SHALLOW SEISMIC STUDIES OF AN EPHEMERAL LAKE (PLAYA) BASIN ON THE SOUTHERN HIGH PLAINS, TEXAS PANHANDLE

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Abstract

Shallow seismic data collected at Sevenmile Basin, a large ephemeral lake (playa) basin in the Texas Panhandle, reveal that subsidence has been an important agent in the formation of the basin. Several hypotheses have been considered for the origin of thousands of playa basins on the Southern High Plains of Texas and New Mexico, including eolian deflation, evaporite or carbonate dissolution and subsidence, piping, and animal activity. Seismic methods, adapted to investigations in the shallow subsurface (200 m or less), provide data that indicate subsidence caused by evaporite dissolution is the most important of these mechanisms at Sevenmile Basin.

Sevenmile Basin is 5.5 by 3.6 km across and 14 m deep and is inset into the Quaternary Blackwater Draw Formation. The Blackwater Draw overlies the upper Tertiary Ogallala Formation, which hosts the economically important Ogallala aquifer. Shallow seismic refraction and reflection data were collected from this unlithified and variably saturated clastic sequence to understand the physical properties, geological history, and hydrogeological framework of playa basins, which are the principal recharge areas for the Ogallala aquifer.

Three-layer velocity models provide good solutions for refraction data. Near surface p-wave velocities (layer 1) range from 317 to 580 m/s, layer 2 apparent velocities range from 796 to 869 m/s, and layer 3 apparent velocities range from 2,051 to 2,755 m/s. Layer 1 is thickest on the upland and at the southern margin of the basin floor (12 to 13 m) and thinnest (5 m) at the northern edge of the basin floor. Layer 2 thicknesses range from 48 to 66 m and vary little across the basin. Elevations at the top of layer 3 are relatively constant across the basin. Shallow test holes and drillers' logs suggest that layer 1 is composed of upper Blackwater Draw Formation and playa deposits, layer 2 consists of upper Ogallala Formation and lower Blackwater Draw Formation deposits, and layer 3 represents a middle Ogallala aquitard that supports a perched aquifer above the main Ogallala aquifer.

Reflection data reveal a clearer picture of basin structure. Seismic sections show a middle Ogallala reflector, a reflector at the top of Permian or Triassic bedrock, and internal bedrock reflectors; the sections also indicate a structural low beneath Sevenmile Basin on all reflectors. Increasing relief with age, from 14 m at the surface to 40 m on the middle Ogallala reflector to 110 m at the base of the Ogallala, can be interpreted as either gradual filling of an erosional feature that existed before Ogallala deposition began, or as evidence of subsidence of underlying Permian evaporite-bearing strata before or during Ogallala deposition. Apparent dips of bedrock reflectors into the basin support the subsidence hypothesis. Ogallala and Blackwater Draw Formation thicknesses greater than the relief on the bedrock surface suggest that subsidence continued during Ogallala deposition and may continue to the present.

Introduction

The purpose of this study was to investigate the origin and development of a playa basin on the Southern High Plains (Fig. 1) using seismic reflection and refraction methods adapted for the shallow subsurface (to 200 m depth). This investigation is part of a larger geological and hydrological characterization of the area surrounding the U.S. Department of Energy's Pantex Plant (Fig. 2), which has included collection of more than 39 km of shallow seismic reflection data. There are many playa basins on and near the Pantex Plant; playa basins are significant because they are the major groundwater recharge points for the Ogallala aquifer (Wood and Osterkamp, 1984; Nativ and Riggio, 1990), which is a regionally important aquifer that is used as a domestic, municipal, industrial, and agricultural water supply across the High Plains. As recharge points, playa basins form a critical part of potential contaminant pathways from surface and near-surface pollution sites to the Ogallala aquifer. Playa basins are enigmatic surface features whose origins have long been debated in the geological community. Seismic methods were chosen for this investigation because they are less expensive and less invasive than drilling and because they were likely to produce geologically interpretable, continuous cross sections rather than discontinuous, interpolated sections based on widely spaced drilling data. Further, encouraging results were obtained in a shallower seismic survey conducted nearby in a similar geologic setting (Miller and others, 1990).

Playa basins are small, nearly circular depressions that are common on the High Plains; more than 20,000 are found on the Southern High Plains (south of the Canadian River, Fig. 1) of Texas and New Mexico (Wood and Osterkamp, 1987). The basins contain playa lakes, which are shallow, ephemeral lakes that, to varying degrees, supply water to underlying aquifers. Playa basins range from tens of meters to several kilometers in diameter and from a few meters to tens of meters in maximum depth. Many playa basins enclose radial channel systems (Reeves, 1990). Ages of playa basins are not well known; reported age estimates for playa and associated lee dune sediments range from a few Ka to more than 33 Ka (Reeves and Parry, 1969; Holliday, 1985; Osterkamp, 1990; Reeves, 1990). Sevenmile Basin is a relatively large, elongate playa basin located 25 km east of Amarillo and 4 km south of the Pantex Plant (Figs. 1 and 2). It measures 5.5 km across in an east-west direction and 3.6 km across in a north-south direction and has a maximum relief of 14 m.

On the Southern High Plains, playa basins are found on the Blackwater Draw and Ogallala Formations (Wood and Osterkamp, 1987). Sevenmile Basin is inset into the Quaternary Blackwater Draw Formation, which is composed mostly of windblown sand, silt, and clay (Eifler, 1969; Holliday, 1989; Gustavson and others, 1991). Common carbonate nodules and buried soil horizons indicate that Blackwater Draw deposits have been altered by soil processes and represent several episodes of deposition between 1.4 Ma and several tens of thousands of years ago (Holliday, 1989). The Blackwater Draw covers most of the Southern High Plains and has a maximum thickness of about 30 m. The Ogallala Formation occurs at the surface across part of the Southern High Plains and beneath the Blackwater Draw where it is present. The Ogallala is a Miocene to Pliocene formation that consists of poorly lithified gravel, sand, silt, and clay (Eifler, 1969) in a rough fining-upward sequence that can be as much as 250 m thick (Seni, 1980). In general, it consists of basal fluvial gravel and sand that partly fill paleovalleys and eolian and lacustrine sand, silt, and clay that cover both paleovalleys and paleouplands (Gustavson and Winkler, 1988). Like the Blackwater Draw, the Ogallala has been modified by soil formation processes. In most areas, the top of the Ogallala is marked by the Caprock caliche, a calcrete formed on the upper Ogallala surface that is as much as 2 m thick (Gustavson and Holliday, in preparation). The Ogallala Formation is the host lithologic unit for the Ogallala aquifer.

In the study area, the Ogallala Formation is separated from underlying Permian or Triassic bedrock by an erosional unconformity. The nearest bedrock exposures are found in the Canadian River valley to the north and Palo Duro Canyon to the south (Fig. 1). The Permian Quartermaster Formation, composed of sandstone, sand, siltstone, and shale, is exposed north and east of the study area near Lake Meredith and southeast of the study area in Palo Duro Canyon (Eifler, 1969). Triassic Dockum Group strata, composed of Trujillo Formation conglomerates, sandstones, and shales and Tecovas Formation shales and siltstones, are exposed northwest of the study area in the Canadian River valley and southwest of the study area in Palo Duro Canyon. A line drawn between the Permian and Triassic contacts in the Canadian River valley and in Palo Duro Canyon passes beneath the study area; bedrock beneath Sevenmile Basin thus may be either Permian or Triassic.

