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FINAL REPORT

ON A

SEISMIC REFLECTION SURVEY

CONDUCTED IN

BENTON COUNTY, WASHINGTON

FY-80 PROGRAM

PASCO BASIN

HANFORD SITE

BASALT WASTE ISOLATION PROGRAM

FOR

ROCKWELL INTERNATIONAL

ROCKWELL HANFORD OPERATIONS

ENERGY SYSTEMS GROUP

RICHLAND, WASHINGTON

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ABSTRACT

The massive Columbia River Basalt Group that underlies the Hanford Site is being considered as a potential geologic repository for spent nuclear fuel. As part of the effort to ascertain and better understand the physical and geological properties of these basalt flows, a multiphased seismic reflection program has been undertaken. The third phase, which was more localized than the previous two phases, constituted the FY-80 program and was designed to more thoroughly define geologic features and structural attitudes in an area in the central part of the Hanford Site. The specific feature of interest is known as the Cold Creek Syncline.

This seismic survey, as in the previous two surveys, utilized the "VIBROSEIS"* energy source and multifold common depth point recording. Based on a brief experimental program conducted at the start of this survey, several modifications were made in the data acquisition and processing parameters in an attempt to improve data quality and resolution in the vicinity of the upper basalt layers. From these data, the structural features of the basalt were determined and it was noted that the Cold Creek Syncline is a rather broad northwest-southeast trending structure that is complicated by the presence of several anomalous features.

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C O N T E N T S

INTRODUCTION

In December of 1979, a semi-detailed seismic reflection survey was instigated by Seismograph Service Corporation on the Hanford Site in Benton County, Washington. It was the third phase of a multiphased seismic program that is being conducted for Rockwell Hanford Operations, Energy Systems Group of Richland, Washington. The project is in support of the assigned tasks undertaken by Rockwell in the Basalt Waste Isolation Program for the U.S. Department of Energy.

The prime purpose of the survey was to more adequately define and delineate the Cold Creek Syncline which is a geologic feature located in the Pasco Basin. In addition to determining the general configuration of this syncline, it was also desired to evaluate the possibility of faulting and/or zones of suspected fracturing that may affect the integrity of the basalt formations.

This portion of the seismic program was preceded by two other reflection surveys. The first was experimental to determine the feasibility of the method and the best approach to be used in obtaining usable data. Results from this survey were published by Rockwell in Bulletin RHO-BWI-C-20 in September of 1978, entitled "Evaluation of Seismic Reflection Surveying on the Hanford Site". It was concluded that the reflection method was able to obtain satisfactory data and that the best overall results were obtained by use of the VIBROSEIS system.

On this basis, the work progressed to the second phase of the program which consisted of vibrating eight rather long reconnaissance lines which were selectively located by the Rockwell staff to aid in the evaluation of the subsurface at the Hanford Site. The results of this survey were submitted in a report to Rockwell. The data did indicate two areas that may have merit relative to potential sites for nuclear waste repositories. They were identified as the Wahluke Syncline located north of Gable Mountain and the Cold Creek Syncline located south of the mountain.

Because the Cold Creek Syncline was considered to be an area of interest on the Hanford Site, the third phase of the seismic program was concentrated in this area. Using the framework established by the previous project, a network of six relatively short lines was designed by the Rockwell personnel to emphasize and clarify the structural aspects of the feature. The methods and procedures used for data acquisition, processing and interpretation of these results are the subject of the following report.

FIELD OPERATIONS AND PROCEDURES

General

As in the past, crew headquarters for the FY-80 project were established in Richland, Washington, and it was necessary to utilize the capabilities of two parties to accomplish and complete the assigned tasks of the new program. They were identified as Party N and Party PG. Field operations and all phases of data acquisition were the responsibility of Party N, whereas Party PG was responsible for on-site data processing and preliminary field interpretation of the results which also included quality control of the incoming field material.

