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AN ANALYSIS OF THE STRUCTURAL PARAMETERS THAT INFLUENCE

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1979-1980. ^{3#}

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1979 - 1980,

ANNUAL PROGRESS REPORT

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AN ANALYSIS OF THE STRUCTURAL PARAMETERS
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APPENDIX A

REGIONAL STRUCTURE DATA

1979 - 1980

Robert C. Shumaker

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THE IMPORTANCE OF REGIONAL AND LOCAL STRUCTURE TO
DEVONIAN SHALE GAS PRODUCTION FROM THE APPALACHIAN BASIN

by

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THE IMPORTANCE OF REGIONAL AND LOCAL STRUCTURE TO
DEVONIAN SHALE GAS PRODUCTION FROM THE APPALACHIAN BASIN

by

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ABSTRACT

The recent energy shortage within the United States of America has drawn governmental interest toward unconventional sources of natural energy. The black, organic-rich gas shales of Devonian and Mississippian age in the continental interior present a huge resource base for that area. The Devonian shale has produced high-quality gas from the Appalachian basin in eastern Kentucky and West Virginia for nearly 100 years, yet little is known of the relationships between the geology and production. This is true because the wells are shallow, and they are drilled largely on a random basis related to available acreage and adjacent production. Geologic structure and production from this area is being studied to determine if there is a relationship between the two. Analyses of 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 is important to development of 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.

A program which utilizes geomorphology, detailed subsurface structure analyses, geochemistry, and high-resolution seismic investigations is being developed to help formulate an exploration rationale. Results of our study may help geologists to locate fractured reservoirs in other foreland troughs, and in particular where the reservoirs are organic rich shales.

Introduction

The Devonian shale is an informal stratigraphic name applied to a body of organic clay-rich sediments that extend across nearly 25% of the North American continent. This black and gray shale generally lies between Mississippian sands or shales and Middle Devonian limestones. The shale onlaps these carbonates along an erosional surface of low relief.

In basins of the western plain states the thin shale is usually called the Woodford shale. In the Illinois basin (Figure 1) the shale is called the New Albany shale (30-100 meters thick), and in the Michigan basin it is called the Antrim shale (25-40 meters thick). Within the western Appalachian basin the thick shale sequence (up to 400 meters thick) is usually called either the Ohio shale or the Chattanooga shale (Figure 2). Stratigraphic problems arise east of this area, within the central portion of the Appalachian basin, where the shales change facies to interbedded sands and silts of the Appalachian deltaic sequence (Figure 3).

Production

The highly organic portions of the Devonian shale sequence usually give up minor amounts of gas and some oil when penetrated by the drill. Occasionally the gas produced will be of sufficient quantity to warrant completion as a commercial gas well. However, it is only within the Appalachian basin that the shale produces large quantities of gas. The major areas of production are in eastern Kentucky in a blanket-like deposit and as discreet fields in southwestern West Virginia (Figure 4). It is this area that is the subject of this report. These fields have produced over one trillion cubic feet during the last fifty years, but the shale has produced shallow gas for local consumption for over 100 years in several areas of the eastern United States. Exploratory gas wells are shallow, being located randomly, either in proximity to other producing wells or on the basis of available acreage in the productive area. Even though nearly 10,000 wells are producing shale gas in eastern

Figure 1. Distribution of Devonian shale within eastern basins

System	Series	Units of New Albany Shale In S.IN.-W.KY.		Units of Ohio Shale In OH.-E.Ky.		Units of Chattanooga Shale In W.VA.-E.TENN.	
Miss.	Lower Miss.	Rockford Limestone		Sunbury Shale		Big Stone Gap Member	
		Jacob's Chapel Bed Henryville Bed Underwood Bed Falling Run Bed	N E W				
DEVONIAN	UPPER DEVONIAN	Clegg Creek Member		Bedford Berea Sequence		Middle Gray Siltstone Member	
		Camp Run Member		Cleveland Shale			
		Morgan Trail Member		Three Lick Bed			
		Selmier Member		Partial Chagrin Shale Equivalent			
		Central Ky. Boyle ls./ch.		OHIO SHALE			
		Blocher Member		H S U R O N S H A L E			
	Mid. Dev.	Onondaga Limestone/ Huntersville Chert/ Needmore Shale		Lower Black Shale Member			

de Wys, 1979

Figure 2. Devonian shale nomenclature: Appalachian basin

Figure 3. Devonian shale facies relationships: Appalachian basin

Figure 4. Study Area - structural parameters that affect Devonian shale gas production

Kentucky and West Virginia, very little was known about the geology of the shale or the cause for its commercial production. Geologists have generally reasoned that fractures create the permeability within the shale necessary to release gas in commercial quantities. However, some geologists have maintained that thin silt stringers in the shale are the reservoir, and a few maintain that matrix porosity in the shale is significant to account for all of the production. Our work supports the interpretation that natural fractures are most important for commercial production.

Background

The recent energy shortage in the United States has focused governmental interest on domestic unconventional sources of natural energy, and the productive Devonian shales contain a huge resource potential of high quality natural gas within the energy starved eastern and mid-continent regions. The magnitude of the potential can easily be seen by calculating the total amount of gas which potentially could naturally escape from the shale. By doing so one arrives at an astronomical figure of between 225 trillion cubic feet and 1861 trillion cubic feet of gas that is locked up within the shale in the Appalachian basin alone (N.P.C., 1979), and it is clear that there is a far greater resource of natural gas locked up within the shale within the other basins of the continental interior. Unfortunately, under present technology, only between 8 and 15 trillion cubic feet of this shale gas is available in the Appalachian basin. The range of 8 to 15 TCF is largely dependent upon the price the producer will receive for the gas: a lower price deters exploration in marginally commercial areas, whereas a high figure would make exploration in these areas more likely.

The United States Department of Energy has funded research designed to evaluate existing production and the future potential of Devonian shales in order to evaluate the potential of the shale and with the ultimate goal of expanding production. All aspects of gas production from the shale are under study in this governmental program, but this report includes only those aspects of the structural geology which affects production.

Before embarking on a discussion of these results, it should be understood that an essential ingredient for commercial production is the presence of a sufficient thickness of highly organic shale and a maturation of that shale which is sufficient to liberate hydrocarbons. Both of these prerequisites are fulfilled over much of the continental interior, and they are both fulfilled throughout the study area. Therefore, the key variables for production from Devonian shale in the study area are its lithology and the structure.

Two aspects of a broadly based structural study have been particularly interesting in regard to understanding the relationships between

shale gas production and geologic structure. The first result comes from the study of fractures found in oriented cores of the shale, and the other comes from the geologic analysis of two producing shale gas fields.

