Landstreamer/Gimbale GeoPhone Acquisition of High Resolution Seismic Reflection Data North of the 200 Areas - Hanford Site

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Contractor for the U.S. Department of Energy
under Contract DE-AC06-08RL14788

P.O. Box 1600
Richland, Washington 99352

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***Landstreamer/Gimbaled Geophone Acquisition
of High-Resolution Seismic Reflection Data
North of the 200 Areas - Hanford Site***

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for CH2MHill Plateau Remediation Company/Fluor Hanford, Contract No. 35789

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SUMMARY

The Confederated Tribes of the Umatilla Indian Reservation (CTUIR) was contracted by the CH2M Hill Plateau Remediation Company (CHPRC, successor to Fluor Hanford as contractor to DOE for cleanup in the Central Plateau area of the Hanford Site) to conduct a geophysical seismic investigation north of the 200 Areas at the Hanford Site in Richland, Washington. The investigation site is within the Hanford Central Plateau and south of the Gable Mountain and Gable Gap Area. The purpose of the investigation was to demonstrate the feasibility of using a landstreamer and gimbaled geophone acquisition approach to collect high-resolution seismic reflection data. The resulting information will be used to compare the landstreamer gimbaled geophone approach to recently acquired data in the 200 East Area using conventional spiked geophones. In addition, this investigation will target reflectors that may give indication of structures such as erosion channels and faulting in the top of the basalt, and evaluate the potential for preferred vertical and horizontal pathways for mobile contaminants in the deep vadose zone and ground water intervals. Specific targets of this seismic survey are the structure on the top of basalt, the top of the Ringold Formation and Lower Mud where present, and other stratigraphic features within the supra-basalt section.

Past operations within the 200 East and 200 West Areas of the Hanford Central Plateau have resulted in elevated ground water levels or "mounding". This discharged waste water has reached the ground water and plume maps indicate that it is partially flowing to the northwest through the Gable Gap Area. Ground water that does flow through Gable Gap has a shorter route and travel time to the Columbia River and the waste poses a potential hazard to the public and environment. Buried river or flood channels that may exist in these sediments may control some of the ground water flow rates and direction. Resolving these channels could help with the cleanup efforts at Hanford.

The landstreamer method used at this site provided a rapid, efficient and inexpensive method of collecting high resolution seismic data with a small crew and little disturbance of the land surface. The survey used both a receiver and source spacing of two meters to collect data over the zone of interest. Using the landstreamer approach, we were able to collect over 700 meters of 96-channel data each day for a total of 11,000 m.

The investigation showed that reflections from the top of basalt were recognizable on the raw shot gathers as well as the processed data. The seismic data were processed using both post-stack and pre-stack migration methods. All of the post- and pre-stack results show a generally rugose basalt surface displaying significant variability over short distances with some evidence of faulting. The highly variable nature of the basalt surface is interpreted to result from significant past erosional events and faulting. Viewing the vertical sections in a three-dimensional view shows possible erosional channels that could represent preferred pathways for contaminant transport. The landstreamer/gimbaled geophone method shows significant promise for characterizing the basalt surface topography in an efficient and cost effective manner.

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1.0 INTRODUCTION

1.1 *Site Location*

The Hanford Site is located in the southeastern portion of Washington State in the Columbia River Basin near Richland, Washington. In total, the site covers an area of 586 mi² (1517 km²) and was used for the production of plutonium for atomic weapons for over 40 years. The area of interest for the seismic survey is bounded by the area north of the 200 East Operable Unit and south and adjacent to the Gable Mountain feature (Figure 1.1-1). This is part of the Hanford Central Plateau. Part of the seismic survey extended into the Gable Gap area located between Gable Mountain and Gable Butte.

1.2 *Objective of Investigation*

Fluor Hanford (FH) requested that a field development test be conducted to demonstrate the feasibility of using a landstreamer and gimbaled geophone acquisition approach to collect high-resolution reflection seismic data in the 200 Areas. The resulting information is to be used to compare the landstreamer/gimbaled geophone approach to recently acquired seismic data using conventional spiked geophones. The data objective was to evaluate the potential for preferred vertical and horizontal pathways for mobile contaminants in the deep vadose zone and groundwater intervals. Specific targets of the seismic surveys are the structure of the top of-basalt, the top of the Ringold Formation and lower mud where present, and other stratigraphic features within the supra-basalt section.

