QUARTERLY REPORT**U.S. DEPARTMENT OF ENERGY
MORGANTOWN ENERGY TECHNOLOGY CENTER
CONTRACT NO. DE-AT21-92MC29267
Task No. 2**

"Analysis of Deep Seismic Reflection and Other Data from the Southern Washington Cascades"
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INTRODUCTION

This report covers the period from March 1, 1993 to May 31, 1993. The overall goals of the program task are to provide a final synthesis of six deep seismic reflection profiles and other geological and geophysical data from the southern Washington Cascades region where a probable extensive deep sedimentary basin has been discovered. This deep sedimentary basin is hypothesized from geological, regional magnetotelluric (MT), gravity, magnetic, and seismic reflection data as described in the American Association of Petroleum Geologists (AAPG) article by Stanley and others (1992). This report analyzed three seismic reflection profiles acquired by the Morgantown Energy Technology Centers in combination with the extensive MT and other data to outline a probable geological model for a thick conductive section of rocks in the southern Washington Cascades (called the Southern Washington Cascades conductor, SWCC). Earlier MT models suggested that the section consisted of an east-dipping package that extended to depths of as much as 20 km but appeared to surface in the Bear Canyon area near Morton, Washington and along the axis of the Carbon River and Morton anticlines. Interpretation of the first three DOE seismic reflection approximately confirmed the MT interpretation and added new information on anticlinal structures and detailed stratigraphy. In this quarterly report, we summarize the progress over the first two quarters of the program for FY93, and project the possible findings during the remainder of the project. A milestone chart for the first two quarters has been submitted separately, along with cost reports, but a copy of these items are attached for completeness.

STATEMENT OF WORK

We list the following tasks to be performed by the U.S. Geological Survey, under Task no. 2, to preface discussions in the remainder of the progress report for the first two quarters of FY93:

1. Conduct an on-site review at the Morgantown Energy Technology Center of western Washington geophysical and geological data necessary for further analysis at the USGS offices in Denver. Such gathered information for review will include but not be limited to METC data and reports, Geotrace processing and seismic section results, well log synthetics for the Chehalis Basin, and geochemical evaluations.
2. Analyze the above geological and geophysical data, and visit Daniel Geophysics (Geotrace) offices in Denver to discuss their views on the value of further processing. The USGS will attempt to obtain any required final processing at Geotrace or at the USGS Denver seismic processing center.
3. Incorporate into the overall effort, the velocity models from the following studies into the overall

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analysis of the geophysical/geological data, in order to refine the hydrocarbon setting of the region: Regional seismic refraction-wide angle geophysical data on a north-south profile that crosses the SWCC. acquired by Walter Mooney of the USGS; a vertical incidence reflection profile using the refraction shots obtained by Scott Smithson of the University of Wyoming in this area.

4. Incorporate into the overall effort, key findings of S. Y. Johnson from the new geological mapping and well-core studies being conducted in the area of the DOE seismic reflection profiles, as part of the USGS "Southern Washington and Northwestern Oregon" (SWANO) basins project.
5. Model and combine magnetotelluric (MT) data from the Carbon River anticline (obtained by the National Earthquake Hazards Reduction Program (NEHRP) with the other seismic and surface geology to derive an accurate lithology for the geophysical models.
6. Utilize refined aeromagnetic and gravity maps for the SWCC area being completed through the SWANO project to develop discrete models to further refine the lithologic/tectonic setting of this area and determine its hydrocarbon potential.
7. Construct any additional synthetic seismograms and ray-trace models of reflection data that may be developed and/or improved by using the refraction data from the USGS regional studies above.
8. Perform refined interpretation of all the seismic sections resulting from the DOE surveys including lines 1, 2, 3, 4, 5, and 6, and the 3-D section. The two StrataSearch seismic lines and the USGS results from the refraction survey and all geophysical/geological information will be incorporated as available and necessary.
9. Synthesize the data into a USGS open-file report as an integrated analysis and interpretation of the geophysical/geological work done in the southwestern Washington area by the USGS and relate it to the reflection seismic profiles done by DOE and provide a copy of the openfile report to DOE/METC.
10. Prepare a final report for DOE/METC on the synthesis of geological and geophysical data and include recommendations for future work in deep methane source rocks based on the evaluation of effectiveness of the DOE seismic effort and the processing used.
11. Participate in the presentation of the results of this work at the annual Natural Gas Conference to be held in the mid to late fall of 1993.

