DOE/ET/12138--T1 (Vol. 1)

West Virginia University

AN ANALYSIS OF THE STRUCTURAL PARAMETERS THAT INFLUENCE GAS PRODUCTION FROM THE DEVONIAN SHALE

ANNUAL PROGRESS REPORT 1979-1980

VOLUME I: EXECUTIVE SUMMARY AND TASK REPORTS

U. S. Department of Energy
Contract number DE-AC21-76ET12138
formerly DE-AC21-76MC05194

October 1980

Department of Geology & Geography
College of Arts & Sciences
Morgantown, West Virginia 26506

DISCLAIMER

West Virginia University

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CONTRACT DE-AC21-76ET12138
Formerly DE-AC21-76MC05194

SUBMITTED BY

DEPARTMENT OF GEOLOGY AND GEOGRAPHY
WEST VIRGINIA UNIVERSITY

ROBERT C. SHUMAKER, PROJECT DIRECTOR

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RESEARCH ASSOCIATES

DISCLAIMER

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PREFACE TO VOLUMES I, II, AND III

This report is written to document progress made during the fourth year of our study for the Eastern Gas Shales (EGSP) Project, and it is organized to meet the needs of readers who have a variety of interests in the project. The first portion of Volume I includes the Executive Summary which gives a general overview highlighting the progress made over this contract year. The second portion of Volume I includes task reports written by the specific task investigators, and it is written primarily for scientists interested in a technical overview of the fourth years' work. Volumes II and III of the report consists of appendices of data compiled by the principal investigators. The appendices serve as a data bank for work accomplished during fiscal 1979-1980. These data can be used by other scientists with the permission of the principal investigator responsible for the specific compilation.

PERSONNEL

Robert C. Shumaker, Project Director

REGIONAL STRUCTURE TASK

Robert C. Shumaker, Principal Investigator

SURFACE STRUCTURE TASK

Jeanette M. Dixon, Principal Investigator *
Thomas H. Wilson, Principal Investigator *

SURFACE FRACTURES TASK

Mark A. Evans, Principal Investigator *
Kevin D. Lee, Principal Investigator *

PRODUCTION AND GEOCHEMICAL TASKS

Jane Negus-de Wys, Principal Investigator
Junior L. Jenkins, Research Associate
Michael A. Hesse, Research Assistant
Lora D. Graves, Laboratory Technician *
Joseph F. Kposowa, Laboratory Technician
John W. Henderson, Geologic Drafting Specialist
Frances M. Sines, Secretary

GEOPHYSICAL TASK

Richard T. Williams, Task Director
James E. Ruotsala, Principal Investigator

GEOLOGIC DRAFTING SPECIALISTS

Peter L. Heiss *
John G. Wright

SECRETARY

Jean A. Toren

Other major contributions to our project were made by:

Jean Cheng Statistics

* No longer attached to project.

5./6.

AN ANALYSIS OF THE STRUCTURAL PARAMETERS THAT INFLUENCE GAS PRODUCTION FROM THE DEVONIAN SHALE

1979 - 1980

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VOLUME I

PART I

EXECUTIVE SUMMARY - BACKGROUND AND PROGRESS 1979-1980

ROBERT C. SHUMAKER

INTRODUCTION

This report presents the scientific results and progress of our efforts toward understanding shale gas production from the Devonian shale within the project area (Figure 1) during fiscal 1979-80. Last year, fiscal 1978-79, we established a positive relationship between basement structure and shale gas production in southwestern West Virginia. This year we completed compilation of geologic data within the adjacent area of eastern Kentucky preparatory to testing the applicability of the relationships observed in West Virginia to eastern Kentucky. In 1980-81 we intend to complete our analysis of the influence of geologic structure on Devonian shale gas production for the entire project area.

In fiscal 1979-80 we also expanded our geochemical analysis of eastern Kentucky to test the applicability of an exploration rationale developed in that area to a broader and more thoroughly sampled area.

We embarked on a computer analysis of recorded tapes of seismic data collected within the Cottageville area. This analysis seeks to determine if frequency and velocity anomalies are associated with fracture porosity. This task is being carried on under a separate contract (DE-AT21-79MC11284, Task Order No. 24) for the upcoming 1980-81 year.

PURPOSE OF THE STUDY

The specific objectives of our contract are given in the section entitled, Objectives, found within the Task Report section of this Volume. In general, the purpose of our research under the EGSP program is to analyze structural parameters of local and regional geology that influence Devonian shale gas production within the contract area (Figure 1). Our project was designed in 1976, initiated in early 1977, and it became fully staffed for significant work in 1978. Efforts thus far have been channeled toward defining the structural parameters that influence shale gas production; but, most significantly, we have developed an exploration rationale for shale gas (fracture porosity) exploration in West Virginia. We are now entering the final compilation and analysis stage of the project which we trust will permit us to characterize the shale over the entire contract area including the eastern Kentucky Big Sandy gas field.

The second goal of the EGSP program at West Virginia University, which is to provide support for geologists and geophysicists studying to obtain advanced degrees in the mineral industry sciences, has been eminently successful in that we have placed nine graduate level geologists in energy related employment.