An FY-80 prefix was assigned to the new lines to distinguish them from those of the previous work. Six rather short lines totaling 34 miles of linear surface coverage were vibrated. They were designated as Lines FY-80-9 thru FY-80-14. The general location of the lines is disclosed by Figure 1. These data were acquired during the calendar period of December 20, 1979, and February 7, 1980. It should be noted that an experimental program was conducted on December 19th and these results are discussed later in the report.

Total recording and drive time for the production portion of the project was logged at 320 hours or 32 ten hour working days. From these figures and the amount of linear surface coverage, it can be seen that the average daily production was 1.06 miles which is equivalent to 112 vibrator points (VP's) per day. These figures vary significantly from those of last year and they were caused by a change in field recording parameters that was suggested by the experimental work conducted prior to starting the production schedule. A discussion of and a reason for the changes is presented in the following portion of the report.

Data Acquisition

Experimental Work

Since this year's seismic program was concentrated in one rather localized area where surface conditions were predominantly soft wind blown sand, it was decided to spend one day conducting experimental

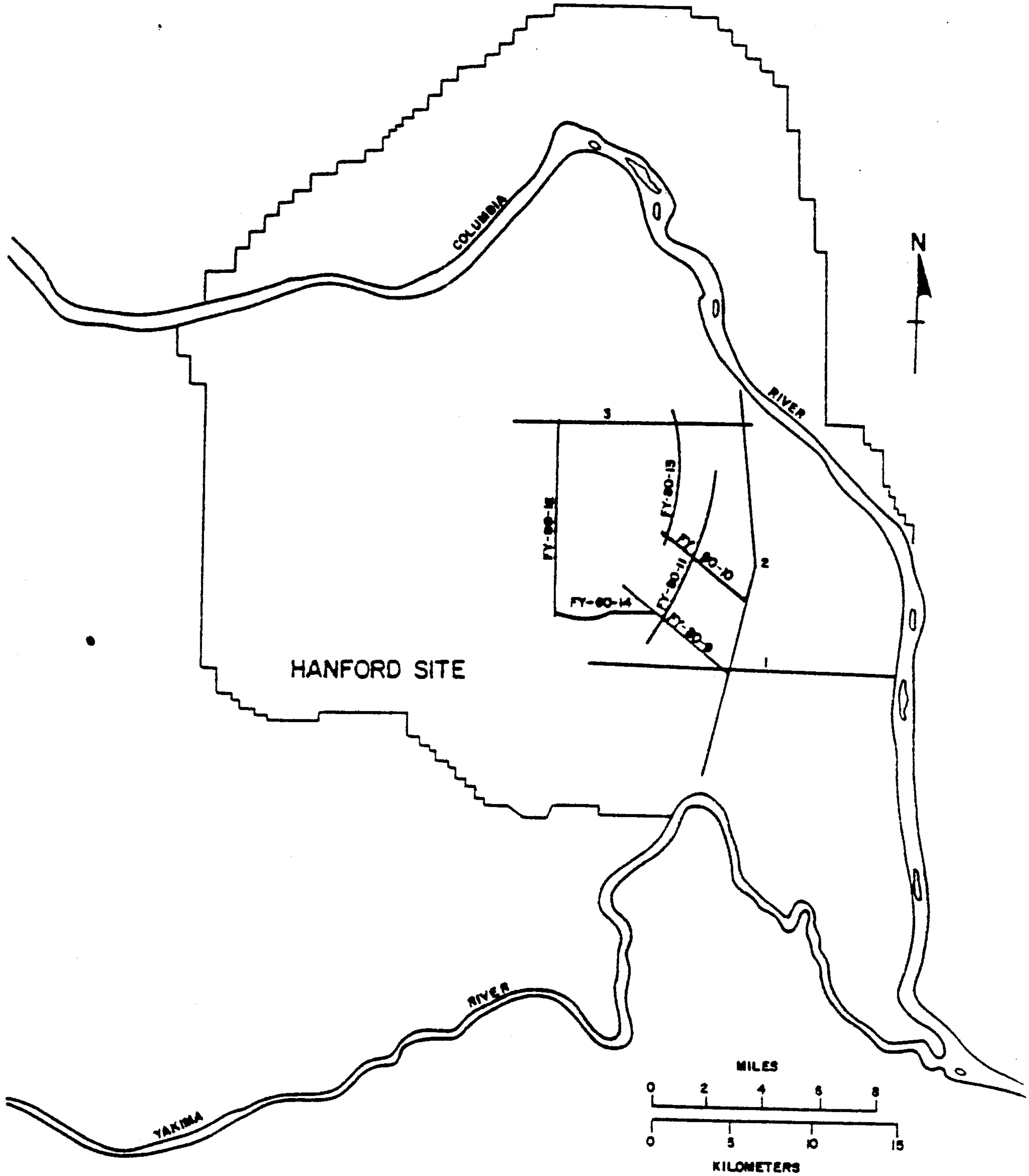

FIGURE 1
LINE LOCATION MAP

work. It was hoped that a more satisfactory solution to the problems of poor signal to noise ratio and residual statics could be determined prior to starting the production work. It was also desired to test the feasibility of shorter source and receiver patterns in enhancing high frequency reflections. To these ends, the following trials were conducted.

The experimental work included a noise spread and a comparison test of several source and receiver patterns. The following patterns were tested:

<u>Geophones</u>

1) 6 phones grouped (noise spread)

2) 18 phones over 100 feet

3) 18 phones over 50 feet

4) 12 phones over 50 feet

<u>Vibrators</u>

1) 1 vibrator (14 sweeps stacked)

2) 3 vibrators - 37.5 feet between vibrators; 5.8 feet move up per sweep for 14 sweeps; 150 feet total pattern.

3) 3 vibrators - 37.5 feet between vibrators; 2 feet move up per sweep for 14 sweeps; 100 feet total pattern.