2.0 BACKGROUND

2.1 *Operational History*

From 1944 until the late 1980's, Hanford's principal objective was the production of plutonium and the refinement of nuclear fuel. This processing and production created over 120 million gallons of waste byproducts and used process water that was discharged directly to the ground (Gephart, 2003). Other waste streams containing radionuclides and chemicals were stored in underground storage tanks. Of the 149 single shell underground tanks, 67 are suspected to have leaked more than 1 million gallons of tank liquid to the vadose zone (Gephart, 2003). All of the contaminants that have entered the vadose zone and that have not decayed will potentially be transported to the Columbia River (Gephart, 2003). The most extensive contaminant plumes observed in groundwater contain tritium, iodine-129, and nitrate. These contaminants originated from multiple sources and are mobile in groundwater. The largest portions of these plumes are migrating from the central Hanford Site to the southeast, toward the Columbia River (Hartman et al., 2009). However, Technetium-99 and uranium plumes, also exceeding standards, are present in the 200 Area, and are migrating to the northwest towards the area between Gable Butte and Gable Mountain (Gable Gap) and the Columbia River (Figure 2.1-1).

RG68120214.10

Figure 1.1-1. The Hanford site is located in south central Washington, north of Richland. Within the Hanford area the seismic survey was conducted north west of the 200 East area (modified after Barnett, 2005).

Figure 2.1-1. Uranium plume in the 200 East Area is shown to be spreading in a north east direction between (a) 1997 and (b) 2008 in the general direction of the Columbia River (Hartman et al., 2009).

2.2 Site Conditions

The Hanford Site operational setting is a windy, arid, high desert climate with asphalt, gravel, and dirt road conditions. Hanford has an average annual rainfall of less than 7 inches per year in current weather conditions. The majority of this precipitation occurs during the winter and spring, with the summers being hot and dry. It is for that reason that the spring and early summer was the best time to collect seismic data for this project. By the mid and late summer season, the natural vegetation dries to the point that off-road travel is not permitted due to the increased fire danger, and the seismic crews were not permitted to travel to sites off of established roads. The average monthly temperatures at the Hanford Monitoring Station range from a low of -0.7°C (31°F) in January to a high of 24.7°C (76°F) in July and the average annual precipitation at the HMS is 17 cm (6.8 in.) (Hoitink and Hendrickson, 2001).

2.3 Geology

The general geologic setting of the 200 East Area includes the Columbia River Basalt Group bedrock approximately 500 to 600 ft below ground surface (bgs) in the south to 60 ft bgs in the north. The basalt is overlain by gravel, sand, and clay deposits of the Ringold Formation and those deposits are overlain by the thick (100 to 400 ft) unconfined, heterogeneous glacial-fluvial gravel, cobble, and sand deposits of the Hanford formation. A generalized map of the surface

geologic features is shown in Figure 2.3-1 and the generalized stratigraphy of the Hanford Site is shown in Figure 2.3-2.

Figure 2.3-1. Geologic and geomorphic map of the 200 East area showing east-west trending synclines and anticlines (Reidel and Fecht, 2005).

Figure 2.3-2. Generalized stratigraphy of the Hanford Site and the 200 East Area. The Columbia River Basalt Group serves as the bedrock in the study area and is interbedded by sedimentary units of the Ellensburg Formation. Atop the CRBG is the sedimentary Ringold Formation. The overlying Cold Creek Formation and Hanford Formation are also sedimentary deposits (Reidel and Fecht, 2005).

Both the Ringold and Hanford formation are the result of great floods and huge lakes covering the Hanford site at least during the past 3 million years (Figure 2.3-3). The Hanford Formation,

for example, is composed of flood bar sediments deposited by the Missoula floods during the Pleistocene Epoch 1 million to 12,000 years ago (Reidel and Fecht, 2005). The Ringold formation is upper Miocene to Pliocene in age (10.5 to 3 million years ago) consisting of continental fluvial and lacustrine sediments deposited on the Elephant Mountain basalt by ancestral Columbia and Clearwater-Salmon rivers during late Miocene to middle -Pliocene time (William et al., 2000; Lindsey, 1995). These formations are generally unconsolidated to semi-consolidated. These floods have both eroded channels in the substrate and deposited large quantities of poorly-sorted sands and gravels (Gee et al., 2007; William et al., 2000). These lakes may have reached a depth of several hundred meters. The resulting sediments also formed desiccation cracks that were filled with finer grained sediments than the surrounding matrix. These fine-grained sediments may act as vertical and horizontal clastic dikes that can control the movement of water and contaminants in the vadose zone and form localized confining layers such as in the lower Ringold Formation. In addition, channels cut in the basalt and Ringold formation that have been filled with sands and gravels may also control the movement of water and contaminants in the vadose zone. Erosion features associated with post-Ringold fluvial incision and Pleistocene cataclysmic flooding created a scoured and channeled surface that was later buried and is often difficult to map (William et al., 2000). Within this buried paleo-channel and scoured area, Ringold-age sediments have been reworked and/or removed and younger, pre-Missoula gravels or the Hanford formation cataclysmic flood deposits of sand and gravel lie directly on top of basalt. William et al. (2000) believe that the erosion seen across the 200 Area was the result of a series of erosional events that scoured out some areas and leaving remnant mounds of Ringold sediments. This is principally based on well log discrepancies.