The evaluation of fractures found in oriented shale cores taken from within the study area in the Appalachian basin (Figure 4) has shed light on the distribution of fractures in an orogenic foreland. Even though several of these cores were taken in what initially was considered undeformed foreland sediment, they all contained natural fractures, joints, to depths of over 6000 feet, and most surprisingly, these cores contained slickensided fractures. In general, systematic joints from these cores form three sets: one related to present day in-situ stress which is thought to be Mesozoic in age (Evans, 1980), and the other two which form an orthogonal, cross and longitudinal, joint system that is Alleghenian in age. The slickenlines of small faults trend parallel to the cross joint strike which support the Alleghenian age of the orthogonal system. Shumaker (1978) suggested that open and mineralized fractures were most prevalent in the highly organic portions of the shale based on studies of the first few oriented cores. Evans (1980) showed that the open and mineralized joints within the shale were most numerous in the highly organic portions of the section based on 13 wells, and he supported the proposal (Shumaker, 1978) that production comes from a porous fracture facies within the highly organic shales in the lower portion of the Devonian shale. This mineralized and more intensely fractured shale section in the commercially productive area is interpreted to be a decollement zone, or perhaps more aptly, a zone of differential shortening. The differential shortening is found in the distal portion of a more extensive area of transport and shortening above decollement surfaces that extends deeper into the section in the more deformed eastern Appalachian basin (Figure 5). An important feature for production from the organic shales is that the fractures are limited vertically so that the enclosing shale forms both the source and the seal for the reservoir and the interconnected fractures form the permeability. It is essential to maintain this relationship during well completion treatment and stimulation so that water from adjacent formations does not enter the chemically sensitive reservoir. The vertical joints presumably form the main channels of permeability, whereas, the small faults probably do not greatly enhance permeability (Heald and Larese, 1978). In plotting the areal distribution of fracture types, it was found that most of the present day commercial production falls within an area of limited tectonic transport as defined by the inclined slickensided fractures, whereas, production from the zone of tectonic transport ranging up to several miles is characterized by higher than normal pressure in blowout zones of little sustained production. Horizontal slickensides predominate in the major transport zones, but inclined slickensides are also very common. Poles to slickensided surfaces plot in a girdled distribution with maxima related to the primary and Reidel shear directions in the large transport areas. In the area of minimal transport a shear system asymmetrically distributed about the horizontal stress direction prevails. A reduction in production is

Figure 5. Structural cross section: eastern Kentucky

found cratonward of the commercial production. Cores taken of the shale in that area show a lack of slickensided surfaces and a decrease in frequency of open or mineralized joints; thus, there is a distinct zone of maximum production related to the distribution of fractures in the organic shales.

A second aspect of our investigation that has application to shale gas exploration comes from a study of two productive fields within the study area of the Appalachian basin. Production data from three fields within the Appalachian basin are available for study, and two, the Midway-Extra and Cottageville fields (Figure 4) have been thoroughly analyzed for this report. The third field is presently under study.

Detailed investigations of the Midway-Extra field of Putnam County, West Virginia, by William W. Schaefer (1979) established a direct relationship between production from the organic portion of the Devonian shale (the lower Huron shale) and the structural trend of the field. Schaefer was able to confirm that initial and final open flows, flows after explosive frac, from wells at Midway-Extra are greatest along the northwestern limb of the Midway anticline; that is, in the adjacent syncline, off structure. He also found a lesser increase in production along the southeastern limb. The striking similarities of high flow rates with structural position along the fold is forcibly brought out by comparing Figures 10 and 11 taken directly from Schaefer's text (1979). Furthermore, he showed that the thickening of the lower Huron shale, the primary reservoir, into the adjacent syncline (Figure 12) suggests growth of the structure during sedimentation. He interpreted this to mean that basement deformation was an important factor in the formation of the Midway anticline. From these data (Figures 10, 11, 12, and 13) at the Midway-Extra field, one cannot be absolutely certain if it is the thicker lower Huron organic shale or if it is fracturing associated with the folding which contributes most to the noticeable increase of off-structure flow rate. One might argue that even if fractures are present, they are not necessarily structural in origin. Such fractures could be caused either by lithologic factors or as the result of differential compaction of thin shale on and thick shale off structure. Regardless of the cause, an empirical exploration rationale was proposed based on Schaefer's study (1979). Direct evidence for the exact and underlying cause for this increased production of off-structure wells was elusive even though Schaefer had made a major guiding breakthrough for an empirical exploration rationale.

If, however, one combines the data from the Midway-Extra field with what is known of the Cottageville field (de Wys and Shumaker, 1978), then additional insight is gained into the specific cause of commercial shale gas production for that portion of West Virginia (Figure 9). At first glance, the structural similarity between Cottageville (Martin and Nuckols, 1976; Nuckols, 1979; and de Wys and Shumaker, 1978) and the Midway-Extra field is not striking. Structurally, the Cottageville field

Figure 6. Natural fractures in Devonian shale cores

Evans, 1980

Figure 7. Slickenside surfaces from Devonian shale cores

Figure 8. Slickenlines trends in Devonian shale cores

Figure 9. Midway-Extra and Cottageville shale gas field area

STRUCTURE-BASE OF BROWN SHALE (L. HURON)

Midway-Extra Field
Putnam County, W. Va.

0 1 2
MILES
C.I. = 20'
W. Schaefer, 1979

Figure 10

Schaefer, 1979

Figure 11. Devonian shale isopotential open flow after stimulation.

0 1 2
MILES
C.I. = 100
MCF/D

LOWER HURON ISOPACH MAP

Schaefer, 1979

Figure 12. Organic-rich Devonian shale (lower Huron)

STRUCTURE AND ISOPOTENTIAL CROSS SECTIONS

Figure 13

appears to lie along a very low relief monoclinial flexure on a southeast dipping regional slope. The cause for the flexure was inferred to be a basement fault (Martin and Nuckols, 1976; and Shumaker, unpublished maps). Detailed interpretation of seismic data collected by Geophysical Services, Incorporated, by Glenn Sundheimer (1978 and 1979) confirmed the presence of the flexure in the sediments and a basement fault directly under the trend of the most productive wells along the southeastern flank of the Cottageville field (compare Figures 14 and 15). Note the southeast regional dip and the subdued flexure including a syncline just updip, northwest from the fault (Figure 14). These structures are similar to, although not identical to, ones mapped by E. B. Nuckols III (1979) from detailed subsurface geologic data. Nuckols has found that sedimentary patterns of the organic shales are complex around this structure. His maps (ibid., 1979) also show that the best production does not uniquely follow the thickest lower Huron organic shale section. The best production lines up with the fault as mapped by Sundheimer (Figure 14). If one eliminates the regional dip from Sundheimer's isotime structure map, then the Cottageville field becomes a low fold with flanking synclines. It is only now that the Cottageville field appears similar to the Midway-Extra field, but Cottageville has far less relief. Keeping this in mind, compare the position of the fault, the fold crestal trace, and the trace of the flanking northern syncline with the production trends at Cottageville as mapped by de Wys and Shumaker (Figures 16, 17, and 18). There is a marked similarity of final open flow trends at Midway-Extra with production as mapped at Cottageville. This similarity is noted by lower productivity along the crest of both structures. At Cottageville there is a near coincidence of productive trends shown on the summary trend map (Figure 19) above and parallel to the basement fault. The trends are not nearly as numerous for the northern syncline (Figures 14 and 19) which, incidentally, may be the southwest terminus of another buried fault. In the case of Cottageville, the identity between structure and production seems far more conclusive than that at Midway-Extra simply because of the greater quality and quantity of data. At Cottageville it is clear that better wells, by all production statistics, occur off structures, and that the best wells generally occur directly above the basement fault. De Wys and Shumaker (1978) contoured the production data at Cottageville (Figures 15 thru 18) with a mechanical style, attempting to avoid bias in their contouring. Had they contoured the production data as Schaefer did with final open flows at Midway-Extra, and if they had both Schaefer's results and Glenn Sundheimer's map when contouring the Cottageville data in 1977, then they would have contoured the Cottageville data to a more linear trend, and the identity of structure and production trends would be more striking.

Using re-interpreted Cottageville as background, one can now go back to Midway-Extra and re-interpret the northwestern flank of the anticline suggesting that it is faulted at the basement level. The justification for this interpretation is the growth aspect of the structure and location

de Wys and Shumaker, 1978

Figure 15. Cottageville - isocontours of highest annual production (1st or 2nd year production)

Figure 16. Cottageville - isocontours of mean annual gas production

Figure 17. Cottageville - isocontours of first five years accumulated gas production - de Wys and Shumaker, 1978

Figure 18. Cottageville - isocontours of total accumulated production

de Wys and Shumaker, 1978

Figure 19. Cottageville - axial trends of contours from production maps de Wys and Shumaker, 1978

of the high productivity wells. At Cottageville such wells are located along and above a proven basement fault. If one concludes that the Midway-Extra field is faulted on both flanks then the marked asymmetry of production is puzzling. This asymmetry may relate to Alleghenian stress being concentrated on the western flank of that structure to create anomalously fractured shale in the detached reservoir horizon along that trend. Clearly Midway-Extra and Cottageville document the importance of geologic structure and specifically, basement faulting, to high production from the shale. The productive asymmetry suggests an interplay with detached Alleghenian deformation along the margin of the pre-existing basement derived faults. It further suggests that the permeability in the detachment horizon, the porous fracture facies, is not a blanket permeability for this part of West Virginia. If it were, then production would be found on the crest of structures. The interplay of basement and detached deformation has been suggested for this area based on other geologic data in an independent study (Shumaker, 1979).

