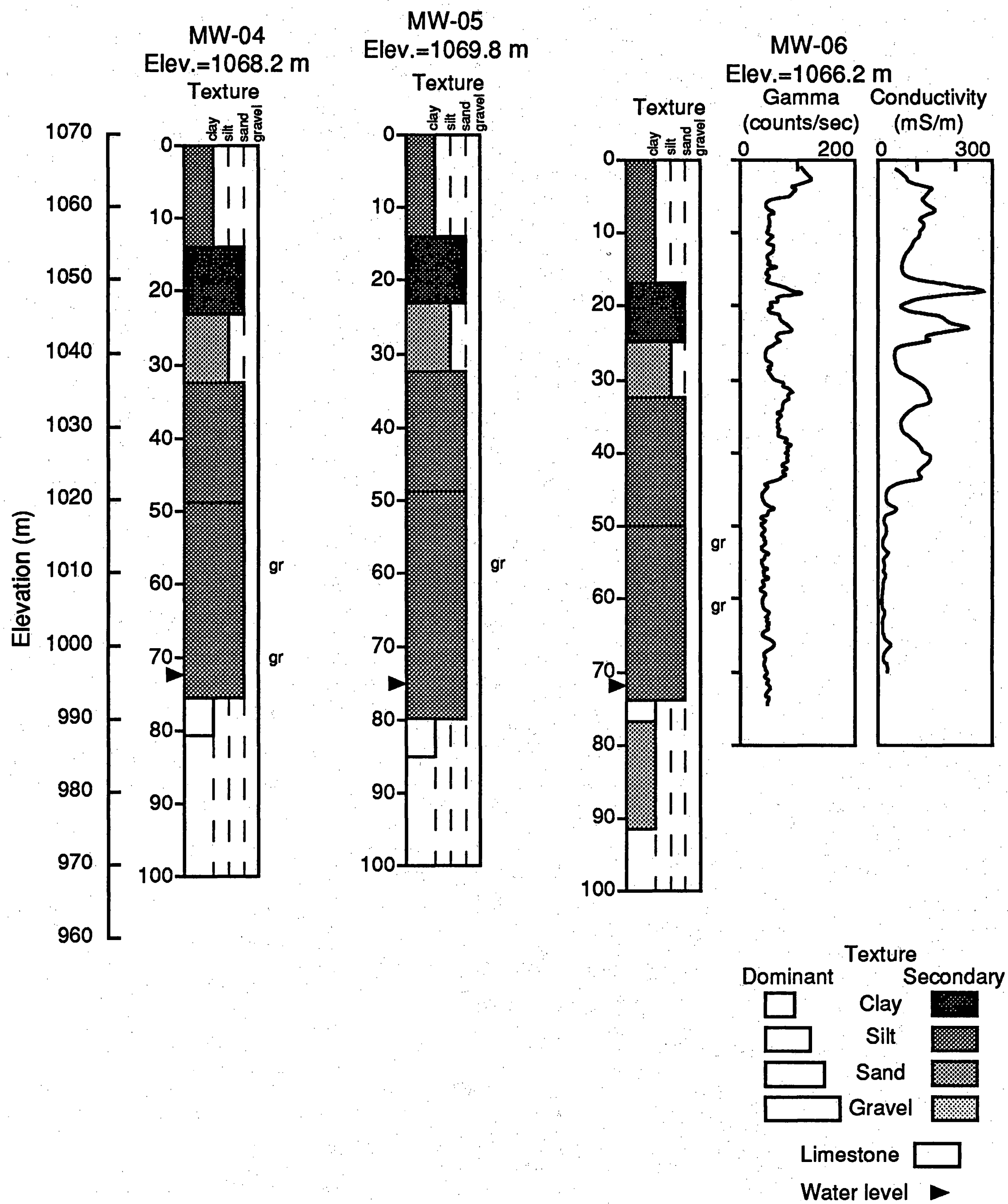

Figure 5. Textural, gamma ray, and conductivity logs of monitor wells FPOP-MW-04, FPOP-MW-05, and FPOP-MW-06. Data from Ebasco (1994). Dominant texture ("silt" of sandy silt, for example) is keyed to width of textural units and secondary texture ("sandy" of sandy silt) is keyed to pattern within textural units.

to a very short offset distance of 10 m (fig. 4b). Velocities calculated for the direct arrival are 353 m/s for the forward (southward) direction and 259 m/s for the reverse (northward) direction. Between 10 m and about 170 m offset, the first critically refracted wave is the first arrival. Apparent velocities calculated for this arrival are nearly the same for forward (807 m/s) and reverse (810 m/s) directions. There is no clear refracted arrival beyond 170 m offset.

The velocity of the direct arrival in the forward direction is less than the velocity of a compressional wave in air, which suggests that either the velocity is miscalculated because of the narrow range of offset distances or the direct compressional wave is weak and a slow-moving surface wave is being detected as the first arrival at very short offsets. In either case, the calculated velocity for the direct compressional wave is too low. Average velocities calculated for the surface layer at the other two refraction spreads are between 420 and 440 m/s and are probably similar to those for the surface layer at spread PRRE1. The true velocity calculated for layer 2 is 808 m/s, similar to that calculated for spread PRRD1. This layer has a southward (basinward) dip of about 1°. Because no second critically refracted arrival was detected, the depth to the top of layer 3 is unknown.