In addition, the Cold Creek unit primarily consists of fine sand and silt with a higher moisture holding capacity (Khaleel et al., 2007). The Uranium plume that is migrating to the northwest (Figure 2.1-1) has a linear appearance that may be controlled by these flood channels.

The youngest basalt flows of the Columbia River Basalt (CRB) Group are the Elephant Mountain Formation that is 10.5 million years old and ranges from 20 to 30 meters thick. The CRB group members have been folded and faulted to form Gable Mountain and Gable Butte. In addition, there are sub-surface anticlinal and synclinal structures present near Gable Mountain Pond that may have controlled some of the flood flows and channel development (William et al., 2000) (Figure 2.3-4). The geologic structures focused the flood energy, causing it to scour out the overlying Ringold sediments, and in some cases eroding down to and possibly into basalt bedrock. These channels were later filled by the younger Pleistocene Hanford sands and gravels. In fact, William (2000) suggests that the Columbia River shifted its course to the north of Gable Mountain after the ancestral river channel became plugged with flood deposits.

Figure 2.3-3. Topographic depiction of Pleistocene flood channels, Hanford Site, Washington (Williams et al., 2000).

Figure 2.3-4. Structure contour map of basalt surface (William et al., 2000).

2.4 Hydrogeology

The various ground water units are grouped according to operable units (Figure 2.4-1). These boundaries are not exact and do not necessarily represent flow boundaries, but rather group the waste sites into manageable components for investigation. The operable unit for the majority of this seismic investigation is within the 200-BP-5 unit; however, there may be a small overlap into the 200-ZP-1 unit. The water levels range from 330 ft bgs in the south to 215 ft bgs in the north. The direction of water flow across the Hanford site is from west to east. This is inferred from water-table elevations (Figure 2.4-2) (Hartman et al., 2007). In the area north of the 200 East Area, the ground water generally has a shallow gradient and is moving north and west through the Gable Gap area through buried paleo-channels (William et al., 2000; Hartman, et al., 2009). This is also shown in William et al. (2000) Plate 10 water table maps (Figure 2.4-3) although the exact boundary where the water divides to flow northwest at the northern boundary of the 200 East Area versus flow to the southeast is not known. At Gable Gap, the groundwater flows through the uppermost unconfined aquifer within the Hanford formation. This is supported by drilling and development activities for well 699-47-60 (William et al., 2000) which indicate that the basal Ringold gravel has low hydraulic conductivity relative to adjacent well(s) completed in the Hanford gravel. It is presumed that the hydraulic contrast between the Hanford and Ringold in the upper unconfined aquifer system results in flow along a preferential path in the Hanford formation north through Gable Gap. This interpretation is reinforced by historical groundwater plume maps and water-table maps (William et al., 2000). Steeper ground water gradients to the west and east are associated with lower permeability sand and gravel of the Ringold Formation at the water table, while the shallower ground water gradients may be associated with higher permeable sand and gravel of the Hanford formation at the water table. (Hartman et al., 2009). The higher permeability may have a direct relation to how quickly contaminants could reach the Columbia River.

The shallowest unit is the Hanford formation. These sediments were deposited between ≥ 3 Ma and 13 Ka and are composed of relatively unconsolidated pebble-to-boulder gravel, fine-to-coarse-grained sand, and silt-to-clayey silt (William et al., 2000). This unit may lie unconformably on top of the basalt in the northern part of the study area. The Hanford formation hydraulic conductivity (K) values are highest of all the hydrogeologic units present (e.g., 1×10^{-1} to 1×10^6 mD) and may not have the cementation characteristics of the Ringold formation.

The Ringold is composed of continental fluvial and lacustrine sediments deposited above the Elephant Mountain basalt by ancestral Columbia and Clearwater-Salmon Rivers during late Miocene to middle-Pliocene time (William et al., 2000). The unit consists of intercalated layers of indurated to semi-indurated and/or pedogenically altered sediment including clay, silt, fine-to coarse-grained sand, and granule-to-cobble gravel. Within the Ringold Formation there is a thick confining layer or lower mud composed of fluvial overbank, paleosol, and lacustrine silts and clay. This is between the Ringold Unit A and Unit C shown in Figure 2.3-2. However, in this study area, the confining mud layer is not present on the Gable Mountain anticline including Gable Gap and the region to the south extending to the northern boundary of the 200-West Area and including most of the 200-East Area. William et al. (2000) suggest that the absence of the Ringold lower mud unit is due to channeling and erosion that appears to have scoured into and completely removed the entire Ringold lower mud unit with the possible exception of small, localized remnants. In fact, they suggest that the basalt uplift and formation of the anticlinal ridges in the 200-East Area

occurred mostly after the Ringold lower mud deposition, thus the Ringold has been eroded by the Pleistocene cataclysmic flooding. Thus, it is not expected to see this as a seismic reflector. Where the Ringold is present, the hydraulic conductivity is between 0.1 to 200 mD.

