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ANALYSIS OF THE STRUCTURAL PARAMETERS THAT INFLUENCE
GAS PRODUCTION FROM THE DEVONIAN SHALE
Volume 1. Executive Summary and Task Reports

Annual Progress Report

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October 1978

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West Virginia University
Morgantown, West Virginia

MASTER

U. S. DEPARTMENT OF ENERGY

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

ANNUAL PROGRESS REPORT
CONTRACT EY76-C-05-5194

SUBMITTED BY
DEPARTMENT OF GEOLOGY AND GEOGRAPHY
WEST VIRGINIA UNIVERSITY
OCTOBER 1978

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VOLUME 1

EXECUTIVE SUMMARY

AND

TASK REPORT

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INTRODUCTION

This report is written to document progress made during the second year of our study for the Eastern Gas Shales Project, and it is organized to meet the needs of readers who have varied interests in the project. The first portion of the report, from the Executive Summary (page 1) through the Schedule of Milestones (page 10), gives a general overview which highlights our progress and problems for the second year. The Task report portion of the text, written by individual task investigators, is designed primarily for scientists interested in technical details of the second year's work. The second portion of the report consists of appendices of data compiled by the principal investigators. Each appendix serves as a data bank for each Task. These data can be used for analysis by other scientists with the permission of the principal investigator responsible for its compilation.

EXECUTIVE SUMMARY

Purpose of the study

The specific objectives of our contract are given in the section entitled Objectives (page 7), but in general, the purpose of our research under the EGSP program is to analyze the structural parameters that influence Devonian shale gas production. As designed in 1976 and as implemented in early 1977 and 1978, our research covers research on both regional and local parameters of geologic structure that affect production within the contract area (Figure 1). As we isolate these parameters, we are to develop, in conjunction with other contractors, techniques or rationales for shale gas (fracture porosity) exploration.

A second goal of the EGSP program at West Virginia University is to support geologists and geophysicists in obtaining advanced degrees in the mineral industry sciences.

Methods of approach and organization

Our method of approach to attain the proposed objectives is through the efforts of several study or work groups: one group is compiling regional structure; a second is studying surface fractures. This past year we have expanded the goals of the surface fracture study to include compilation and analyses of subsurface fractures found in oriented shale cores. A third group is studying shale gas production in detail where data is available. A fourth study group is investigating surface structures which have potential to be productive in the subsurface, and a fifth group is studying ground water-lineament-gas production interrelationships.

LEGEND

- Outcrop area of Devonian rocks
- Devonian Black Shale gas production
- Contract area

Geophysical test site

1 Petersburg

2 Parsons

CSD

Figure 1

These five study groups, that is, regional structure, fractures, surface structures, production, and ground water studies, are carried under the U. S. Department of Energy's Eastern Gas Shales Program resource inventory tasks.

The final study group, geophysical studies, is carried under the U. S. Department of Energy's Eastern Gas Shales shale characterization tasks. Its task is to develop inexpensive seismic and resistivity techniques which can locate fractures.

In essence, the first two tasks, that is, regional structure and fracture studies, are designed to provide a regional or basin structure data base for the entire project. The structural type studies seek to document, by analytical field work, those details of structures which are either similar to structures producing gas or those structures which we feel are prospective. The production studies will seek out and study those gas fields where detailed well production records are available that permit thorough analysis and documentation of the geologic parameters that influence gas production from the shale. The geophysical studies are charged with the task of developing inexpensive geophysical techniques that can locate shallow fracture zones of high permeability.

The attention of all study groups focuses on fracture porosity within the shale; its origin, distribution, and methods of locating zones of more intense fracturing. It is important to realize then, that even though each study group is carried under either the resource inventory or the characterization tasks of the EGSP, our program was organized so that each group has the additional goal of defining parameters that would be useful in exploring for potentially productive fracture porosity in shale. Often overlooked is our goal to develop a method or methods for selecting areas for drilling shale wells that have a higher than normal potential for shale gas production. I also want to emphasize that this basic research applies to other DOE projects such as the tight sands project, methane drainage, mine hazards, underground coal gassification, etc. Indeed, any project which deals with fractured rocks will be interested and derive benefits from our work on fractures and fracture production.

Major accomplishments 1977-1978

Because we have completed one year of research effort at full staff levels, we are now beginning to see tangible results of our efforts toward obtaining the objectives of the contract. Progress was made in all study groups toward attaining their specific goals in the characterization and resource inventory tasks. Major accomplishments are reported here, and specific accomplishments are reported under the individual task reports.

Noteworthy accomplishments during 1977-1978 include:

- 1.) Documentation of the geologic parameters that affect shale gas production from the Cottageville field (Figure 1). The significant variable controlling production within the field appears to be the presence of a porous fracture facies within the Huron shale. The fracture porosity in this field apparently relates to minor flexing of the shale over a basement fault. (E. B. Nuckols, manuscript in preparation)
- 2.) A hydrologic study of the area in and around the Cottageville field (Figure 1) has been completed; and preliminary associations among lineaments, water productivity, and shale gas productivity have been proposed. Furthermore, an association between bicarbonate and water hardness, and shale gas production has been noted. (Jones and Rauch, 1978)
- 3.) A pilot study of the Cottageville field has been completed and published. The report proposes several innovative methods for the analysis of shale gas fields comparing geologic parameters and production parameters which can be then applied or modified and applied in other production studies. (de Wys and Shumaker, 1978)
- 4.) A relationship between geologic structure and shale gas production similar, but not identical, to that noted at Cottageville was established by William Schaefer for the Midway Extra field of West Virginia (Figure 1). This research is being directed by the director of this contract, but it is privately funded. The results of this research will be available by January 1, 1979, as a Master's Thesis from the West Virginia University Department of Geology and Geography. (Schaefer, manuscript in preparation)
- 5.) Recognition of an inverse relationship between initial open flow production for shale gas wells and major lineaments as mapped on satellite imagery was found. (E. Werner, 1978)
- 6.) We recognized a porous fracture facies within the Devonian shale of eastern Kentucky and extreme southern West Virginia. The preferred interpretation of several working hypotheses is that the fracture facies of eastern Kentucky relates to tectonic shortening across the shales. (Shumaker, 1978)
- 7.) A working relationship was established with the Kentucky-West Virginia Gas Company to study the Eastern Kentucky gas field using their data and our manpower. Study of open flow data and stratigraphy has been initiated. (de Wys and Shumaker, 1978)

- 8.) Our shallow seismic system was successfully field tested, and we identified a shallow fracture zone by lack of coherent reflections across a photo lineament at our second test site. (Kirk, 1978)

It is clear at this point in our program, based on our preliminary efforts at Cottageville, that there are certain of our tasks which appear to have more promise toward our exploratory goal of "developing a method or methods of selecting areas for drilling shale gas wells that have a potential for shale gas production." At present, the most promising of our tasks in this respect include: Regional structure, thru detailed shallow structure map preparation over basement fault zones; ground water, by lineament, water quality, and water quantity comparison; and geophysics, thru detailed shallow seismic and resistivity surveys.

It is stressed that these are first results from work done primarily in the Cottageville area of West Virginia. Further study and testing are required to see if results obtained there can be applied first to areas similar to Cottageville and then to other areas dissimilar to Cottageville, like the Eastern Kentucky gas field. We are cautiously optimistic about these approaches. Should our tests and research continue to be positive thru the upcoming contract year, we would expect to expand these tasks and recommend specific areas or well sites to be drilled.

Problem areas

The only significant problem that we have encountered during this contract lies in the area of administering the contract under state regulations. We have the wholehearted support of the University administration, and our relationships and communication with DOE-METC and their representatives, Science Applications, Incorporated, and the U. S. Geological Survey have been good. However, intra-state relationships are filled with rules, red tape, and direct meddling which have caused delays and even the postponement of certain task events.