Refraction Spread PRRE3

Spread PRRE3 is located on the upland south of Playa 5 along reflection line PRLE (fig. 2). Direct waves were the first arrivals for both forward (shots north of receivers) and reverse (shots south of receivers) data at offsets of 15 m or less (fig. 4c). The large difference between calculated direct wave velocities in the forward (499 m/s) and reverse (383 m/s) directions is due to arrival time uncertainties and short offset ranges for these arrivals. The first critically refracted wave is the first arrival between 15 and 165 m offset in the forward direction and between 15 and 190 m in the reverse direction. Apparent velocities calculated for the first refracted arrival are 873 m/s for the forward direction and 950 m/s for the reverse direction. A second critically refracted wave is the first arrival out to an offset of 290 m for the forward direction and to 350 m for the reverse direction. Apparent velocities for this wave are 2206 m/s in the forward direction and 2025 m/s for the reverse direction.

True velocities and layer dips calculated for spread PRRE1 indicate a low-velocity surface layer that is about 6 m thick. Its average velocity, 433 m/s, is similar to that for the surface layer at spread PRRD1. Below this is an intermediate-velocity layer that is calculated to be 55 m thick. It has a velocity of 910 m/s, and its upper surface dips less than 1° to the south. The deepest layer detected has a calculated velocity of 2111 m/s. Its upper surface is calculated to be 61 m deep and has an apparent dip of 3° to the south. From descriptions of sediments drilled at well FPOP-MW-04, located about 400 m west of spread PRRE3 (fig. 5), the surface low-velocity layer is a relatively organic-rich sandy clay. Higher velocities in layer 2 probably reflect higher pedogenic carbonate content in sediment with a texture similar to that in layer 1. Layer 3 may represent a well-indurated horizon within the Ogallala Formation or it may represent a critical refraction along the water table, which occurs at a depth of 72 m in well FPOP-MW-04.

Reflection Data

Reflection Line PRLD

Line PRLD crosses Playa 5 from east-northeast to west southwest (figs. 1, 2, and 6a) and is 1900 m long (table 2). Data quality along this line is moderate because of severe wind noise and the presence of a very loose surface layer on the playa floor. Inconsistent seismograph triggering also reduced data quality along the western 500 m of this line, which is deleted from the seismic section (fig. 6b).

Despite data quality problems, major and minor reflecting horizons are visible on line PRLD (fig. 6a). Major reflecting horizons are named, from shallowest to deepest, Horizons 0, 1, and 3. These horizons tie with similarly named horizons on crossing line PRLE. Reflections from Horizon 0 arrive at about 100 ms two-way time and are most prominent east of the playa floor between survey points (SP) 30 and 100 (figs. 6a and 6b). This reflector may continue westward to SP 190 beneath the playa floor, but the reflection is not as strong. The reflector is absent west of SP 190. Two-way arrival times for this reflector can be converted to depths using a velocity function derived from PRLD reflection data and a nearby vertical seismic profile (fig. 7). Calculated depths to Horizon 0 range from 24 to 35 m east of SP 100 (fig. 8). Where present along line PRLD, the elevation of this horizon is between 1033 and 1045 m (fig. 9). Descriptions of samples from well FPOP-MW-05 (fig. 5) show textural changes from clayey sand to sandy silt at 23 m depth and from sandy silt to silty sand at 32 m depth that may produce enough contrast in acoustic properties to cause a reflection. This reflecting horizon also occurs near the expected depth of the Ogallala caprock.

Several minor reflectors are evident on line PRLD beneath the playa floor between 100- and 200-ms