The area of the seismic study is where William et al. (2000) identified possible communication between a confined upper basalt aquifer and the suprabasalt aquifer system.

Figure 2.4-1. Ground water operable units (Hartman, et al., 2009).

Figure 2.4-2. Water table and inferred flow directions in March 2008 (Hartman et al., 2009).

Figure 2.4-3. 1999 revised water table, upper unconfined aquifer (William et al., 2000).

3.0 SEISMIC METHODOLOGY

3.1 *General Description*

The objective of this study was to conduct a field test using a landstreamer with gimbaled geophones to acquire 96 channels of high-resolution reflection seismic data north of the 200 Areas of the Hanford Site. The scope of work involved collection of over 11 km of seismic data at 2 m spacing, and with a target depth of 75 to 600 ft. The program design is shown in Figure 3.1-1 with the line designations and locations highlighted in red.

3.2 *Equipment*

The seismic source was a 227 kg accelerated weight drop. The mechanism consisted of a 227 kg (500 lb) steel ram which was raised and released by a hydraulically powered hook. Once released, the ram was accelerated by a large elastic band to strike a steel plate (60 cm x 60 cm) on the ground. The height of the ram above the ground when it was released was about 60 cm but varied considerably depending on the terrain. A photograph of the accelerated weight drop is shown in Figure 3.2-1.

The survey used a rapid deployment CHR0121015 Landstreamer manufactured by HL Technologies. The streamer was equipped with 96 SM-7 gimbaled geophones manufactured by Input/Output Inc and spaced at 2 m. Each of the geophones used 30 Hz velocity sensors which are gimbaled for 360° roll with 180° pitch tolerance. A photograph of a geophone connected to the landstreamer is shown in Figure 3.2-2. The recording system was a set of four Geometrics Geode seismographs linked together. Each Geode was connected to 24 of the geophones along the landstreamer. The recording was initiated when the ram struck the plate via an electronic trigger. The digitized data were transmitted to a laptop computer where the recording is stored.

Figure 3.1-1. Schematic showing location of the eight 2D seismic profiles and their naming. The nine profiles comprise 11 km of seismic line data.

Figure 3.2-1. Photograph of the 227 kg accelerated weight drop. The 227 kg steel ram is lifted and released by hydraulic hook and accelerated by the large elastic band.

Figure 3.2-2. A cylindrical gimbaled geophone connected to the landstreamer during deployment. The weight of the geophone couples the geophone to the ground. The cable is sheathed with reinforced Kevlar to prevent tears or damage during use.

3.3 Landstreamer Seismic Technology

A landstreamer is a multichannel seismic cable with takeouts at fixed intervals. Each takeout is connected to a single self-orienting geophone. This cable is designed to be pulled behind a vehicle. The durability of the streamer is important to prevent damage to the streamer as it is pulled over uneven ground.

A towed land cable was developed and patented by Kruppenback and Bedenbender (1976) to increase the efficiency of collecting seismic data. Due to its similarity to a marine streamer, it has become known as the “Landstreamer” (Inazaki, 1992). The landstreamer system used for this experiment has self-orienting gimbal-mounted geophones in sturdy 1 kg cylindrical casings which are designed to sit on the ground (Figure 3.3-1). The cable is made with reinforced Kevlar sheathing and uses water proof connectors for the geophones. By eliminating the need to plant individual geophones and connect them to cables, the landstreamer approach is significantly more efficient than the conventional spiked geophone approach.

The landstreamer has been used successfully in a number of surveys including Inazaki’s seismic survey (2004) over concrete as well as over ice surveys in Antarctica (Determann et al., 1988, Eiken et al., 1989, Betterly et al., 2007). However, fewer documented surveys have been conducted over off-road or rugged terrain. Van der Veen et al. (1998, 2001) conducted an experiment comparing the signal response of a gimbaled and a spike geophone in an off-road situation. When the gimbaled geophones were dragged in a self-generating furrow, the performance of both geophone types was almost indistinguishable. Miller et al. (2003) showed that gimbaled geophones compared favorably with spiked geophones when side-by-side tests were conducted on a variety of surfaces. Figure 3.3-2 shows comparisons of the response of spiked geophones to gimbaled geophones.

Figure 3.3-1. Photograph showing traditional spiked geophone and a gimbaled geophone. The streamer can simply be pulled to desired location without having to plant individual geophones (modified after Miller et al., 2003).

