Appendix Q
HydroGeophysics – Seismic Survey Results
MEMO

To:  
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Arturo Burgos, PG – ASARCO LLC

From:  
Frank Skocypec, PE, PG

Date:  
July 21, 2008

Copies:  
Project File  
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ARCADIS Project No.:  
AZ001022.0009.10004

Subject:  
Draft Summary of Refraction Seismic Survey, ASARCO El Paso Smelter Facility

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Introduction

This technical memorandum provides a summary of the seismic refraction survey conducted to support the preliminary slurry wall design and conceptual site model by identifying the topographic bedrock surface in the lower part of the Parker Brothers Arroyo, Smeltertown property and adjacent floodplain areas. Refraction seismic surveys are a well-established geophysical tool to accomplish this objective provided the subsurface geologic velocity layers increase with depth between the ground surface and underlying bedrock.

Geology and Hydrogeology

The Rio Grande floodplain traverses across the western perimeter of the upland area and is characterized by the Rio Grande alluvium underlain by Cretaceous shale, sandstone and limestone below the northern and Smeltertown areas and Tertiary andesite intrusive beneath the southern extent of the upland Smelter Facility. Floodplain materials are unconsolidated and generally consist of fine grained sands, silts and clays. A basal gravel layer, above the underlying bedrock, has been identified in the alluvial deposits in floodplain well MW-132D and Parker Brother Arroyo extraction/observation wells EX-1, EX-2 and OBS-1. Groundwater occurs within an unconfined alluvial aquifer at approximately 8 to 10 feet below ground surface (ft/bgs).
Seismic Data Acquisition

The field data was collected by hydroGEOPHYSICS, Inc. (HGI) a geophysical consulting and service company based in Tucson, Arizona. The data was recorded during a six day period from June 22nd through 27th, 2008 and included a total of ten independent seismic refraction survey lines for a total lineal distance of 5,430 feet. HGI utilized a Geode 48-channel seismic recording system with geophone groups placed every 10 feet with a total of 9 shots per spread (four offsets and 5 shots within the geophone spread). HGI conducted a series of preliminary field tests along Line 5 to determine the best shot stacking sequence for maximum signal-to-noise (S/N) production. To that end, the energy source used was a truck mounted Propelled Energy Generator (PEG) weighing about 40 kilograms with additional elastic bands for increased signal energy penetration into the subsurface. The refraction seismic survey line coverage was limited to surface areas and property currently owned by ASARCO, LLC. The refraction survey location base map and profile of each seismic refraction line is presented in Appendix A.

During the field acquisition of refraction data, a high signal-to-noise (S/N) ratio was the primary data quality objective to accurately pick the first break arrivals at large offset distances. The large source and receiver offset distances were required to record refractor arrival information in the floodplain and Smeltertown areas where the bedrock surface was suspected to range from 60 to 100 feet below ground surface. The S/N ratio compares the level of a desired signal (such as bedrock refractor first break energy) to the level of background noise. The higher the ratio, the less intrusive the background noise is. It is when the background noise level interferes with the first arrival energy that the refractor velocities and subsequently depth can not be calculated. The primary reason for the loss in the S/N ratio was due to the proximity of the lines to major roadways coupled with poor soil conditions (loose and energy absorbent) specifically within the Smeltertown and floodplain areas. The first arrival picks were generally of good quality to a maximum offset distance of ~150 to 200 feet horizontally from each shot point location in the floodplain and Smeltertown area. Beyond 200 feet or approximately 20 geophones from any given shot point, the first arrival times became noisy and difficult to pick. Therefore, the maximum potential depth of penetration was reduced, in certain site-specific areas, for any given source and receiver array.

Findings

Given the data acquisition challenges identified, the refraction seismic survey provided insightful subsurface information;

1. The first arrival velocity picks generated by the refraction seismic survey independently identified the shale bedrock material (~6,500 feet per second [ft/sec]). This is best evidenced at the east end of Line 3 and the intersection with well EP-122D. The calculated interval velocity is in good general agreement with published interval velocity values;
(2) East-west trending Line 3 depicts the shale bedrock at ~ 40 feet below ground surface (ft/bgs) near well EP-122D and increasing thickness of lower velocity alluvial deposits and overburden material (estimated > 60 feet) towards the Rio Grande River north of the American Canal dam structure. This is in general agreement with the perceived depositional accumulation of alluvial sediments and overburden material towards the central portion of the Rio Grande River system;