The central problem addressed by this study is the origin and development of Sevenmile Basin. Many hypotheses have been considered for the origin of various types of playa basins, including (1) eolian deflation and lee dune deposition (Gilbert, 1895; Evans and Meade, 1945; Judson, 1950; Reeves, 1966), (2) carbonate dissolution in the Ogallala and Blackwater Draw Formations and deflation or piping of playa sediments (Price, 1944; Osterkamp and Wood, 1987; Wood and Osterkamp, 1987), (3) dissolution of underlying Permian evaporites or Cretaceous carbonates and related subsidence

(Johnson, 1901; Baker, 1915; Evans and Meade, 1945; Gustavson and others, 1980; Reeves, 1990), and (4) animal activity (Reeves, 1966, 1990). It has been recognized that no single process is responsible for the formation of all playas and that different playas have different developmental histories (Reeves, 1990; Gustavson and Holliday, in preparation). Seismic methods adapted for the shallow subsurface are an ideal approach to determining playa origins in general and the importance of subsidence in particular.

Methods

Shallow refraction methods were used to collect compressional velocity information from the Blackwater Draw and Ogallala Formations and the underlying Permian to Triassic bedrock and to determine the gross geometry of these units. Refraction data were acquired in 1992 at three reversed spreads located on the upland north of Sevenmile Basin, at the northern margin of the basin floor, and at the southern margin of the basin floor (Fig. 3). Reversed refraction data were obtained by placing the seismic source at four locations: one shotpoint at each end of the geophone spread, one shotpoint one-half the spread length from the north end of the spread, and one shotpoint the same distance from the south end of the spread. The energy source was a trailer-mounted weight-drop unit fitted with an elastic band to accelerate the weight downward (Table 1). The source was repeatedly fired at each shotpoint until the accumulated signals were large enough to clearly show the first arrivals on the seismic record. First arrival times were picked on a Macintosh Quadra 700 using the software package Seismic Processing Workshop. Arrival times and offset distances were exported to a spreadsheet program, where layer assignments were made and thicknesses and velocities were computed.

The seismic reflection survey was designed to optimize data recovery from the depth interval of interest, which extended from the top of the Ogallala at a depth of about 20 m to the base of the Ogallala at an anticipated depth of 100 to 200 m. Reflection line

PRL7 begins on the upland north of Sevenmile Basin, extends 4.5 km across the basin, and terminates on the upland south of the basin (Fig. 3). Noise, filter, and source tests were performed to set equipment and acquisition parameters (Table 1). Noise tests indicated that important noise sources in this area were wind, vehicular traffic on the adjacent road, and a nearby railway line. We attempted to minimize noise during data collection by waiting for vehicles and trains to pass, but wind noise was largely unavoidable. Filter tests were conducted to optimize the low-cut filter setting; the goal was to set the filter low enough to allow the deepest reflections of interest to be recorded, but as high as possible to reduce unwanted source-produced surface waves. A setting of 32 Hz produced the best compromise; this setting was lowered to 16 Hz when wind noise overcame later arrivals at the higher filter setting. Source tests were used to determine the near offset (source to closest geophone distance) and the number of shots at each shotpoint. Inspection of field records collected during these tests resulted in a near offset selection of 20 m (near enough to identify shallow reflections but far enough from the source to avoid the strongest surface waves). Four shots per shotpoint increased the signal-to-noise ratio by partly cancelling wind and other random noise.

Production reflection data were collected in 1992 using the common midpoint (CMP) technique (Mayne, 1962; Steeples and Miller, 1990). The acquisition geometry was asymmetric, with the source (accelerated weight drop) trailing the spread. The shotpoint and geophone spacings were both 5 m and the reflection data are 24 fold (Table 1).

After each day of field acquisition, seismic data were transferred to a Macintosh Quadra 700 computer and stored on 8 mm tape. Data processing was accomplished using Seismic Processing Workshop (SPW). Processing was performed using procedures common to many types of seismic reflection data (Yilmaz, 1987). Steps included translating shot records from seismograph format to SPW format, surgically muting the source-produced air wave, editing dead or noisy traces, adjusting traces to a common elevation datum, applying a velocity filter to mute slow-moving surface waves, deconvolving shot records, applying a band-pass filter to reduce noise, sorting into CMP gathers, performing velocity analysis at every twentieth CMP, correcting for normal moveout, stacking traces in a CMP gather to make a single CMP trace, and applying automatic gain control to enhance weak events.

Refraction data

First arrival times for each refraction spread, when plotted against offset distance, can be grouped into three sets (Fig. 4). The first set is closest to the source and falls on a line that passes near the origin. These first arrivals are from a compressional wave that travels directly (not reflected or appreciably refracted) from the source to the geophones. This phase is the first arrival between the nearest geophone (2.5 m from the source) and the crossover point, which is where the first refracted arrival overtakes the direct wave. The crossover distance for these data ranges from 20 to 50 m. Compressional velocities for the layer in which the direct wave travels (layer 1) ranged from 317 to 580 m/s (Table 2). Layer 1 thicknesses are between 12 and 14 m beneath spread PRR1 at the north upland and between 11 and 13 m beneath spread PRR3 at the southern basin floor (Fig. 5). Layer 1 thins to between 3 and 9 m beneath spread PRR2 at the northern basin floor.

A critically refracted wave assigned to layer 2 is the first arrival between the first crossover point at 20 to 50 m from the source to the second crossover point at 140 to 210 m from the source (Fig. 4). Best-fit compressional velocities computed for this refracted arrival range from 796 to 870 m/s. Elevations at the top of layer 2 decrease from between 1052 and 1054 m on the northern upland to between 1042 and 1044 m at the southern basin floor (Fig. 5). Its thickness also decreases from about 63 m at the northern upland to about 55 m at the southern basin floor.

Beyond the second crossover point to the maximum offset of 352 m, a second critically-refracted wave was the first arrival (Fig. 4). This wave, assigned to layer 3, traversed the spread at velocities of 2,051 to 2,755 m/s, significantly higher than waves traveling in overlying layers. Elevations at the top of this layer were similar across the basin: 986 to 994 m at the northern upland, 987 to 991 at the northern basin floor, and 981 to 995 at the southern basin floor (Fig. 5).

Geologic control on refraction interpretations is provided by a drillers' log of well 6-44-9D, which is located about 1,800 m east of refraction spread PRR1 (Fig. 3) and was drilled to a depth of 120 m. Additional geologic data include cores from seven holes augered to depths of 10 to 27 m across Sevenmile Basin by the Bureau of Economic Geology. Although there are limits to the geologic information that can be gleaned from minimal lithologic descriptions common in drillers' logs (Fig. 5), the following observations can be made: (1) the upper two units in the lithologic log consist of 28 m of "topsoil" with caliche and fine sand and represent eolian facies of the Blackwater Draw Formation that have been modified by soil formation processes; (2) the base of the Ogallala at about 953 m elevation is marked by the first occurrence of "redbeds" (Permian Quartermaster Formation or Triassic Dockum Group) in the lithologic description; and (3) above the basal gravelly clay, the Ogallala is generally a unit that fines upward from gravelly sand near the base to sandy clay near the top. Cores obtained by the Bureau of Economic Geology were all within a generally finer-grained, lacustrine facies of the Blackwater Draw Formation.

Seismic layer 1, with its low velocities and relative thinness (3 to 14 m), correlates to the upper Blackwater Draw Formation. It is probably composed of eolian deposits on the upland adjacent to the basin and eolian and lacustrine facies on the basin floor. The base of layer 1 may have no geologic significance other than occurring at the base of the weathering horizon or where pedogenic carbonate has been deposited. Seismic layer 2 has velocities roughly twice as high as those in layer 1, but the velocities remain low enough to be typical of unconsolidated clastic sediments. This layer is 50 to 60 m thick and extends from the lower part of the Blackwater Draw Formation to the lower part of the Ogallala Formation; if the drillers' log is representative of this area, the layer consists of sediments ranging from coarse sand to sandy clay.