Conclusions

There are a multitude of ways to develop fractures, and thereby potential fracture permeability; to mention a few: basement deformation, detached deformation, compaction, sedimentary diagenesis, overburden removal, etc. Based on analyses of producing shale gas fields in the Appalachian basin, it is concluded that basement growth faulting is the most effective means of producing commercially effective porosity within West Virginia. The importance of this understanding and the application of these exploration guidelines to southwestern West Virginia are heightened by a substantiating observation made by Don Neal (1979) concerning the coincidence of higher initial open flows from shale gas wells located on the flanks of geologic structures from the adjacent area of southern West Virginia. We are presently extending our structural analysis into eastern Kentucky, and preliminary results suggest that linear highly productive trends within a more blanket-like production in eastern Kentucky are related to the interplay of basement faults and detachment deformation. Based on analysis of shale cores it is further concluded that the organic portions of the Devonian shale contain a porous fracture facies that forms the major reservoir horizon for shale gas production. Commercial production in the Appalachian basin coincides with a zone of limited tectonic transport at the terminus of more extensive movement found to the east. This commercial zone is characterized by inclined slickensided fractures and mineralized and open vertical joints. Marked asymmetry of production along the flanks of producing structures suggest that the interplay of horizontal transport at the margin of basement-derived faults is the area for maximum development of open fractures in the organic shales.

It is not suggested that the rationale developed thru analysis of the Appalachian basin is a unique solution for the location of fracture porosity in organic shales found in all foreland basins. However, it is

a model that may have application to other geologically similar areas, and it therefore should be tested in those areas.

The application of the rationale to the interior basins of the continental United States which lack detached horizontal transport is open to question. It would appear, based on the results of this study, that the flanks of basement structures, particularly at intersecting basement fault trends, appear most prospective. However, if the shale acts as a seal in such areas, it also seems reasonable to presume that faults of small throw and/or monoclinial flexures are the most prospective structural features. If such flanking structural positions do hold higher potential, it is essential that well completion fracture treatments of limited size be designed to preserve that seal to limit entry of formation water from adjacent units. Chemically foreign water placed in the shale generally will severely damage the reservoir and invalidate any commercial success.

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APPENDIX BSURFACE STRUCTURE STUDIES

1979 - 1980

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TECHNIQUES AND TESTS
FOR MEASURING JOINT INTENSITY

by

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December 1979

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ABSTRACT

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.

INTRODUCTION

The Middle and Upper Devonian clastic rocks referred to as the Devonian shales in the Appalachian Basin have been known and used as a source for gas since the early 1900's. Decreases in national energy resources have increased the economic attractiveness of the Devonian shales and in unconventional methods needed to explore for and recover their gas.

Anomalous intense fracturing has been cited as a reason for hydrocarbon production from reservoirs in the Devonian shales of the Appalachian Basin as well as in other areas. (Hereafter, fracture will be used to mean natural fractures that are not faults; most such fractures are systematic or nonsystematic joints.) Increased water-well yields, coal mine roof falls, and some construction problems also are associated with an increase in fracture intensity; a causal relationship is commonly assumed or demonstrated. Accordingly, a method to measure fracture intensity and locate or predict locations of areas in intense fracturing or jointing would be generally useful. In particular, it would be useful in exploration areas where little or no subsurface data are available. As part of the Eastern Gas Shales Project, funded by the U.S. Department of Energy, such a method was developed (Wheeler, 1978a; 1979a; Dixon, 1979a; 1979b; Wheeler and others, 1979; Wheeler and Dixon, in preparation). This

paper reports the development and some field tests and applications of this method. The purpose is to characterize exposed systems of natural fractures considered to be analogues of buried fractured gas reservoirs (Wheeler, 1978a; 1978b) in order to assist in exploration for gas in the Devonian shales.

Four test areas were chosen for this study. Three of the test areas straddle one or more large structural lineaments of the type that Wheeler and others (1979) described and named cross-strike structural discontinuities, or CSD's. Hereafter, lineament is defined as one of those CSD's unless otherwise stated. Note that CSD's are not always associated with photolineaments seen on satellite or aircraft images, and usually are larger, more diffused, and more complex structurally than are photolineaments (Table 1 of Wheeler and others, 1979). First, the Parsons structural lineament in the eastern Plateau province, Tucker County, West Virginia (Figures 1 and 2), was chosen to develop and test field and analytical methods for measuring joint intensity. Second, the Petersburg structural lineament and adjacent terranes, along the Allegheny Front in Grant and Pendleton Counties, West Virginia (Figures 1 and 2), were studied to determine how the fracturing effects of a lineament varies with depth below ground level and with different lithologies. The

FIGURE 1

TECTONIC FEATURES OF NORTH CENTRAL WEST VIRGINIA

FIGURE 2. Structural axes west of the dashed line are for the most part based on subsurface information (modified from Cardwell and others, 1968).

third study, in the Plateau province in Taylor, Barbour, and bordering counties (Figures 1 and 2), was to determine the westward extent of the Parsons and Petersburg lineaments. Finally, the purpose of the fourth study, in northeastern Monongalia County, West Virginia (Figure 1), was to measure the effect of an overlying stream channel on coal cleat intensity.

TEST AREA 1: DEVELOPMENT OF METHODS AND PARSONS LINEAMENT, TUCKER COUNTY

SETTING

The Parsons structural lineament in the Plateau province in eastern West Virginia (Figure 1) was chosen to develop and test a method of measuring joint intensity, because previous studies (Wheeler and others, 1979; Wheeler and Holland, 1978a; 1978b) indicate that rocks exposed in the lineament are more intensely jointed than are rocks of the same unit and in the same structural positions exposed outside the lineament. The lineament is a northwest-trending alignment of disruptions in the regular northeast-trending folds and reverse faults characteristic of the eastern Plateau and Valley and Ridge provinces (Figure 2; Gwinn, 1964; Cardwell and others, 1968). The lineament is at least 30 miles long and six to seven miles wide, according to interpretations of terrain-corrected gravity, structural, topographic and LANDSAT data (Wheeler and others, 1979). This study deals with systematic joints in interbedded siltstones, mudstones, and shales of the Middle and Upper Devonian Chemung Group in Tucker County. Only the Chemung (mainly siltstones) was studied in order to reduce the effects of different lithologies. Bed thicknesses range from 0.2 to 200 cm (0.08 to 79 in), and typically are 10 to 30 cm (4.0 to 12.0 in). In western Tucker County, the Parsons

lineament crosses the outcrop belt of the Chemung rocks exposed in the cores of the northeast-trending Deer Park, Etam, and Elkins Valley anticlines (Figure 3; Cardwell and others, 1968; Gwinn, 1964).