Figure 3.3-2. Comparison of response of a gimbaled and a traditional spiked geophone placed in a shallow furrow on the ground. (a) The seismic trace of the spike (solid line) and the gimbaled (dotted line) from the common seismic source. (b) The amplitude spectrum of both geophones. (c) The difference of the phase between the spike and gimbaled geophone (Van der Veen et al., 1998).

3.4 Seismic Data Acquisition Procedure

Eight seismic profiles were collected during the 2009 Hanford 200 East seismic survey. These surveys were conducted in agreement with accepted standards of practice ASTM (2005). Each profile consisted of stations at 2 m spacing; the station numbers began with 0 and were labeled with even numbers representing their position on the ground. To start a profile, the geophone array was placed along the profile so a geophone was located at each station from 0 to 190. The source proceeded to shoot through, or roll into the geophone array to build up reflection point coverage (fold) over the end of the line (Figure 3.4-1). That is, the source shot at stations 0-194 with a 1.5 m perpendicular offset from the geophone line. At station 196 the source moved in-line with the geophone array. At each station thereafter the source shot at every station, but each time the source moved forward to the next station the geophone array was also moved forward one station (Figure 3.4-2). By continuing to pull and shoot at each remaining station, the 6 m off-end spacing between the source and the nearest geophone was preserved. The 6 m offset was maintained through the survey by connecting the geophone streamer to the source with a chain (Figure 3.4-3) and the streamer was pulled forward by the source/pickup truck using the chain connector. Each time the source was advanced to the next station, it was pulled slightly past the target station. Then the source was moved back to align with the station. This maneuver

relieved tension on the cable by adding slack to the landstreamer cable so that vibration and engine noise was reduced.

Figure 3.4-1. At the beginning of each profile line, the geophones were located at stations 0-190 (stations are on even numbers). The source shot at each station 0-194 with a 1.5 m perpendicular offset from the line.

Figure 3.4-2. After the source had shot through the line as in Figure 3.4-1, the source was moved inline with the geophones with a 6 m source to 1st geophone offset. At each station thereafter the source shot at every station, and each time the source moved forward to the next station, the geophone array was also moved forward one station.

Data collection over railroad tracks on profiles 2B and 3 required additional equipment. In order to pull the geophone streamer over the tracks, a plywood bridge was constructed. Three sheets of plywood were connected with metal hinges; and, the seams were covered with plastic lids (Figure 3.4-4). No shots were taken at the stations located on the railroad tracks. To shoot the stations up to the tracks, a Polaris Ranger utility vehicle (UTV) was used to position the source close to the tracks. The UTV was able to get the source closer to the tracks than the truck could. After the stations up to the tracks had been shot the source vehicle was relocated across the tracks and the survey continued with the source towing the streamer over the bridge. The geophones on the bridge at each shot were, as a consequence, not well coupled to the ground.

Figure 3.4-3. The pickup truck with trailer weight drop is connected to the geophone streamer with a chain. When the truck and weight drop move forward, the streamer is towed along behind it to preserve the source offset from the geophone array. Before shooting at a station, the truck with the weight drop must pull just past the station then back up to allow slack in the chain to reduce vibration along the streamer.

Figure 3.4-4. Three sheets of plywood were connected with metal hinges and bolts to create a bridge over the railroad tracks. The plastic lids were added to prevent any part of the streamer from catching on the seams between the sheets of plywood.

At each source location, the source was activated five times and the individual records were summed (stacked) into a single record. This summing (vertical stacking) serves to increase the data signal-to-noise ratio by attenuating random noise. It is also useful because the first shot compresses the ground under the plate and the next four shots have improved coupling. The number of stacks per station was determined based on the prior noise testing conducted near the 200 East Area in March 2009. The acquisition parameters used for the survey are listed in Table 3.4-1.

Table 3.4-1. List of acquisition parameters used for seismic profiles.

Source type	500-lb accelerated weight drop
Recording system	24 channel Geometrics Geode 24 bit seismographs
Source offset	source in-line offset 6 m source perpendicular offset 1.5 m for shoot through source perpendicular offset 0 m for off-end shooting
Vertical stack	5
Receiver interval	2 m
Nominal fold	48
Live channels	96
Sampling rate	0.5 ms
Record length	2.0 s

Seismic surveying with the landstreamer generally required three people. Deployment of the landstreamer took about 45 minutes. During deployment, one person drove the truck while two others worked together to pull the landstreamer out of the bed as the truck moved forward along the profile. Then the tasks of connecting the Geodes, setting up the computer, laying out the trigger wire and adjusting the landstreamer were quickly and easily accomplished with three people sharing the duties.