The top of seismic layer 3 occurs at about 990 m elevation at all three refraction sites (Fig. 5 and Table 2). It was originally thought to represent bedrock beneath the basin based on higher velocities (2,051 to 2,755 m/s) calculated from its refracted arrival. However, lithologic logs and Ogallala water level data from nearby wells such as 6-44-9D suggest that the base of the Ogallala is some 40 m deeper. There is only a slight change in lithology noted in the drillers' log at the top of layer 3, from a coarse sand below the top to a medium sand above it. This change is insufficient to cause such a large increase in seismic velocity. A more likely explanation for the velocity increase is an increase in competence of the material. Increased competence could be related to post-depositional calcic cementation either as a pedogenic horizon or a groundwater calcrete, or it could reflect a different depositional facies such as a fresh-water limestone. Interestingly, this Ogallala horizon occurs at an elevation that is nearly identical to that of an aquitard that has been encountered above the main Ogallala aquifer in several wells at the Pantex Plant. The aquitard supports a perched Ogallala aquifer that has been penetrated by many wells in the area. The interpretation of the top of layer 3 as a competent Ogallala aquitard is further strengthened by velocity data from a vertical seismic profile conducted by the Bureau of Economic Geology in well OM105 in the south central part of the Pantex Plant (Fig. 2). Interval velocity data from this well indicate sharply higher seismic velocities between the elevations of 980 to 990 m (2,226 to 3,500 m/s) than in Ogallala deposits above (985 m/s) and below (1,392 m/s) the high velocity interval. A thin perched aquifer was encountered above this unit at well OM105.

Reflection data

Although refraction data provide velocity information and the depth to an important Ogallala horizon, the data do not reveal depth to bedrock or help to understand the origin and development of Sevenmile Basin. Unprocessed field records from the reflection survey, on the other hand, recorded reflected energy from several subsurface horizons within the depth range of interest (Fig. 6). Continuous reflectors appear as hyperbolas on field records (over an appropriate offset range), with curvature decreasing with velocity and depth. Other phases (direct wave, ground-coupled air wave, surface waves, and critically refracted waves) propagate across the geophone spread at generally constant speeds; on field records, they form straight lines with slopes inversely proportional to seismic velocity. The four reflection fragments visible in field record PRL70329 (Fig. 6) have zero offset travel times of about 0.120, 0.180, 0.250, and 0.335 s and moveout velocities ranging from 600 to 1500 m/s. These reflectors represent horizons at depths of 30 to 250 m.

Reflection line PRL7 (Fig. 7) is a time section across Sevenmile Basin constructed from every fourth CMP. Original CMP spacing was 2.5 m; CMP spacing in this section is 10 m. Nevertheless, several important features are visible. There are two prominent reflectors that cross the entire basin. The shallower of the two occurs at a two-way time of 0.110 s north of the basin and then deepens to 0.210 s in the central basin before rising to 0.150 s at the southern basin margin. The deeper reflector also deepens toward the center of the basin; two-way times associated with this reflector increase from 0.200 s at the northern and southern basin margins to 0.280 s at the basin center. Beneath the deeper, continuous reflector are many less continuous reflectors that have southerly apparent dips on the northern half of the basin and northerly apparent dips on the southern half of the basin. These reflectors occur between about 0.200 and 0.500 s two-way time; beneath them there is little coherent seismic energy.

Two-way times on the reflection section can be converted to depth if the velocity profile is known. At Sevenmile Basin, velocity information comes from three sources: refraction surveys, velocity picks from the reflection data, and a vertical seismic profile acquired at a nearby water well. Velocity profiles calculated from refraction data (Table 2 and Fig. 8) show that layer 1, with velocities of 317 to 580 m/s, would fall between 0 s and a maximum of 0.060 s of two-way time. Layer 2, with velocities of 796 to 870 m/s, could be present as early as 0.021 s and as late as 0.208 s. The top of layer 3, with velocities of 2,051 to 2,755 m/s, could be encountered between 0.170 and 0.208 s. The bottom of layer 3 cannot be estimated because no layer deeper than layer 3 was detected in the refraction data. Refraction time-velocity relationships such as these (Fig. 8) could be used to convert reflection two-way times to depths, but these velocities might not be representative of entire layers if the refractions occurred within calcrete horizons or well-indurated zones that are of limited vertical extent. Further difficulties with velocity profiles derived from refraction surveys are illustrated by velocity picks made from reflection data at Sevenmile Basin (Fig. 9). These picks, made from CMP gathers spaced every 50 m along the reflection line, suggest that seismic velocities increase almost linearly from about 0.050 to at least 0.500 s. A linear least-squares fit to the velocity picks yields a velocity function as follows:

$$\text{velocity} = (\text{two way time}) \times 2{,}361.5\ \text{m/s}^2 + 484.8\ \text{m/s}$$

The validity of the velocity picks is corroborated by downhole geophysical data collected at Ogallala monitoring well OM105 about 5 km northwest of Sevenmile Basin (Fig. 2). Arrival times were measured in the well at 3 m intervals from the surface to the bottom of the well at 122 m. Velocities calculated for downhole data agree well with velocity picks made from reflection data from the surface to 0.250 s (Fig. 9), the deepest level measured in the well.

The velocity function derived from CMP gather velocity picks was used to convert time picks on the two major reflecting horizons to depth (Fig. 10). Elevations on horizon 1 reach 1020 m at northern end of the basin, decrease to 950 m at the basin center, and increase to 995 m at the southern edge of the basin. Similarly, elevations on horizon 2 reach 980 m north of the basin, decrease to 870 m at the basin center, and increase to 970 m south of the basin. Surface topography, with a total relief of 14 m, is a subdued expression of underlying relief of 70 m on the shallower horizon 1 and 110 m on horizon 2. Unit thicknesses calculated from elevations at the surface, horizon 1, and horizon 2 (Fig. 11) show central basin thickening between every surface. Unit thickness between horizon 2 and the surface increases from 100 m at the basin margin to 180 m at the basin center; likewise, the thickness between horizon 2 and horizon 1 increases from 25 to 70 m and the thickness between horizon 1 and the surface increases from 70 to 110 m.

Geologic interpretations of features evident on the reflection line were made using drillers' logs of nearby water wells, shallow cores from seven augered holes at Sevenmile Basin, core and geophysical logs collected at Pantex well OM105, and regional maps of the Ogallala aquifer (Bowers and McReynolds, 1990). At the margins of Sevenmile Basin, reflection horizon 1 occurs at elevations of 995 to 1020 m. These elevations are too high to represent bedrock, but they are near those calculated for the top of refraction layer 3 within the Ogallala Formation. At about this same elevation, a fine-grained zone has been encountered in numerous wells at the Pantex Plant. This zone may represent an aquitard for a perched aquifer within the Ogallala Formation but above the main Ogallala aquifer. Reflection horizon 1 is thus a middle Ogallala reflector that probably represents the upper part of a perching layer beneath Sevenmile Basin.

The deeper reflecting horizon, horizon 2, occurs at 970 to 980 m elevation at the basin margins. These elevations are similar to those reported for the Triassic bedrock in nearby water wells and in published depth to bedrock maps (Bowers and McReynolds, 1990). Further evidence of a major lithologic change at this horizon is a change in reflector character. The few reflections above this horizon tend to have high amplitudes and are generally discontinuous, whereas reflections below horizon 2 are more closely spaced, more laterally continuous, and have lower amplitudes (Fig. 7). Horizon 2 is thus interpreted to be the top of bedrock, which might be either the Permian Quartermaster Formation or the Triassic Dockum Group.

Discussion

There are at least three possible hypotheses that can explain why surface topography mimics subsurface structure at Sevenmile Basin. From least likely to most likely, these are (1) Ogallala and Blackwater Draw sedimentation in a previously existing erosional feature, (2) sedimentation in an existing subsidence basin with no subsidence during Ogallala and Blackwater Draw deposition, and (3) sedimentation in an existing subsidence basin with subsidence continuing during Ogallala and Blackwater Draw deposition.

The first hypothesis, deposition in an existing erosional feature such as a river valley, can be rejected because Sevenmile Basin is roughly circular and because reflectors within the Permian or Triassic bedrock dip toward the center of the basin rather than follow the regional bedrock dip. Modification of regional dip can be explained by subsidence of underlying strata but not by erosion.