METHODS

A total of 1594 systematic joints were measured at 143 stations (Figure 3). Wherever feasible strike, dip, and the following four other variables were measured on each joint: (1) exposed depth, the total exposed extent of a joint in the direction perpendicular to bedding; (2) exposed length, the total exposed length in a direction parallel to bedding (a joint's true depth and true length are rarely exposed in a measurable fashion); (3) spacing, the perpendicular distance to the adjacent joint in the same set (Stubbs and Wheeler, 1975; Wheeler and Stubbs, 1979); (4) bed thickness, the thickest bed through which the joint penetrates. Exposure size, regularity or irregularity of spacing, and the number of joint sets exposed determined the number of measurements taken per station. Every attempt was made to measure a representative sample of joints. Fifty-four percent of the joints were measured in roadcuts; the rest in streamcuts and stream pavements.

Joint intensity is defined as joint surface area per unit volume of rock. It is estimated or measured by cal-

FIGURE 3. Index map showing the extent of the Chemung outcrop belt and station locations in Test Area 1.

culating inverses of average spacings of individual joint sets, summed over all sets in an exposure (Vialon and others, 1976; Dixon, 1979a; 1979b; Wheeler, 1979a; Wheeler and Dixon, in preparation). The measure of intensity incorporates the effects of true joint size, exposed joint size, and joint abundance (Wheeler and Dixon, in preparation). If, for example, four joint sets were exposed in an outcrop, then the following formula would be used to estimate intensity (I) from average spacings ($\bar{S}$):

$$I = 1/\bar{S}_1 + 1/\bar{S}_2 + 1/\bar{S}_3 + 1/\bar{S}_4.$$

Regardless of the number of joints measured or the number of sets in an exposure, only one intensity (I) measurement is calculated for that exposure. Statistical analyses and contour maps of joint intensity, joint spacing, and bed thickness were produced with local modifications of the Statistical Analysis System, an orientation plotting program (E. Werner, written and oral communications, 1978 and 1979), and the SYMAP contouring and mapping program.

Reproducibility of data (operator variance) is important in measuring joint intensity. To test this, four operators, with experience in measuring joint orientation but with extensive to no experience in measuring joint intensity, measured strike, dip, and spacing at three stations in the Chemung Group. No instructions or assis-

tance beyond those included in this paper were given. The operators worked independently, often taking measurements at different places on the exposure and at different times. The exposures varied in size, type, and structural complexity. Although the number of joints measured varied greatly among operators (Table 1), the intensities did not differ significantly (alpha level of 0.05, by the Least-Squares Means and the Kruskal-Wallis tests (Davis, 1973; Gibbons, 1976)). Thus intensity measurements obtained in this and other studies can be considered reproducible, probably objective, and therefore valid. One should note that even if significant variations were to occur between two operators, real differences in relative intensities between exposures can be detected by a single operator as long as he or she is consistent from exposure to exposure. Operator consistency ensures valid relative intensities. Consistency between operators is necessary if comparisons of data are made between operators.

RESULTS

A circular histogram of all measured joints shows three sets: N 35-55°W (transverse to folds), N 25-45°E (longitudinal to folds), and N 80°E - N 80°W (diagonal to folds), with the northwest set dominating (Figure 4d). All three sets appear north, within, and south of the lineament, but in different relative abundances (Figures

TABLE 1. OPERATOR VARIANCE

Operator	Station 33		Station 87		Station 35	
	I	n	I	N	I	n
1	0.24	12	0.21	12	0.09	19
2	0.08	32	0.19	31	0.20	40
3	0.22	25	0.04	17	0.19	42
4	0.10	11	0.15	16	0.14	16

Table 1. Intensities (I) and number of observations (n) measured at data stations in Tucker County.

FIGURE 4. Circular histograms of joints taken (a) north, (b) within, (c) south of the Parsons lineament and (d) a composite of all measured joints.

4a, b, and c). In addition, a N 05-10°W set appears south of the lineament (Figure 4c). A comparison of the orientations of joints taken at roadcuts and in streams shows that the three main sets are exposed with the same relative abundances in both exposure types (Figures 5a and b). The scatter in orientations is reduced slightly in the stream joints, perhaps because many stream joints were measured on pavements where the greater map exposures of the joints would allow better estimations of orientations.

A SYMAP map (computer-generated contour map) of joint intensity shows more intense jointing within the Parsons lineament than outside (Figure 6). SYMAP maps of mean spacings of the three main joint sets were made to determine what, if any, relationship exists between the Parsons lineament and the spacings of the joint sets. The northeast-striking set appears to be most directly related to the lineament by having small spacings (high intensities) most closely associated with the lineament (Figure 7). The northwest-striking set appears to be only slightly related to the lineament (Figure 8), and the east-striking set appears little, if at all, related (Figure 9). The mean spacings of each set support that statement (Table 2). A comparison of mean spacings of all joints indicates a slight increase in joint spacing (a decrease in intensity) south of the lineament as op-

(a) ROAD CUT JOINTS

(b) STREAM JOINTS

FIGURE 5. Circular histograms of joints measured (a) along roadcuts, and (b) along streamcuts and stream pavements.

FIGURE 6. Contour map showing joint intensity, plotted at each station. Northwest-trending lines indicate the boundary of the Parsons lineament, drawn on this map by 5 geologists independently. The 5 choices of the boundaries differed by less than one mile.

FIGURE 7. Contour map of the mean spacing, plotted at each station, of the northeast-striking joint set. Parsons lineament is bounded by the solid lines taken from Figure 6.

FIGURE 8. Contour map of the mean spacing, plotted at each station, of the northwest-striking joint set. Parsons lineament is bounded by the solid lines taken from Figure 6.

FIGURE 9. Contour map of the mean spacing, plotted at each station, of the east-striking joint set. Parsons lineament is bounded by the solid lines taken from Figure 6.

TABLE 2. MEAN SPACINGS OF JOINT SETS IN TUCKER COUNTY

Location	Joint Set											
	Northeast			Northwest			East-West			All		
	n	$\bar{s}$	σ_s	n	$\bar{s}$	σ_s	n	$\bar{s}$	σ_s	n	$\bar{s}$	σ_s
North	50	31	30	232	22	20	136	22	14	587	25	22
Within	79	17	16	270	19	19	172	25	24	711	21	20
South	15	28	13	18	30	27	36	42	40	164	28	22

Table 2. Mean spacing in cm ($\bar{s}$), number of observations (n), and Standard deviations in cm (σ_s) of each joint set north, within, and south of the Parsons lineament.

posed to north of the lineament.

A SYMAP map of average bed thickness shows a northeast trending band of thin beds, reflecting the thinner beds of the lower Chemung rocks exposed along the crests of the Deer Park and Elkins Valley anticlines (Figure 10). Many of the higher-intensity exposures occur in thinner beds (Figures 6 and 10). However, the strongest trends found in the spacing and intensity maps are generally elongated to the northwest and north, whereas that of the bed thickness map is northeast. Thus, I conclude that a factor other than bed thickness also controls joint intensity. (Statistical analysis shows only a minor correlation between bed thickness and joint spacing). That factor apparently is the Parsons lineament.

Large, northeast-trending anticlines plunge into the Parsons lineament (Figures 2 and 3; Cardwell and others, 1968), which may have increased the intensity of the transverse (northwest-striking) joint set on the anticlinal noses. Smaller, northeast-trending anticlines with wavelengths on the order of half a kilometer are more numerous in the lineament than outside it (Trumbo, 1976), and may increase the intensity of the longitudinal (northeast-striking) set there. The diagonal (east-striking) joint set bears no clear relationship to folds or faults associated with the lineament, but it also shows no clear increase in intensity inside the lineament (Fig-

FIGURE 10. Contour map of the mean bed thickness, plotted at each station. Parsons lineament is bounded by the solid lines taken from Figure 6.

ure 8 and Table 2). However, the southward increase in relative abundance of the east-striking set (Figure 4) may be caused by the more northerly strike of the Elkins Valley and Etam anticlines (Figure 3). The east-striking set would then be transverse to those folds.