4) 2 vibrators - side by side; 3.8 feet move up per sweep for 14 sweeps; 50 feet total pattern.

All four geophone patterns were tested simultaneously with each of the four vibrator patterns. A 30-120 Hertz, 10 second sweep was used in all tests.

The most prominent noise pattern indicated by the noise spread was the air blast generated by the vibrators. The 100 foot geophone pattern using 18 phones per trace appeared to best attenuate this unwanted energy. As hoped for, the shorter patterns did show slightly higher frequency reflections on the far offset traces; however, the overall continuity and reflection quality was inferior to that of the 100 foot pattern. The final decision for the most adequate geophone pattern was, therefore, unchanged from that selected for the previous work.

Determination of the most optimum vibrator pattern was a more difficult choice. As previously indicated, the longer vibrator patterns again disclosed slightly better attenuation of the air wave and more difinitive reflection continuity. As an additional test of the field recording parameters, it was decided to sum a varying number of sweeps for each of the three vibrator patterns and compare these results. It was found that 14 sweeps per VP showed very little, if any, improvement over 6 sweeps. Based on this conclusion, the number of sweeps per VP was changed to 6 per station for conducting the production work; however, an additional change was implemented. It was the doubling of the number of vibrator points to be acquired by vibrating at every station instead of every other station. By so doing, the Common Depth Point (CDP) coverage was increased from 12 fold to 24 fold and it was believed that this added coverage would result in better statistical information for residual statics and dynamic corrections which are extremely critical in the processing phase of the operation.

In summary, the choice for the optimum vibrator pattern consisted of 3 vibrators in tandem, spaced approximately 37.5 feet apart and with 5.8 feet move up between sweeps. The number of sweeps was reduced from 14 to 6 per station with a corresponding reduction in pattern length from 150 to 100 feet. VP interval was also changed from 100 to 50 feet resulting in 24 fold CDP coverage.

Production Parameters

The following outline summarizes the final selection of parameters and type of equipment used in conducting this survey.