(3) Lines 6A, 6B and 7 were recorded to obtain subsurface information on the thickness of alluvial deposits and topography of underlying bedrock surface within and perpendicular to the Parker Brothers Arroyo. North-south trending Line 7 shows a "bowl-shaped" lower velocity layer (~3,000 ft/sec) typically encountered with high conductivity geologic material as identified in extraction wells EX-2 and OBS-1. Additionally, the underlying shale bedrock observed in these wells was independently verified with the refractor velocity breaks and shows minimal structural relief trending from south to north. Line 6A trends east-west depicting an elevated and slightly undulating shale bedrock topographic surface. Line 6B trends northwest to southeast and depicts an increase in the underlying shale bedrock elevation towards the southeast; and

(4) Two independent refraction seismic lines, 1B and 1C, were generally oriented from north to south along the proposed realigned slurry wall location. Line 1B begins at monitoring well EP-59 and indicates a shale bedrock surface (~50 ft bgs) with a dramatic thickening of lower velocity alluvial deposits towards the Smeltertown sparge treatment building. Line 1C generally trends parallel to the American Canal from southwest end of Line 1B and finishes on ASARCO property at monitoring well MW-132D. This well encountered underlying limestone bedrock at approximately 66 ft bgs. Due to the data acquisition challenges previously identified, Line 1C did not record a usable offset refractor velocity consistent with limestone (~12,000 ft/sec).

A complete copy of HGI's technical memorandum is included as Appendix B.

References:


APPENDIX A

REFRACTION SEISMIC PROFILES
Seismic Refraction Survey - Line 1A
(looking east)

Velocity Legend
- 0 - 2000 ft/sec
- 2000 - 2500 ft/sec
- 2500 - 3000 ft/sec
- 3000 - 3500 ft/sec
- 3500 - 4000 ft/sec
- 4000 - 4500 ft/sec
- 4500 - 5000 ft/sec
- 5000 - 5500 ft/sec
- 5500 - 6000 ft/sec
- 6000 - 6500 ft/sec
- 6500 - 7000 ft/sec
- 7000 - 7500 ft/sec
- 7500 - 8000 ft/sec
- 8000 - 8500 ft/sec

Line Location Map

Vertical Exaggeration 3:1

ARCADIS U.S., Inc.
ASARCO El Paso Smelter
EL Paso, TX

Date: July, 2008
Plate 2

2302 North Forbes Blvd. - Tucson, Arizona 85745 - (520) 647-3315
Seismic Refraction Survey - Line 1C
(looking northeast)

Line 5 Intersection 687 ft

Distance along line (ft)

Vertical Exaggeration 3:1

Velocity Legend
- 0 - 2000 ft/sec
- 2000 - 3500 ft/sec
- 3500 - 5000 ft/sec
- 5000 - 6500 ft/sec
- 6500 - 9000 ft/sec
- 9000 - 9500 ft/sec

Line Location Map

ARCADIS U.S., Inc.
ASARCO El Paso Smelter
EL Paso, TX

Date: July, 2008
Plate 4

2302 North Forbes Blvd. • Tucson, Arizona 85745 • (520) 647-3315
Seismic Refraction Survey - Line 3
(looking north)

Velocity Legend
- 0 - 2000 ft/sec
- 2000 - 3500 ft/sec
- 3500 - 5000 ft/sec
- 5000 - 6500 ft/sec
- 6500 - 8000 ft/sec
- 8000 - 9500 ft/sec

Line Location Map

Vertical Exaggeration 3:1
Seismic Refraction Survey - Line 4
(looking north)

Velocity Legend
- 0 - 2000 ft/sec
- 2000 - 3500 ft/sec
- 3500 - 5000 ft/sec
- 5000 - 6500 ft/sec
- 6500 - 8000 ft/sec
- 8000 - 9500 ft/sec

Vertical Exaggeration 3:1
Seismic Refraction Survey - Line 5
(looking north)

West

0  50  100  150  200  250  300  350

East

3720
3710
3700
3690
3680

Elevation (ft)

Distance along line (ft)