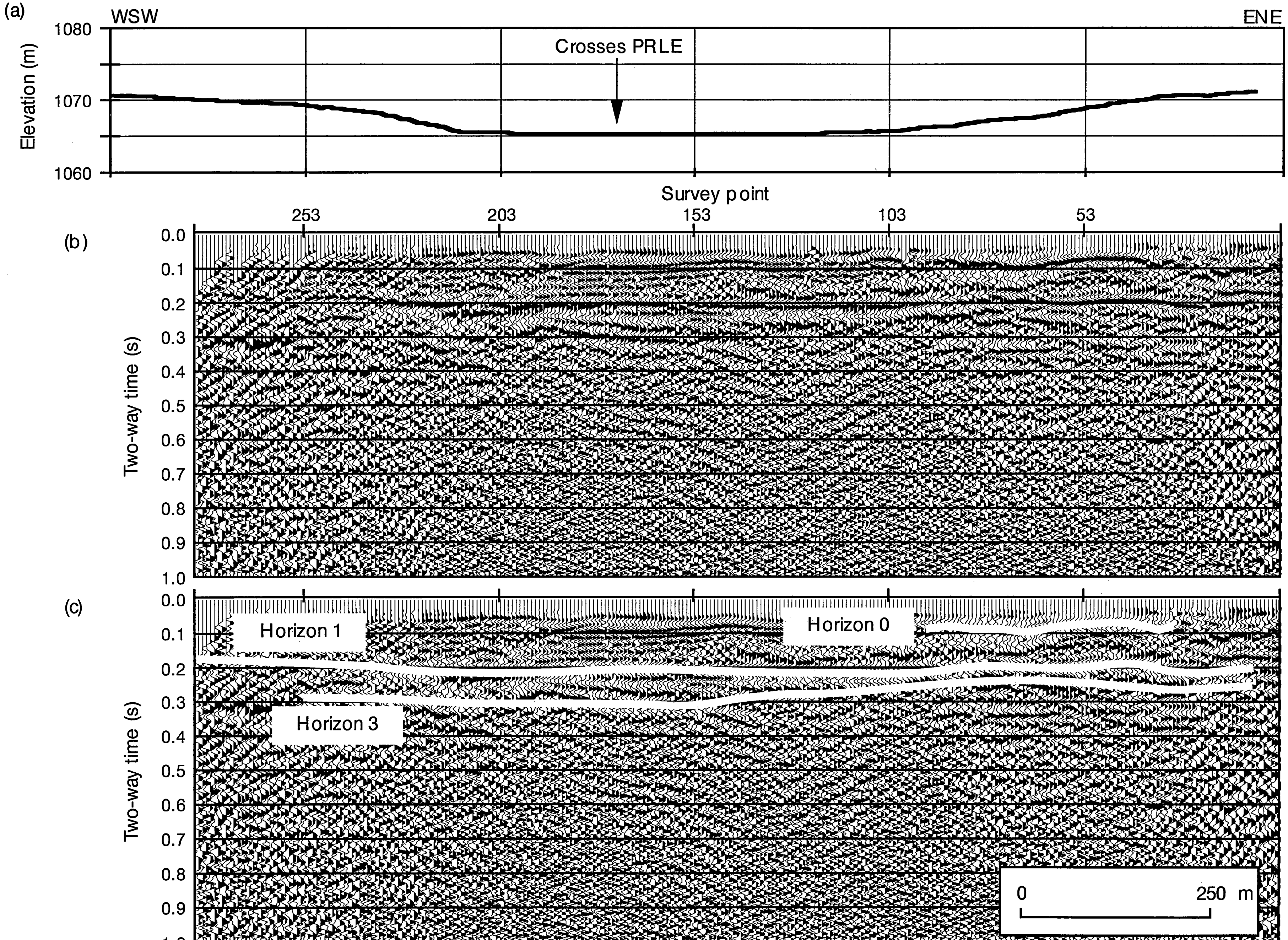

Figure 6. Surface elevation, uninterpreted seismic section, and interpreted seismic section along reflection line PRLD. Survey points are shown on x-axis. Two-way times relative to 1093-m elevation datum.

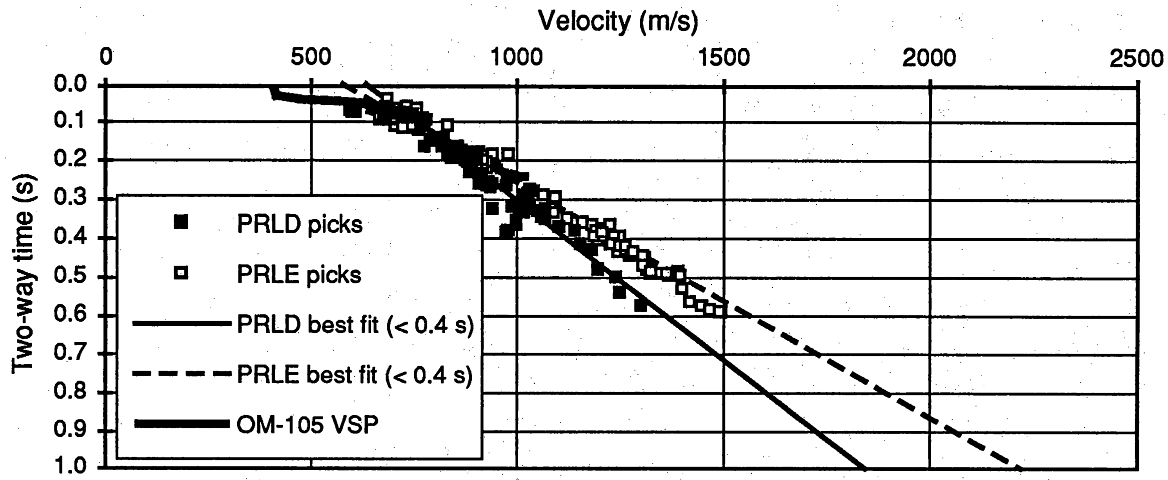

Figure 7. Stacking velocity picks and best-fit velocity functions for reflection lines PRLD and PRLE. Also shown is velocity profile from vertical seismic profile at well OM-105.