For instance, the regulations regarding the purchase of items, sometimes very inexpensive but key items, is so complex as to be extremely slow. Because of the complexity we often obtain confusing, or what turn out to be incorrect, directions from State and University administrative employees. Too often the vendor suffers by lack or delay of payment because of our ineptness, and indeed many large companies will no longer deal with the State. This can also directly affect the price of purchased items. A significant morale factor this summer was the delayed payment of per diem and expense monies which fell two months behind submission of forms. This occurred during the summer field season, and, of course, it caused considerable hardship among our graduate students. Indeed, if it were not for the loyalty and dedication of our students to our program, some might have given up in disgust.

Of more import to me and to University academic (research) freedom was the freeze on spending invoked by the Governor this past winter and spring during the coal strike. The confusion was so great during this strike at the State administrative level that all the principal investigators under our contract were not certain if they would be paid or if they would be let go should the strike continue over several months. The contract director was denied, thru lack of timely approval, travel to a DOE-METC sponsored event to which he was directly invited. This is a precedent, once set, that will be difficult to break. Indeed, just this past month, the State executive branch refused federal travel funds to the director of this grant to attend the Geological Society of America National meeting in Toronto on the grounds that State regulations permitted only two members of a State organization to travel to an international meeting. Two other geologists from the faculty had obtained permission to attend this meeting, and, therefore, all other requests were denied. It was only thru intrusion of the University officials that travel was permitted on federal funds at the very last minute. Of the utmost importance, again, is the precedent that a chief executive of a state can impound federal research monies at his own behest. The faculty of the Department of Geology is lodging its disapproval of this unilateral act, but it seems unlikely that this disapproval will even be acknowledged, let alone cause any official affirmative action concerning the expenditure of federal monies in university research. It is now very clear that the University faculty are under the direct control of the State irregardless of the source of revenue or funds, and that the scientific merit of an academic enterprise comes clearly second to the desires of the State executive branch. The control comes not thru direct censure but thru the ultimate say on how and when federal monies will be spent.

OBJECTIVES

The general objective of our project under contract EY76-C-05-5194 is to study the structural parameters of the Devonian shales that effect 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 effect 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.

DELIVERABLES

<u>ITEM</u>	<u>STATUS</u>
1. Cross sections in areas where seismic and production studies are performed.	In progress - sites 1 & 2 complete.
2. Isopach maps of producing and otherwise key recognizable horizons in areas of seismic and production studies.	Cottageville - complete.
3. Maps of net thickness of radioactive (>20 API units) black shale in areas of production studies.	Cottageville - complete.
4. Structure contour maps on a maximum of 10 units for WV and eastern Kentucky as data is available.	All but one map complete.
5. Structure contour maps for organic rich shale facies for WV and eastern Kentucky as data is available.	Data not yet available.
6. Structure contour maps on reflected horizons in areas of resistivity and seismic studies.	In progress.
7. A description of the characterization, interpretation, and westward extension of at least one cross-strike structural discontinuity (CSD) in the Appalachian basin.	In progress.
8. A description of the development and methodology of intensity measurement for systematic joint systems and a discussion of outcrop joint system correlation with photolineament, CSD, and subsurface structure patterns.	In progress.
9. A model of shale fracture origin in specific areas of WV and eastern Kentucky based on outcrop and core analysis. The model will include a statistical analysis of fracture and slickenside orientation data from cores.	In progress.
10. Lineament map of eastern Kentucky and WV from data that exists and is developed for joints, fractures, photolineaments, and stress data.	In progress.

DELIVERABLES

<u>ITEM</u>	<u>STATUS</u>
11. Lineament and fracture maps of the areas selected for production studies.	Cottageville - complete.
12. A geologic map of WV and eastern Kentucky including all lineament data compiled for Deliverable Item 10.	Incomplete.
13. A report on the feasibility of using ground water occurrence and yield data as a tool for gas exploration based on from one to three detailed study areas. Also included will be a discussion on the correlation of ground water yield and lineaments.	Cottageville - complete.
14. A report on the design, development, and use of a high sensitivity shallow seismic tool and the results of this tool's use in three shallow producing areas which are fractured and in several non-producing areas which are fractured. This will include the results of seismic surveys done in the ground water study area(s).	In progress.
15. A report on the design, development, and use of resistivity equipment and the results of this equipment's use in selected ground water study area(s).	In progress.
16. A map of Devonian shale oil and gas pools in eastern Kentucky and WV.	Complete.
17. Maps of various production characteristics related to geologic conditions in the areas selected for production studies.	Cottageville - complete.
18. A map of eastern Kentucky and WV showing areas which have a high probability of Devonian shale gas production.	Not initiated yet.
19. A report of the structural characteristics of the surficial geologic units occurring in the three areas selected for production studies and in selected areas that do not have hydrocarbon production.	Not initiated yet.
20. A report on the correlation of geology, lineaments, fracturing, and oil and gas production.	Not initiated yet.
21. A report on the amount of bed-parallel extension faulting and fracturing outcrops in eastern WV including an assessment of the significance of these structural features in Devonian shale gas production.	In progress.

SCHEDULE OF MILESTONES

<u>MILESTONE</u>	<u>STATUS</u>
1. Initiate study of geologic structure types.	Due 10/1/77 - complete.
2. Initiate correlation studies of geologic data (surface and subsurface), and shale gas production data.	Due 10/1/77 - complete.
3. Initiate ground water studies over the Cottageville gas field and surrounding non-productive areas to determine if this type of study has potential for use in exploring for Devonian shale gas.	Due 12/1/77 - complete.
4. Collect information needed for preparing geologic structure maps contoured up to ten suitable stratigraphic units for which information is available.	Due 12/1/77 - complete.
5. Initiate correlation of core fracture orientation data with other structural data.	Due 12/1/77 - complete.
6. Select three formations for analysis of structure types and identify areas in which the formations are exposed.	Due 1/1/78 - modified to areas rather than formations.
7. Initiate bed-parallel extension faulting and fracturing studies.	Due 3/1/78 - complete.
8. Complete a statistical study of lineament and production data for the Cottageville Devonian shale gas field to determine if a relationship exists between gas production and lineament location, density, and orientation.	Due 4/1/78 - complete.
9. Complete structure maps using data collected in Milestone 4.	Due 5/1/78 - all but one map complete.
10. Conduct a shallow seismic survey of a selected area of known faulting or fracturing to determine if the faults or fractures can be readily identified from the seismic data.	Due 7/1/78 - complete.

SCHEDULE OF MILESTONES

<u>MILESTONE</u>	<u>STATUS</u>
11. Complete the processing and interpretation of seismic data obtained in Milestone 10.	Due 8/1/78 - complete.
12. Conduct shallow resistivity survey over the same area selected in Milestone 10 to determine if the "Tripotential" method has a high potential for detecting fractures and/or faults.	Due 8/1/78 - complete.
13. Complete collection and compilation of data on structure type for one of the formations selected in Milestone 6.	Due 9/1/78 - modified to study areas rather than formations.
14. Complete the analysis and interpretation of resistivity data obtained in Milestone 12.	Due 9/30/78 - complete.
15. Complete analysis of data obtained in Milestone 13.	Due 9/30/78 - modified to study areas rather than formations.

EDUCATION

All nine principal investigators have made satisfactory progress toward attaining advanced degrees in Geology. This fall, all principal investigators employed by DOE under this grant are enrolled half-time in graduate studies leading toward advanced degrees in Geology. In addition, several graduate students have been paid on an hourly basis for their part-time work in the project.

It is difficult to estimate the long term benefits that other University students will derive from use of equipment purchased with DOE funds. We know that it will be significant.

EQUIPMENT

During the second year of the project the following major pieces of equipment were purchased:

1. Multi-spectral edge enhancing system for analysis of remote sensing imagery.
2. Portable drill rig for mounting on seismic truck.
3. Portable recording and direct reading altimeters.
4. Mounting of multi-spectral camera in WVU-Cessna aircraft was delayed by the unexpected high cost of installation (\$6,000). Matching funds were requested of the State of West Virginia, but a decision was delayed by the Governor's freeze on spending from February thru June, 1978.