The two remaining hypotheses agree that subsidence played an important role in basin formation and differ only in whether subsidence ended before Ogallala deposition began or whether it continued during Ogallala and Blackwater Draw deposition. No definitive choice can be made based on available evidence. Increased relief from the surface to the middle Ogallala reflector to the top of Permian or Triassic bedrock could be explained by subsidence during deposition, but it could also be explained as gradual filling of an existing subsidence basin. Total Ogallala and Blackwater Draw thickness, which reaches 180 m and exceeds the maximum relief of 110 m on the oldest surface, suggests that there has been enough sedimentation to fill the basin. The fact that Sevenmile Basin exists at the surface today may be the strongest evidence supporting continued subsidence during Ogallala and Blackwater Draw deposition.

Subsidence beneath Sevenmile Basin is probably caused by dissolution of underlying Permian bedded evaporites (halite, gypsum, and anhydrite) and collapse of overlying strata. Dissolution of Permian evaporites underlying the Southern High Plains began in the late Cretaceous or early Tertiary and continues to the present, as suggested by historic surface collapse features and brine discharge by all major streams draining the Southern High Plains (Gustavson and others, 1980). Dissolution is known to occur along broad zones beneath the Canadian River valley, along the caprock escarpment, and along the northern and eastern margins of the Palo Duro and Dalhart Basins (Gustavson and others, 1980); it also is reported to occur in isolated areas away from the major dissolution fronts (Reeves and Temple, 1986).

Several large playa and alkali lake basins on the Southern High Plains have been affected by dissolution-related subsidence. At Lake McConnell, 9 km west of Pampa (Fig. 1), 48 m of salt has been removed from Permian formations at depths of 240 to 300 m below the surface (Gustavson and others, 1980). Reeves and Temple (1986) reported that 15 of the 21 large alkaline lake basins on the Southern High Plains are associated with salt dissolution. Reeves (1990) suggested that the largest of the playa basins on the Southern High Plains (those with areas greater than 10 km^2) are underlain by areas of Permian salt bed dissolution that have developed from long-term infiltration of aquifer water along regional fractures.

Relief of 100 m on the bedrock surface beneath Sevenmile Basin implies dissolution of at least that much evaporite. This amount is not unusual; structure contour maps on the base of the Ogallala show as much as 120 m of local relief, and as much as

335 m of evaporite has been removed from beneath some areas of the Southern High Plains (Gustavson and others, 1980).

Conclusions

Seismic refraction and reflection methods adapted to the shallow subsurface were used to investigate the origin and development of an ephemeral lake basin on the Southern High Plains. Seismic refraction data successfully detected a competent horizon within the Ogallala Formation that may be an aquitard for a perched Ogallala aquifer, but did not help determine depth to bedrock beneath Sevenmile Basin or reveal much useful geological information regarding basin formation.

Seismic reflection methods were more labor intensive (and expensive) than refraction methods, but yielded all the information that the refraction survey did as well as more geologically interpretable data that allowed discrimination of several competing hypotheses of playa basin formation. The reflection line across Sevenmile Basin contained two major reflecting surfaces. The shallowest, at depths of 70 to 110 m, is probably the aquitard for a perched Ogallala aquifer. The deepest, at depths of 100 to 180 m, is a reflection from the top of the Permian or Triassic bedrock. Seismic reflection data also revealed that relief on surfaces increases with age, from 14 m at the land surface to 70 m on the middle Ogallala reflector to 110 m at the base of the Ogallala. Reflectors from within the bedrock have apparent dips toward the basin center.

It is clear from the reflection data that subsidence has played a major role in the formation of Sevenmile Basin. This basin occurs above a deeper subsidence basin within Permian or Triassic bedrock. The subsidence that formed the basin probably continued during Ogallala and Blackwater Draw deposition and may continue today. The most likely cause of the subsidence is evaporite dissolution within Permian strata.

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Figures

Figure 1. Location of the study area in the Texas Panhandle. Lightly shaded area represents the High Plains surface. The Southern High Plains are south of the Canadian River.

Figure 2. Location of Sevenmile Basin study area (dashed rectangle), regional shallow seismic reflection lines (thick lines), and playa lakes (outlined and shaded areas).

Figure 3. Locations of refraction spreads PRR1, PRR2, and PRR3 (shaded lines) and reflection line PRL7 (solid line) across Sevenmile Basin. Nearby playa lakes are outlined and shaded. Elevation in m above sea level.

Figure 4. First arrivals, layer assignments, and best-fit layer velocities (in m/s) for refraction spreads PRR1, PRR2, and PRR3. Shots are north of the spread for forward data and south of the spread for reverse data.

Figure 5. Comparison of drillers' log from water well 6-44-9D (leftmost column) with a cross section across Sevenmile Basin constructed from refraction data. Widths of units in lithologic column are keyed to dominant texture. Patterns filling lithologic units are keyed to secondary texture (light gray=gravel, dark gray=sand, black=clay). Patterns filling refraction units correspond to layer assignments (white=layer 1, light gray=layer 2, dark gray=layer 3).

Figure 6. Unprocessed field record PRL70329 from the seismic reflection survey of Sevenmile Basin (left) and interpreted types of recorded seismic energy (right). A display gain of 6 dB was applied to the field record to enhance weak arrivals.

Figure 7. Uninterpreted (upper panel) and interpreted (lower panel) reflection line PRL7. Upper panel is composed of every fourth CMP from the original processed sections, resulting in a trace spacing of 10 m. Horizon 1 is the middle Ogallala reflector and horizon 2 is the base of the Ogallala Formation. Deeper reflectors are from Permian and Triassic bedrock.

Figure 8. Six seismic velocity profiles inferred from forward and reverse refraction spreads PRR1, PRR2, and PRR3. Because the base of layer 3 was not reached, only the two-way time to the top of layer 3 is known.

Figure 9. Stacking velocity picks for reflection line PRL7, linear best-fit velocity function, and average velocity profile for vertical seismic profile acquired in well OM105.

Figure 10. Elevations along reflection line PRL7 of the land surface, horizon 1 (middle Ogallala reflector), and horizon 2 (basal Ogallala reflector). Depths for horizons 1 and 2 calculated from reflector two-way times and the best-fit velocity function.

Figure 11. Sediment thickness along reflection line PRL7 between horizon 1 (middle Ogallala reflector) and the surface, between horizon 2 (basal Ogallala

reflector) and the surface, and between horizon 1 (middle Ogallala reflector) and horizon 2 (basal Ogallala reflector).

Tables

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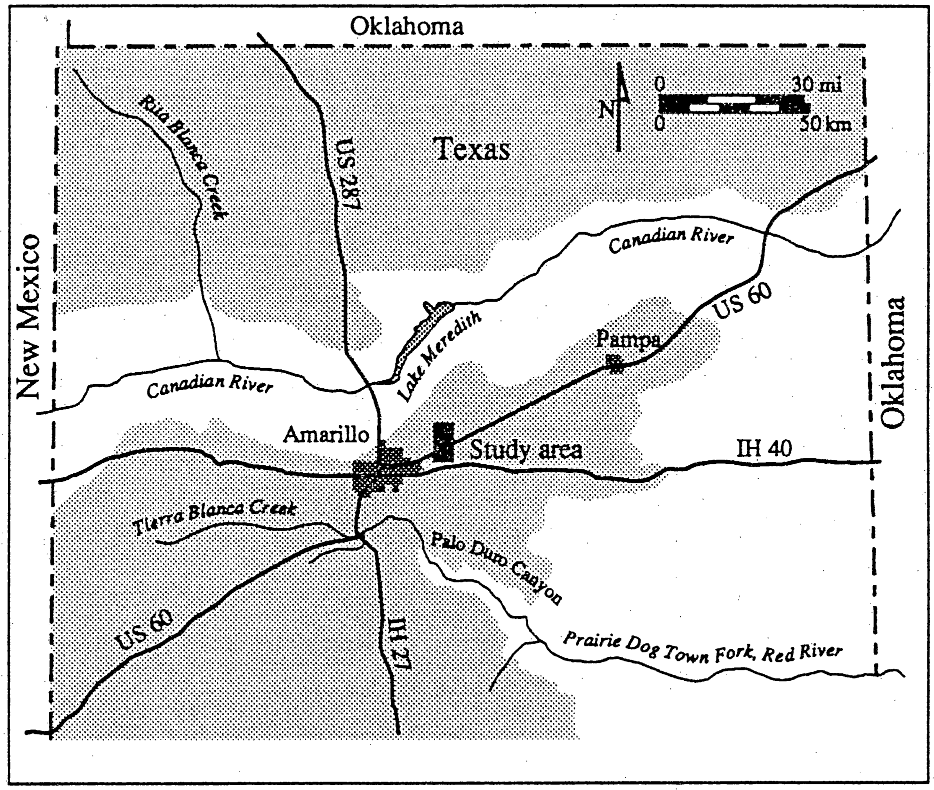