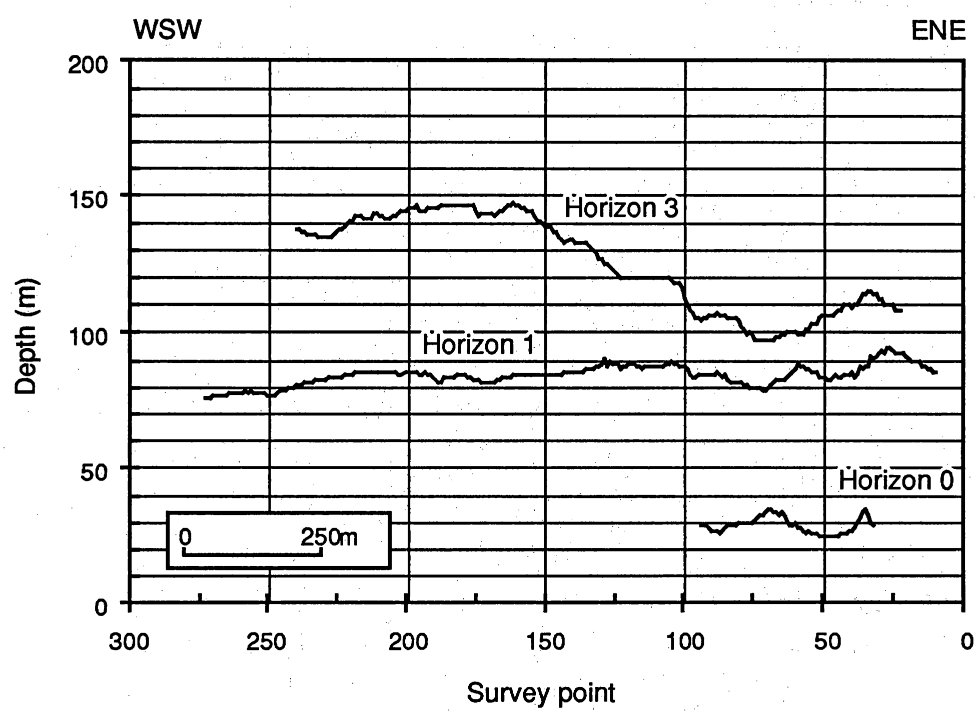

Figure 8. Calculated depths to seismic horizons 0, 1, and 3 along reflection line PRLD.

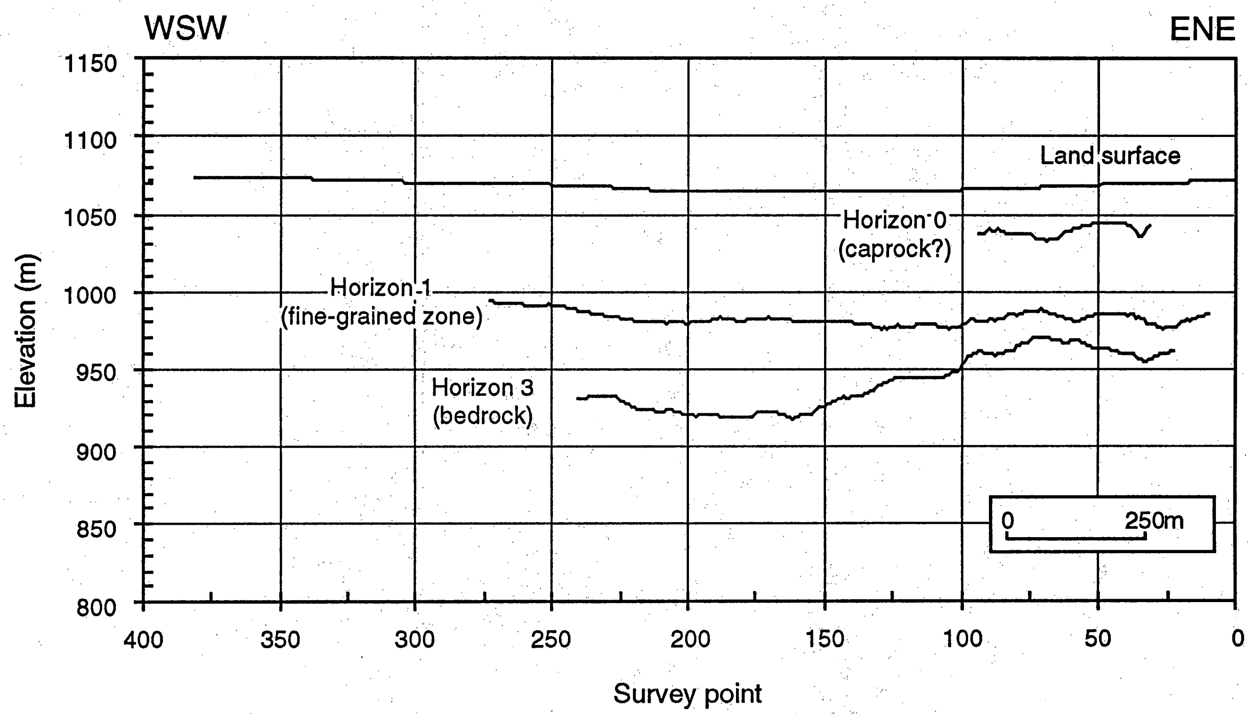

Figure 9. Cross section along line PRLD showing elevations of Horizons 0 (top of the Ogallala Formation), 1 (top of Ogallala fine-grained zone), and 3 (top of bedrock).

two-way time (fig. 6b). They are not as strong as the major reflectors and have limited lateral extent. The number of reflectors varies with position across the playa floor. There are as many as four reflectors between SP 150 and 200 beneath the western part of the playa, but only one or two between SP 100 and 150 beneath the eastern part of the playa. Because they are restricted to the playa floor, these reflectors probably represent past periods of lacustrine deposition within the upper part of the Ogallala Formation. The differing number of horizons across the playa floor indicates that each depositional episode may not have covered the entire floor of the modern playa basin.

The most prominent reflector on line PRLD is Horizon 1, which is at about 200-ms two-way time (fig. 6b,c). It is found at slightly later times beneath the playa floor (200 to 220 ms) than beneath the upland (180 to 200 ms). Depths calculated for Horizon 1 range from 76 to 95 m (fig. 8) and are shallower at the western end of the line. Calculated elevations for this horizon are 975 to 994 m above sea level (fig. 9), with the lowest elevations beneath the playa floor. Textural and water level data from well FPOP-MW-05 show that Horizon 1 has an elevation that is near that of the Ogallala water table (994 m) and that of a thin "limestone" at an elevation of 985 to 990 m described in the textural log of the well (Ebasco, 1994). The most likely source of the Horizon 1 reflector is the carbonate zone because it has a large velocity contrast with surrounding unconsolidated material, it better fits the calculated elevations of Horizon 1, and Horizon 1 has lower elevations beneath the playa than outside of it, which would not be expected if Horizon 1 were a reflection from the Ogallala water table. Calculated elevations of Horizon 1 are near those of a fine-grained zone that perches ground water above the main Ogallala aquifer beneath parts of the Pantex Plant. At Playa 5, however, Ogallala water elevations are higher than those of the perching horizon.