During the third year of the project the following major pieces of equipment will be purchased:

1. Nikon SCB Labophote Microscope with Objective 4X, 10X, 40X, 100X and with Nikon PFM camera and Manual.
2. Mounting of multi-spectral camera in WVU-Cessna aircraft, if the State of West Virginia provides matching funds.

FINANCES

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

PUBLICATIONS

Listed below are the titles of articles published during 1977-1978 which report the results of our research efforts.

We are including a copy of each manuscript written over the past year in the Appendices (see appropriate appendix by task title).

During this past year we also presented two papers at the Enhanced Oil and Gas Recovery and Improved Drilling Methods Meeting at Tulsa, Oklahoma. In 1977 we presented two papers at the First Eastern Gas Shales Symposium, and in October of 1978 we presented five papers and six poster displays at the Second Symposium of the Eastern Gas Shales Program.

Titles of articles published in fiscal year 1977-1978

de Wys, J. Negus and Shumaker, R. C., 1978, Pilot Study of Gas Production Analysis Methods Applied to Cottageville Field, Department of Energy, MERC/CR-78/6.

Jones, D. S., and Rauch, H. W., 1978, A Hydrologic Study of Water Well Yields and Ground-water Quality Related to Stratigraphic and Structural Settings in Western Jackson County, WV, unpublished research report submitted to Appalachian Regional Commission Mid-Ohio Valley Regional and Development Council and also to METC/DOE - open file report.

Kirk, Keith G., 1978, High Resolution Seismic Survey at Forest Glen, proceedings volume of the Department of Highway Conference on geophysical evaluation of the Forest Glen metro site, 11 p.

Shumaker, R. C., and others (staff of 8), 1977, Structural Parameters that Influence Devonian Shale Gas Production in West Virginia and Eastern Kentucky: A Summary of Progress for 1976-1977, Proceedings of Symposium on Enhanced Oil and Gas Recovery and Improved Drilling Methods, 4th Annual Department of Energy Symposium, Oklahoma, August 1978.

Shumaker, R. C., 1978, Porous Fracture Facies in Devonian Shales of Eastern Kentucky and West Virginia, Geological Society of America, Southeastern Section Symposium entitled "Western Limits of Detachment and Related Structure in the Appalachian Foreland."

Wheeler, R. L., 1978, Cross-strike Structural Discontinuities: Possible Exploration Tool in Detached Forelands, Geological Society of America, Southeastern Section Symposium entitled "Western Limits of Detachment and Related Structure in the Appalachian Foreland."

Wilson, T. H. Dixon, J. M., Shumaker, R. C., Wheeler, R. L., 1978, Fracture Patterns Observed in Cores from the Devonian Shale of the Appalachian Basin, Geological Society of America, Southeastern Section Symposium entitled "Western Limits of Detachment and Related Structure in the Appalachian Foreland."

PRINCIPAL INVESTIGATORS' REPORTS

ON

RESOURCE INVENTORY TASKS

AND

SHALE CHARACTERIZATION TASKS

3.1.1 Current status of work and scheduled deliverables

During the past year we completed the preliminary structure map compilation (see Figure 2) with the data readily available to us. This means that coverage is complete for West Virginia, but that eastern Kentucky coverage includes only basement structural maps and surface form-line structure maps. The Kentucky Geological Survey supplied basement well tops, and we generated the basic data to construct the form-line structure maps. Data for structural horizons is lacking; so we cannot construct other maps. We are in the process of negotiating with the Kentucky-West Virginia Gas Company to use their well data file to construct additional regional structure maps for eastern Kentucky at the shallower horizons. Our first discussion with Kentucky-West indicates that they are in agreement for us to use their data file with restrictions to respect certain confidential aspects of the data. These maps are fundamental to the evaluation of the parameters that affect shale gas production in eastern Kentucky. Inasmuch as we feel that the fractures (porosity) of that area were caused by tectonism, it is imperative that structure maps be available for our analysis.

3.1.2 Problem areas and suggested improvements

None.

3.1.3 Work plan for fiscal year 1978-1979

We plan to compile the eastern Kentucky data next summer. During this coming winter we are building detailed regional structure maps in the area between the Cottageville and the Midway Extra fields (Figure 1). Both of these fields show the strong influence of structural geology on shale gas production, but the relationships are not consistent for each field. In both fields basement faults appear to be important to shale gas productivity thru fracturing of the slightly flexed Devonian Huron shales. It is important to map the shallow horizons in detail if we are to understand the structural-production interrelationships, and if we are to predict where gas might be discovered between these two fields. Our plans call for compilation of well data for the area between the Midway Extra field and Cottageville field areas by the end of December and for completion of detailed structure maps for that area by June, 1979. If an agreement with Kentucky West can be made, we plan to have compiled all shallow structure data for eastern Kentucky by the end of the summer, September 1, 1979.

* * * * *

Figure 2

3.1 Work Package 2100-2-2 STRUCTURE STUDIES

Jeanette M. Dixon

3.1.1 Current status of work and scheduled deliverables

Eastern Kentucky cross-section: A one to one down to basement cross-section was constructed across the Big Sandy gas field to illustrate the geologic setting of the area.

Core fracture studies: Four cores were examined for fractures and slickensides. Two Cottageville wells were in poor condition and no slickensides were found which could be oriented. Lincoln County wells #20402 and 20403 were examined and slickensides were oriented, measured, and analyzed. The results are in the manuscript by Wilson, Dixon, Shumaker, and Wheeler (1978) in review for the Proceedings of the Southeastern G.S.A. section meeting, 1978.

Parsons Lineament fracture study, Tucker County, West Virginia: From May through July, 1978, 1673 joints were measured for strike, dip, length, depth, and spacing in the Chemung outcrop belt in western Tucker County, West Virginia. The purposes of this study are to develop a method of measuring joint intensities of an area and to test the method on the Parsons Lineament. The Chemung outcrop belt was chosen in order to minimize intensity changes due to lithology variations.

Preliminary results show that there is generally no variation in joint orientations across the lineament. The most dominant set trends N45°W. Two prominent sets trend N85°W and N35°E.

Preliminary results also indicate that the rocks within are more intensely fractured. This is measured in area of fractured rock per unit volume of rock.

3.1.2 Problem areas and suggested improvements

No problems.

3.1.3 Work plan for fiscal year 1978-1979

The following items are planned for the next year:

1. Maps showing orientations of joints: December 1, 1978
2. A contour map showing joint intensities in western Tucker County, across the Parsons Lineament: December 1, 1978

3.1 Work Package 2100-2-2 STRUCTURE STUDIES

J. M. Dixon

3.1.3 Work plan for fiscal year 1978-1979 - continued

3. Contour maps showing average spacing of the main joint sets:
December 1, 1978.
4. Report on the joint study of the Parsons Lineament: January 1, 1979.
5. Further fracture studies determining joint intensities, yet to be finalized.
6. A study on operator variability of measuring joint style elements.

* * * * *

3.1.1 Current status and deliverables

1. During the first nine months of the year, efforts were primarily concentrated on fracture studies of the oriented Devonian shale cores. Concurrent surface structural studies were concentrated on the examination of bedding orientation data collected earlier in the Middle Mountain syncline where Middle Devonian organic rich black shales are exposed at the surface in the Valley and Ridge Province in Pendleton County, West Virginia. Structural examination of the shales in this area is of interest to us in that they are exposed along the Parsons cross-strike structural discontinuity thus permitting a detailed investigation into the effects of this structural lineament on the exposed Middle Devonian shales.