Line 1C Intersection 41 ft
EP-05 107 ft TD 20 ft

Vertical Exaggeration 3:1

Velocity Legend

0 - 2000 ft/sec
2000 - 2500 ft/sec
3500 - 3600 ft/sec
5000 - 6500 ft/sec
6500 - 8000 ft/sec
8000 - 9500 ft/sec

Line Location Map

ARCADIS U.S., Inc.
ASARCO El Paso Smelter
EL Paso, TX

Date: July, 2008
Plate 7

hydroGEOPHYSICS

2302 North Forbes Blvd. • Tucson, Arizona 85745 • (520) 647-3315
Seismic Refraction Survey - Line 6B
(looking northeast)

Velocity Legend:
- 0 - 200 ft/sec
- 200 - 1200 ft/sec
- 1500 - 5000 ft/sec
- 5000 - 6500 ft/sec
- 6500 - 8500 ft/sec
- 8500 - 9500 ft/sec

Vertical Exaggeration 3:1
APPENDIX B

HGI TECHNICAL MEMORANDUM
TECHNICAL MEMORANDUM

TO:        Frank Skocypec (ARCADIS U.S., INC)
FROM:      Chris Baldyga (hydroGEOPHYSICS, Inc.)
SUBJECT:   Seismic Refraction Results for the ASARCO El Paso Smelter
DATE:      July 16, 2008

INTRODUCTION

This technical memorandum is intended to describe the refraction seismic surveying completed at the Asarco El Paso Smelter Site (herein referred to as the site) in June 2008 under contract to ARCADIS U.S., INC by hydroGEOPHYSICS Inc (HGI). The site was being evaluated for a potential slurry wall trench to provide a barrier of subsurface flow across the International Border with Mexico. As well, other areas were surveyed to more fully understand bedrock conditions around the site. The site was located in El Paso, Texas.

SUMMARY

A summary of the geophysical surveys and results are as follows:

1) Ten lines of refraction seismic survey were completed totaling 5,430 feet. Field data were acquired during a six-day period occurring June 22nd – 27th, 2008.

2) Due to a combination of source strength, proximity to major transportation infrastructure (roads and railways), and poor soil conditions (loose and energy absorbent), the first arrival picks were generally good quality to a maximum of 150-200 feet from the shot point locations. Beyond 200 feet, the times to first arrivals were very noisy and extremely difficult to pick.

3) The results, showing velocity profiles along each of the ten lines, provided depth estimates for the interfaces between alluvium/colluvium and higher velocity rock units that may represent bedrock in some areas of the site.

4) The survey results indicate bedrock comprised of shale is approximately 8,500 feet per second which is in agreement with published values.

5) The survey results do not indicate the presence of a deeper limestone unit that is
known to occur at the southern end of the site (near Well # EP-132D), partly due to a combination of mitigating factors such as the proximity of the site to a major roadway and in some cases less than favorable locations for geophone placement (i.e., low coupling) in areas with high amounts of slag and/or gravel.

6) The survey results indicates that the shale unit or unit comparable in rock velocity is generally shallower towards the eastern portions of the site which are more distant from the axis of the Rio Grande River that forms the western boundary of the site. The high velocity rock layer appear to dip downwards towards the Rio Grande.

SEISMIC SURVEY METHOD AND RESULTS

Purpose and Objective
The objective of the refraction seismic survey work was to characterize subsurface conditions for a proposed slurry wall trench through what is referred to as “Smeltertown”. The information gained from the survey is intended to aid in the expected rippability of subsurface strata overlying bedrock upon which the slurry wall will be built. In areas away from the proposed slurry wall, the thickness of channel-fill alluvium and bedrock was to be determined.

Method
Seismic refraction surveys model geologic structure based on the behavior of artificial energy introduced into the earth. This behavior can be traced along individually traveled, refracted ray paths of acoustic energy. Refraction seismics can be used to delineate refractor interfaces, such as that between loose alluvium and competent bedrock. Essentially, compressive energy is introduced into the earth and the subsequent behavior of the earth is monitored by a series of geophones spaced co-linearly at regular intervals along the ground surface.