Statistical analysis of exposed lengths and exposed depths of measured joints shows no relationship to the Parsons lineament (Table 3 and 4). These measurements are greatly affected by exposure type and size. Stream pavements yield longer joint measurements while road and stream cuts yield deeper measurements. Further, as Wheeler and Dixon (in preparation) demonstrate, the effect of joint size is incorporated in the measurement of intensity. Therefore, depth and length need not be measured in a joint intensity study and will not be further discussed in this paper.

Individual sets may show close spacings at stations outside the lineament as seen in Figures 7, 8, and 9. This may be caused by exposure type, exposure orientation, position relative to a structure, or other factors. However, it is only the intensity measurement which quantifies the total effect of all joints in an exposure and gives the best measurement of how fractured the rock is in the exposure. In intensity investigations generally, the mean spacings of individual joint sets should be used only as an aid to identifying possible causes of intense

TABLE 3. MEAN EXPOSED LENGTH OF JOINT SETS IN TUCKER COUNTY

Location	Joint Set								
	Northeast			Northwest			East-West		
	n	$\bar{l}$	σ_s	n	$\bar{l}$	σ_s	n	$\bar{l}$	σ_s
North	46	84	106	246	52	47	139	62	75
Within	73	36	55	293	61	76	170	67	130
South	16	88	115	21	75	65	38	151	112

Table 3. Mean exposed length in cm ($\bar{l}$), number of observations (n), and standard deviations in cm (σ_s) of each joint set north, within, and south of the Parsons lineament.

TABLE 4. MEAN EXPOSED DEPTH OF JOINT SETS IN TUCKER COUNTY

Location	Joint Set								
	Northeast			Northwest			East-West		
	n	$\bar{d}$	σ_s	n	$\bar{d}$	σ_s	n	$\bar{d}$	σ_s
North	46	24	25	245	24	29	139	34	47
Within	74	16	26	292	26	30	172	24	32
South	16	8	3	21	14	15	24	26	26

Table 4. Mean exposed depth in cm ($\bar{d}$), number of observations (n), and standard deviations in cm (σ_s) of each joint set north, within, and south of the Parsons lineament.

jointing and not as an overall intensity indicator.

Analyses of high-altitude aircraft and LANDSAT infrared images (Trumbo, 1976) show lineaments with preferred orientations similar to those of the three main joint sets and to the trend of the Parsons lineament (Trumbo, 1976, Figure 17-22). Map densities of these lineaments visible on LANDSAT images appear to be an aid in identifying or locating the Parsons lineament, but do not specifically define the boundaries or zones of highest joint intensity. Three large LANDSAT lineaments are sub-parallel to the structural lineament (Figure 11).

FIGURE 11. Parsons and Petersburg lineaments and related LANDSAT lineaments as identified by Dixon, Trumbo (1976), and Sites (1978).

TEST AREA 2: ALLEGHENY FRONT AND PETERSBURG LINEAMENT SETTING

The intersection of the Petersburg lineament with the Allegheny Front in Grant and Pendleton Counties, West Virginia (Figure 1), was studied to determine how the fracturing effects of a lineament vary with depth below ground level and with different lithologies. The Front is the western limb of the Wills Mountain anticline and there Pennsylvanian through Devonian rocks are exposed. The average strike and dip of measured beds are N 25-30°E, 20-30°NW. Sites (1978) found that east of the Front in the Valley and Ridge province, the lineament is an almost east-west band from 3 to 5 miles wide, characterized by plunging folds and disrupted bed orientations. Sites did not measure intensity or joint spacing. LaCaze (1978) examined the Pennsylvanian Homewood Sandstone rocks on top of the Allegheny Front and found the Petersburg lineament there to be characterized by plunging folds and disrupted bed orientations and by a decrease in joint spacing (i.e. an increase in joint intensity). The great vertical exposure of rock down the Front affords an excellent opportunity to measure any change in the lineament's effect with depth and on different lithologies. Any variation found down the Front could be partly caused by elevation change, partly by stratigraphic change and/or partly by structural level, but I assume at least some com-

ponent of the latter.

METHODS

A total of 498 joints were measured at 29 stations (Figure 12) in the Middle Devonian black shales, the Middle and Upper Devonian Chemung and Catskill interbedded sandstones, siltstones, and shales, and the Lower Mississippian Pocono sandstone and conglomerate. Joint strike, dip, and spacing were measured. At least one station was measured in each unit north, within, and south of the Petersburg lineament. Statistical analyses and circular histograms were produced as described above for Test Area 1.

RESULTS

A circular histogram of all measured joints shows one dominant set centered at N 80-85°W, and lesser sets (in decreasing order of prominence) centered at N 45-50°W, N 10-20°E, and N 35°E; a minor set is centered at N 50°E (Figure 13d). The N 50°E set is not found south of the lineament (Figures 13a, b, and c). Otherwise, joint orientations north, within, and south of the Petersburg lineament are similar.

Joint intensities were calculated and plotted by unit (Figure 14). In order to eliminate the effects of the different units and lithologies so that all intensity measurements could be compared, the aligned ranks were

FIGURE 12. Index map of station locations along the Allegheny Front (modified from Reger and Tucker, 1924; Tilton and others, 1927). Mgr - Mississippian Greenbrier, Mmc - Mauch Chunk; Ppv - Pennsylvanian Pottsville.

FIGURE 13. Circular histograms of joints taken (a) north, (b) within, (c) south of Petersburg lineament and (d) a composite of all joints measured.

FIGURE 14. Joint intensities measured along the Allegheny Front. Dashed lines indicate the boundary of the Petersburg lineament.

used (Lehmann, 1975). Aligned rank intensities were calculated by subtracting the intensity value of a station from the mean intensity of that rock unit. This centers all intensity values around zero. Joint intensities inside the lineament were found to be significantly higher (alpha level of 0.05) than outside as calculated by the Kruskal-Wallis test (Gibbons, 1976). The mean intensity is slightly less south of the lineament than it is north of it. A comparison of mean spacings of the four main sets shows that all four sets are closer spaced inside the lineament (Table 5). Thus all sets are contributing to the increase in intensity.

At the Allegheny Front in Grant and Pendleton Counties, the section from the Devonian Oriskany Sandstone to the top of the Mississippian Pocono Formation is approximately 7400 feet thick (Reger and Tucker, 1924; Dennison, 1963). From the top of the Pocono to the top of the Pennsylvanian Homewood Sandstone, the section is another 850 to 1800 feet thick, yielding a total of 8250 to 9400 feet of section (Reger and Tucker, 1924). The total elevation difference is about one half mile. Because all sampled rocks from the top of the Oriskany to the top of the Pocono, and the Homewood, are more intensely fractured inside the lineament, it is reasonable to assume that the rocks between the Pocono and the Homewood are also more intensely fractured inside the lineament. Even though

TABLE 5. MEAN SPACINGS OF JOINT SETS ALONG ALLEGHENY FRONT

Location	Joint Set											
	East-West			Northwest			N 15°E			N 35°E		
	n	$\bar{s}$	σ_s	n	$\bar{s}$	σ_s	n	$\bar{s}$	σ_s	n	$\bar{s}$	σ_s
North	49	121	102	37	116	80	21	157	103	15	108	59
Within	68	59	52	15	81	28	38	49	26	45	56	23
South	12	81	36	23	134	80	13	117	44	2	238	88

Table 5.. Mean spacing in cm ($\bar{s}$), number of observations (n), and standard deviations in cm (σ_s) of each joint set north, within, and south of the Petersburg lineament.

only exposed rocks have been measured for joint intensity, it is unlikely that, in a structural lineament which affects folding, faulting, bed disruptions, and jointing of strata, fracturing in the Petersburg lineament is only a superficial phenomenon. It seems reasonable to assume that the increased fracturing of rock within the lineament extends at least one half mile deep from the top of the Front down to the Oriskany Sandstone. Whether or not the lineament affects the entire 8250 to 9400 vertical section to the west is not known at this time.