Deliverables:

- (1) Status reports on the acceptability of processing for three most recently acquired DOE seismic lines and other important findings during performance of this task.
- (2) Progress report on geological interpretation of the seismic data.
- (3) Progress report on combined interpretation of seismic data and all other available geophysical data.

- (4) USGS open-file report.
- (5) Final report to DOE.
- (6) Abstract, paper as required for DOE/METC Natural Gas Conference.

DISCUSSION OF PROGRESS

The following discussion provides a summary of progress in the third quarter of the fiscal year and is supplemental to the progress report submitted March 2, 1993 that covered the 1st and 2nd quarters.

1. A Voyager Petroleum report with significant seismic reflection data from the northern Carbon River anticline (near Black Diamond, WA), including data tapes have been obtained from Voyager Petroleum in Denver. These data will be very useful in understanding the key anticlinal structures in the region of the SWCC and can be published in the integrated reports that discuss the DOE reflection and MT data. An example of one of these profiles is shown in Figure 1.
2. Line drawings of all of the available reflection data have been made with notations including reflector brightness, as a prelude to further digital processing of the data. Correlation of reflections from DOE line 4 using a key well in the northern Chehalis Basin to the area west of Bear Canyon suggests the Skookumchuck formation is easily mappable in the reflection data when keyed to the well. Skookumchuck formation reflections can be traced to a point where they onlap onto volcanic units mapped as Northcraft formation. Because the Skookumchuck is upper Eocene and the Northcraft is middle Eocene, this causes a stratigraphic problem and may imply that the volcanic units are actually Ohanapecosh Formation of Oligocene age. However, careful study of the Skookumchuck reflections show that they do not necessarily extend to the Bear Canyon outcrops being studied by Sam Johnson, thus the question of these units existence in the Morton anticline is still unanswered, but reflectivity studies will be done to analyze this possibility further. Other very useful seismic reflection data from the area near the SWCC has been purchased from Lauren Corporation (formerly StratSearch), Denver, by other USGS programs. We have analyzed several profiles in the central part of the Chehalis Basin and northwest of the SWCC. These profiles provide other details of middle Eocene stratigraphy and basin development. Significantly, one of the profiles has also been previously purchased by DOE, but more recent processing of the data set by Lauren has produced a highly improved reflection section that shows key deep reflection in the area of the east end DOE seismic reflection profile no. 6, crossing the axis of the Morton anticline, within the SWCC. One of the Lauren profiles near Tenino, Washington in the Puget Basin is keyed to wells that were used to characterize the stratigraphy of the lower Eocene marine rocks, notably the McIntosh Formation, that are important to interpretation of the SWCC. This profile shows a very clear stratigraphy with about 2-3 km of middle Eocene to Oligocene marine sedimentary rocks, underlain by 3-4 km of McIntosh Formation equivalents and generally consist of very high-quality data that is easily correlative with the key wells. Line drawings of these profiles will be included in the final report on this project.
3. Bandpass, muting, and FK filtering of key parts of the DOE seismic reflection data in the Morton anticline has been completed using the public domain modeling software SU, developed at the Colorado School of Mines. We will also construct velocity models and continue color plotting of the processed reflection profiles.
4. Sam Johnson continues to study core from wells in the SWCC region and conduct additional surface mapping. Several key findings have emerged from this study. In a well (Storm King, Mineral No. 1) north of Morton, Washington, two marine intervals were found in the Puget Group rocks, suggesting a final transgressive, regressive stage to the marine environment in the SWCC region. In addition, detailed study of core from a well north of Seattle shows that a major volcanic event

occurred with silicic components within the margin of Siletzia (marine mafic complex that forms the basement for most of western Washington). This finding both supports the rifting model for generation of the mafic complex and provides a pinning point for the rift margin. This well is located exactly on the north-south gravity and magnetic gradient that has been interpreted by C. A. Finn, Branch of Geophysics, to represent the eastern margin of Siletzia in the Puget Sound region. Integrated studies of the well data, gravity/magnetic data, and seismicity data are proceeding to obtain further knowledge of the basement structures and their role in development of the sedimentary basins in the SWCC and Puget Lowland regions. A major basin has been identified in the Seattle area, long known from evidence provided by a large gravity low (called the Seattle basin anomaly). The USGS has obtained many hundreds of km of marine seismic data from Puget Sound that shows up to 10 km of Eocene and younger sedimentary rocks in this basin. The data is keyed to a deep well on the north side of the Seattle basin. The reflection data also clearly outline the Crescent basement and warping of the basement from north to south. Processing and interpretation of this data continues by Sam Johnson, Chris Potter, and Tom Pratt, USGS.