The seismic survey itself also worked well with three people. One person was responsible for taking notes, one person operated the weight drop and one person drove the truck and communicated with the weight drop operator. The person driving the vehicle also served as a second set of eyes to verify the data quality of each record before they were summed. Without major problems or breakdowns, between 45 and 55 stations could be shot per hour. Without major downtime, we were able to collect over 700 meters of line data each day for a total of 11,000 m.

At the end of a profile about 30 minutes were required to pick up the landstreamer and put away equipment. One person was needed to drive the truck while two others helped spool the landstreamer into the truck bed. Shutting down the software and disconnecting the Geodes took about 5 minutes. The efficiency of this particular survey was further increased because the equipment was able to be left in place over night. Otherwise, more time would have been spent in the set up and tear down of the survey each day.

3.5 *Prior Studies*

Several long seismic lines were collected in the late 70's early 80's for the Basalt Waste Isolation Project (BWIP) investigation (Figure 3.5-1). The purpose of this survey was to assess the viability of the basalt formation for possible use as a repository for the nation's nuclear waste.

A previous seismic survey in 1979 (SSC, 1980) utilized a three truck Vibroseis system as the energy source vibrating at every other station. These data were gathered with a 48 channel system in a split spread configuration that resulted in a 12-fold CDP stack. The station spacing was 50 feet and 18 geophones were used per trace. The lines are shown on Figure 3.5-1 as FY-79-3 and FY-79-4.

The results of this previous survey showed that the reflections associated with the top of the basalt were the strongest and most coherent energy band noted (SSC, 1979). Interpretations showed examples of possible or tentative high angle reverse faulting with minimal displacement throughout the survey. The interpretation was based on severe and radical character changes, reflection time offsets, rapid changes in dip, reflection discontinuities, and apparent diffraction patterns (SSC, 1979). Some of the evidence for faulting was good, and in other instances, it was inconclusive. SSC's 1980 report (SSC, 1980) discussed that some of these interpreted faults may instead be the result of buried stream channels, unconformities, highly eroded surfaces, lithologic changes, poor data quality, and inconsistencies in processing results. Thus they labeled previously faulted zones as "seismic anomalies". None of this changed their interpretation on line 4 discussed below.

In the Gable Mountain Area on SSC's line 4, they interpreted a strong north dipping basalt surface north of the structure. South of the structure, there was a gentler south dipping surface. The crest may have an erosional surface, and there may be a possible fault close to the center of the feature. They also interpreted an extension of Gable Butte as a faulted anticlinal structure.

A 1980 survey was similar to the 1979 survey in the layout except the vibrator point spacing was increased to every station resulting in 24 fold data (SSC, 1980). The only 1980 line that was close to the current study was line FY-80-12.

Within the boundaries of the 200 East Area, Bay Geophysical collected seismic data during the spring of 2008. The majority of the data were collected with 4 meter geophone spacing. Bay Geophysical did shoot a seismic line along Baltimore Road in the 200 Area with 2 meter spacing. They used a vibratory source and collected a total of 74,000 line feet of seismic data.

Their interpretation identified two north-south channels or depressions in the surface of the basalt. The basalt top indicated the possible presence of minor faulting. The supra-basalt section was not well resolved in their data. The Baltimore line with 2 meter geophone spacing may have resolved the H2 and H3 Hanford Formation boundaries (SGW-39675, 2009).

Figure 3.5-1. Seismic reflection line locations from surveys conducted for the Basalt Waste Isolation Project (SSC, 1980).

3.6 Noise Test

The noise test in March 2009 used both the 500 pound accelerated weight-drop and a 12 pound sledgehammer to generate seismic signals recorded by the 96 channel, 2 m spacing landstreamer cable. The locations of the noise tests are shown in Figure 3.6-1.

Figure 3.6-1. Locations of March 2009 noise tests.

During the testing, the position of the weight drop relative to the landstreamer was adjusted to determine optimum placement or distance (source offset) from the first active geophone. The number of repeat weight drop impacts required to generate sufficient seismic signal was varied between 4 to 9 stacks. Recording parameters such as record length, sample interval, and filter settings was also tested during the noise testing. In addition, the landstreamer cable was towed along the ground surface to verify proper action (cable remains straight) during movement.

An example of the accelerated weight drop data verses the sledgehammer data is shown in Figure 3.6-2. Based on noise test results, an end-on seismic array with a 6 meter source offset was chosen as the optimal geometry for production shooting with the weight drop.

Figure 3.6-2. Comparison of seismic data at location 7 obtained from a 500 lb. accelerated weight drop (top) with the data obtained from a sledgehammer (bottom). The left sides of the figures represent raw shot gathers; the right sides are fk-filtered versions of the same shot gather.