Compressional (P) waves are compressional-dilational events in which the wave front travels in the direction of a propagating wave and is the first form of energy detected by the geophones. The earth coupled geophones provide time-motion histories (seismic traces) that are recorded by a seismograph. Initial arrivals of the head waves are then selected from each seismic trace and travel times (in milliseconds) are determined. Formation velocities are then estimated from inverting linear sequences of travel times. The velocities at which refracted waves travel is a function of media densities, joint aperture, micro-fracturing density, and other structural characteristics that can be caused by weathering, including secondary porosity. Among measurable geophysical properties, the range of rock densities is one of the more constant, least variable parameters. However, the specific density of a particular rock type can be extremely variable.

Data processing for the seismic refraction method consisted primarily of accounting for energy source and geophone locations, making adjustments or topographic changes along the geophone array profiles, and determining the first arrival times at the geophones. The final step was to determine subsurface acoustic properties using one of three inversion methods: time-term least squares, delay-time, or tomographic inversion. For the present study, we chose SeisImager2D
(Geometrics, Inc. San Jose, CA). The software incorporates all of the features necessary for accurate representation of subsurface properties, including the first break pick, inversion, and plotting.

The first step for data processing was to pick the time for first arrival of energy at the geophone from each of the shots, also known as first break picking. Each geophone had a separate first break pick for each shot. The first break picking was conducted with the Pickwin module of SeisImager2D.

Interpretation of first breaks was conducted using the tomographic inversion routine of SeisImager2D. This method starts with an initial velocity model (generated by a time-term inversion and iteratively traces rays through the numerical model) with the goal of minimizing the root-mean squared (RMS) error between the observed and calculated travel times. Tomographic inversion is generally best used when velocity contrasts are known to be more gradational than discrete. In cases where strong horizontal velocity variations are known to exist, and in extreme topography, processing can lead to erroneous results with time-term least squares and delay-time inversion, depending on the severity. Thus, tomographic inversion was chosen for the Asarco El Paso Smelter Site. The final output of the inversion modeling is a profile (X and Z dimensions) of acoustic velocity beneath each geophone spread.

In summary, the processing steps consist of:

1) selection of first arrival times, applying gains and filters as needed
2) inputting geophone and shot-point surveyed locations
3) assigning layers to appropriate velocity slopes on the time-distance (T-D) plot
4) inverting data to velocity layers
5) evaluating the results
6) iteratively repeating steps four and five until a satisfactory fit to the data is obtained

**Logistics**

Ten shallow refraction seismic survey lines were completed around the site. Figure 1 shows the line layout and the location of pertinent wells that have useful borehole data.
Figure 1. Refraction Survey Base Map

The survey was performed during the period June 22\textsuperscript{nd} – 27\textsuperscript{th} by hydroGEOPHYSICS, Inc. (HGI), a geophysical consulting and service company based in Tucson, Arizona. On-site personnel for HGI were Mr. Christopher Baldyga, Senior Project Manager and Shawn Calendine, Staff Geoscientist I was responsible for data acquisition.

The Geode (Geometrics, Inc. San Jose, CA) 48-channel seismic system was used. The Geode seismic recorder is the next generation of seismic recording system, combining traditional seismic recorders with the flexibility and convenience of a distributed system. Geophone placement was every 10 ft with 9 shot points per spread. The source was a truck mounted Propelled Energy Generator (PEG) weighing about 40kg with additional elastic bands for increased signal. Shot records were viewed on a PC Laptop after each shot. The shot record (seismogram) was also saved to the computer and stored for subsequent processing. A real-time noise monitor showing all geophones was carefully scrutinized during shots to ensure that noise levels were at a minimum for each shot. This included watching for breaks in traffic flow.

Preliminary line locations and elevations were measured using a professional grade GPS system by HGI. A fiberglass measuring tape was used for geophone placement. For consistency, all elevations and line distances are shown in feet. Distances along lines shown in the cross-sections are relative to the first geophone location that is specific to that line. Line parameters are shown in Table 1.
Table 1. Line Parameters for the Refraction Survey