The geologic map (Figure 3) is taken from Tilton and others, 1927, with structural details added from recent field work. Field mapping of this area located additional reverse faults within the plunging nose of the syncline. The northwest vergent Elkhorn Mountain anticline adjacent to the southeast limb of the Middle Mountain syncline is an allocthonous block whose northwest limb is sheared by high angle southeast dipping reverse faults which may rise from a decollement in the Ordovician Reedsville Formation (Sites and Wheeler, 1977; Perry, 1975). The faults observed in the Middle Mountain syncline may be related to secondary splay thrusts dying out within the ductile Middle Devonian shales.

The contour maps shown here are constructed from bedding orientations collected in detail over the structure. The maps are covered by an orthogonal grid and the strikes or dips within the cells of this grid are averaged and plotted at the center of each cell and then contoured. The standard deviations of the samples from each cell are also plotted and contoured.

Bedding disruption probably associated with the two southernmost faults is indicated in the contours of dips and their standard deviations (Figure 4). The extent of these disruptions has been used to estimate the lengths of these faults. These contours also reveal that bedding disruption in this area is more widespread than might be expected in association with these faults, and may in part be due to fold terminations

GEOLOGY AND STRUCTURE MIDDLE MOUNTAIN SYNCLINE

Figure 3 Geology and structure of the Middle Mountain Syncline
(Tilton, et al. 1927)

Figure 4 Contours of the absolute value of dip and their standard deviations.

3.1.1 Current status and deliverables - continued

in the underlying Devonian Oriskany sandstone, and flowage within the shales as the syncline plunges out.

The northernmost fault occurring in the upper Middle Devonian Braillier Formation has approximately 80 feet of displacement and produces no effect on the dip or standard deviation contours; however, strike contours (Figure 5) show some disruption in this area that may be related to this fault.

The strike line map (Figure 5) is constructed by plotting the average strike from each cell as a vector on the map surface and approximating the continuous outline of the structure by drawing lines to which these vectors are tangent. The strike line map and the contours of standard deviation of strike again reveal bedding disruption associated with the observed faulting. Changes in the orientation of the axial trace of the syncline are easily observed in both the strike line and standard deviation maps.

These contour maps have been particularly useful as a field tool in additional mapping of structure within the Middle Devonian shales this past summer. Outcrop in these incompetent black shales is often limited and accurate mapping of structures is consequently difficult. Bedding orientation data represented in this fashion and combined with field observations permits a more reliable structural interpretation. Additional field investigation will examine the structural significance of other irregularities observed in these contours.

In addition to the field mapping and the contour maps, Mellis contoured equal area projection of poles to bedding taken from the shales exposed along both limbs of the syncline (Figure 6) indicates that bedding becomes more disrupted and steeply dipping within the Parsons lineament.

At this point, the surface structural studies in the Middle Devonian black shales exposed in the Middle Mountain syncline where this structure is intersected by the Parsons cross strike structural discontinuity reveals that a zone exists within which these organic rich shales have undergone more intense flowage and faulting, that this zone is co-linear with the Parsons structural lineament, and that the more intense deformation therein is associated with changes in structural level and fold terminations occurring across this lineament.

Figure 5 Contours of strike and standard deviation of strike, and strike line maps.

Figure 6 Mellis contoured equal area projections of poles to bedding north of and within the Parsons structural lineament.

3.1.1 Current status and deliverables - continued

2. In addition to field mapping in the Middle Mountain syncline this past summer, a fracture study was initiated. This study will investigate orientation, length, width, and frequency parameters of the fractures in the Middle Devonian black shales in the Middle Mountain syncline to determine what effects the Parsons structural lineament may have on these fracture parameters.
3. A gravity survey has been initiated in Pendleton County, West Virginia, to provide additional data that will be combined with that previously collected by Byron Kulander and Stuart Dean (1978). Gravity modeled balanced cross sections will eventually be constructed on either side of the Parsons lineament in an attempt to uncover subsurface structural relationships to this surface cross strike structural discontinuity.

Perry, W. J. Jr., 1975, Tectonics of the Western Valley and Ridge Fold Belt, Pendleton County, West Virginia: A Summary Report. Jour. Research U.S.G.S., Vol. 3, no. 5.

Tilton, J. L., Prouty, W. F., and Price, P. H., 1927. Pendleton County Report. West Virginia Geological and Economic Survey, 384 pages, two maps.

Wheeler, R. L., and Sites, R. S., 1977. Field studies of the Parsons and Petersburg Structural Lineaments, West Virginia. Abstract, AAPG National Meeting.

3.1.2 Problem areas and suggested improvements

None

3.1.3 Work plan for fiscal year 1978-1979

1. Additional field mapping, if required, will be undertaken in the fall and coming spring. Analysis of bedding orientation contours will be completed this fall.

3.1 Work Package 2100-2-2 STRUCTURE STUDIES

T. H. Wilson

3.1.3 Work plan for fiscal year 1978-1979 - continued

2. Collection of fracture data will be completed early next summer. Subsequent data analysis will be completed by the end of the year.
3. The gravity survey currently underway should be concluded by early November. Data reduction will be completed in early December. It is hoped that balanced cross sections can be constructed and modeled by no later than May 1979.

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3.2 Work Package 2100-2-1 FRACTURE STUDIES

T. H. Wilson

3.2.1 Current status and deliverables

Work in this area has been completed. The results of this study are contained in the attached paper authored by Wilson, T. H., J. M. Dixon, R. C. Shumaker, and R. L. Wheeler, titled "Fracture Patterns Observed in Cores from the Devonian Shale of the Appalachian Basin." This paper was submitted for the Proceedings of the Southeastern Section Geological Society of America Symposium on Western Limits of Detachment and Related Structures in the Appalachian Foreland. Paper currently in review.

3.2.2 Problem areas and suggested improvements

None

3.2.3 Work plan for fiscal year 1978-1979

No additional work is scheduled in this area for the coming year.

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3.1 Work Package: 2200-1-2 FRACTURE STUDIES

Brian R. Long

3.1.1 Current status and deliverables

The 1978 field season allowed the completion of 135 additional stations to bring the total number of stations collected in the course of the study to 289. The 1978 field season concentrated on several major areas of interest:

First, stations were run in the Devonian shale outcrops located through the use of 7-1/2 minute Kentucky geologic maps. These stations extend from Vanceburg, Kentucky, in the northeast to Dale Hollow Lake, Tennessee, in the southwest along the east flank of the Cincinnati Arch. The aim of these stations is to establish fracture patterns in the Devonian shale within the outcrop area nearest to the Big Sandy gas field.

Second, measured Devonian sections by Potter, Kepferele and Provo were separated in the field into their lithologic units and joint information was noted for each unit. The intent of these measurements is to determine differences in fracture data within the Devonian shale sections.

Third, plots of coal cleat strikes collected in the 1977 field season indicated that cleat orientations generally remain consistent over relatively large areas. However, the data did indicate changes in orientation in the Prestonsburg and Hazard, Kentucky, areas. Additional coal stations were run in these areas to provide better resolution of the data. Additional data on sandstone and shale joints were collected routinely at these stations wherever available.

The information collected during the 1978 field season has been separated into lithologic groups and placed in computer data sets. Data from both field seasons has been used to generate an outcrop location map and up-dated rose diagram maps for sandstone, coal, shale, and limestone lithologies in eastern Kentucky. The Devonian shale and limestone information has been plotted on maps that match the western border of the previously mentioned eastern Kentucky maps.

3.1.1 Current status and deliverables - continued

Statistical tests on the 1977 field data were run by Dana Bunner and some tentative results were obtained. A test of correlation between bed thickness and joint spacing indicates only a poor correlation in limestones to a very poor correlation in sandstones and shales. Testing for a relationship between joint strikes and joint spacing showed a possible correlation in sandstone, shale, and limestone.

Composite roses of joint strikes for the entire 1977 field area were computer plotted by lithology. Statistical tests indicate only limestone is significantly different from a uniform distribution; however, all lithologies showed slight peaks in two possible orthogonal sets. These sets were isolated from the shale data and plotted alone to show the areal distribution of possible regional trends. The remaining data (with regional peaks removed) was plotted as residual shale trends. The regional trends proved to be fairly uniformly distributed over the eastern Kentucky area. The residual plot trends appear inconclusive for determining local fracture domains independent of regional trends.