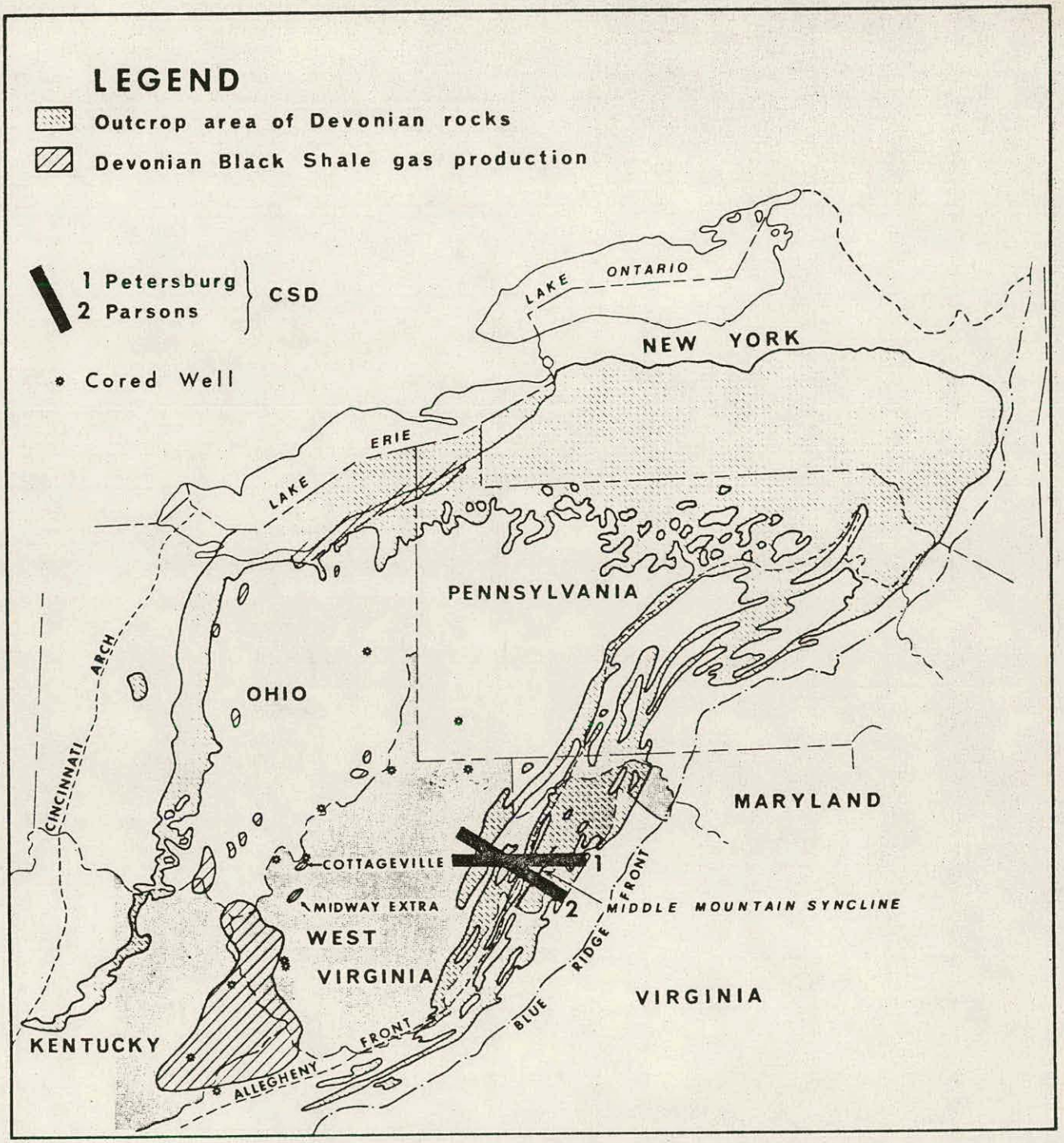

Figure 1. Contract area

METHODS OF APPROACH AND ORGANIZATION

We have attacked the problem of locating fracture zones within the Devonian shale along several avenues: thru remote sensing studies, subsurface and surface geologic studies, thru geochemical and geophysical studies, and by hydrologic studies. Our attack has been broad, covering several disciplines, and yet it has been integrated into one work contract to achieve the stated goals. Our method of approach to attain the contractual objectives is thru the organization of our efforts into several tasks: one task is compiling the regional structure; a second task has studied surface fractures and subsurface fractures found in oriented shale cores. A third task studied shale gas production in detail where reliable production data is available. A fourth task is investigating surface structures which would have production potential if found in the subsurface, and a fifth task completed its study in 1979 of ground water-lineament-gas production interrelationships. These five study groups, that is: regional structure, fractures, subsurface structures, production, and hydrologic studies, have been carried under one yearly contract supported under the EGSP Resource Inventory Tasks.

Another study group, a geophysical task, has been carried under the EGSP Shale Characterization Task. The geophysical group has developed an inexpensive seismic system which can be used to assist in locating shallow fracture zones.