Recording Unit

Instrumentation	-	Texas Instruments DFS IV digital recording system with 800 BPI 9 track tape drive and instantaneous floating point amplifiers
Number of channels	-	48
Gain mode	-	Instantaneous floating point
Low-Cut filter	-	27 HZ 36 decibels per octave slope
Hi-Cut filter	-	124 HZ 72 decibels per octave slope
Notch filter	-	60 HZ
Sample rate	-	2 milliseconds
Format	-	SEG-B
Record Length	-	11.25 seconds

VIBROSEIS Source

Type vibrators	-	Y-600 with SSC VIBK electronics, center mounted on trucks
Number of vibrators	-	3
Sweep generator	-	Pelton, radio transmitted signals
Sweep frequency	-	30 - 120 HZ
Duration	-	10 seconds

Listening time	-	1.25 seconds
Vibrator pattern	-	3 in tandem 37.5 feet apart
Number of sweeps	-	6 per vibrator pattern
Pattern length	-	100 feet total with 5.8 foot move-up per sweep
Vibrator pattern interval	-	50 feet (resulting in a 24 fold stack)

Spread Geometry

Configuration	-	Split-straddle, 3 station gap between traces 24 and 25
Station interval	-	50 feet
Near trace offset	-	100 feet
Far trace offset	-	1250 feet

Detectors

Geophone type	-	Mark Products L25E
Frequency	-	40 HZ
Number per trace	-	18 phones - 3 strings of 6 connected in series - parallel
Phone pattern	-	Straddling station in-line, 100 feet coverage (6 foot uniform spacing)

DATA PROCESSING

General

On-site data processing was accomplished through the use of trailer mounted equipment which was the equivalent of that used for the previous work. The computer hardware consisted of a Raytheon 704 24K central processing unit, an array transform processor, two vacuum tape drives, two fixed head disk memories with 1.5 megabyte total capacity, teletype, card reader, and an electrostatic plotter. Phoenix software was provided to enable full seismic data processing.

The processing group designated as Party PG utilized the computer to analyze the initial experimental data, perform all data reduction, prepare brute stacks and preliminary final stacks. After the completion of all data acquisition, the processing was transferred to Party PH in Denver, Colorado, where the final processing was accomplished using the Phoenix I system which has a more sophisticated software package to aid in final data presentation. Additional velocity analyses were generated on Lines FY-80-12, 13 and 14 in an attempt to further refine these data. Automatic statics and post stack enhancement techniques were applied to all six of the new lines. Final display and filming was also completed by this group.

Figure 2 presents a generalized flow diagram of the steps used in processing the FY-80 data. The programs and processes were essentially the same as those used during the previous work; however, there were several deviations from the established normal that were implemented.