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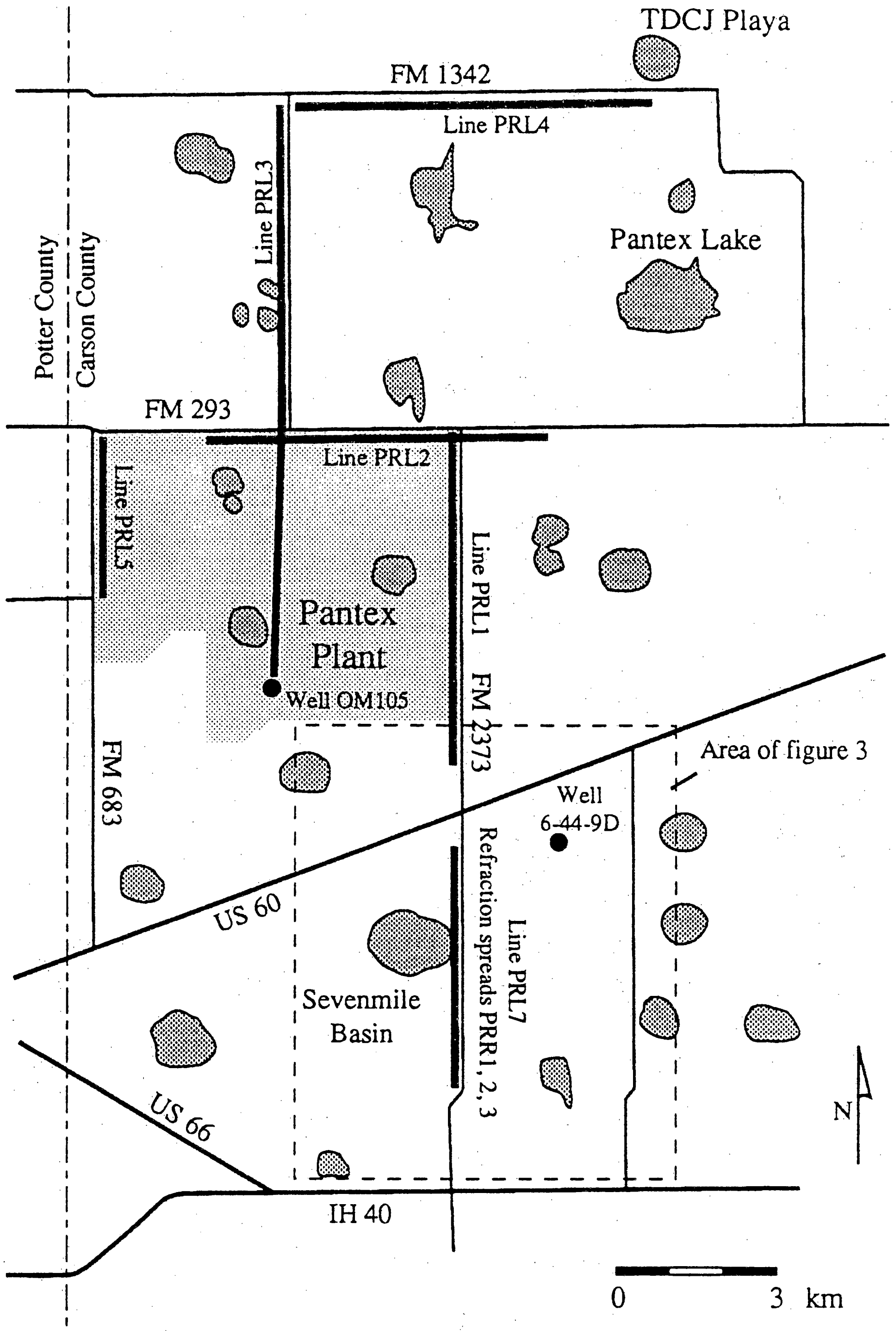

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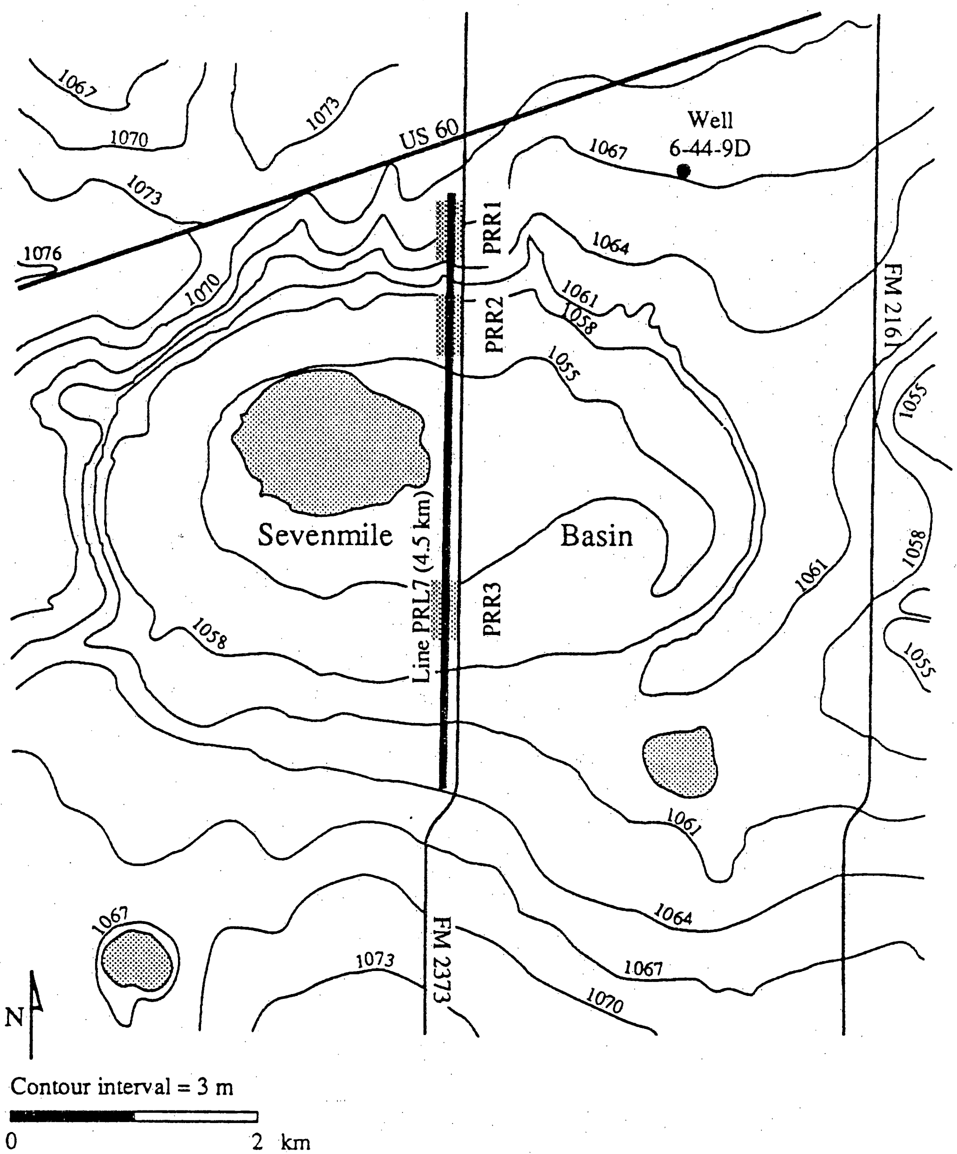