Moderate seismic data quality along line PRLD has rendered Horizon 3 difficult to interpret (fig. 6b,c). Horizon 3 is tentatively interpreted at between 230- and 300-ms two-way time along the line. The horizon has later arrival times beneath the playa floor, particularly on its western part between SP 150 and 200. This area coincides with the lateral extent of several minor reflectors within the upper part of the Ogallala Formation. Calculated depths to Horizon 3 increase from about 100 m beneath the upland east of the playa floor to 135 to 145 m beneath the playa floor (fig. 8). Consequently, calculated elevations of Horizon 3 decrease from 950 to 970 m beneath the upland to as low as 918 m beneath the playa floor (fig. 9). The deepest monitor well drilled near Playa 5, FPOP-MW-06, was drilled only to 91 m, a depth insufficient to reach Horizon 3. The strength of this reflector, its apparent relief, and the lack of other, deeper strong reflectors suggest that it is a reflection from Permian or Triassic bedrock.

Reflection Line PRLE

Line PRLE is 1900 m long and crosses Playa 5 from north-northwest to south-southeast (figs. 1, 2, and 10a; table 2). Data quality is good for most of the line (fig. 10b), except beneath parts of the playa floor where the surface soil was loose. Three major reflectors and many minor reflectors are visible across much of the line. The major reflectors, named Horizons 0, 1, and 3, correlate with similarly named reflectors on line PRLD.

The shallowest of the major reflectors is Horizon 0, which arrives at about 100 ms (fig. 10b and c). It is strongest beneath the upland north of the playa floor (SP 1 to 140), is absent or weak beneath the playa floor, and is present beneath the upland south of the playa (SP 250 to 350). Depths for this horizon, calculated from the velocity function derived for line PRLE (fig. 7), range from 21 to 47 m (fig. 11). Elevations on Horizon 0

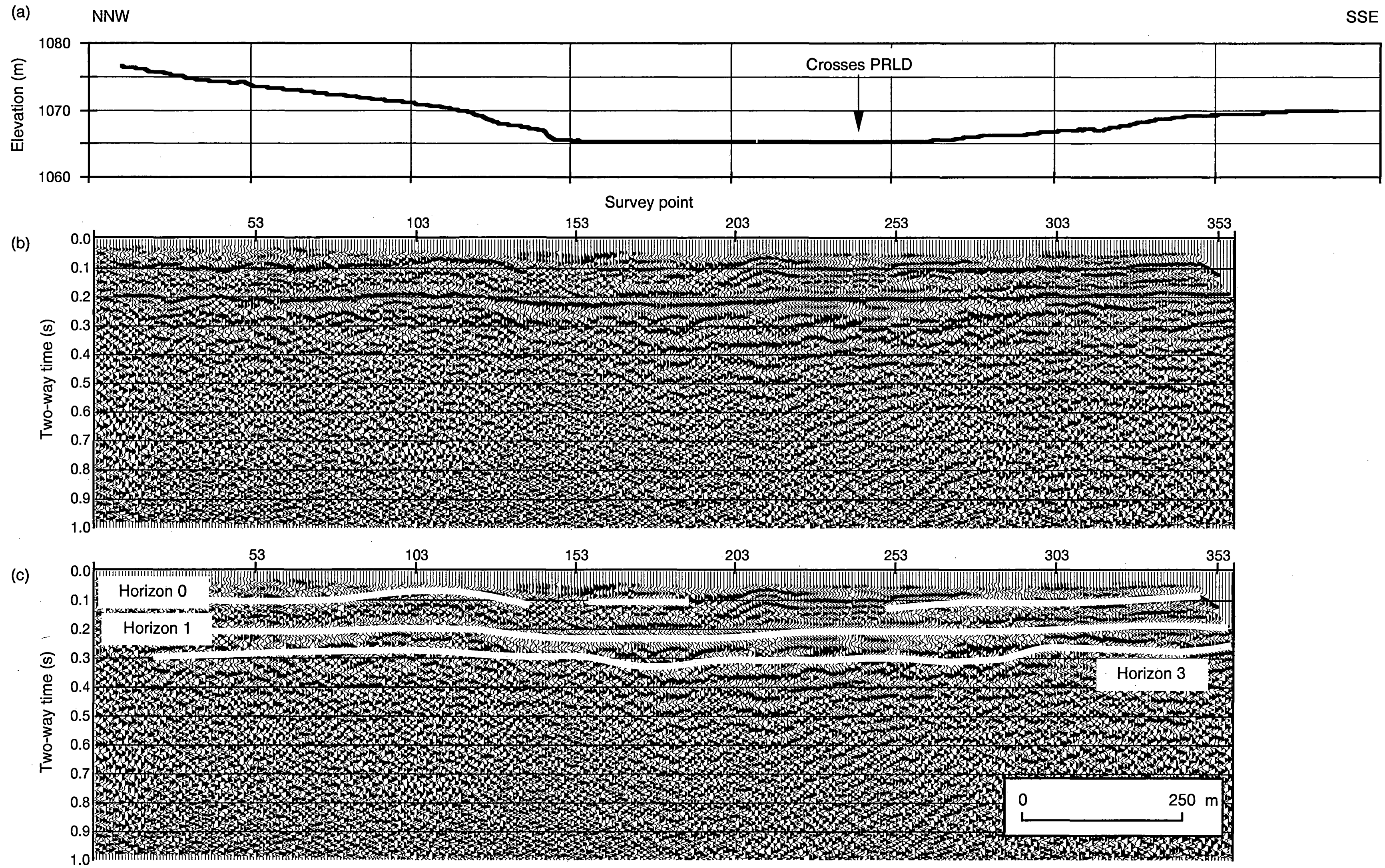

Figure 10. Surface elevation, uninterpreted seismic section, and interpreted seismic section along reflection line PRLE. Survey points are shown on x-axis. Two-way times relative to 1093-m elevation datum.