GENERALIZED PROCESSING FLOW DIAGRAM

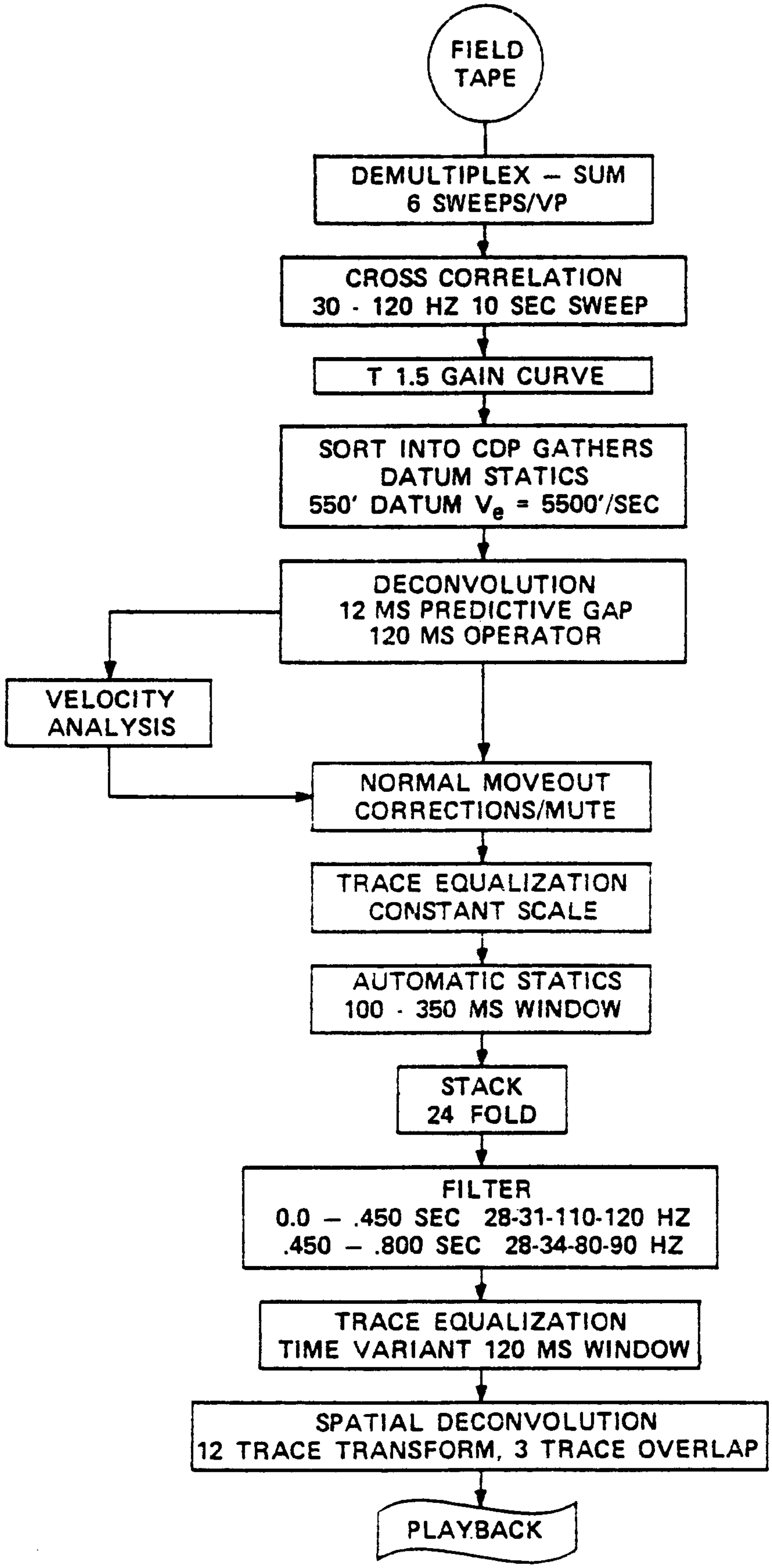

FIGURE 2

They involved the deconvolution (DCON) parameters, the spatial deconvolution program and most notably a change concerning the increase in stacking coverage from 12 fold to 24 fold. These variations will be discussed in more detail later in the report.

The primary objectives in processing the FY-80 data were to enhance the quality of the reflection associated with the top of the basalt, and also, those that may result from stratified layers immediately above and below the basalt. Past experience, based on the interpretation of results and the examination of synthetic seismograms, has indicated that very few, if any, reflective events were noted below depths of 1500 to 2000 feet below the surface. They were either nonexistent or almost completely obscured by multiples. In view of this situation, it was decided to concentrate the processing efforts on techniques and parameters that emphasize the shallow data even at the risk of adversly affecting the deeper information. The above conclusions were based on the premise that the shallow basalt discloses geologic structure similar to that of the older flows.

After the data were summed and reformatted, the record lengths were shortened from 1.25 seconds to 0.8 seconds of data to be processed. This helped compensate for the additional processing time required by use of the 24 fold coverage and still allowed the display to be equivalent to approximately 4000 feet of subsurface section. A detailed discussion of the processing steps employed to accomplish all of these desired results follows.

Data Reduction

Demultiplexing and Summing

All field data were demultiplexed and reformatted from Society of Exploration Geophysicist B (SEG-B) format into Phoenix trace sequential fixed point format. The instantaneous floating point gain was recovered during demultiplexing; however, a gain recovery limit was set in order to attenuate noise bursts which may have resulted from traffic or other related interference near the recording spread. Vertical summing was also performed during the demultiplexing operation. It was accomplished by digitally adding or combining the six records obtained from the 6 sweeps at each vibrator pattern into one output record per VP.