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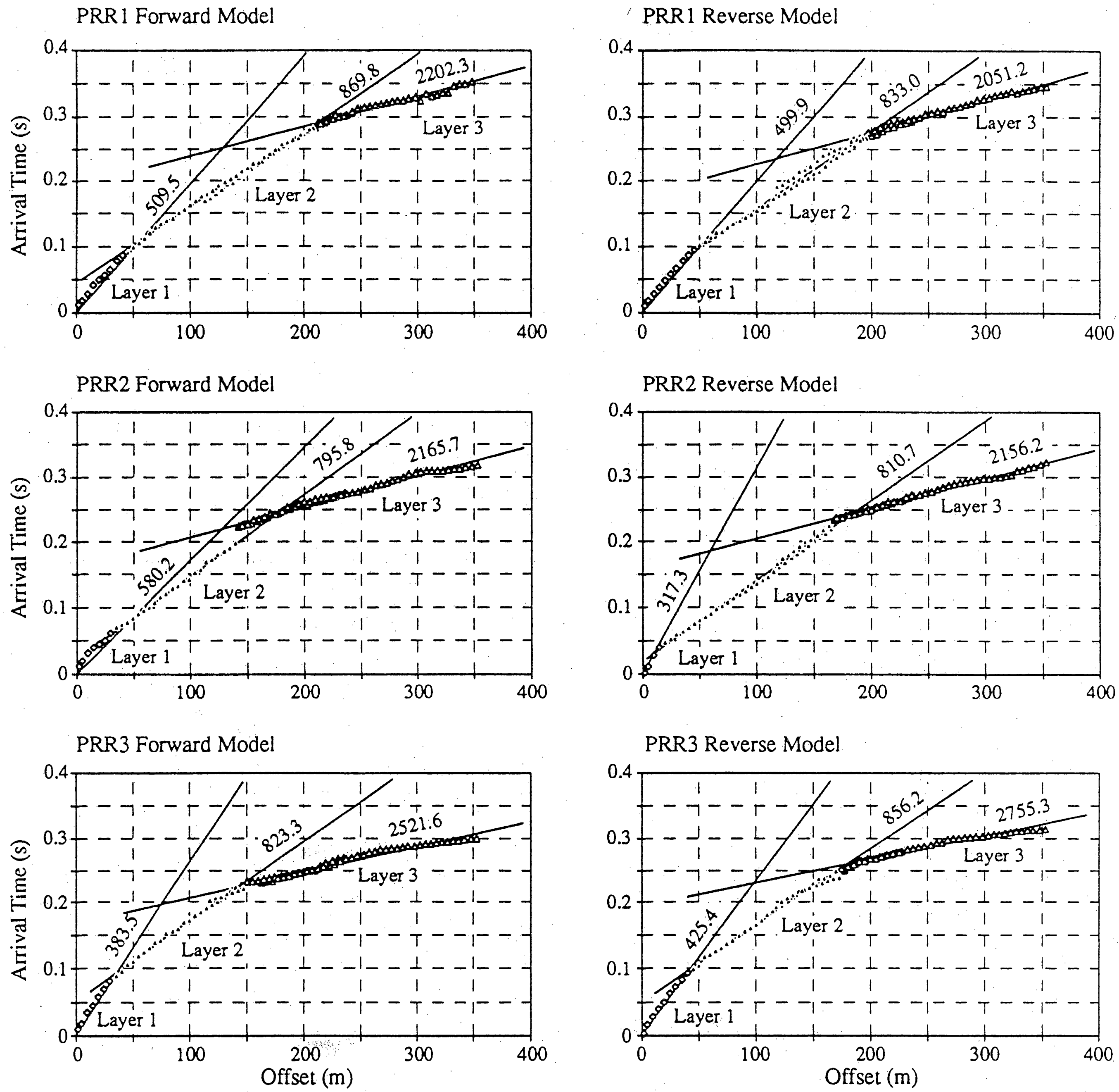

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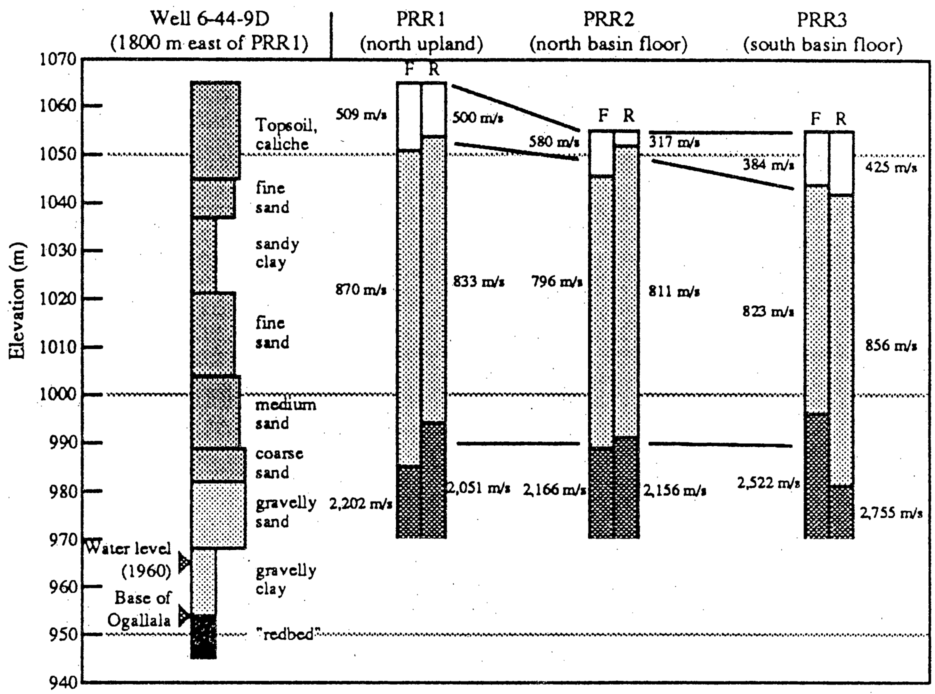