<table>
<thead>
<tr>
<th>Line</th>
<th>Beginning Coordinate</th>
<th>End Coordinate</th>
<th>Length (ft)</th>
<th># Shots</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>(373088.8,10666670.6)</td>
<td>(373552.4,10666216)</td>
<td>370</td>
<td>4</td>
</tr>
<tr>
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<td>(373007.4,10666180.2)</td>
<td>(373084.5,10666663.7)</td>
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<td>5</td>
</tr>
<tr>
<td>1b</td>
<td>(373037.1,10665120.2)</td>
<td>(373304.3,10665987.7)</td>
<td>850</td>
<td>16</td>
</tr>
<tr>
<td>1c</td>
<td>(373588.7,10664445.7)</td>
<td>(373031.4,10665149.7)</td>
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</tr>
<tr>
<td>3</td>
<td>(372933.3,10666350.9)</td>
<td>(373298.6,10666401)</td>
<td>360</td>
<td>7</td>
</tr>
<tr>
<td>4</td>
<td>(372919.8,10665633.4)</td>
<td>(373336,10665673.9)</td>
<td>420</td>
<td>6</td>
</tr>
<tr>
<td>5</td>
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<tr>
<td>6a</td>
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<td>(374323.8,10666203.1)</td>
<td>460</td>
<td>7</td>
</tr>
<tr>
<td>6b</td>
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<td>(373895.3,10666294.1)</td>
<td>460</td>
<td>9</td>
</tr>
<tr>
<td>7</td>
<td>(373552.4,10666216)</td>
<td>(373595.3,10667044.3)</td>
<td>830</td>
<td>15</td>
</tr>
</tbody>
</table>

Results

The resultant data plots display an interpreted geologic section based on the modeled interface between low and high velocity media. The low velocity medium is assumed to represent highly weathered alluvium consisting of various amounts of sand gravel and clay. The higher velocity medium is assumed to represent shale or equivalent unit having similar rock velocities.

Average velocities from the tomographic inversions are also presented for six different velocity ranges. Those ranges are outlined in the table below in Table 2.

Table 2: Assigned Velocity Layers and Colors

<table>
<thead>
<tr>
<th>Rock Velocity (ft/sec)</th>
<th>Assigned Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>1500 – 2,000</td>
<td></td>
</tr>
<tr>
<td>2,000 – 3,500</td>
<td></td>
</tr>
<tr>
<td>3,500 – 5,000</td>
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<tr>
<td>5,000 – 6,500</td>
<td></td>
</tr>
<tr>
<td>6,500 – 8,000</td>
<td></td>
</tr>
<tr>
<td>8,000 – 9,000</td>
<td></td>
</tr>
</tbody>
</table>

The following results are discussed below with little discretion given to the actual line number but rather given to lines that have good well information and the tie lines associated with them. For example Line 3 has good bedrock information and intersects Line 1A; therefore they are discussed in order.
Line 3
The length of the Line 3 profile was 360 feet and was collected from west to east (Figure 2). For this line and all lines, competent weathered alluvium overlies competent, higher velocity material. The range in velocities is between 1,500 ft/sec and 9,000 ft/sec. The ratio of the overall average of the top layer to bottom layer is approximately one to six, and is high enough to delineate two distinct geologic layers based on the average velocities. Overburden thickness ranges from 30 to 40 feet, approximately, with decreasing overburden thickness to the east. The well, EP-122D, intersects the line at 350 feet and indicates that shale is encountered at an elevation of 3,690 feet which is approximately 40 feet below ground surface. This correlates with a velocity change indicating that shale is approximately 8,500 feet per second.

Line 3 intersects Line 1A at 95 feet.

Figure 2. Line 3 Inversion Results

Line 1A
The length of the Line 1A profile was 470 feet and was collected from south to north (Figure 3) but is displayed with north towards the left side of the page making the viewpoint looking east. The intersection with Line 3 occurs at 205 feet. The depths to the different velocity layers are in reasonably good correlation with those in Line 3. The range in velocities is between 1,500 ft/sec and 6,500 ft/sec which is lower than the range observed in Line 3. The ratio of the overall average of the top layer to bottom layer is approximately one to four, and is high enough to delineate two distinct geologic layers based on the average velocities. Overburden thickness ranges from 40 to 50 feet, approximately. It does not appear that shale is encountered within the profile based on the lower velocities found at depth within the section.

Line 1
The length of the Line 1 profile was 370 feet and was collected from south to north (Figure 4) but is displayed with north towards the left side of the page making the viewpoint looking east. This line does not intersect with any other line but rather forms a northern extension to Line 1A. The beginning point of Line 1 is approximately 43 feet north of the last geophone location along Line 1A. The depths to the different velocity layers are in reasonably good correlation with those found at the end of Line 1A. The range in velocities found in Line 1 is 1,500 ft/sec to 8,000 ft/sec. The ratio of the overall average of the top layer to bedrock is approximately one to four, and is high enough to delineate two distinct geologic layers based on the average velocities. Overburden thickness ranges from 40 to 50 feet, approximately. The first arrival picks were sometimes difficult to assess in therefore there is some doubt about the abrupt change in topography of the different layers moving north along the profile. There is indication that a higher velocity material starting at 150 feet along profile but again can be attributed to poorer quality first break picks.