The boundaries of the Petersburg lineament were determined from joint intensity measurements taken in this study and are in general agreement with the boundaries assigned by Sites (1978) and LaCaze (1978) as discussed earlier. LaCaze also found a general decrease in joint intensity to the south. The most intensely fractured exposures found in each unit both in this study and in that by LaCaze form a crude east-west alignment and may represent an axis of fracture deformation in the lineament.

A LANDSAT lineament can be easily seen extending sub-parallel to the Petersburg lineament from Petersburg westward through Elkins (Figure 11; Sites, 1978). This lineament appears to aid in locating the Petersburg structural lineament, but it does not specifically locate the area of intense fracturing.

TEST AREA 3: WESTWARD EXTENSIONS OF THE PARSONS AND PETERSBURG LINEAMENTS

SETTING

The westward extensions of the Parsons and Petersburg lineaments would be useful in locating areas of intense jointing in the central Plateau province where the gas producing Devonian rocks are buried. The low-dipping, massive sandstones and conglomerates of the Lower and Middle Pennsylvanian Pottsville Group and Allegheny Formation were chosen for this study (Figure 1) because their outcrop belt extends across both lineaments and provides good exposures. The overlying Upper Pennsylvanian Conemaugh Group is poorly exposed. No previous related studies in this area have been found.

METHODS

Three hundred and eighty-two joints in 69 exposures, in a band approximately 47 miles long and 14 miles wide, were measured for strike, dip, and spacing (Figure 15). Unlike test areas 1 and 2, for which a representative sample of joints was measured at each exposure, nearly all of the few joints found in this test area were measured.

The data stations were grouped into sub-areas according to their positions relative to the lineaments. In Figure 15, "O" sub-areas are outside the lineaments and "I" sub-areas are inside the lineaments. Circular histo-

FIGURE 15. Index map of data stations taken in the Westward Extensions area.

grams of joints in each sub-area were plotted (Figure 16). Joint intensities were analyzed statistically. Boundaries of the lineaments were determined initially by extending the boundaries from test areas 1 and 2 westward, and refined finally by results of the joint intensity measurements.

RESULTS

A comparison of joint intensities measured across a north-south traverse in the study area shows a marked increase in intensity within both the Parsons and Petersburg lineaments (Figure 17). Intensities of sub-areas west of the lineaments (0-2, 0-3, and 0-8 in Figure 15) are low, and suggest that the high intensity joint systems of the lineaments are either disrupted or terminated in eastern Upshur and Marion Counties.

Intensity measurements of the 69 exposures fall into two distinct groups. Data stations with intensities greater than 0.005 cm^{-1} are located within the lineaments and those with intensities equal to or less than 0.005 cm^{-1} are located outside the lineaments. Only two intensity measurements greater than 0.005 cm^{-1} are found outside the lineaments (both are 0.006 cm^{-1}), and only two intensity measurements less than 0.005 cm^{-1} are found inside the lineaments (they are 0.004 cm^{-1} and 0.003 cm^{-1}). A statistical comparison by Least-Squares Means (alpha level

FIGURE 16. Circular histograms of joints taken outside (O) and inside (I) the Parsons and Petersburg lineaments, Test Area 3.

Joint Intensity of Westward Extensions of the Parsons and Petersburg Lineaments

J.M. Dixon

FIGURE 17. Dots represent intensity values for 52 of the 69 data stations of Figure 15 that fall roughly on a north-south traverse.

of 0.05) shows that the intensities inside both parts of the Parsons lineament, which appears to be split into two narrow bands (also suggested in Test Area 1, Figure 6), are similar to the intensities inside the Petersburg lineament, even though the lineaments are separated by over 20 miles (Figures 15 and 17). The comparison shows the sub-areas outside the lineaments to be similar to each other. However, an over-all southward increase in spacing (and decrease in intensity) can be easily seen when comparing mean spacings in each sub-area (Table 6). The small sample sizes in sub-areas 0-7 and 0-8 occur because with such wide spacings, only a small number of joints are exposed. This southward decrease in intensity and increase in spacing is consistent with the southward changes recorded by this investigator in the Parsons lineament in Tucker County (Table 2), in the Petersburg lineament along the Allegheny Front (Figure 14), and by LaCaze (1978) in the Petersburg lineament on top of the Front.

A comparison of circular histograms of measured joints does not show a particularly simple pattern across all of test areas 1, 2, and 3, but rather a changing pattern more consistent with the orientations of the lineaments (Figure 18). North of the Parsons lineament in both Tucker and Taylor Counties (Figure 18), the dominant northwest-striking joint set parallels the trend of the lineament. Both histograms are fairly simple. Inside

TABLE 6. MEAN SPACING OF MEASURED JOINTS IN THE WESTWARD EXTENSIONS AREA

Location	n	$\bar{s}$	σ_s	Location	n	$\bar{s}$	σ_s
O-1	40	503	243	I-1	52	278	180
O-2	8	404	182	I-2	56	286	197
O-3	42	455	262	I-3	40	372	294
O-4	36	535	377				
O-5	43	657	433				
O-6	27	840	573				
O-7	8	946	427				
O-8	9	709	134				

Table 6. Mean spacing in cm ($\bar{s}$), number of observations (n), and standard deviations in cm (σ_s) of joints measured in the Westward Extensions area. For sub-area locations, see Figure 14.

Figure 18.

the lineament, the northwest set is prominent and the east-west set is enhanced. In the wedge between the Parsons and Petersburg lineaments, the joint pattern becomes more complex and the northwest-striking joint set loses its dominance. The southern edge of the Parsons lineament exhibits a transitional pattern. Inside the Petersburg lineament, the east-west joint set dominates the pattern. Finally, south of the Petersburg lineament, the joint pattern becomes less complicated. The joint patterns in the sub-areas west of the lineaments also are relatively simple (Figure 18). Thus the two lineaments constitute and divide domains of different joint fabrics.

Sharp correlations between the joint patterns in the lineaments and the trends of the lineaments may be masked by the joint strikes associated with folds. The dominance of the northwest-striking joint set in Tucker County may occur because the northwest (fold transverse) joints are enhanced by joints associated with the similarly trending Parsons lineament. The enhancement of the east-west set in the Parsons lineament may be caused by the more northerly-trending Elkins Valley and Etam anticlines influencing joint trends in that area, or by whatever mechanism or mechanisms forming the lineament. The enhancement of the east-west set in the Petersburg lineament may be caused by the lineament's development.

The complexity of the joint pattern in the wedge

between the Parsons and Petersburg lineaments (Figure 18), the presence of two thrust faults contained within the wedge (Figure 2), and the terminations or bending of folds associated with the lineaments (Figure 2) suggest a possible interaction between the two lineaments. It may be that the lineaments were formed by differential ramping of detached strata, as suggested by Gwinn (1964), Sites (1978), LaCaze (1978), and Wheeler (1978a; 1978b), or that the lineaments were formed as a result of basement structures propagating upward or reactivating during detachment deformation, as suggested by Wheeler (1979b), or by a combination of both. Because many such lineaments do involve basement structures (Wheeler, 1979b), basement involvement in the formation of the Parsons and Petersburg lineaments is a reasonable hypothesis. The northwest trend of the Parsons lineament is compatible with Central Appalachian deformation trends and may be more detachment related, whereas the east-west trend of the Petersburg lineament may suggest a different origin such as basement structure.

Two preliminary studies of gas fields in and around the Parsons and Petersburg lineaments indicate that gas production decreases inside the lineaments (R. Wheeler and D. Skoff, written and oral communication, 1979). However, much of the production information comes from areas where the Devonian shales are on or near the surface. The in-

crease in fracturing may have broken the reservoir's seal and allowed the gas to escape. In areas further west where the shales are deeper, the increased fracturing inside the lineaments may enhance gas recovery where the seal is more likely unbroken. Detailed studies would be needed to determine more precisely the effects of the lineaments on gas production.