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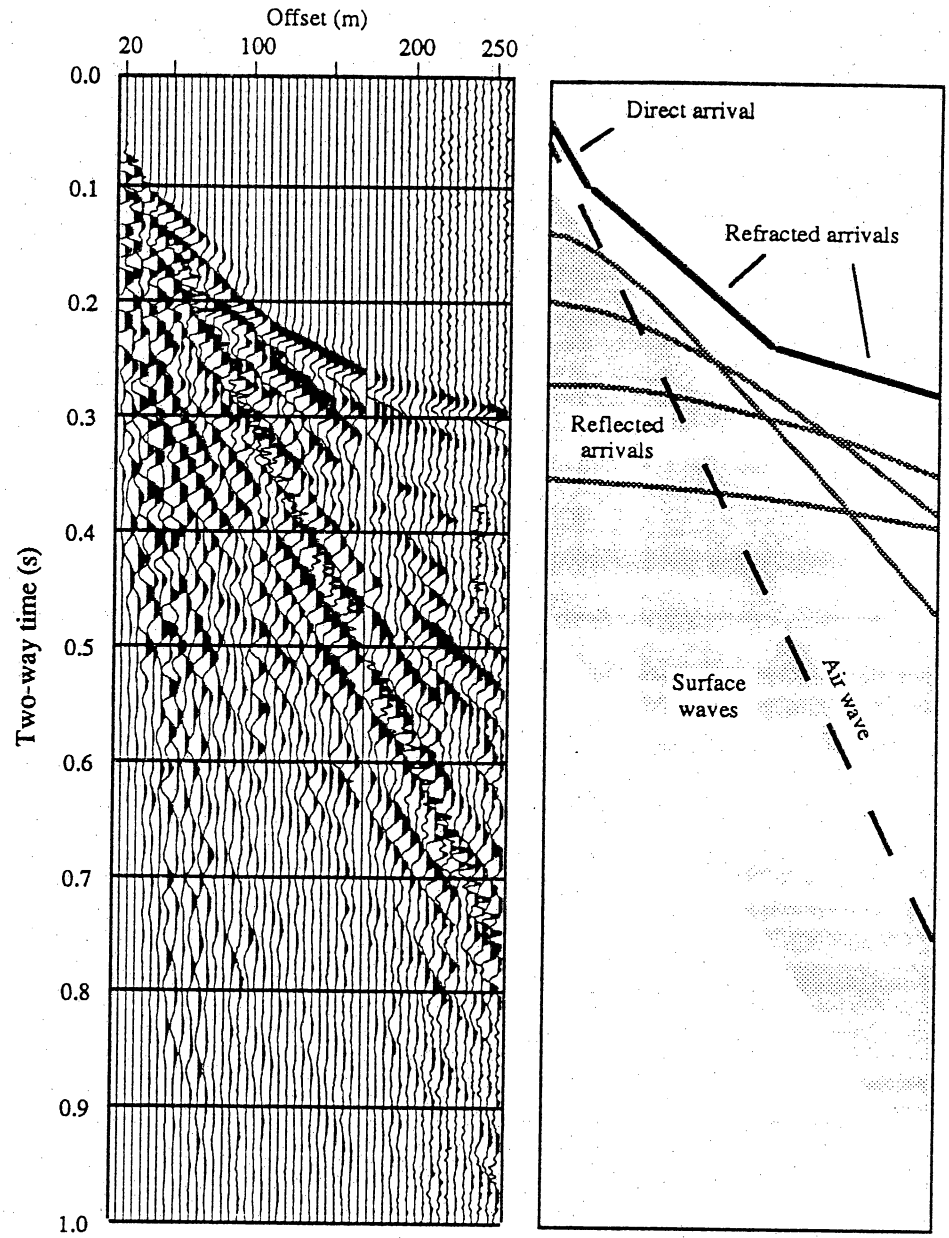

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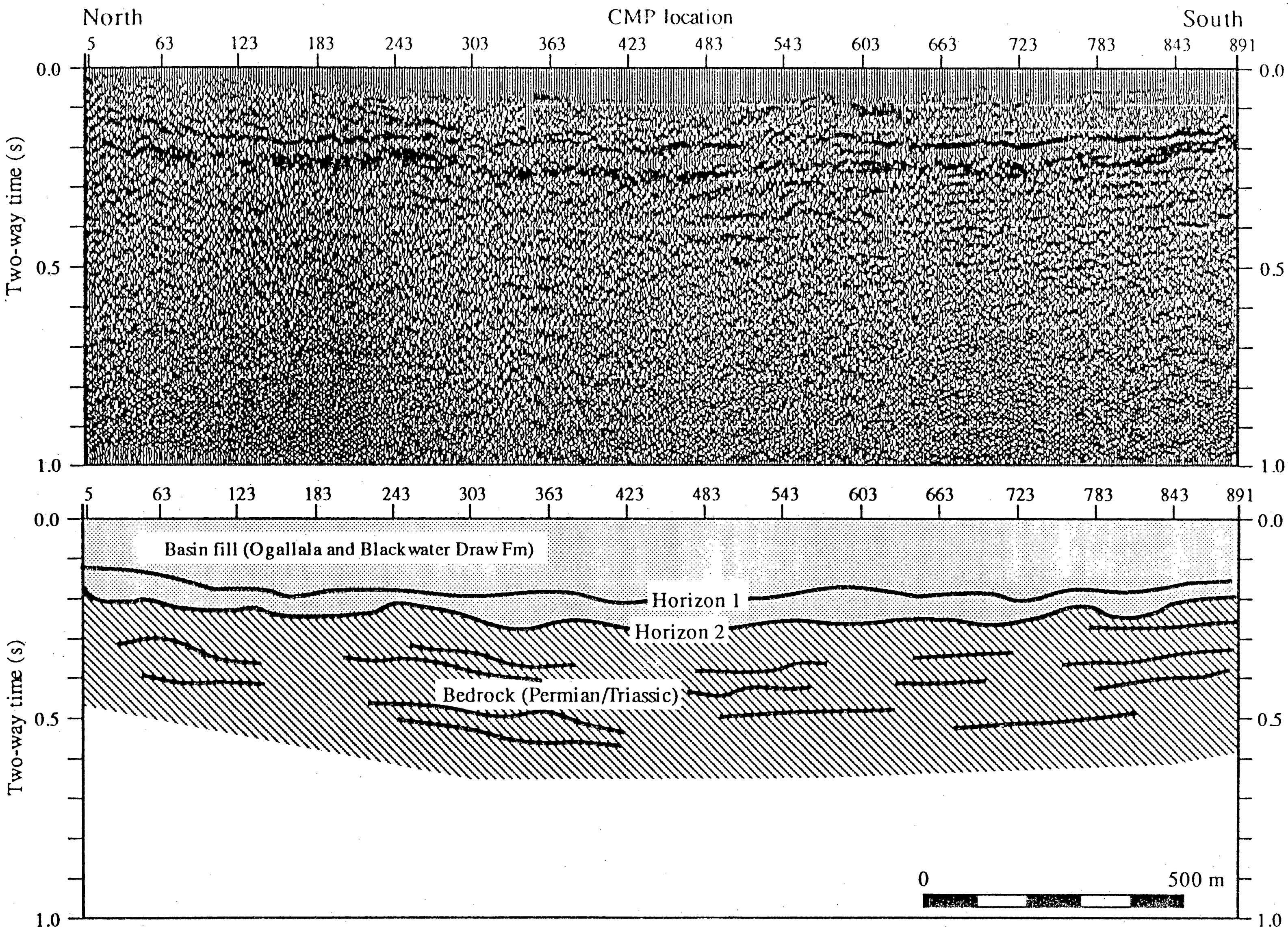

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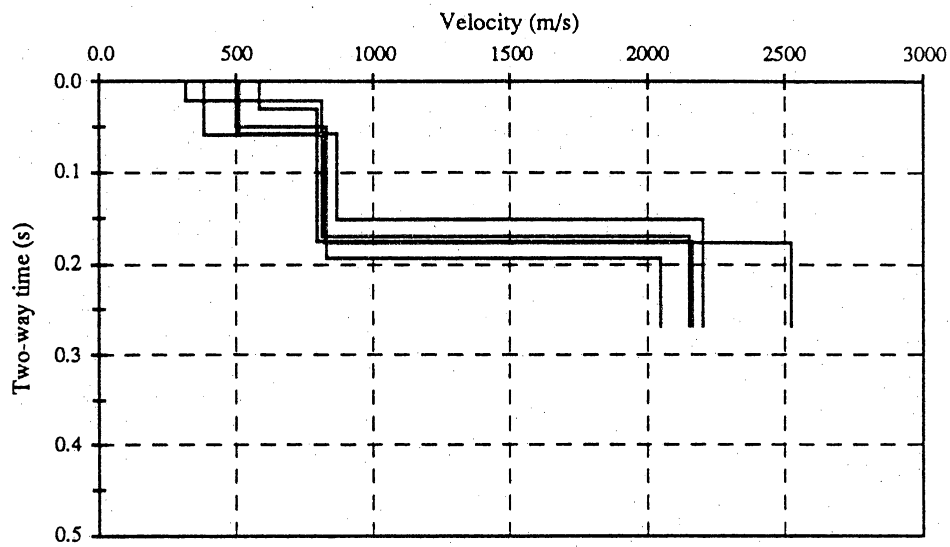