Figure 3. Line 1A Inversion Results
Figure 4. Line 1 Inversion Results

Line 7
Lines 7, 6B and 6A are on the eastern side of the major highway that bisects the site. The length of the Line 7 profile was 830 feet and was collected from south to north (Figure 5) but is displayed with north towards the left side of the page making the viewpoint looking east. The range in velocities found in Line 1 is 1,500 ft/sec to 9,500 ft/sec. The ratio of the overall average of the top layer to bottom layer is approximately one to six, and is high enough to delineate two distinct geologic layers based on the average velocities. Overburden thickness ranges from 30 to 40 feet, approximately, with decreasing overburden thickness remaining relatively constant throughout the section. If the Line 3 was extended into Line 7 the intersection point would occur at 245 feet. The elevation of this shale layer at this intersection point is approximately 2 feet higher than what is found at EP-122D which occurs at the end of Line 3.

There are three wells, EX-1, OBS-1, and EX-2, that intersect the line at 31, 73 and 107 feet respectively. All indicate that shale is encountered at an elevation of 3,690 feet which is approximately 40 feet below ground surface and correlates with a velocity change indicating that shale is at least 8,500 feet per second. Between the shale and ground surface, a “bowl” of low velocity material appear to correlate with the known location of a high hydraulic permeability (gravelly) zone.

Line 7 intersects EP-85 at 450 feet along profile but this well does not terminate in shale and is not used for calibration discussions. The intersection Line 6B occurs at 469 feet along profile.
Figure 5. Line 7 Inversion Results

**Line 6B**
The length of the Line 6B profile was 470 feet and was collected from northwest to southeast (Figure 6). The intersection with Line 7 occurs at 28 feet. The depths to the different velocity layers are in reasonably good correlation with those in Line 7. For this line, competent alluvium overlies higher velocity material. The range in velocities is between 1,500 ft/sec and 9,000 ft/sec which is similar to the range observed in Line 7. The ratio of the overall average of the top layer to bottom layer is approximately one to six, and is high enough to delineate two distinct geologic layers based on the average velocities. Overburden thickness ranges from 40 to 50 feet, approximately. It appears that shale is encountered within the profile and gradually increases in elevation towards the southeast with an accompanied decrease in alluvial thickness. The highest elevation at which the shale occurs is at the end of the line at 3700 feet which is about 12 feet higher than at the beginning of the line.

Figure 6. Line 6b Inversion Results
**Line 6A**

The length of the Line 6A profile was 460 feet and was collected from west to east (Figure 7). This line does not intersect with any other line but rather forms an extension to Line 6B. The first geophone of Line 6A is approximately 33 feet east of the last geophone location along Line 6B. The depths to the different velocity layers are in reasonably good correlation with those in Line 6B. The range in velocities is between 1,500 ft/sec and 9,000 ft/sec which is similar to the range observed in Line 6B. The ratio of the overall average of the top layer to bottom layer is approximately one to six, and is high enough to delineate two distinct geologic layers based on the average velocities. This section is comprised of thicker higher velocity layers than any other line. Bedrock topography is much more undulating as well. It should be noted that the first arrival picks for this line were very clean and had viable data for almost the entirety of the record for each shot point.

![Figure 7. Line 6a Inversion Results](image)

**Line 1C**

The following discussions for Lines 1C, 1B, 5 and 4 refer to lines collected in what is referred to as “Smeltertown”. The length of the Line 1C profile was 830 feet and was collected from southeast to northwest (Figure 8) but is displayed with northwest towards the left side of the page making the viewpoint looking northeast. The range in velocities found in Line 1 is 1,500 ft/sec to 7,000 ft/sec. The ratio of the overall average of the top layer to bottom layer is approximately one to four, and is high enough to delineate two distinct geologic layers based on the average velocities. There is one deep well, MW-132 that intersects the line at 5 feet. This well indicates that limestone is encountered at an elevation of 3,655 feet which is approximately 66 feet below ground surface and should correlate with a velocity change in excess of 12,000 feet per second. However these velocities are not detected, primarily due to lack of clean first arrivals at depth near these geophones. Additionally, the inversion software does not allow for constraining the model to known boreholes. The inverted velocity within this profile ranges from 1,500 ft/sec to 7,000 ft/sec but for the most the majority of the profile is less than 6,500 ft/sec.