Eastern Kentucky joint maps are deliverable in December, 1978.

3.1.2 Problem areas and suggested improvements

No problems

3.1.3 Work plan for fiscal year 1978-1979

Up dating of all computer maps by lithology will be completed.

The Devonian shale in the measured sections will be separated by stratigraphic units and statistically tested against one another to confirm possible differences. Consistent joint trends in these stratigraphic units may possibly be reflected in joint information obtained at surrounding Devonian outcrops. Other statistical tests on Devonian shale will determine central tendencies for bed thickness, vertical extent, horizontal penetration and spacing.

Coal face cleat strikes will be segregated and plotted on maps to view changes in orientation throughout eastern Kentucky. Changes in coal cleat strikes may indicate possible subsurface structures related to gas production.

All joint data will be reviewed in relation to the structural geology of eastern Kentucky. Possible relations between jointing and major features such as the Rome Trough, the Pine Mountain Thrust, and the Kentucky River fault system will be investigated.

* * * * *

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

3.1.1 Current status of work and scheduled deliverables

During the past six months fractures in the Reel Energy #3 D/K core, METC #1 core, and the Lincoln #20403 core have been studied and logged. The data was then plotted and tested statistically.

The Reel Energy #3 D/K well showed three major natural fracture sets: N70°E, N35°E, and N55°W. Preferential mineralization was noted in these fractures. The slickenline trend was N70°E as was the major strike of core-induced fractures. The METC #1 core showed two main natural fracture sets, N70°W and N80°E. Slickenlines trend primarily N70°W. Reports on results of the study of these two cores are nearly complete.

At the time of this report the study of the Lincoln 20403 core is not yet complete. However, the data available suggest dominant N65°E and N30°W natural fracture sets as well as preferential mineralization in the fractures.

3.1.2 Problem areas and suggested improvements

A problem exists in the very poor condition of the cores to be studied: Lincoln #20403, Lincoln #20402, Jackson #11940, and Jackson #12041. The cores are deteriorated, broken, and intervals are missing where samples have been taken.

3.1.3 Work plan for fiscal year 1978-1979

During the next year plans call for completing data collection and analysis on the aforementioned cores and possibly the Nickolas-Coombs core. A summary report will be written for each of the cores studied. Then, all available data will be integrated into a regional study of subsurface fractures in the Devonian shales and their influence on production.

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3.1 Work Package 2200-1-2 FRACTURE STUDIES

Kevin D. Lee

3.1.1 Current status of work and scheduled deliverables

I was brought onto the project July 1 of this year and field work was immediately undertaken to obtain joint and macro-structure data in the Devonian shales along the Pine Mountain thrust in Eastern Kentucky. The data collected is currently being processed, with hopes of having preliminary results by the end of this year.

3.1.2 Problem areas and suggested improvements

None

3.1.3 Work plan for fiscal year 1978-1979

1. Continue to process field data in the following ways:
 - A) Construct stratigraphic columns where data were collected to show macro structure and joint data in their respective stratigraphic positions.
 - B) Construct a cumulative plot of all joint data for each stratigraphic column.
 - C) Construct cumulative plots of joint data for different stratigraphic intervals in the Devonian shales.
2. Resume field work in the spring.
3. Process new field data from 2. in the fall.

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3.1 Work Package 3200-5-1 PRODUCTION STUDIES

✓
J. 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, and
- 3.4 Work Package 3200-4-1 OIL AND GAS MAPS

The most significant contributions and progress during the past year in these tasks are:

- "Pilot Study of Production Analysis Methods Applied to Cottageville Field," MERC/CR-78/6, authored by J. Negus de Wys and R. C. Shumaker

This pilot study was based on raw production data over 28 years from 63 wells. Production and production decline were related by trend axes of isocontour maps to axial trends of isocontour maps of geological parameters. (Presented with additional analysis at Tulsa, MERC, Lakeview, etc.) See Figures 7-17.

- Completion of 13 preliminary cross sections through the eastern Kentucky gas field(s). About 60 formation density geophysical logs have been correlated for these cross sections. Gas occurrence has been plotted, where known, on the stratigraphic sections. Structural and stratigraphic sections are presented. These cross sections were presented at the Eastern Devonian Gas Shales Symposium at Lakeview, 1978. See Figures 18-32.
- Negotiation for, compilation of, and computer contouring (SYMAP and ADMIN MAP) of initial open flow data on 4750 wells in the eastern Kentucky gas field(s), covering about 3000 square miles in parts of ten (10) counties. Portions of the hand contoured map have been favorable compared with computer drawn maps. However, for exploration purposes, the precision of the hand drawn map is deemed desirable. This comparison was presented at the Eastern Devonian Gas Shales Symposium in October, 1978, at Lakeview. See Figure 33.
- Preliminary trend analysis of initial open flow data in terms of patterns and trend angle subsets, and possible relationships to regional tectonics. See figures 34-39.
- Construction of a 3-D plexiglass model (5' X 4' X 6') of eastern Kentucky gas field(s) showing: 6 structural stratigraphic cross sections of Berea through Lower Huron stratigraphy, gas occurrence, extrapolated Protosalvinia zone in the Mid-Huron, and a nail histogram representing the initial open flow data. (Exhibited at the Eastern Devonian Shales Symposium at Lakeview, 1978.) See Figures 40 and 41.

- continued -

- Negotiation for, attainment of, and preparation for lithologic and geochemical study of well cuttings from 10 wells (~500-700 samples) in the study area of the eastern Kentucky gas field(s). See Figure 12 for well locations, designated by open circles.
- Negotiation for: the release of a basement seismic map, and an additional structure study to be made on two horizons, the data to be obtained from drillers' logs of ~4750 wells in the eastern Kentucky gas field(s). This latter work will be initiated in the summer of 1979 in cooperation with Kentucky-West Virginia Gas Company (Ernie Jenkins), whose generous cooperation has made the entire eastern Kentucky gas field(s) study possible.

Cottageville Study

A MERC-CR-78-6 report presents the data used for the pilot production study of Cottageville gas field. Additional analysis since the referenced report was undertaken and presented both in the Tulsa DOE meetings, 1978, and the Eastern Gas Shale Symposium at Lakeview, 1978. Figure 7 shows the axial trends of production, production decline, and geological parameters, as presented in the pilot study report. These axes were then plotted on compass rose diagrams. Trends of geological parameters are shown in Figure 8, those of production parameters are shown in Figure 9, and those of calculated ($\frac{\Delta p}{p_1}$) production decline trends are shown in Figure 10. These groups of narrow angle trends were then compared one with another. Figure 11 shows production trends compared with geological trends. Figure 12 shows production decline trends compared with geological trends. All trends are shown in Figure 13.

Data in Figure 13 shows a NW-SE trend of highest annual production, initial pressure, and total production to be unrelated to the geological parameters in the study. This is suggestive of the existence of a fault or faults at the angle shown. If the maps of the three production parameters are then examined with the NW-SE angle under consideration (Figures 14, 15, and 16), such an interpretation of NW-SE trending faults or fault in the western part of the field appears quite reasonable. The proceedings of the EGS Symposium, 1978, will show that E. B. Nuckols and seismic studies do suggest such faulting.

Figure 17 shows the discussed relationships in the Cottageville field presented as a stack block diagram. Several interesting conclusions may be drawn. Initial well pressures show correlation with or dependency on all geological parameters considered. Since the geological factors relate to dip/strike of producing and structurally controlling strata, and to fracture facies which undoubtedly contribute to

Figure 7 Trend axes of 12 isocontour maps of Cottageville gas field including geological, gas production, and gas depletion parameters. (From de Wys and Shumaker, MERC/CR-78/6)

Figure 8 Plot of axial trends of geological parameter isocontour maps on a compass rose. Darker center histogram represents the number of areal trends. Note the NE-SW clustering of trend angles.