TEST AREA 4: COAL CLEAT INTENSITY

SETTING

Measuring differences in coal cleat intensities and features associated with those changes could be of use in coal mining in predicting roof falls, pillar strength, increasing mineral matter, or other such problems. The purpose of this study is to determine if variances in cleat intensities could be detected and to observe the effects of an overlying stream channel on two coal seams.

The north wall of a large east-trending roadcut (the first cut east of Exit 10, U.S. Route 48) in eastern Monongalia County, West Virginia (Figure 1), was chosen for the study because of the exposure of the entire stream channel and because of the great lateral extent of the roadcut. At the base of the outcrop are layers of interbedded siltstones and shales with two layers of Upper Freeport coal (T. Jake, oral communication, 1978) which vary in thickness from 35 to 70 cm (14 to 28 in). Overlying this is a channel sequence with a thin, argillaceous coal at the base and channel and pointbar sands on top (Figure 19).

METHODS

Face and butt cleats were measured for orientation and spacing in the two coal seams. Stations are located in the seams directly above the values plotted on the

STREAM CHANNEL vs COAL CLEAT INTENSITY

J.M. DIXON

FIGURE 19. Cross-section of roadcut in Test Area 4 and graph of mean spacings and coal cleat intensities.

graph (Figure 19). Both primary cleats (wide but equally spaced cleats which penetrate much or all of the seam) and secondary cleats (closely but often irregularly spaced cleats which penetrate only a few layers of the seam) (Ting, 1977) were measured. At each station, ten spacings of primary face and butt cleats were measured and the number of secondary cleats per 10 centimeters were recorded. Although some differences in cleat intensities were detected in the secondary cleats, their great variability within a short distance reduces their reliability. Orientations of joints in clastic rocks and of cleats were plotted on circular histograms (Figure 20).

RESULTS

Three sets of cleats were found: N 70-80°W (face), N 05-25°E (butt), and N 50-55°W (diagonal) (Figure 20a). These sets resemble the three bedrock joint sets found: N 65-90°W, N 25-40°E, and N 45-50°W (Figure 20b). The face cleats, which formed transverse to the Chestnut Ridge anticline, and the diagonal cleats are straight, regularly spaced, and smooth suggesting a tectonic origin. The butt cleats are crenulated, irregularly spaced, and rough suggesting a non-tectonic origin such as dehydration or devolatilization (Ting, 1977).

A graph of mean spacings of primary face and butt cleats and of primary cleat intensity (Figure 19) shows

(a) COAL CLEATS

(b) ROCK JOINTS

FIGURE 20. Circular histograms of (a) coal cleats and (b) bedrock joints in Test Area 4.

that the coals tend to be 1.5 to 3.0 times more intensely fractured under the channel than outside. Whether or not this difference in cleat intensity holds true in all stream channels is secondary to the fact that variations in cleat intensity can be quantitatively measured. This could be of value in the mining industry.

SUMMARY AND CONCLUSIONS

1. Joint spacing was found to be the only necessary measurement, other than strike and dip, to determine joint intensity.
2. No significant difference in operator variance was detected when measuring joint intensity. This not only adds credence to the validity of measurements, but it indicates that comparisons between different studies and different investigators can be made.
3. The Middle and Upper Devonian Chemung rocks in the Parsons lineament are more intensely jointed than the same rocks outside. The northeast-striking joint set contributes most, the dominant northwest set slightly, and the east-west set least, to that increased intensity.
4. Rocks in the Petersburg lineament are more intensely jointed than rocks outside. The four main joint sets, centered at N 80-85°W, N 45-50°W, N 10-20°E, and N 35°E all contribute to the increase in intensity.
5. On the Allegheny Front, the four units studied, the Middle Devonian black shales, the Middle and Upper Devonian Chemung Group and the Catskill Formation, and the Mississippian Pocono Formation, all reflect the increase in joint intensity inside the Petersburg lineament. These increases, along with the increase in intensity in the Pennsylvanian Homewood Sandstone,

suggest that the Petersburg lineament affects rock at least one half mile below ground level.

6. Joint intensities measured in the Pennsylvanian Pottsville Group and Allegheny Formation indicate that the high-intensity joint system of the Parsons lineament extends into and is disrupted or terminated in Taylor County, West Virginia. The high-intensity joint system of the Petersburg lineament extends to the Upshur-Randolph County line where it is disrupted or terminated.
7. Circular histograms of measured joints suggest that joint orientations reflect the orientations of the Parsons and Petersburg lineaments.
8. 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.
9. The joint patterns, associated thrust faults and fold terminations and bends, and other lineaments' associations with basement structures, suggest that the Parsons and Petersburg lineaments may be associated with basement structure.
10. Variations in coal cleat intensities can be detected. This study reveals greater intensities under a stream channel than outside. The detection and quantification of these changes could be useful in the mining

industry as an aid in predicting roof falls, pillar strength, and other such problems.

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APPENDIX A

STATION LOCATIONS IN TUCKER COUNTY
(in UTM Grid Coordinates)Key to Abbreviations:

STA - station number

<u>STA</u>	<u>LATITUDE</u>	<u>LONGITUDE</u>	<u>STA</u>	<u>LATITUDE</u>	<u>LONGITUDE</u>
001	4328.280	615.120	050	4333.900	617.470
002	4329.710	613.710	051	4333.790	618.170
003	4330.340	614.080	052	4334.940	614.420
004	4330.800	610.530	054	4333.600	613.450
005	4329.340	612.220	055	4338.430	623.520
006	4325.480	613.100	056	4338.780	622.980
007	4325.200	612.500	057	4338.280	620.510
008	4325.870	611.720	058	4339.400	620.080
009	4327.030	611.250	059	4340.170	619.370
010	4326.430	611.070	060	4341.340	618.560
011	4326.920	610.600	061	4341.940	617.730
012	4323.350	611.100	062	4339.500	622.920
013	4323.170	610.800	063	4339.920	623.300
014	4322.600	610.180	064	4340.420	623.310
015	4329.560	611.700	065	4343.180	623.170
016	4330.600	606.530	066	4342.680	624.210
017	4328.020	603.700	067	4341.220	623.180
018	4325.610	602.990	068	4341.650	624.310
019	4324.870	602.920	069	4337.770	621.360
020	4323.480	602.570	070	4337.480	620.910
021	4319.750	602.580	071	4335.990	619.440
022	4319.980	611.050	072	4337.620	614.910
023	4320.060	611.070	073	4339.380	616.180
024	4322.170	609.520	074	4336.200	611.610
025	4322.020	608.870	075	4336.270	612.530
026	4327.130	610.470	076	4336.540	613.300
027	4327.270	610.340	077	4337.210	613.890
028	4327.500	609.300	078	4333.230	616.750
029	4327.920	608.600	079	4333.020	616.460
030	4327.800	607.570	080	4332.420	615.920
031	4333.670	611.010	082	4326.500	616.700
032	4333.480	611.250	083	4332.900	612.910
033	4332.480	611.380	084	4334.700	612.430
035	4331.160	609.720	085	4335.520	611.590
036	4326.640	610.970	086	4335.390	610.920
037	4325.270	612.380	087	4334.810	610.980
038	4325.210	612.490	088	4333.730	609.500
040	4324.700	612.700	089	4330.370	609.760
041	4324.800	612.880	090	4329.880	609.590
042	4324.880	613.080	091	4330.320	608.650
043	4325.060	613.230	092	4329.730	608.640
044	4325.120	613.300	093	4329.950	606.990
045	4325.180	613.350	094	4329.450	606.720
046	4325.250	613.420	095	4331.600	605.670
047	4334.540	616.240	096	4332.160	605.300
048	4334.000	616.680	097	4332.870	604.300
049	4333.980	616.960	098	4332.960	603.770