In essence, the first two tasks, regional structure and fracture studies, were designed to provide a regional or basin structure framework for the entire project. Compilation of this framework should be completed in the upcoming year, fiscal 1980-81. The surface structure studies have documented, by analytical field work, those details of structure which are either similar to structures which produce gas or those structures which we feel are prospective for shale gas production. This study is largely completed. Production studies have been completed for three gas fields where production records are available thru cooperating private companies that permit analysis and documentation of geologic parameters that influence gas production from the shale. Basin data collection has been completed for all three areas, and reports have been written on each individual area. A comparison of results and the application of an exploration rationale developed from our study of two fields in West Virginia is to be applied to the entire study area during fiscal 1980-81 as a test of that rationale. The geophysical studies have developed an inexpensive geophysical technique that can locate shallow fracture zones of high permeability. We have found that resistivity surveys can locate shallow fracture zones. For fracture zones several thousand feet below the surface, we are developing an inexpensive seismic method. Field testing of this system will continue under a separate contract (DE-AT21-79MC11284, Task Order No. 24) during 1980-81. The hydrologic studies completed their analysis in fiscal 1978-79, and found that a direct relationship was found between short lineaments and production. We have coordinated these studies so that most of the task groups are working in specific shale gas producing areas where we have reliable production data (Cottageville, Midway-Extra, and the Big Sandy fields, - Figure 1).

It is emphasized that our basic research approach, while being developed for the organic Devonian shales, has direct application to many other DOE projects such as Tight Sands, Methane Drainage, coal mine hazards such as roof falls, underground coal gasification, etc. Indeed, any project which deals with fractured rocks will be interested and derive benefits from our work on fractures and gas production from fractured shale.

MAJOR ACCOMPLISHMENTS 1979-1980

We have completed three years of research effort at full staff levels, and we have now completed those segments of the geologic research that will lead to obtaining the contract objectives within the upcoming year.

The attention of all study groups focuses on fracture porosity within the shale: its origin, distribution, and the methods of locating zones of more intense fracturing. As indicated above, we have succeeded in developing a rationale for selecting areas to drill shale gas wells that have a higher than normal potential for shale gas production. This rationale was developed in a limited area of the basin, west central West Virginia. This rationale suggests that wells located in thick organic shale up-dip from a syncline, that is, on the lower part of anticlinal limbs, produce more shale gas than any other area. The optimum producing area appears to be above deeply buried basement faults. We anticipate testing the applicability of this rationale to a much broader area in eastern Kentucky in the upcoming year to see if it is applicable to the entire commercially productive area.

We have found a direct relationship between the geochemical parameters of the shale in eastern Kentucky and shale gas production there. This past year we have expanded our analysis of this area to further investigate the relationship. A positive relationship exists between several geochemical trend maps of elements and minerals in the shale and areas of major production. Trend maps of oxides of Al, Ca, Fe, K, Mg, Mn, P, Si, and T show similarities to maps of density of high gas producing wells. The Ca and Mg oxide trends are related to fracture filling by calcite and dolomite. The K, Al, and Si oxide trends are indicative of clastic depositional relationships. Strata-specific geochemical trend maps and more regional maps, including work by the University of Kentucky and the West Virginia Geological Survey, are now in progress.

Our geophysical program to develop inexpensive techniques for locating shallow fracture zones has met with mixed success. We have been able to locate very shallow fracture zones by resistivity surveys. However, our efforts to develop an inexpensive seismic method have met with technical and equipment problems. However, the past year we solved most of these problems, and results are sufficiently encouraging to anticipate field testing of the system during the next year. The redesigned system should be able to record seismic events from the shale within the economic depth range of the producing area.

The results of geochemical studies for the next contract year will be reported under Contract number DE-AC21-76-ET12138, and the results from geophysical investigations will be reported under Contract number DE-AT21-79MC11284, Task Order No. 24.

FINANCES

The responsibility for financial accounting for this grant lies with the controller of West Virginia University. Detailed financial reports are forwarded to DOE by the controller's office as separate reports.

PUBLICATIONS

An important aspect of our investigation is our responsibility to disseminate the results of our research to the scientific community and private companies interested in exploration for shale gas production. To accomplish this, we have presented the following articles either in talks during fiscal 1979-80 or in published journals. Copies of these articles appear in Volumes II and III of this report.

Beebe, Robert R., and Henry W. Rauch, "Lineaments and Ground-water Chemistry as Exploration Tools for Devonian Shale Gas in the Midway-Extra Field of West Virginia": DOE/EGSP-ES/AAPG Symposium, Lakeview Inn, Morgantown, WV 26505, October 1979.

Cheng, Jean, "A Statistical Analysis of Geochemical Data for the Eastern Kentucky Gas Field": Unsponsored Research.

Dixon, Jeanette M., "Techniques and Tests for Measuring Joint Intensity": Final Report, UGR File no. 260, DOE/METC, Morgantown, WV 26505.

Dixon, Jeanette M. and Thomas H. Wilson, "The Parsons Cross Strike Structural Discontinuity as an Exploration Area for Fractured Gas Reservoirs": DOE/EGSP-ES/AAPG Symposium, Lakeview Inn, Morgantown, WV 26505, October 1979.

Evans, Mark A., "Fractures in Oriented Devonian Shale Cores from the Appalachian Basin": Final Report, UGR File no. 259, DOE/METC, Morgantown, WV 26505.