Figure 9 Plot of axial trends of production parameter isocontour maps on a compass rose.

Figure 10 Plot of axial trends of production decline parameter isocontour maps on a compass rose. The trends shown here are slightly more restricted than production trends.

Figure 11 Comparison of geological parameter trend axes with production trend axes. This relationship could be interpreted to show geological control of available, recoverable gas, and thus indicative of faults, fractures, and porosity, permeability trends.

Figure 12 Comparison of geological parameter trend axes with production decline trend axes.
This relationship may suggest geological control of fracture trends and permeability.

Figure 13 Comparison of axial trends of geological, production, and production decline parameters. Only one angle of production data trends (slightly NW-SE) shows no correlation with geological trends used. This is suggestive of a possible fault trend. Latest interpretation by seismic data, as well as interpretation by E. B. Nuckols, is in agreement. (See EGS Symposium, 1978, Proceedings)

Figure 14 Isocontours of Highest Annual Production (from de Wys and Shumaker, MERC/CR-78/6). Axial trends running NNW-SSE are not related to any geological parameter used, suggesting the possibility of a fault or faults in that orientation.

Figure 15 Isopressure contours of Initial Well Pressures. (From de Wys and Shumaker MERC/CR-78/6). Lack of correlation with geological parameters studied suggests the possibility of faulting along the axial trend NNW-SSE.

Figure 16 Isocontours of Total Accumulated Production. (From de Wys and Shumaker, MERC/CR-78/6). The NNW-SSE axial trends in this map and in the two preceding maps suggest possible faulting in this trend which shows no correlation with other geological parameters.

Figure 17 Stack block diagram showing graphically the production and production decline relationships to geological parameters in the Cottageville Field.

free gas availability and serve as a gas conduit system, such relationships are very reasonable. Highest correlation of all production parameters is to the top of the Onondaga limestone which lies 500' stratigraphically below the producing strata. This more rigid rock surface must have had a pronounced effect on differential compaction of the Devonian shales above, as well as forming a fairly rigid framework for basinal configuration at the commencement of Lower Huron deposition. Basement structural anomalies would be reflected to a lesser degree on the surface of the Onondaga, especially fault block movement. The Rome Trough lies to the south of the Cottageville field with the major downthrown graben trending NE-SW. The field is on an upthrown block on the northside of the trough. The regional dip is to the SE.

The Cottageville Pilot study was conducted with available raw production data (over 28 years) as a preliminary investigation to the study of the eastern Kentucky field(s) with 4750 data points.

Eastern Kentucky Gas Field(s)

Figure 18 shows the structural setting of this coalescence of many smaller fields known as the eastern Kentucky field(s). The Rome Trough is observed to trend NE-SW across the northern sector of the field, and to turn more sharply north in West Virginia as it passes to the south of the Cottageville field. The Pine Mountain thrust to the south parallels the Rome Trough and bounds the eastern Kentucky gas field(s) in that direction. Not commonly observed is the fact that gas production also occurs to the south of this thrust. The main trend of the Appalachian orogeny parallels more nearly the NE-SW trend of the Rome Trough in West Virginia where it is more sharply N than in Kentucky. This point will become important later in a discussion of initial open flow data trends. The basement structure is observed to come from a high point (-3000') to the NW of the field, dipping at approximately 100' per 1 mile to -12,000' and then starting back up to a low knob of -10,000' east of the gas field. Extension of the Paint Creek Uplift has been suggested as the explanation of the broad anticlinal structure of the northern part of the gas field. This gentle anticlinal structure broadens, then bifurcates to the south and is bounded on the west by small faults. The stratigraphic nomenclature is shown in Figure 19. The cross sections (Figures 20-32) are located on Figure 18 by darker lines with lettered identification. A detailed analysis of these sections, when finalized, will accompany a later report.

The gas occurrence noted on cross sections is not complete. Where gas is not noted, therefore, it may be due to incomplete data rather than lack of occurrence. This aspect will be further studied and posted.

Figure 18 Basement structural setting of the eastern Kentucky gas field(s). Downthrow edges of fault blocks are shaded. Rome Trough is shown trending NE-SW across the northern part and turning more to the north in West Virginia. The study area is darker gray.

NOMENCLATURE FOR CROSS-SECTIONS

BEREA/BEDFORD	Berea Sandstone and Bedford Shale, uncivided
CLEVELAND	Cleveland Member of Ohio Shale of Ohio Blue = Black Shale Green = Gray Shale
THREE LICK	Three Lick Bed of Provo, Kepferle, and Potter, 1977
UPPER HURON	Upper Part of Huron Member of Ohio Shale of Ohio
MIDDLE HURON	Middle Part of Huron Member of Ohio Shale of Ohio
LOWER HURON	Lower Part of Huron Member of Ohio Shale of Ohio

Figure 19 Nomenclature approved by the U.S.G.S. for stratigraphic units included in the eastern Kentucky gas field study.

NORTH
E'
PERRY COUNTY

LESLIE COUNTY

SOUTH
E
PERRY COUNTY

**CROSS SECTION E'-E
EASTERN KENTUCKY
GAS FIELD**

J. Negus de Wys May, 1978

Datum Top of Berea

Figure 20 Cross section E'-E of Top of Berea through Lower Huron with formation density geophysical log traces.

Figure 21 Cross section B-B' with formation density geophysical log traces.

Figure 22 Cross section K'-K with formation density geophysical log traces.

Figure 23 Cross section E'-E showing stratigraphic correlation with reference to Top of the Berea. Horizontal to vertical scale ratio is 1:163 to exaggerate structure within units.

Figure 24 Cross section B-B' showing stratigraphic relationships. Datum is the Top of the Berea.

NORTHWEST

K'

LAWRENCE COUNTY

DATUM TOP

OF BEREA

MARTIN COUNTY

PIKE COUNTY

SOUTHEAST

K

DATUM TOP

OF BEREA

CROSS SECTION K'-K EASTERN KENTUCKY GAS FIELD

J. Negus de Wys May, 1978

DATUM TOP OF BEREA

Figure 25 Cross section K'-K showing stratigraphic relationships. Datum is Top of the Berea.

CROSS SECTION E'-E EASTERN KENTUCKY GAS FIELD

J. Negus de Wys May, 1978

Figure 26 Structural-stratigraphic cross section E'-E. Vertical scale is 163 times that of horizontal to show structure.

Figure 27 Structural stratigraphic cross section F'-H.

Figure 29 Structural stratigraphic cross section K'-K.

Figure 30 Structural stratigraphic cross section A-A'.

Figure 31 Structural stratigraphic cross section B-B'.

Figure 32 Structural stratigraphic cross section C-C'.

The most evident stratigraphic aspects of the cross sections are 1) the fine intertonguing of black and gray shales in the Cleveland and 2) the thickening (not always the same ratio with all units) of the black shale sequence to the east and especially northeast. During the Lower Huron, Middle Huron, and Cleveland times the depositional basin appears to have been actively growing in depth. This could in turn be due to periodic plate edge collisions preceding the final impact which provided the force for the Appalachian orogeny. More in depth discussion and interpretation will follow in a later analysis where basinal axes and changing basinal axes will be considered relevant to the black shale deposition deformation and fracturing. Dip of the Devonian black shales is 30-50" per mile in this area.

The fine intertonguing of black and gray shales in the Cleveland was noted in the formation density logs and checked in cores and cuttings. As may be noted in the cross sections, the gray units may be intertonguing gray shales extending to the east to merge with the thick Chagrin gray shales. This relationship will be explored further in analysis.