Cross Correlation

The next step in processing was to cross correlate the summed records with the 10 second 30-120 Hertz sweep that was used in collecting the field data. This sweep was taken from the recording unit sweep generator and recorded through the instrument system; thus, any phase distortion inherent to the recording system, especially low-cut and notch filters, would also be present in the sweep. This phase distortion was then removed from the data by the cross correlation process. At this point a $T^{1.5}$ exponential gain curve was applied to the results to compensate the loss of reflection signal amplitude with depth.

Geometric Corrections

Datum Statics

Static corrections were calculated and applied to the data to relate the surface elevations of the source and receiver locations to a common horizontal reference plane. All lines except Line FY-80-12 were corrected to a 550 foot flat datum immediately after cross correlation. FY-80-12 was in an area of more abrupt and greater overall elevation changes than the other lines; and therefore, it was corrected to a sloping datum to enable a more uniform analysis of time variant corrections such as those required for normal moveout and the initial mute. It was corrected to the 550 foot datum after stack. Both the elevation datum and the correction velocity of 5500 feet per second were the same as those used for the 1979 survey.

Trace Header Modifications, Sorting and Editing

All traces on each correlated record were identified according to their CDP locations, source locations, receiver locations and source to receiver offsets in preparation for normal moveout and residual static corrections. In addition, all noisy or dead traces were flagged to prevent stacking with valid traces. The data traces were then arranged on the tape in proper CDP order.

Velocity Analysis and Normal Moveout Corrections

Normal moveout corrections were computed from constant velocity stacks. These stacks were made on fifteen to twenty adjacent CDP's and were usually acquired at half mile intervals. These analyses ranged from 3,000 to 16,000 feet per second and they served as the basis for the determination of spatially variant velocity functions that were used to calculate the normal moveout corrections. In general, it was found that these stacking velocities varied from approximately 3,000 feet per second near the surface to 5,500 to 6,500 feet per second near the top of the basalt and then rapidly increased to more or less 13,000 feet per second at a time of 800 milliseconds. The accuracy of these velocity determinations was checked by applying the resulting moveout corrections to 100 percent shotpoint displays. Anomalous conditions were investigated and adjusted accordingly.

Data Enhancement

Deconvolution (DCON)

In the prescribed manner for determining parameters, a set of several DCON operators were applied to a representative portion of the data. These trials were designed to test data enhancement of spiking DCON versus DCON with different predictive gaps. Because of the overall high level of ambient noise in this data, it was found that there was very little difference between any of the DCON trials. After studying the results, it was decided to use predictive DCON with a 12 millisecond gap and 120 millisecond operator. The operator remained the same as that for the previous work; however, the major change was from the spiking to predictive with the hope of enhancing the continuity in the data. The main purpose of the spiking DCON had been to balance frequencies and produce maximum uniformity of data across a large area where reflection signal character varied significantly. Because the seismic program for this year was much more localized, reflection character was more uniform, and predictive DCON was considered to be the most appropriate method to use. It should be noted that the data were deconvolved before velocity analysis.

Gain and Mute Application

Following the DCON process and the corrections for normal moveout, an initial mute was applied to the data. The object of the mute was to remove the refraction first break energy so that the first arrival events would not be stacked with the reflection events. A constant window scaling function was applied after the muting process to amplify weak data traces relative to stronger data traces.

Automatic Statics and Stack

Residual statics due to variations in weathering thickness and velocity were handled through an automatic statics program. All traces belonging to a CDP gather were aligned to a pilot which consisted of a summation of all traces within this CDP group and a weighted summation of three adjacent traces on each side of the gather. The pilot trace was thus a tapered mix of seven adjacent CDP's. Those traces that were being aligned belonged to the center CDP and the alignment was completed through a correlation process over a 100 to 350 millisecond window.