Negus-de Wys, J., "Geochemical Studies in the Eastern Kentucky Gas Field": DOE/EGSP-ES/AAPG Symposium, Lakeview Inn, Morgantown, WV, October 1979.

Negus-de Wys, J., "Lithology Studies in the Eastern Kentucky Gas Field": DOE/EGSP-ES/AAPG Symposium, Lakeview Inn, Morgantown, WV, October 1979.

PUBLICATIONS - continued

Negus-de Wys, J., "Possible Plate Tectonics Effects on the Eastern Kentucky Gas Field": DOE/EGSP-ES/AAPG Symposium, October 1979.

Negus-de Wys, J., "The Anatomy of a Large Devonian Black Shale Gas Field": 26th International Geological Congress, Paris, France, July 1980.

Negus-de Wys, J., "The Eastern Kentucky Gas Field": Final Report, UGR File no. 262, DOE/METC, Morgantown, WV 26505.

Negus-de Wys, J., and J. J. Renton, "Inorganic Geochemistry as an Exploration Tool": 26th International Geological Congress, Paris, France, July 1980.

Negus-de Wys, J., and J. J. Renton, "Preliminary Depositional Model for Upper Devonian Huron-age Organic Black Shale in the Eastern Kentucky Gas Field": SPE/DOE meeting, Pittsburgh, PA, May 18-20, 1980.

Nuckols, III, E. B., "The Cottageville Gas Field, Jackson County, West Virginia: A Case Study of Devonian Shale Gas Production": Final Report UGR no. 261, DOE/METC, Morgantown, WV 26505.

Shumaker, Robert C., "The Importance of Regional and Local Structure to Devonian Shale Gas Production from the Appalachian Basin": 26th International Geological Congress, Paris, France, July 1980.

VOLUME I

PART II

PRINCIPAL INVESTIGATORS' REPORTS

ON

RESOURCE INVENTORY TASKS

AND

SHALE CHARACTERIZATION TASKS

OBJECTIVES

The general objective of our project under contract DE-AC21-76ET12138 (formerly DE-AC21-76MC05194) is to study the structural parameters of the Devonian shales that affect gas production in eastern Kentucky and West Virginia.

To that end our program is specifically designed to:

1.) Collect, compile, and analyze geologic data to construct regional structure maps of eastern Kentucky and West Virginia.

2.) Determine if structural types and styles affect production, and determine if minor structures as mapped in outcrop could influence production characteristics.

3.) Determine if shallow seismic surveys can detect near-surface faults and fracture zones, and if such structures can be detected, to further determine how fractures relate to both production from the shale and to lineations observed on remotely sensed data.

4.) Determine if a relationship exists between ground water movement and shale gas productivity.

Through the integration of our work with others it is our ultimate goal to discover if relationships exist between Devonian shale gas production and geologic structure. If such a relationship is established, we will attempt to develop a method or methods for selecting favorable sites to drill shale wells that have a greater potential for gas production than the norm for that region.

SCHEDULE OF MILESTONES

MILESTONE	STATUS
1. Map showing the orientation of various fractures in cores from West Virginia and eastern Kentucky - 5-31-80	Complete
2. Report integrating and comparing fracture density and orientation data from oriented cores in West Virginia and eastern Kentucky - 9-30-80	Complete
3. Map showing LANDSAT linears around cores in West Virginia and eastern Kentucky, and a map showing general linear patterns around cored wells - 5-31-80	Complete
4. Report on feasibility of using shear wave seismic data to locate shallow fracture zones - 6-1-80	Not feasible - report not required
5. Design field procedure and obtain equipment to implement shear wave study - 7-1-80	Not feasible - report not required
6. Report on results of locating shallow fracture zones by shear wave seismic methods - 9-1-80	Not feasible - report not required
7. Report comparing relationships of final open flow for approximately 4750 wells in eastern Kentucky with detailed stratigraphic and regional structural studies (300 wells) - 9-30-80	Complete
8. Detailed structure maps for approximately 4000 wells in the eastern Kentucky gas field - 5-30-80	Complete
9. Report comparing detailed structure of the eastern Kentucky shale gas field compared with final open flow data for approximately 4750 gas wells - 9-30-80	In progress
10. Regional maps showing structure near or on the top and base of the Devonian shale for eastern Kentucky and western West Virginia - 9-30-80	Complete

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TECHNICAL SUMMARIES

Each investigator has written a technical abstract covering the results of his or her research for this part of Volume I. These synopses are specifically designed for the technical reader and should lead that reader, if he is interested in more detail, to the manuscripts in Volumes II and III of this report.

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3.1 Work Package 2100-2-1 REGIONAL STRUCTURE STUDIES — Robert C. Shumaker

3.1.1 Current status of work

Analyses of structural data compiled under this contract, primarily oriented cores taken in the shale, suggest that most commercial production relates to the presence of highly organic shale and natural fractures, and that optimum production is found where mineralized fractures occur within the highly organic layers. Slickensided fractures formed in response to Appalachian stress within the areas of commercial production further suggest that differential tectonic shortening (detachment) across the shales plays a role in developing fracture permeability. Three transitional zones of movement have been found that can be characterized by their fracture patterns within the shales:

(1) an outer or cratonic zone of tensional joints with no evidence of differential movement within the shale.