Location of 4750 wells (Kentucky-West Virginia Gas) is shown in Figure 33. Initial open flow for these wells is the basis for computer drawn isocontour maps (SYMAP and ADMIN MAP) of the entire field. Small portions of these maps have been compared with a hand contoured version of the same data. (Presented at EGS Symposium at Lakeview, 1978.) The comparison is favorable for a regional or overall view of the field. For exploration, the averaging of data points by the computer program smears the contours to an unacceptable degree. Hand contouring would appear to be the most desirable method at this time for exploration work. The hand contoured map is nearing completion.

By dividing the initial open flow data into >2 , >1 , $>.5$, and $<.5$ MMcf/day categories, a pattern becomes immediately apparent (Figure 33). By connecting all wells with an initial open flow of $>.5$ MMcf/day where not separated by lesser value wells, the pattern shown in Figure 34 is obtained.

Linear trends with subsidiary patterns begin to be visible. Presented here are some preliminary observations concerning trends. These linear trends appear to be important but will require more analysis in combination with other data.

Figure 35 shows a tracing of all linear trends from the pattern in Figure 34. These are proven, producing trends! The magnitude of the initial open flow values suggests that the wells from which these trends are constituted produce more free gas initially than surrounding wells. (Compare Figures 33 and 34.) This in turn suggests free space, faults, or fracture zones. With such a line of reasoning it may be suspected that the trend traces in Figure 35 show zones of more intense fracturing.

Figure 33 Location of approximately 4750 gas wells in Devonian shale used in the eastern Kentucky gas field study. The original of this figure is color coded for the breakdown into >2, >1, >.5, and <.5 MMcf/day.

Figure 34 Pattern resulting from the connection of all wells with initial open flow >.5 MMcf/day. See previous figure for comparison. Note linear trends and subsidiary curvilinear patterns.

Figure 35 Sketch of trends in initial open flow pattern of wells with values $>.5$ MMcf/day from pattern in Figure 28.

Now, if these traces are separated into groups of roughly the same direction trend lines, Figures 36 - 39 may be produced. Essentially, four directions of fractures pop out. These may represent two sets, of one combination or another. The set shown in Figures 36-37 exhibits traces approximately perpendicular and parallel to the Appalachian orogenic axis. En echelon groups are apparent in both trend traces. The set shown in Figures 38-39 exhibits traces approximately perpendicular and parallel to the Pine Mountain Thrust and the Rome Trough. The traces could be paired in different combinations.

Two main kinds of fractures in black shales are described in the literature as 1) those filled with quartz or other minerals and 2) open fractures which must have formed either in the absence of such mineral-rich solutions or after the time of impregnation of existing fractures by such solutions. Some are partially filled. Both unfilled and partially filled fractures contribute to porosity and would thus contribute to the recovery of gas. Such recovery is reflected in the initial open flow patterns in the present study.

It would appear there were at least two generations of fractures and more probably several generations. These observations would suggest a tensional interpretation of at least two of the trace trends shown here.

Interpretation and evaluation of this data will be presented in more detail in a future report.

3-D Plexiglass Model

A 3-D plexiglass model of structural stratigraphic sections of the eastern Kentucky gas field, gas occurrence, and initial open flow (as a histogram on the base) was constructed and exhibited at the EGS Symposium at Lakeview, 1978.

The area covered by the model is shown in Figure 40. A photograph of the model is shown in Figure 41.

Papers were presented and meetings attended as described in the quarterly report.

The tasks described above are on schedule.

Figure 36 Sketch of NE-SW trend traces in initial open flow pattern of wells with values >5 MMcf/day. This trend is ~parallel to Appalachian orogenic axis and at an acute angle to the Pine Mountain Thrust to the south. This trend parallels magnetic intensity trends especially in the area of the Rome Trough. Note en echelon arrangement of some trend lines.

Figure 37

Sketch of E-W trend traces in initial open flow pattern of wells with values $>.5$ MMcf/day. This trend is $\sim$ perpendicular to the Appalachian orogenic axis and at an acute angle to the Pine Mountain Thrust. These traces are almost perpendicular to those in Figure 30. Note en echelon groups of traces in the western part of the field. This angle approximates that of regional data trend shown by surface trend analysis program on the initial open flow data.

Figure 38 Sketch of N-S trend traces in initial open flow pattern of wells with values $>.5$ MMcf/day. This trend is approximately perpendicular to the axis of the Pine Mountain Thrust and that of the Rome Trough in this area.

Figure 39 Sketch of NE-SW trend traces in initial open flow pattern of wells with values $>.5$ MMcf/day. This trend approximately parallels the Pine Mountain Thrust and the axis of the Rome Trough in this area. Note en echelon groupings in the western part of the field.

Figure 40 Area covered by 3-D plexiglass model of structure, stratigraphy, gas occurrence, and histogram of initial open flow data on 4750 wells.

Figure 41 Photograph of 3-D plexiglass model in WVU laboratory.

During this past year we submitted a preliminary draft manuscript of a production study on the Cottageville - Mount Alto field (Figure 1) by E. B. Nuckols to the U. S. Department of Energy - METC. This report documents the interrelationships between production and geologic parameters. Of premier importance to gas production is the presence of open and mineralized natural fractures in the Huron shale over a deeply buried basement fault. Evidentially slight flexing of the shale over the fault permitted differential fracturing of the Huron shale, and this flexing kept those fractures open to permit transmission of mineralizing fluids and shale gas within that stratigraphic unit.

After review, revision, and if approved by DOE-METC, the report will be re-submitted in final form. Acceptance of that report will conclude our formal production study of the Cottageville field.

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* No longer attached to project.

Subtask - Identify 3 areas in which to conduct ground water studies.

3.1.1 Current status of work and scheduled deliverables

A ground-water study has been initiated and completed in the Cottageville area of Jackson County, West Virginia. Field and laboratory work were conducted by Mr. D. Scott Jones. See the appendix to this report for a research progress report and a published paper giving both data and results of this study.

A second ground-water study has been started in the Midway Extra gas field area of northern Putnam County, West Virginia. This study is similar to that in the Cottageville area. Mr. Robert Beebe is conducting the field and laboratory work, and to date has collected physical data from 86 domestic water wells in the Midway Extra area. See Table 1 in Appendix E for most of these data. Some wells have been sampled for ground-water quality analysis.

The above-mentioned report, research paper, and table are the only deliverables scheduled for the annual report.

3.1.2 Problem areas and suggested improvements

No problems were encountered in our study of the Cottageville area. Some time delays in doing field work created temporary problems for Mr. Beebe in the Midway Extra area. These problems are explained in the past two quarterly reports. It is anticipated that Mr. Beebe will be caught up with most field research work within the present quarter.

3.1.3 Work plan for fiscal year 1978-1979

We plan to complete our research project and submit reports and scientific papers on our findings for the Midway Extra study. A third research project will be planned and started in the eastern Kentucky study area. This ground-water study will be similar to those in the Cottageville and Midway Extra areas; it will be conducted by a new M.S. degree candidate in Geology, under the supervision of Dr. Henry Rauch.

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3.2 Work Package 3200-2-3 SURFACE RESISTIVITY

Henry W. Rauch

Subtask - Conduct resistivity surveys over ground water study areas (defined under 3200-1-2).

3.2.1 Current status of work and scheduled deliverables

Resistivity surveying has been completed across selected photolineaments in the Cottageville study area. There are no deliverables for this annual report.

3.2.2 Problem areas and suggested improvements

Resistivity surveying has been delayed in the Midway Extra study area, because of temporary problems mentioned above. We do not anticipate further delays in field work during fiscal year 1979.

3.2.3 Work plan for fiscal year 1978-1979

Results of resistivity surveying for the Cottageville study area will be given in a report within the next six months, after D. Scott Jones completes his M.S. thesis which will contain the relevant data. Likewise, resistivity surveying for the Midway Extra study area will be conducted and reported within the next year.

We are putting less stress on the resistivity surveying in order to do more ground-water quality analyses than originally planned for the Midway Extra study area. The latter work is deemed to be more potentially useful in developing new exploration tools for Devonian shale gas.