After completion of all geometric corrections and data enhancement techniques thus far discussed, the traces within a CDP (usually 24 for 24 fold stacking) were then stacked or summed together. These results were output to tape for further processing.

Post Stack Processing

Band-Pass Filtering

A time variant band-pass filter was applied to the data immeiately after stack to attenuate noise outside the frequency range of the primary reflections. Between 0 and 450 milliseconds, the band-pass filter was limited to the frequency range of the sweep and had a cosine tapered low-cut from 28 to 34 Hertz and a high-cut from 110 to 120 Hertz. From 450 to 800 milliseconds the high-cut end was reduced to 80 to 90 Hertz.

Time Variant Scaling

Automatic gain control (AGC) was applied to the data to compensate for amplitude fluctuations due to changes resulting from stacking and band-pass filtering. This AGC or time variant scale function used a 120 millisecond sliding window in which the gate or center sample of the window was amplified or attenuated based on the RMS amplitude of the entire window.

Spatial Deconvolution (SPACON)

The last major step in the processing was the application of a spatial filtering program. It was selected over the coherence filter program of last year because it seemed to more subtly discriminate against random noise lineups particularly in very noisy areas with poor or weak reflection signals. The SPACON program was designed to attentuate random noise and enhance the coherent events. This was accomplished by taking two-dimensional transforms of 12 adjacent CDP's, normalizing the resulting F-K spectrum and applying a noise attentuating matched filter. This result is then inversely transformed back to the time domain. The 12 trace transforms were taken at 9 trace intervals thus providing a 3 trace overlap.

The preceding program was the final step in the normal sequence of processing and the only remaining task was to display and film the results. This was accomplished and the data were presented in cross section form using the variable area-wiggle trace mode of presentation.

DATA INTERPRETATION

General Discussion

An interpretation of the results pertaining to the FY-80 survey was conducted as a dual phased project. The first phase involved a cursory on-site field interpretation and it was primarily to insure quality control of the data acquisition and the processing techniques; however, a tentative structural evaluation was also made. The second phase was a final interpretation that was made in Tulsa, Oklahoma, and it involved the preparation of a contoured map indicating the subsurface structural conditions as determined from the finalized sections. A final report was also generated and it covered all phases of the entire effort.

Field interpreting was the responsibility of the Party Chief and as such he approved processing procedures and was in charge of establishing parameters that would yield optimum results. He also prepared a weekly project report that outlined the status of all portions of the work. An interim report was submitted upon completion of each line and it contained a brief discussion of the structural aspects disclosed by the data on the preliminary sections.

Prior to a detailed discussion of the FY-80 seismic results, it is believed prudent to mention a change in the interpretive approach relative to faulting that has been used to interpret these data and also to revise some of the data from the 1979 survey. An examination of maps and sections from the 1979 survey disclosed an excessive number of proposed zones of faulting. The feasibility of these faults was questioned in the written portion of the original report; however, it was decided to present them as one of a number of possible subsurface phenomena. The current philosophy still recognizes these zones as representing areas of anomalous conditions but it does not necessarily relate these anomalies to faulting. The apparent discontinuities, reflection offsets, diffractions, character changes, dip factors, and other criteria usually associated with faulting may also be indicative of situations completely independent of faulting. Some examples of these possibilities are flow terminations, buried stream channels, unconformities, highly eroded surfaces, lithologic changes, extremely poor data quality and finally inconsistencies in processing results that are caused by severe and irregular variations in the near surface materials which bring about the application of erroneous static and dynamic corrections.

In conjunction with the above reasons and the generally inconclusive evidence for faulting, it was decided that the proposed zones of faulting would be changed to areas of seismic anomalies. On the maps, the faults would be replaced by a symbol (large colored circle) that represents the location of an area associated with a seismic anomaly of undetermined nature.

This decision necessitated the revision of some of the 1979 data. Changes were made on those lines in the immediate vicinity of the FY-80 program and they included Lines 1-1, 1-2, 2-1, 2-2, 3-1, and a portion of 3-2 between VP's 780 and 940. The remaining lines from the 1979 survey have not been revised. These revisions have been incorporated with the current interpretation of the FY-80 data.