(2) a foreland zone of inclined (slickensided) shear fractures and tensional fractures, and

(3) a foreland zone of recognizable tectonic transport defined by mineralized and slickensided bedding plane fractures.

The commercial gas production lies with zone 2 of the foreland area. Fortunately, this foreland area coincides with the depositional center of the highly organic Devonian shales. Maximum production occurs within the zone above the margin of basement block faults where unique stress fields occurred during Appalachian deformation. The stress fields developed an extremely porous fracture facies within the organic shales. In this unique trap the shale acts as the source and seal, and the mineralized fractures, probably developed in ancient high-pressure zones, serve as the reservoir.

The optimum structural position for development of the reservoir, a porous fracture facies, is slightly up-dip from synclines, on the lower part of the anticlinal limb. The development of the fracture facies is not symmetrical on the basement folds, but one flank produces far better than the other. The cause for this is under investigation.

3.1.2 Problem areas

Renewal of our contract has been delayed because of changes in personnel, causing confusion and loss of documents in the process. Extension of time under this contract permits continuity of work but may cause some delay in deliverables for the upcoming year.

3.1 Work Package 2100-2-1 REGIONAL STRUCTURE STUDIES Robert C. Shumaker

3.1.3 Work plans for fiscal year 1980-1981:

(1) Compile, integrate, and summarize the work accomplished under contract numbers E-(40-1)-5194, EY-76-C-05-5194, DE-AC21-76MC05194, and DE-AC21-76ET12138 entitled "An Analysis of the Structural Parameters that Influence Gas Production from the Devonian Shale".

(2) Assist other D.O.E. contractors in their summary reports.

* * * * * *

3.1 Work Package 3200-5-1 PRODUCTION STUDIES — Jane Negus-de Wys

This report considers work completed under:

3.1	Work Package 2100-1-1	CROSS SECTIONS
3.2	Work Package 2100-1-2	ISOPACH MAPS
3.3	Work Package 2100-2-1	STRUCTURE CONTOUR MAPS
3.4	Work Package 3200-4-1	OIL AND GAS MAPS

3.1.1 Current status of work and scheduled deliverables

Work completed under these tasks is summarized in part in papers written and presented during the period October 1, 1979, to September 30, 1980. Copies of these papers and final report on eastern Kentucky accompany this annual report.

1) Negus-de Wys, J., Lithology studies in Eastern Kentucky Gas Field: DOE/EGSP-ES/AAPG Symposium, Lakeview Inn, Morgantown, West Virginia, October, 1979. Oral presentation, abstract and paper published in proceedings.

2) Negus-de Wys, J., Geochemical studies in Eastern Kentucky Gas Field: DOE/EGSP-ES/AAPG Symposium, October, 1979. Oral presentation, abstract and paper published in proceedings.

3) Negus-de Wys, J., Possible plate tectonics effects on the Eastern Kentucky Gas Field: DOE/EGSP-ES/AAPG Symposium, October, 1979. Oral presentation, abstract and paper published in proceedings.

4) Negus-de Wys, J., and J. J. Renton, Preliminary depositional model for upper Devonian Huron-age organic black shale in the Eastern Kentucky Gas Field: SPE/DOE meeting, Pittsburgh, PA, May 18-20, 1980. Oral presentation and abstract published in proceedings.

5) Negus-de Wys, J., and J. J. Renton, Inorganic geochemistry as an exploration tool: 26th International Geological Congress, Paris, France, July, 1980. Oral presentation, abstract published in proceedings, in press in French geochemical journal.

6) Negus-de Wys, J., The anatomy of a large Devonian black shale gas field: 26th International Geological Congress, Paris, France, 1980. Oral presentation, published abstract and paper in pre-Congress proceedings.

7) Negus-de Wys, J., The Eastern Kentucky Gas Field: Ph.D. dissertation, West Virginia University, Morgantown, West Virginia 26506, and open file final report on DOE contract no. DE-AC21-76MC05194 (formerly EY-76-C-05-5194), METC, 1979.

3.1 Work Package 3200-5-1 PRODUCTION STUDIES — Jane Negus-de Wys

3.1.1 Current status of work and scheduled deliverables - continued

In addition I served as Technical Chairman for the Appalachian Basin Symposium March 31 - April 2, 1979, Lakeview Inn, Morgantown, West Virginia.

The most significant contributions during this year's work period include:

- Completion of the Eastern Kentucky Gas Field Study in which gas occurrence and production is related to regional structure, stratigraphy, lithology, and geochemistry;
- initiation and completion of first nine months of study on a two-year geochemistry project in which XRF and XRD analyses is being performed on cuttings from the upper Devonian black shale sequence from 12 wells in eastern Kentucky, ranging from 25 to 75 samples per well;
- completion of 180 geochemical data trend, strato-specific maps on the geochemistry project. These include elemental and mineralic data. Maps were both hand-contoured and computer-run;
- completion of 16 elemental and 14 mineralic graphs on each of the 12 wells sampled in eastern Kentucky, for the Ohio shale sequence;
- development of a procedural method, using a variety of studies, for locating a well site in high gas producing areas. A series of 15 maps was used in this process;
- acceptance, presentation, and publication of two papers at the 26th International Geological Congress in Paris, France, 1980, on the research results on this contract;
- exchange of geology faculty between Bristol University, Bristol, England, and West Virginia University and initiation of student exchange proposal;
- continuation of and extension of Devonian shale research by Gulf Research Center as a result of presentation of geochemistry data on this contract.