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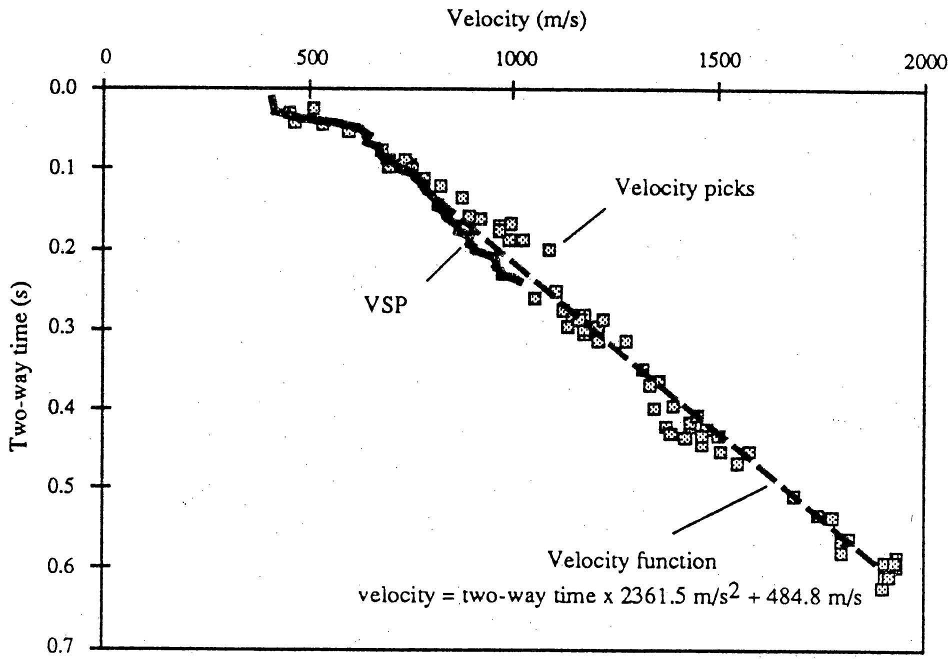

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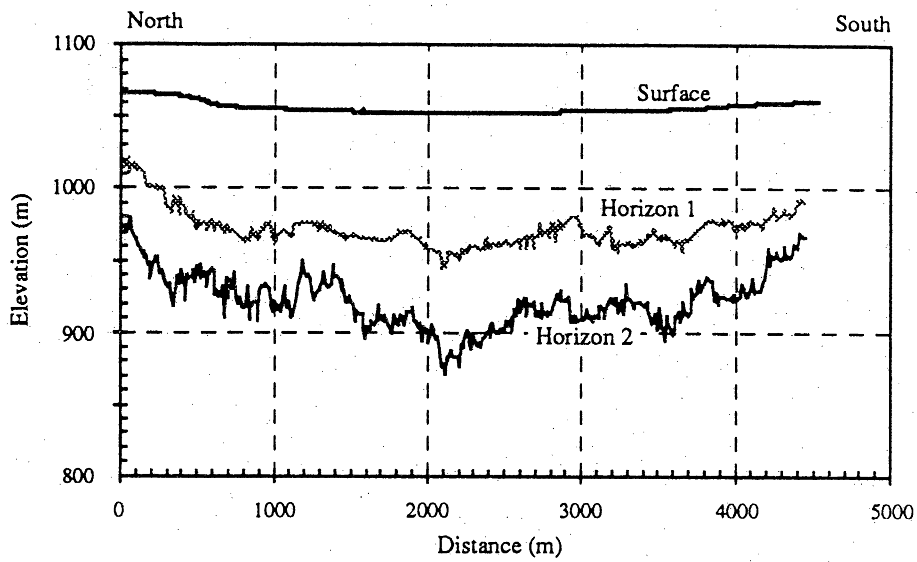

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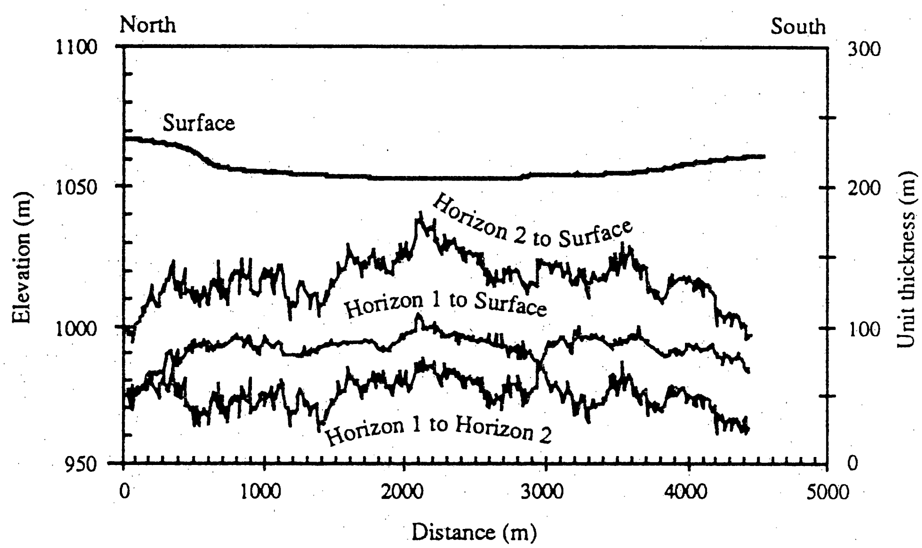

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Table 1. Equipment, recording parameters, and acquisition geometry used during seismic refraction and reflection data collection at Sevenmile Basin.

	Refraction	Reflection
Source	230 kg accelerated weight drop (Bison EWG III)	230 kg accelerated weight drop (Bison EWG III)
Spread length	235 m	235 m
Source offset	0 to 352.5 m	20 to 255 m
Geophones	Mark L-40A (40 Hz)	Mark L-40A (40 Hz)
Geophones in array	1	1
Geophone spacing (m)	5 m	5 m
Seismograph	Bison 9048	Bison 9048
Recording channels	48	48
Sample interval	0.001 s	0.001 s
Record length	1 s	1 s
Analog low-cut filter	4 Hz	variable (16 to 32 Hz)
Analog high-cut filter	500 Hz	variable (180 to 500 Hz)

Table 2. Summary of refraction data from Sevenmile Basin.

Refraction Spread	Layer	Velocity (m/s)	Thickness (m)	Depth to top (m)	Elevation at top (m)	Two-way time to top of layer (s)
PRR1F	1	509.5	14.4	0.0	1066.0	0.000
(shooting south)	2	869.8	66.0	14.4	1051.6	0.057
	3	2202.3		80.4	985.6	0.208
PRR1R	1	499.9	12.4	0.0	1066.0	0.000
(shooting north)	2	833.0	60.1	12.4	1053.6	0.050
	3	2051.2		72.5	993.5	0.194
PRR2F	1	580.2	9.1	0.0	1055.0	0.000
(shooting south)	2	795.8	57.3	9.1	1045.9	0.031
	3	2165.7		66.4	988.6	0.175
PRR2R	1	317.3	3.3	0.0	1055.0	0.000
(shooting north)	2	810.7	60.5	3.3	1051.7	0.021
	3	2156.2		63.8	991.2	0.170
PRR3F	1	383.5	11.4	0.0	1055.0	0.000
(shooting south)	2	823.3	48.3	11.4	1043.6	0.059
	3	2521.6		59.7	995.3	0.177
PRR3R	1	425.4	12.8	0.0	1055.0	0.000
(shooting north)	2	856.2	61.0	12.8	1042.2	0.060
	3	2755.3		73.8	981.2	0.203