3.7 GPS Survey

The stations were initially located with a surveying tape and marked with pin flags. The locations of each shot point were later recorded with a Leica 1200 Global Positioning System (GPS) by Leica Geosystems (Figure 3.7-1). The base station was set up over well 699-52-55B for the entire GPS data collection. The co-ordinate quality (CQ) of collected points ranged between 0.011 m and 0.045 m with most points having a CQ near 0.020 m. While acquiring points on profile 2C, the rover lost contact with base station. As a result, the radio signal from the base station was increased and the rover was able to maintain contact with the base station over the entire profile. The GPS data were processed with Leica GeoOffice software. With the true coordinates and elevation of Well 699-52-55B, the software corrected the locations of the survey points relative to the location and elevation of the base station.

After the field work was completed, some slight problems appeared with the GPS data, especially on profile 2C. Between stations 1640 and 1644 the coordinates were not evenly spaced, and two coordinates were at the same station. To fix this problem interpolation was used to relocate these stations. The problem was probably due to long distance and lack of sight between the rover and base station.

Figure 3.7-2 is a base map showing the locations of all of the survey stations referenced to well 699-52-55B.

Figure 3.7-1. Photograph of Leica GPS base station set up over well 699-52-55B along seismic profile 3. The GPS antenna receives satellite signals and communicates via Bluetooth with the computer. Location data is transmitted from the base computer to the rover with radio signal.

Figure 3.7-2. Base map showing all seismic survey station locations. All station locations are referenced to well 699-52-55B which was location on survey profile 3.

4.0 RESULTS

4.1 Seismic Data Processing

The seismic processing was performed by TRICON Geophysics, Inc. Seismic data were processed to bid specifications as shown in Table 3.4-2. Steps included both pre-stack and post-stack time migration as well as pre-stack depth migration. Check-shot surveys that were conducted in the survey area were used to constrain seismic velocities for pre-stack depth migration.

Table 3.4-2. Data processing bid specifications used by TRICON geophysics to process seismic data.

Data reformatting
Trace edit
Geometry assignment
Gain recovery/spherical divergence
Surface consistent amplitude scaling
Trace balancing
Surface wave removal (f-k filtering)
Surface consistent deconvolution
Spectral whitening and balance
Refraction statics/Tomo statics
CDP sort
Interactive first velocity analysis
2-D normal moveout (NMO) corrections
Mute
Brute stack
2-D surface consistent residual statics
Intermediate stack
2nd interactive velocity analysis
2-D surface consistent residual statics
4th order NMO analysis & Application (eta) Trim Statics
*Final Stack Output to tape for workstation loading: plots supplied to client
2-D finite difference migration, FK or Omega X one pass migration with time variant spectral whitening
Final filter and gain modification: Time variant trace equalization to adjust RMS levels to parity.
Post-Stack signal enhancement (Noise reduction filter applied after stack.)
*Final Stack
2-D finite difference <u>depth</u> migration after * above followed by final filter, gain modification, and post-stack signal enhancement as above
Final Stack

4.2 Geologic Interpretation

The processed data clearly show the top of the basalt boundary throughout the study area. Figures 4.2-1, 4.2-2 and 4.2-3 show uninterpreted and interpreted pre-stack depth migration (PSDM) data in fence diagram for the study area. Throughout the study area possible faults were present and are suggestive of highly fractured and weathered basalt. The basalt bedrock appears to be dipping toward the south (Figure 4.2-4). A contour plot (Figure 4.2-5) was created from

the interpreted top of basalt (in time) from the PSTM data to illustrate the general shape of the basalt contact with smoothing of localized variations. While the basalt surface is overall planar, we interpret basalt topography variations to be due to indicate erosion or glacial scour of the basalt surface and faulting.

Cataclysmic flooding that flowed across the Hanford site, including the Central Plateau, has removed much of the older Ringold formation that used to cover this site. A map by William et.al. (2000) (Figure 4.2-6) shows what remains of the lower Ringold confined aquifer. This represents the Ringold Unit 9C which is the deepest confined aquifer in contact with the basalt surface. While most of the Ringold sediments have been eroded from this area, results of the seismic survey suggest the presence of remnant mounds of these Ringold sediments. Evidence of these mounds can be seen in profile 2C (Figure 4.2-7).

The theoretical vertical resolution of the survey calculated with an average velocity of 2500 m/s and a frequency of 60 Hz was is 10 m using the Rayleigh criterion. The theoretical lateral resolution of the survey at a depth of 125 m was calculated to be 72 m using the first Fresnel zone calculation. This is for unmigrated data. For migrated data, the guideline for horizontal resolution is $\frac{1}{2}$ wavelength or about 20 m. In other words, the smallest channel this survey is capable of detecting reliably is on the order of 10 m thick and 20 meters in width.