5. Seismicity for the SWCC region has been studied as an aid to tectonic modeling. The distribution of strike-slip faults and associated transpressive features has now been mapped in detail. Also, seismicity plots along DOE seismic profiles 1, 2, and 3 show that the thrust interpreted to occur in the Stanley et al. (1992) paper is clearly outlined by the seismicity patterns. In addition, the seismicity in the Morton anticline area seems to outline this major structural feature. One of the plots generated in this study is shown in Figure 2, with the seismicity superimposed on the geological/geophysical cross-section from Stanley et al. (1992).
6. We have developed new software for 3D visualization of gravity, magnetic, MT and seismic data using a proprietary graphical system called IDL. This software will be used to provide a 3D view of the combined data sets for optimal visualization of the structures in the region.
7. Preparation of illustrations for the USGS open-file report on integrated analysis and interpretation of all data from the southern Washington Cascades has been started and writing of this report will proceed when key interpretations are completed. These interpretations include the nature of the Skookumchuck/Northcraft contact in the area west of Bear Canyon and the relationship of Bear Canyon stratigraphy to this contact. Secondly, the nature of the Morton anticline, including the age of formation of the structure and its closure, is a key study item that is continuing, using ray-trace modeling of 3D seismic data in the Morton area. An outline of this report has been completed and when all modeling and illustrations have been completed, the report will be written, with a draft expected to be completed by October 15, 1993.
8. As has been discussed by DOE and the USGS, a stratigraphic test well is badly needed in the Morton area and past reports have outlined the best location for this well. New interpretations, when completed under the current project, may better pinpoint the most suitable location for a test well. Hunt Oil Company has leased significant holding recently in the Morton area with the intent to drill a gas test. Hunt geologists have told me that they have identified good source rocks in the area and have good reason to believe that there are high-porosity reservoir rocks in the Puget Group. They base their assessment of reservoir rock potential on the evident porosity found in Puget Group rocks in mines in the Morton area. This porosity is due to acid leaching of the rocks from regional low-temperature geothermal fluid flow. This geothermal leaching is in contrast to the more predominant effect normally found of clay mineral development that restricts porosity. Such clay mineral or secondary alteration development resulted in low porosity-permeability in gas wells drilled by Shell Oil in the Columbia Plateau play area. If acid leaching of the rocks in the Morton anticline area can be demonstrated, the overall potential of the area becomes much more significant. Hopefully, Hunt Oil will be successful in their endeavor to drill

a gas test and many of our questions stemming from the geophysical studies can be answered. In addition, low-level activities continue to generate a deep-drilling project in the SWCC area that would be funded by the interagency drilling program (formerly DOSECC).

9. All work for synthesis of the data is on schedule and reports should be completed as specified, allowing a full presentation of the results of the work at the annual Natural Gas Conference in the fall of 1993.

DISCLAIMER

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FOURTH QUARTER GOALS

This progress report summarizes work during the third quarter of the project during FY93. Field geological mapping, continued processing and plotting of seismic reflection data and study of regional tectonics will continue into the fourth quarter. Completion of modeling and preparation of illustrations for the final report will be the focus of the latter part of the fourth quarter, in expectation of a presentation at the Northwest Oil and Gas Association meeting in Bend, Oregon during September.

FIGURE CAPTIONS

Figure 1-Sample reflection section and geological interpretation based on Voyager seismic data from the Carbon River anticline near Black Diamond, Washington.

Figure 2-Cross-section of seismicity in a 0.5 degree swath following Highway 12 (largely coincident with seismic profiles 1-3). Purple lines on the west end outline seismicity possibly associated with a bend in the Siletzia plate that is also expressed in "dipping reflections" observed on seismic profile 1. The St. Helens seismic zone (SHZ) seismicity appears to merge with a shallow zone that mimics the Morton anticlinal structure. The purple line on the east near the Skate Mtn. anticline outlines east-dipping seismicity related to the thrust that cores this anticline (also see reflection events on Fig. 3).

Figure 3-Color plot of muted, amplitude-coded seismic reflection data from DOE seismic profile no. 3. Color attribute analysis and display of processed seismic data and models is now possible with software resident on the Branch of Geophysics computer system.

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