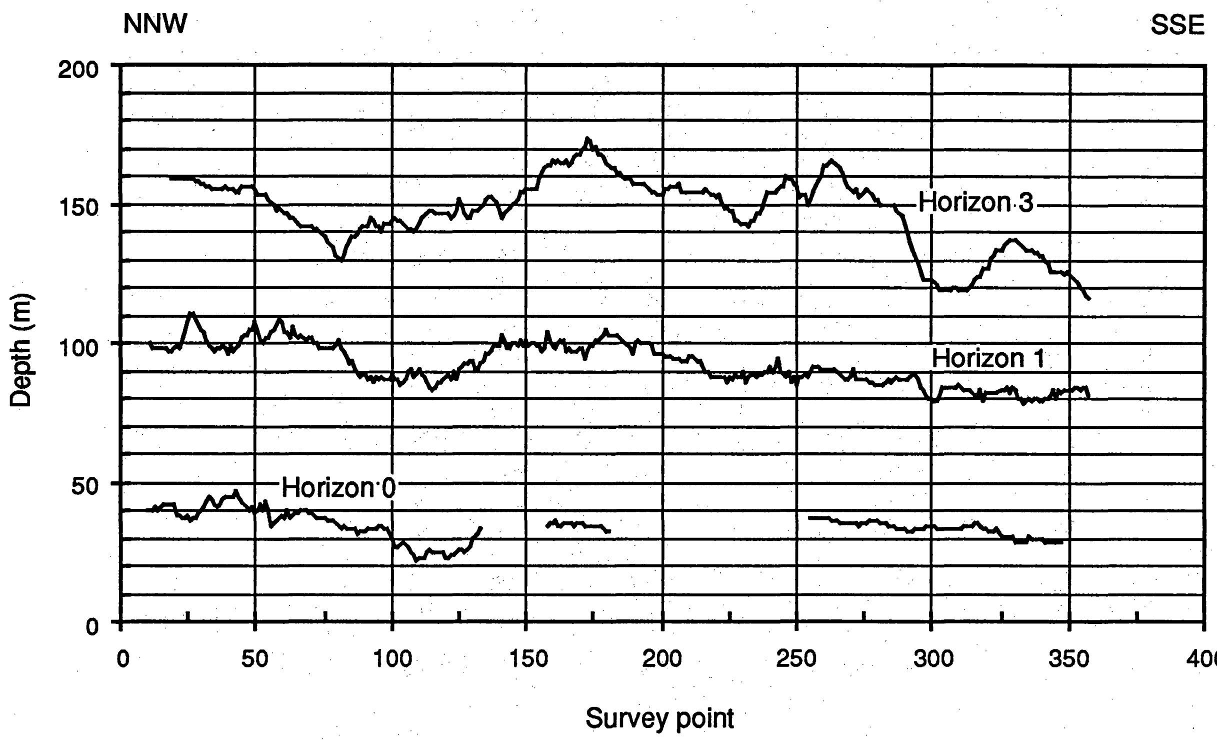

Figure 11. Calculated depths to seismic horizons 0, 1, and 3 along reflection line PRLE.

vary from 1030 to 1049 m above sea level and decrease from the upland to the playa floor (fig. 12). Elevations calculated for Horizon 0 near monitor well FPOP-MW-06 (fig. 2) are near that of a textural change from clayey sand to sandy silt at about 25-m depth (fig. 5), which is also the base of a clay-rich unit that has high gamma count rates and has high electrical conductivity as recorded on geophysical logs of well MW-06. This horizon also occurs at the expected depth of the Ogallala caprock, where increased pedogenic carbonate content may contribute to reflector strength.

There are several minor reflectors of limited lateral extent that are between 100- and 200-ms two-way time beneath the southern part of the playa floor (SP 200 to 250). These reflectors are similar to those seen on line PRLD and probably represent phases of lacustrine sedimentation during upper Ogallala deposition.

Horizon 1 is found at about 200 ms and is the strongest of the major reflectors (fig. 10b,c). This reflector arrives later beneath the northern part of the playa floor (SP130 to 210) at 200 to 220 ms and is earliest at 190 ms at the southern end of the line. Calculated depths of Horizon 1 range from 80 to 110 m and generally shallow to the south (fig. 11). Horizon 1 elevations vary from 960 to 990 m above sea level and are lowest beneath the playa floor (fig. 12). Elevations calculated for Horizon 1 where it passes near monitor well MW-06 correlate