3.1 Work Package 3200-5-1 PRODUCTION STUDIES — Jane Negus-de Wys

3.1.1 Current status of work and scheduled deliverables - continued

The geochemistry trend maps of some elements and minerals are showing high strato-specific correlations with

1) gas occurrence and production,
2) fractures, and
3) environment of deposition.

It is too early in analysis to make further statements at this time.

3.1.2 Problem areas and suggested improvements

With three months left on the first year of the geochemistry project, it is still unknown whether the second year will be funded by GRI. With interest shown through geochemistry papers accepted for AAPG (2 papers) and the 26th International Geological Congress (2 papers) and published, and with the interest and funding support shown by Gulf Research in a research grant, one might question the lack of ongoing DOE support for the second year of this two-year proposal. It would be nice to complete a project in which so much outside interest has been shown.

3.1.3 Work plan for fiscal year 1980-1981

The next three months will complete the first year on this planned two-year study. Remaining to complete this year is the map comparison of strato-specific geochemical data with gas occurrence and production, structure, stratigraphy, fractures, and lithology in eastern Kentucky. This would permit evaluation of the work to date in that area, in terms of promise as an exploration tool.

The second year was to expand the work to a more regional basis as well as specific fields in West Virginia or for prediction. The data base has been accumulated to a large extent for this second year's work.

* * * * * *

3.1 Work Package 2100-1-1 SEISMIC

James E. Ruotsala
Richard T. Williams

3.1.1 Current status of work and scheduled deliverables

Work on seismic investigations of the shale during fiscal year 1979-1980 consisted of continued evaluation of the Bison seismograph as an exploration tool, and examination of existing Vibroseis data from the Cottageville, West Virginia, area. No field work was funded for this fiscal year.

Regarding the seismograph, a number of problems of unknown origin were identified in the system during field work in fiscal year 1978-1979. The precise origins of those problems have been found and corrected, and it is now believed that the system is working at its design capability. Basically two problems were isolated and corrected. The first problem was related to the geophone filter circuit which was designed and constructed by an Electrical Engineering graduate student at West Virginia University. The fault was that the filter was designed for input signal levels of 1 millivolt or less, while geophones typically produce signal levels as great as 1 volt. The second problem was related to the mechanism by which recording by the seismograph was initiated. The Bison seismograph records a limited-length time series by storing the digitized geophone signal in solid-state memory. Because of the length limitation it is necessary to initiate the recording in precise syncronization with the seismic shot. Two circuits provided by the seismograph manufacturer failed to accomplish this reliably. The problem was corrected by a locally designed circuit which detects the cessation of current flow through a blasting cap, and starts the seismograph.

A full-scale test of the seismograph was conducted on May 19 at the Pricetown, West Virginia, coal gassification site. The seismograph worked as designed, and the results of the test were reported in the Quarterly Progress Report for May-June 1980.

Regarding the Cottageville Vibroseis data, the original records of a seismic reflection survey made in 1977 were obtained. This data has never been correctly interpreted. This data set consists of approximately 65,000 seismic traces covering a surface area of about 12 square miles in and near the area of high gas production at Cottageville. Analysis of this data, in preparation for interpretation, was begun.

3.1.2 Problem areas and suggested improvements

Use of the Bison seismograph as an effective means of recording seismic reflection data is still hampered by the limited dynamic range of the recording system. This problem was discussed in some

3.1.2 Problem areas and suggested improvements - continued

detail in the 1978-1979 Annual Report. A possible solution to this problem has been found, although it has not been field tested. An electronic circuit which compresses the analog signal from the geophones and limits the dynamic range has been constructed. The circuit differs from traditional AGC circuits in that signal compression is done in a controlled, recoverable manner. The system has been found to work well in laboratory conditions on simple wave forms, but testing under field conditions on complex seismic data remains to be done.

3.1.3 Work plan for fiscal year 1980-1981

Seismic investigations of shale gas production will continue under Task Order 24 of contract DE-AT21-79MC11284.

* * * * * *

3.1 Work Package 2100-2-2 STRUCTURE STUDIES — Jeanette M. Dixon

3.1.1 Current status of work

During the 1979-80 contract year the final report on fracture studies of the Parsons and Petersburg structural lineaments was to be completed.

The final report (due September, 1980) was completed and submitted February 7, 1980. The following is the abstract from that report. (The complete final report can be found in Volume II of this Annual Report.)