Detailed Discussion

As previously noted, the FY-80 program has contributed approximately 34 miles of additional seismic control to that of the Hanford Site. The added control was in the form of 6 new lines of profile that were located south of the Gable Mountain structure and in an area associated with the subsurface feature known as the Cold Creek Syncline.

An interpretation of the results was made based on information taken directly from the processed sections. In general, these data were believed to be satisfactory as the overall quality of the results was considered reasonable for the area. A map was prepared using this information and it was identified as Near Top of Basalt. The map was made in time from values associated with and derived from a reflection that was usually the strongest and most consistent event on the sections. It was believed to originate from the Elephant Mountain Flow as determined from the results of several uphole velocity surveys conducted in the area. The reflection times on the map have been graded relative to the validity of the pick. Many areas of questionable continuity have been indicated and they were believed to be the result of poor statics which have played havoc with the results over the entire area. Some of the zones of questionable continuity were identified as possible seismic anomalies and they were indicated as such on the map.

The old and new data were tied at several locations throughout the area and no problems were encountered. Character correlations between the lines were also believed reasonable thus further insuring the compatibility of the data.

The structural interpretation of the subsurface was presented on the contoured map and several notable anomalies were disclosed. The most prominent feature was that of the Gable Mountain structure. Immediately south of this structure, a shallow syncline was shown separating the major feature from a proposed anticlinal trend that is believed associated with Gable Butte. The most radical departure from the gentle southwest dip into the Cold Creek Syncline was noted in conjunction with Line FY-80-10. These data suggested an anticlinal fold that was interpreted as possibly associated with an extension of a spur from the Gable Butte feature. The symmetry of the Cold Creek Syncline was severely affected by this feature and an attempt was made to lower these data and remove the structure. This proved fruitless as the data on the sections appear to be properly interpreted; however, two seismic anomalies have been noted on Line FY-80-10 between VP's 300 and 420. They may be indicative of abnormal subsurface conditions or unresolved residual static problems that could affect the data. It should also be noted that an equivalent situation is suggested by the data in the saddle area of Line FY-80-11 between VP's 400 and 480. The proximity of these two areas may have established an elongated zone of erroneous data or seismic anomalies that warrant further investigation.

Several other areas are shown as being associated with seismic anomalies; however, they are believed to be of minor consequence and not worthy of additional discussion. The remaining structural attitudes as presented on the map are believed to be representative of regional subsurface conditions.

CONCLUSIONS AND RECOMMENDATIONS

The results of the FY-80 program have added considerable data to an area that may be a prime candidate for the location of a repository. Prior to the survey, very little was known about the definition of the Cold Creek Syncline; however, with the addition of these data, a more definitive delineation of the feature has been made. It appears to be in an area of minimal deformation with a relatively stable environment. The symmetry of the feature was considerably affected by the apparent anticlinal flexure disclosed by Line FY-80-10 and further investigation in this area is recommended to aid in the confirmation of this anomalous condition. The use of a smaller grid in the area between Lines FY-80-11 and 12 would certainly help to resolve the problem and also yield results that would be beneficial in establishing the integrity of the basalt in this localized portion of the area.

As previously discussed, the interpretive efforts used in resolving the current seismic data from the Pasco Basin do not fully support the abundant number of faults that were submitted with the 1979 report. As a consequence of this philosophy, the faults were removed and replaced by a symbol indicating the presence of a seismic anomaly which is a bonafide classification regardless of the interpretational differences. The FY-80 data were interpreted in this manner and the 1979 data relevant to the immediate area were also revised when necessary to conform to this conclusion.

In summary, it is believed that the current interpretation is a more realistic evaluation of the subsurface and should reveal attitudes that are representative of the general structural trends in the area. It also isolates several unresolved geophysical and geological anomalies that may warrant further investigation.

Respectfully submitted,

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