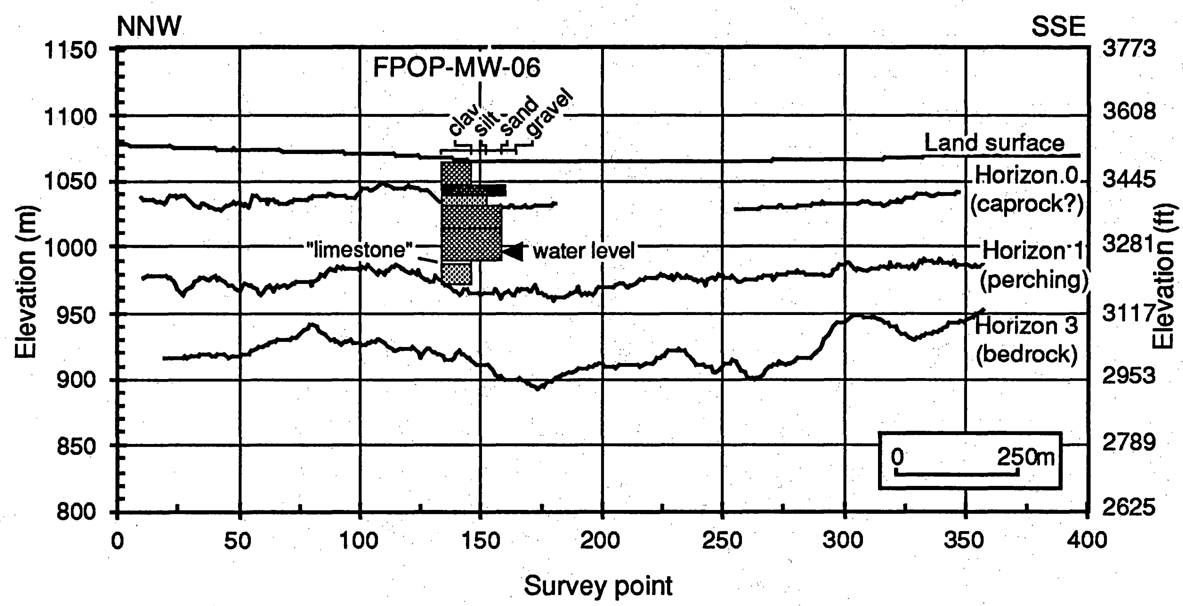

Figure 12. Cross section along line PRLE showing elevations of Horizons 0 (top of the Ogallala Formation), 1 (top of Ogallala fine-grained zone), and 3 (top of bedrock). Also shown is textural log of monitoring well FPOP-MW-06 (fig. 5).

to a "limestone" described during drilling of the well (fig. 5) at an elevation of 990 m. The Ogallala water table is another possible correlation to Horizon 1, but its elevation is 995 m, several meters higher than Horizon 1.

Despite better quality data collected along line PRLE, Horizon 3 is difficult to pick across the entire line (fig. 10b,c). Tentative interpretations show this reflector arriving between 260 and 320 ms, with the latest arrivals beneath the playa floor (SP 150 to 300). Arrival time is earlier beneath the upland south of the playa floor (260 to 280 ms) than it is beneath the upland north of the playa floor (280 to 300 ms). There is considerable relief on this surface; calculated depths for this horizon range from 120 to 170 m and generally shallow to the south (fig. 11). Greatest depths to Horizon 3 are found beneath the playa floor between SP 150 and 280. Estimated elevations on this horizon generally increase southward from 915 m at the north end of the line to 950 m at the south end (fig. 12). Horizon 3 reaches its lowest elevation, 890 m, directly beneath the playa between SP 150 and 280. Stratigraphic interpretation of this horizon is hindered by the fact that the horizon is deeper than any of the three monitoring wells drilled near Playa 5. Nevertheless, it does correlate with Horizon 3 on line PRLD and probably is a reflection from Permian or Triassic bedrock.

A few minor reflectors are present between what is interpreted as Horizon 3 and about 600 ms two-way time (fig. 10b). These reflections are probably from stratal boundaries within Permian bedrock. Some of these reflectors appear to dip toward the center of the basin enclosing Playa 5.

DISCUSSION

Velocity Structure from Refraction Data

Refraction data can be used to examine near-surface velocity variations that arise from differences in soil texture, mineralogy, moisture content, and pedogenic alteration that might be present in playa and interplaya areas. Lower direct wave velocities in playa floor settings than in adjacent upland settings, for example, were used to infer that pedogenic carbonate is less abundant beneath playa floor soils than it is in adjacent areas at Sevenmile Basin, Pantex Playa 3, and Pantex Lake (Paine, in press). At Playa 5, the presence of very loose surface sediment on the playa floor and a short offset range for direct wave observation on the upland did not allow meaningful comparisons of near-surface seismic velocities.

At longer source-receiver offsets, a second critically refracted wave was the first arrival at refraction spreads PRRD1 and PRRE3. It is possible that this refraction is from the Ogallala water table, but the calculated depths for this refractor are shallower than the known water table depths. If the second critically refracted wave is a water table refraction, the discrepancy in depth could be explained if velocities calculated from the first critically refracted wave are lower than those of the entire thickness of that layer. This is not likely in the Blackwater Draw and Ogallala Formations because pedogenic carbonate horizons are common. These horizons can have significantly higher seismic velocities than sediments above and below them; thus, it is more likely that the depth to the second refractor would be overestimated rather than underestimated. Interval velocities calculated from a vertical seismic profile acquired in Pantex well OM-105 (Paine, 1992) show clearly that there is considerable vertical variation in velocity within the Blackwater Draw and Ogallala Formations and that there are at least two high-velocity zones within the Ogallala that are underlain and overlain by lower velocity sediments.