Anomalous intense jointing has been cited as a reason for gas production from fractured shales, coal mine roof falls, some construction problems, and increased water-well yields. Accordingly, a method for measuring joint intensity and locating areas of intense fracturing would be generally useful. The Parsons and Petersburg structural lineaments, in the Plateau province of north-central West Virginia, were chosen to develop and test a method for measuring joint intensity because previous studies indicated that these lineaments were broad zones of intense jointing. The project developed in four related test areas. First, the Parsons lineament in the eastern Plateau province, Tucker County, West Virginia, was chosen to develop and test field and analytical methods for measuring joint intensity. Second, rocks of the Middle and Upper Devonian Chemung Group and Catskill Formation, and the Mississippian Pocono Formation along the Allegheny Front, were studied to determine how the fracturing effects of the Petersburg lineament varies with depth and with different lithologies. Third, in the Plateau province, rocks of the Lower and Middle Pennsylvanian Pottsville Group and Allegheny Formation were measured to determine the westward extent of the lineaments. Finally, a large roadcut in northern West Virginia, which exposes two coal seams and an overlying stream channel, was chosen to study the effects of a stream channel on coal cleat intensities. Joint spacing was found to be the only necessary measurement, other than strike and dip to determine joint intensity. Rocks inside the Parsons and Petersburg lineaments were found to be more intensely jointed than rocks adjacent to the lineaments. Along the Allegheny Front, results suggest that the Petersburg lineament affects rock at least one half mile below ground level. Farther west in the Plateau province, joint intensities measured indicate that the high-intensity joint systems of the Parsons and Petersburg lineaments are disrupted or terminated. Air photograph and LANDSAT lineaments may be an aid in locating structural lineaments or areas of intense jointing, but do not necessarily define or bound such areas. Intensity of cleats in coal is greater under the stream channel than outside.

3.1.2 Problem areas

None

3.1 Work Package 2100-2-2 STRUCTURE STUDIES — Jeanette M. Dixon

3.1.3 Work plans for fiscal year 1980-1981

None: work under this task is complete.

* * * * * *

3.1 Work Package 2100-2-2 STRUCTURE STUDIES — Thomas H. Wilson

3.1.1 Current status of work

Title and Conclusions of Final Report

CROSS-STRIKE STRUCTURAL DISCONTINUITIES -

TRANSFER ZONES AND TEAR FAULTS IN THE CENTRAL APPALACHIANS OF WEST VIRGINIA

CONCLUSIONS

Surface structural studies along the Middle Mountain syncline and Elkhorn Mountain anticline indicate that the Parsons structural discontinuity cutting these structures is a zone across which displacement along a Martinsburg detachment is transferred to Juniata, Wills Creek and Middle Devonian detachment horizons southwest of the discontinuity but is confined to the Martinsburg northeast of the discontinuity. The structural relationships across the discontinuity can be explained by representing the discontinuity as a transfer zone (Dahlstrom, 1969) within which shortening is taken up by smaller displacements along more numerous faults and by increased numbers of smaller folds. Shortening across the Middle Mountain syncline and Elkhorn Mountain anticline is discontinuous northeast along strike across the discontinuity; however, displacement along the Martinsburg detachment northeast of the discontinuity ramps up to higher structural levels producing an equivalent amount of shortening northwest across the resultant Cave Mountain anticline (Figure 1). Instead of tear faults across the structure, constant shortening is accommodated mechanically by a transfer zone.

In the Silurian-Devonian formations of the Plateau the transfer is seen to oscillate northeast to southwest, back and forth to the northwest across the Plateau producing the Horton, Blackwater, and Glady anticlines and in part the Deer Park and Elkins Valley anticlines.

The expression of the Parsons discontinuity, however, is not confined to detachment in the Ordovician Martinsburg Formation and higher level detachment intervals. Detached structures in the Cambrian-Ordovician dolomite and carbonate sequence are also related to the expression and development of the structural discontinuity. The Deer Park and Elkins Valley anticlines are related in part to ramping through the Cambrian-Ordovician sequence. A northeasterly swing in fold trends along the plunging nose of the Deer Park anticline (Wheeler, 1976) is related to a tear fault in the Cambrian-Ordovician sequence beneath the plunging noses of the Elkins Valley

and Deer Park anticlines (Figure 2). The required right-lateral tear could be produced if slip along the Rome beneath the Elkins Valley anticline continued over a longer period of time or at a greater rate than slip beneath the Deer Park anticline.

Cambrian-Ordovician involvement is not confined to the Plateau segment of the Parsons discontinuity. The Bergton-Crab Run and Adams Run anticlines of the Valley and Ridge in Rockingham County, Virginia, are related to ramping of the Cambrian-Ordovician sequence and both anticlines plunge out southwest across the Parsons discontinuity. A tear fault in the Cambrian-Ordovician sequence has been proposed across the plunging noses of these two folds on the basis of an abrupt change in shortening in that sequence across the discontinuity and a substantial left lateral swing in surface fold traces across the discontinuity.

The transfer zone mechanism also explains the surface Silurian-Devonian expression of the Petersburg discontinuity. In addition, subsurface information indicates that a broad transfer zone occurs in the Cambrian-Ordovician sequence across the Petersburg discontinuity (Figure 2).

Descriptions of structural discontinuities in Wheeler and others (1978) suggest that most central and southern Appalachian cross-strike structural discontinuities may actually be transfer zones.