Line 1C intersects Line 5 at 687 feet.
Figure 8. Line 1c Inversion Results

**Line 1B**
The length of the Line 1B profile was 850 feet and was collected from southwest to northeast (Figure 9) but is displayed with northeast towards the left side of the page making the viewpoint looking southeast. This line intersects with Line 4 at approximately 544 ft and forms a northeasterly extension to Line 1C. The beginning point of Line 1B is approximately 47 feet northwest of the last geophone location along Line 1A. The range in velocities found in Line 1B is 1,500 ft/sec to 8,000 ft/sec. The ratio of the overall average of the top layer to bottom layer is approximately one to four, and is high enough to delineate two distinct geologic layers based on the average velocities. Overburden thickness ranges from 40 to 50 feet, approximately. The character of the overburden appears to be dipping gently to the southwest and is evidenced by the appearance of the high velocity shale layer between 750 and 850 feet along profile. The elevation of this shale unit is about 3675 feet at the northeast end of the profile.

Figure 9. Line 1b Inversion Results

**Line 5**
The length of the Line 5 profile was 360 feet and was collected from west to east (Figure 10). The intersection with Line 1C occurs at 41 feet. The depths to the different velocity layers are in reasonably good correlation with those in Line 1C. The range in velocities is between 1,500 ft/sec and 6,500 ft/sec which is lower than the range observed in Line 3. The ratio of the overall
average of the top layer to bottom layer is approximately one to four, and is high enough to
delineate two distinct geologic layers based on the average velocities. Overburden thickness
ranges from 40 to 50 feet, approximately. It does not appear that shale is encountered within the
profile based on the lower velocities found at depth within the section. However, there is a
general trend in the observed results showing that the strata dip slightly to west/southwest away
from the plant.

Line 5 intersects EP-65 at 107 feet along profile. This well is shallow and does not terminate in
shale, thus not used for calibration discussions.

![Figure 10. Line 5 Inversion Results](image)

**Line 4**
The length of the Line 4 profile was 420 feet and was collected from west to east (Figure 11).
The intersection with Line 1B occurs at 41 feet. The depths to the different velocity layers are in
reasonably good correlation with those in Line 1B. The range in velocities is between 1,500
ft/sec and 6,500 ft/sec. The ratio of the overall average of the top layer to bottom layer is
approximately one to four, and is high enough to delineate two distinct geologic layers based on
the average velocities. Overburden thickness ranges from 40 to 50 feet, approximately. It does
not appear that shale is encountered within the profile based on the lower velocities found at
depth within the section. However, there is a general trend in the observed results showing that
the strata dip slightly to west/southwest away from the plant.

Line 4 intersects EP-64 at 150 feet along profile but this well is shallow and does not terminate
in shale and thus not used for calibration discussions.
CONCLUSIONS & RECOMMENDATIONS

The first arrival picks were sometimes difficult to assess in part due to several mitigating factors adversely affecting the signal/noise ratio. This manifested in picking first arrival to a maximum of 200 feet or 20 geophones from any given shot point and thus reducing the maximum potential depth of penetration for this chosen array.

The known limestone outcrop was not detected by this survey due to the depth of the layer. However a known shale unit at about 40 feet depth produced a change in velocity of 8,000 to 9,000 ft/sec, which corresponds to published average P-wave velocities for shale. This particular shale unit appears to be absent or too deep to detect in the southern portion of the site but appears at the end of Line 1B and into Lines 3, 7, 6A and 6B. The general trend of this bedrock shale unit dips down towards the west away from the plant. For each line a general description was provided stating the absence or presence of the shale unit and how much corresponding overburden is expected. The seismic velocities obtained from the tomographic inversion were distributed across 6 ranges and displayed accordingly in the figures.

We thank ARCADIS and Asarco for the opportunity to participate in this investigation. We hope these results provide useful insight into the overall investigation.

Respectfully Submitted,

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