Figure 4.2-1. Uninterpreted prestack depth migration data over the entire survey area. The basalt bedrock contact can be clearly seen across each of the seismic profiles. Surface dimensions are northings and eastings in m.

Figure 4.2-2. Interpreted prestack depth migration data over the survey area. The upper boundary of the basalt bedrock is highlighted in blue and exhibits a rugose character. Surface dimensions are northings and eastings in m.

Figure 4.2-3. Seismic prestack depth migration results over the study area. The upper boundary of the basalt bedrock is highlighted in blue with possible faults in the basalt highlighted in orange. Surface dimensions are northings and eastings in m.

Figure 4.2-4. Seismic prestack depth migration results for profiles 2A, 2B and 2C. The basalt surface is dipping generally to the south. Surface roughness is probably due to faulting. Surface dimensions are northings and eastings in m.

Figure 4.2-5. Contour plot showing top of basalt in time (seconds) along with the location of each of the profiles. Horizontal axis is easting and vertical axis is northing. The top of the basalt is deeper to the south and to west. Contour plot exhibits contouring artifacts to the north where data coverage is sparse. The contouring process also smooths localized anomalies that can be seen on the individual seismic profiles. Axes are northings and eastings in meters.

Figure 4.2-6. Structure contour map of the Ringold Formation, Unit 9C (William et al., 2000).

Figure 4.2-7. Prestack depth migration data from profile 2C. Structure observed to overlay the basalt bedrock is interpreted to be remnant mounds of Ringold Sediment. Horizontal axes in m.

5.0 CONCLUSIONS

The landstreamer method used at this site provided a rapid, efficient and inexpensive method of collecting high resolution seismic data with a small crew and little disturbance of the land surface. The survey used both a receiver and source spacing of two meters through the zone of interest. Using the landstreamer approach, we were able to collect over 700 meters of 96-channel data each day for a total of 11,000 m. Moreover, a weight drop impact source provided adequate energy for imaging and a Vibroseis source was not necessary.

The investigation showed that reflections from the top of basalt were recognizable on the raw shot gathers as well as the processed data. The seismic data were processed using both post-stack and pre-stack migration methods. All of the post- and pre-stack results show a generally rugose basalt surface displaying significant variability over short distances with some evidence of faulting. The interpreted data show that the basalt bedrock surface ranges in depth from approximately 75 to 125 m and generally dips downward to the south. A possible channel at the basalt surface is apparent on lines 1A and 4A trending in a north-south direction. The highly variable nature of the basalt surface is interpreted to result from significant past erosional events and faulting. Viewing the vertical sections in a three-dimensional view shows possible erosional channels that could represent preferred pathways for contaminant transport. Finally, the landstreamer/gimbaled geophone method shows significant promise for characterizing the basalt surface topography in an efficient and cost effective manner.

5.1 Future Work

CHPRC will review the field test results and assess the feasibility of further characterization using this geophysical approach. If CHPRC determines the approach to be the best approach technically and economically for meeting the data objectives, additional line miles could be acquired under a Phase II investigation to map the top of basalt surface, stratigraphy within the supra-basalt section, presence or absence of paleochannels, and faults within in the 200 East Area and nearby Gable Mountain Gap Area.

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APPENDIX A – poststack migrated data

A-1. Post stack seismic profile 1A.

A-2. Post stack seismic profile 1B.

A-3. Post stack seismic profile 2A.

A-4. Post stack Seismic Profile 2B.

A-5. Post stack seismic profile 2B2.

A-6. Post stack seismic profile 3.

A-7. Post stack seismic profile 4A

A-8. Post stack seismic profile 4B.

APPENDIX B – prestack depth migrated data

B-1. Prestack depth migration seismic profile 1A.

B-2. Prestack depth migration seismic profile 1B.

B-3. Prestack depth migration seismic profile 2A.

B-4. Prestack depth migration seismic profile 2B

B-5. Prestack depth migration seismic profile 2B2.

B-6. Prestack depth migration seismic profile 3.

B-7. Prestack depth migration seismic profile 4A.

B-8. Prestack depth migration seismic profile 4B.

APPENDIX C – prestack time migrated data

C-1. Prestack time migration seismic profile 1A.

C-2. Prestack time migration seismic profile 1B.

C-3. Prestack time migration seismic profile 2A.

C-4. Prestack time migration seismic profile 2B.

C-5. Prestack time migration seismic profile 2B2.

C-6. Prestack time migration seismic profile 3.

C-7. Prestack time migration seismic profile 4A.

C-8. Prestack time migration seismic profile 4B.

A-9. Post stack seismic profile 2C.

B-9. Prestack depth migration seismic depth migration seismic profile 2C.

C-9. Prestack time migration seismic profile 2C.