Playa Basin Subsidence

Three observations from seismic refraction and reflection data suggest that subsidence has influenced the formation of the basin that encloses Playa 5. First, refraction data from spread PRRD1 show basinward dips that increase from 1.5° to 3° for progressively deeper seismic layers. Second, seismic reflection sections show that relief between the basin floor and adjacent areas increases with burial depth and thus age, increasing from 6 m of relief at the modern surface to 30 m of relief on Horizon 1 (interpreted to correlate to the fine-grained zone that perches ground water beneath parts of the Pantex Plant), to 50 m on Horizon 3, the interpreted top of Permian or Triassic bedrock (fig. 13). Third, minor reflectors interpreted to be within Permian bedrock show dips toward the basin center beneath the playa floor. As at Sevenmile Basin, Pantex Playa 3, and Pantex Lake, subsidence appears to have influenced playa basin formation at Playa 5. Locally dipping reflectors within bedrock suggest that the subsidence is related to dissolution of salt within underlying Permian strata.

Because the ages of the seismic reflectors are not known, subsidence rates cannot be determined. Subsidence rates can be estimated by using maximum relief on a horizon as a proxy for amount of subsidence and minimum burial depth of that horizon as a proxy for age. These proxies show that Playa 5 has a subsidence history that is similar to that of Playa 3 and Pantex Lake (fig. 13), with average subsidence rates of 0.33 to 0.42 m of subsidence per meter of sediment accumulation. Average subsidence rates for Sevenmile Basin are more than twice as high as those at the other basins.

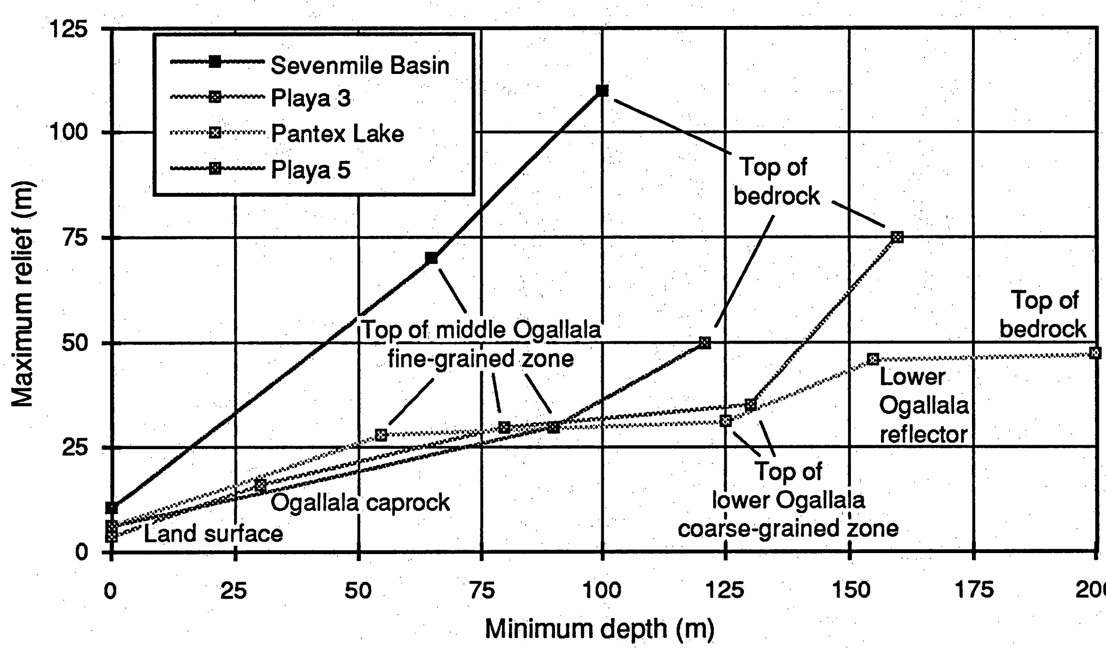

Figure 13. Relationship between maximum relief and horizon depths for Sevenmile Basin, Playa 3, Pantex Lake, and Playa 5.

CONCLUSIONS

Seismic refraction and reflection data collected at Playa 5 on the former Pantex Ordnance Plant revealed information on the physical properties and development of the playa basin. Refraction surveys show that the surface layer is a few meters thick and has typical seismic velocities of 420 to 440 m/s. The surface layer is underlain by a layer with higher seismic velocities of 808 to 910 m/s that has similar texture but probably more pedogenic carbonate. Two of the three seismic refraction surveys detected a deeper layer at more than 60-m depth having significantly higher seismic velocities of about 2000 m/s. This layer probably represents a competent horizon above the modern Ogallala water table that has been cemented by either pedogenic or hydrologic processes.

Seismic reflection data collected across the basin show that relief on seismic horizons increases with age. Modern surface relief at Playa 5 is 6 m, which increases to 30 m on Horizon 1. This horizon, described as a "limestone" in drillers' logs of three nearby monitoring wells, is interpreted to be correlative to a fine-grained zone that perches ground water beneath parts of the Pantex Plant. It does not perch ground water at Playa 5 because its elevation is below that of the main Ogallala water table. Relief further increases to 50 m on Horizon 3, which is interpreted to be the top of Permian or Triassic bedrock. Internal bedrock reflectors dip toward the basin center beneath the playa, suggesting that subsidence related to dissolution of underlying Permian salt has contributed to the development of the basin enclosing Playa 5. Subsidence at Playa 5 has occurred at average rates of 0.33 to 0.42 m per meter of deposition. These rates are similar to those estimated from seismic data collected across Playa 3 and Pantex Lake and are less than half those inferred for Sevenmile Basin.

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