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3.3 Work Package 3200-5-1 STRUCTURE/PRODUCTION CORRELATION

H. W. Rauch

Subtask - Correlate all data and attempt to establish a relationship between geologic features, lineaments, fractures, ground water, and oil and gas production.

3.3.1 Current status of work and scheduled deliverables

Data comparisons and statistical tests have been performed to test for associations between ground-water data and Devonian shale gas production for the Cottageville study area. Results for both photolineaments and ground-water quality have been compared to the production rates from nearby gas wells, and associations have been noted. Data and results for the Cottageville study area are presented in a research paper which appears on pages 196-205 of Preprints of the Second Eastern Gas Shales Program-Volume I. This paper also appears in the appendix of this annual report.

Water quality data was obtained from three additional waterwells near Cottageville, to further test our associations between water quality and gas well yeild. These three wells are in the low gas-producing area (less than 100 MCF/day initial flow). Two of the three wells support the conclusions drawn from previous data, while one well is an exception to the rule. These three additional wells give an inconclusive test of the tentative water quality-gas yeild associations. Unfortunately, we were unable to get additional quality data for other water wells in the high-producing gas well area, because of inaccessibility of roads and a scarcity of waterwells in this area.

3.3.2 Problem areas and suggested improvements

None

3.3.3 Work plan for fiscal year 1978-1979

We will complete the photolineament and water well analyses for the Midway Extra study area. The data will then be statistically and graphically tested for associations among photolineaments, ground-water quality, and the yeilds of nearby gas wells. The results will then be compared to those for the Cottageville study area, to make general conclusions about the applicability of photolineament analysis and ground-water quality as exploration tools for Devonian shale gas. All data and results will be reported in progress reports and in a research paper within the next year.

A study of photolineaments and water wells will be started in eastern Kentucky next year, but conclusions regarding associations of measured data to gas well yeild will not be available until fiscal year 1980.

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3.4 Work Package 3200-5-3 LINEAMENT/STRUCTURE CORRELATION H. W. Rauch

Correlate fractures and lineaments derived from photo analysis with results of ground water tests to determine if any relationship exists between ground water production and the occurrence of lineaments.

3.4.1 Current status of work and scheduled deliverables

See both the report and the research paper by D. Scott Jones and Henry Rauch, located in the appendix of this report, for a presentation of data and the results of statistical comparisons; the report and research paper summarize the associations between photolineaments and waterwells for the Cottageville area.

3.4.2 Problem areas and suggested improvements

None

3.4.2 Work plan for fiscal year 1978-1979

An analysis of possible associations of both ground-water chemistry and water well yeild with photolineaments will be made for the Midway Extra study area next year. Results of this analysis will be given in progress reports and in a research paper.

A similar study will be started for an area in eastern Kentucky next year, but data analysis and conclusions will not be available until fiscal year 1980.

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3.1.1 Current status and deliverables

Research has continued to progress on the geophysical tasks. The initial testing of the seismic system was completed and several problems discovered and corrected. The hydraulic energy source was abandoned and an acetylene cannon was developed and field tested. This new energy source proved ineffective since it would malfunction when placed down water-filled holes. Much time and effort were spent attempting to remedy this problem, but no solution could be found; so the acetylene cannon was set aside for the more conventional source, explosives. The amplitude and frequency response of various explosive sources were examined and the optimum explosive source chosen.

The initial field testing at the Department of Transportation test site near Washington, D. C., showed the system worked well but had several severe noise problems. Most of the winter and early spring months were spent eliminating this electrical noise.

Field testing began in June at the Wetzel County test site and was completed in August. The later part of August and parts of September and October were spent analyzing this data and writing up the results from the test site.

Parts of September and October were spent at the test site near Cottageville, W. Va., where survey lines were chosen and holes drilled for the seismic survey. Resistivity data was also collected at this time (see 3200-2-3 SURFACE RESISTIVITY). Appended to this report is a report that summarizes the work performed at the Wetzel County, W. Va., test site.

3.1.2 Problem areas and suggested improvements

Several problems developed throughout the year and were solved. These problems are summarized below.

- The hydraulic energy source was perfected and tested and found to be unsuitable in uncompacted soils and because the amplitude of high frequency waves was insufficient.
- An acetylene cannon was then designed, built, and tested as an energy source. This source proved effective until water-filled holes were encountered, where it malfunctioned.

3.1.2 Problem areas and suggested improvements - continued

- Several types of electrical problems arose but these were all eventually overcome.
- A heavy period of rainfall in July destroyed most of the shallow bore holes at the Wetzel County site necessitating redrilling and a several week set back in schedule.

The system could be dramatically improved by utilizing a seismograph with at least 12 channels, and better yet, 24. Systems with sufficient sampling rates and up to 24 channels have become commercially available in the past year.

Also a four person field crew instead of two would be much more efficient provided two vehicles were used instead of one. The first vehicle would drill the shallow auger holes while the second vehicle would contain the geophysical equipment and crew.

3.1.3 Work plan for fiscal year 1978-1979

The first quarter of the next fiscal year will be spent collecting data at the Cottageville test site. Data will be collected just as long as weather permits. The remainder of the first quarter and most of the second quarter will be spent analyzing data and report writing. If insufficient data is collected during the first quarter, additional data will be gathered when the weather clears in the spring.

By the end of the fiscal year 1978-1979, we will have completed collection of seismic data, the analysis of that data, and we will submit a final report on that data.

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3.1 Work Package 3200-2-3 SURFACE RESISTIVITY

Keith G. Kirk

3.1.1 Current status and scheduled deliverables

Work is on schedule and selected resistivity surveys have been performed over select areas of the ground water study area (Task 3200-1-2) and in conjunction with the seismic investigation at the Cottageville W. Va., test site (Task 2100-1-1).

A preliminary analysis of the data at the Cottageville test site indicates the possible presence of a fault that appears to correlate well with a high zone of production in the Cottageville field. The seismic work planned in this area should determine if a fault exists.

3.1.2 Problem areas and suggested improvements

None.

3.1.3 Work plan for fiscal year 1978-1979

Complete collection of resistivity data; complete data analysis and final report.

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3.1.1 Current status of work and scheduled deliverables

During the past summer work was begun on the problem of processing the reflection seismic data now being obtained. We now have the hardware necessary to interface our digital cassette tape deck to a PDP-11 minicomputer, which will reformat the data and write it on a tape that can be read by the IBM 360/370 system.

Computer procedures for plotting seismic data and computing and plotting synthetic seismograms have been written.

Some study of the current literature pertinent to the problem of geophysical exploration for fracture zones in shales has been done, revealing very little directly applicable to our problem. However, from general considerations, it would seem that reflection seismic data is of value in two ways:

- 1) Detailed subsurface mapping to reveal features with which fracturing may be associated;
- 2) Attenuation studies of the seismic data for direct detection of shale fracturing.

3.1.2 Problem areas and suggested improvements

One problem is finding or developing an energy source for reflection seismic data acquisition that is safe, reliable, doesn't require permits, and which yields good data.

Another problem that is going to be serious in the future is the almost total lack of sonic logs in the areas of interest. Without good sonic well logs, a meaningful geologic evaluation of our seismic data is not possible.

3.1.3 Work plan for fiscal year 1978-1979

We will begin plotting, processing, and interpreting seismic data, first from Cottageville.

Work will be done this winter to evaluate several energy sources, both down hole and surface sources. This will involve field tests of energy sources with the recording geophones down a several hundred foot hole. This will be an attempt to record

3.1 Work Package 2100-1-1 SEISMIC

J. E. Ruotsala

3.1.3 Work plan for fiscal year 1978-1979 - continued

the source wavelet. In addition to evaluating the energy sources, this data will be useful in the processing and interpretation of reflection data.

Plans for next summer's field work will be made. The geographic areas selected and the field procedures used will depend on what instrumentation is available.

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