A study of systematic joint intensity in the Parsons discontinuity across the Middle Mountain syncline indicates that increased folding and faulting in the transfer zone produces more intensely jointed rock.

Exploratory drilling has been recommended on vergent limbs opposite structural culminations on either side of structural discontinuities. An isopach of drilling depth to the base of the Devonian shales has been included with this report (Figure 3).

3.1.2 Problem areas

None

3.1.3 Work plan for fiscal year 1980-81

None: Work complete. Final report due for delivery in early December 1980.

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3.1 Work Package 2200-1-2 FRACTURE DENSITY AND ORIENTATION Mark A. Evans

3.1.1 Current status of work

During the 1979-1980 contract year a final report was prepared on fracture density and orientation entitled: Fractures in Oriented Devonian Shale Cores from the Appalachian Basin. The following is an abstract of that report:

Examination of thirteen oriented Devonian shale cores from the Appalachian Basin revealed considerable fracturing and shearing at depth. Fracture frequency and orientation measurements were made on the fractures in each core. Fractures and associated structures were differentiated (when possible) into core-induced fractures, unmineralized natural fractures, mineralized natural fractures, slickensided fractures, and slickenlines. Core-induced fractures exhibit a consistent northeast orientation both areally and with depth. This consistency indicates the presence of an anisotropy which is interpreted to be related to an east to northeast trending maximum compressive stress developed in eastern North America by the convective flow in the mantle associated with spreading along the Mid-Atlantic Ridge. Natural fracture, slickenside, and slickenline orientations are related to: 1) northwest directed tectonic compressive stresses associated with Alleghenian deformation, 2) stresses associated with local faulting, and 3) the same east to northeast maximum compressive stress responsible for the core-induced fractures. Higher frequencies of natural fractures and slickensides are associated primarily with incompetent, high-organic shales. Natural fractures occur most frequently in the Marcellus Shale, Tully Limestone, Geneseo Shale, West Falls Formation, and the Lower Huron Member of the Ohio Shale. Slickensided fractures occur most frequently in the Marcellus Shale, Tully Limestone, Geneseo Shale, West Falls Formation, base of the Java Formation, and Lower Huron and Cleveland Members of the Ohio Shale. These observations are consistent with a fracture facies concept that proposes fracture development in shales that have acted as decollement zones during Alleghenian deformation. Detailed reports are included for each of the thirteen cores investigated.

3.1.2 Problem areas

None

3.1.3 Work plan for fiscal year 1980-1981

None: the final report of the work package was completed and delivered during February 1980.

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3.1 Work Package 2200-1-2 FRACTURE STUDIES

Kevin D. Lee

3.1.1 Current status of work

The work plan for this year was to complete maps and finish my work on the subsurface structure of the eastern Kentucky area by June 30. The target date was not met because I chose to expand my study and construct additional maps to better understand the nature of certain structures within the eastern Kentucky field and because my thesis chairman was temporarily absent.

The areas of detailed investigation within the eastern Kentucky field include the Warfield fault in Martin County, the D'Invilliers anticline of eastern Pike County, the southern nose of the Paint Creek Uplift in Floyd, Knott, and Perry Counties, and an anomalous area in southern Floyd County.

The structural maps and interpretations of these areas will be included in my final report which is expected to be delivered around November 1, 1980. The following is an abstract of that report:

The purpose of this study was to locate subsurface structures that may affect shale gas production in the eastern Kentucky field. In order to accomplish this, detailed structure contour maps were drawn on the top and bottom of the Ohio shale. Data from 4,200 wells show that the Ohio shale in the southwestern portion of the field dips regionally to the south, whereas, in the northeast portion of the field, the Devonian dips regionally to the southeast. The divergence in dip creates a broad structural arch in Pike and Floyd Counties that plunges southeastward. The structures found in this study formed during several episodes of deformation, responding to stress and strain involving the basement and cover, as well as just the sedimentary cover. The Paint Creek Uplift, a broad, low basement arch in Morgan, Magoffin, and Breathitt Counties was apparently active throughout the Paleozoic and influenced the development of structures in the gas field on its northwestern boundary. The D'Invilliers anticlinal-synclinal structure in eastern Pike County is located over a southern extension of a proposed basement fault in West Virginia and along the New York-Alabama Lineament. The D'Invilliers structure was later cut by a strike-slip fault. The Warfield fault in Martin County is not part of the southern boundary of the Rome Trough but lies just south of the boundary, and is on the uplifted southeastern rim of the trough. Offset on the fault in the subsurface, from the Mississippian Newman Limestone to the basement, is down to the south, whereas, offset at the surface is up to the south. Both the Warfield and D'Invilliers structures are considered basement involved, but both may also contain some detachment deformation. Certain faults, such as the cross fault cutting the Warfield

fault, show growth during early Mississippian sedimentation, and the Warfield fault was determined not to be the southeastern margin of the Rome Trough as was previously suspected. Several linear zones of structural disruption, at high angles to the trend of the detached Pine Mountain thrust, are interpreted to be tears limited to the sedimentary cover.

3.1.2 Problem areas

None

3.1.3 Work plan for fiscal year 1980-1981

None: work under this task is complete. Final report submitted during November 1980.

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