<u>STA</u>	<u>LATITUDE</u>	<u>LONGITUDE</u>	<u>STA</u>	<u>LATITUDE</u>	<u>LONGITUDE</u>
099	4335.130	604.140	125	4335.620	620.390
100	4334.770	604.430	126	4335.480	620.620
101	4334.580	605.560	127	4335.230	621.170
102	4327.190	613.480	128	4335.380	613.380
103	4327.880	612.700	129	4335.680	615.170
104	4328.090	612.320	130	4335.770	614.900
105	4328.470	611.660	131	4335.920	614.580
106	4328.170	612.150	132	4336.110	614.550
107	4327.110	612.150	133	4336.510	615.130
108	4326.600	612.760	134	4337.230	615.220
109	4327.870	610.340	135	4323.160	610.330
110	4328.220	610.350	136	4323.690	609.170
111	4332.660	611.480	137	4323.900	609.100
112	4332.780	612.030	138	4320.770	607.490
113	4333.500	612.080	139	4323.120	608.840
114	4333.540	611.400	140	4322.550	609.540
115	4331.860	612.480	141	4322.370	608.360
116	4338.610	621.520	142	4323.480	607.630
117	4339.480	621.580	143	4322.870	607.460
118	4340.370	621.090	144	4323.010	604.680
119	4338.450	621.620	145	4338.960	617.630
120	4338.150	620.740	146	4338.430	617.360
121	4338.780	620.220	147	4338.110	617.150
123	4337.580	619.920	148	4337.660	616.910
124	4335.950	619.720	149	4337.800	616.690

APPENDIX B

TUCKER COUNTY DATA

Key to Abbreviations:

- STA - station number
- STRI- joint strike
- DIP - joint dip
- LNG - joint length (in cm)
- DTH - joint depth (in cm)
- SPA - joint spacing (in cm)
- BED - bed thickness (in cm)
- EX - type of exposure: R = roadcut, S = stream pavement, SC = streamcut
- ST - indicates into which of three main joint sets the joint falls: NW = north-west, NE = northeast, EW = east-west
- LO - location with respect to the Parsons lineament: IN = within, NO = north, SO = south
- GR - group with respect to the Parsons lineament: IN = within, OT = outside

<u>STA</u>	<u>STRI</u>	<u>DIP</u>	<u>LNG</u>	<u>DTH</u>	<u>SPA</u>	<u>BED</u>	<u>EX</u>	<u>ST</u>	<u>LO</u>	<u>GR</u>
001	N45W	88SW	106	048	060	020	R	NW	IN	IN
001	N46E	90NW	004	022	013	015	R		IN	IN
001	N45W	88SW	148	020	002	015	R	NW	IN	IN
001	N46E	90NW	007	017	044	017	R		IN	IN
001	N46E	90NW	027	029	060	020	R		IN	IN
001	N45W	88SW	084	021	007	021	R	NW	IN	IN
001	N45W	88SW	074	022	002	022	R	NW	IN	IN
001	N45W	88SW	075	039	005	020	R	NW	IN	IN
001	N46E	90NW	007	015	014	015	R		IN	IN
001	N46E	90NW	009	008	014	008	R		IN	IN
001	N46E	90NW	012	008	022	008	R		IN	IN
002	N84W	81SW	013	002	007	002	R	EW	IN	IN
002	N30E	90NW	026	003	003	003	R	NE	IN	IN
002	N84W	81SW	005	002	005	002	R	EW	IN	IN
002	N45W	90SW	010	125		003	R	NW	IN	IN
002	N20E	90NW	110	070	010	004	R		IN	IN
002	N20E	90NW	087	065	003	004	R		IN	IN
002	N78W	90SW	007	005		005	R		IN	IN
002	N60W	90SW	023	010	007	010	R		IN	IN
002	N60W	90SW	063	011	015	011	R		IN	IN
002	N45W	90SW	027	007		007	R	NW	IN	IN
002	N45W	90SW	035	007	002	007	R	NW	IN	IN
002	N80E	80SE	040	012	045	012	R	EW	IN	IN
002	N30E	90NW	024	001	008	001	R	NE	IN	IN
002	N30E	90NW	020	001	005	001	R	NE	IN	IN
002	N30E	90NW	021	001	008	001	R	NE	IN	IN
002	N30E	90NW	018	001	004	001	R	NE	IN	IN
002	N45W	90SW	100	010	016	010	R	NW	IN	IN
002	N70W	90SW	027	005	016	005	R		IN	IN
002	N30E	90NW	016	001	008	001	R	NE	IN	IN
002	N30E	90NW	005	001	006	001	R	NE	IN	IN
002	N84W	81SW	022	003	016	003	R	EW	IN	IN
002	N84W	81SW	036	002	015	002	R	EW	IN	IN
002	N84W	81SW	020	004	010	004	R	EW	IN	IN
002	N84W	81SW	010	004	004	004	R	EW	IN	IN
002	N84W	81SW	023	004	010	004	R	EW	IN	IN
003	N34E	90NW	028	015	033	015	R	NE	IN	IN
003	N34E	90NW	035	015	017	015	R	NE	IN	IN
003	N34E	90NW	055	015	020	015	R	NE	IN	IN
003	N34E	90NW	045	015	008	015	R	NE	IN	IN
003	N34E	90NW	054	015	024	015	R	NE	IN	IN
003	N87E	80NW	153	015	030	015	R	EW	IN	IN
003	N87E	80NW	055	015	020	015	R	EW	IN	IN
003	N87E	80NW	036	015	022	015	R	EW	IN	IN
003	N87E	80NW	070	015	020	015	R	EW	IN	IN
003	N87E	80NW	033	015	016	015	R	EW	IN	IN
003	N87E	80NW	078	015	016	015	R	EW	IN	IN

<u>STA</u>	<u>STRI</u>	<u>DIP</u>	<u>LNG</u>	<u>DTH</u>	<u>SPA</u>	<u>BED</u>	<u>EX</u>	<u>ST</u>	<u>LO</u>	<u>GR</u>
003	N34E	90NW	012	003	007	003	R	NE	IN	IN
003	N34E	90NW	010	003	004	003	R	NE	IN	IN
003	N34E	90NW	007	006	008	006	R	NE	IN	IN
003	N87E	80NW	013	006	011	006	R	EW	IN	IN
003	N60W	85SW	105	044	030	006	R		IN	IN
004	N45W	88NE	135	048	050	010	R	NW	IN	IN
004	N45W	88NE	107	020	020	010	R	NW	IN	IN
004	N45W	88NE	175	015	005	010	R	NW	IN	IN
004	N50E	90NW	001	008	036	008	R		IN	IN
004	N50E	90NW	003	026	035	010	R		IN	IN
004	N50E	90NW	020	010	007	010	R		IN	IN
004	N50E	90NW	025	010	012	010	R		IN	IN
005	N55W	73NE	007	005	011	005	R	NW	IN	IN
005	N40E	15SE	007	007	007	007	R	NE	IN	IN
005	N55W	73NE	015	007	008	007	R	NW	IN	IN
005	N40E	15SE	005	007	003	007	R	NE	IN	IN
005	N40E	15SE	005	005	004	005	R	NE	IN	IN
005	N40E	15SE	001	005	002	005	R	NE	IN	IN
005	N55W	73NE	011	005	005	005	R	NW	IN	IN
005	N55W	73NE	020	006	007	006	R	NW	IN	IN
005	N84E	77SE	022	014	005	014	R	EW	IN	IN
005	N84E	77SE	042	003	005	003	R	EW	IN	IN
005	N84E	77SE	019	008	010	008	R	EW	IN	IN
005	N84E	77SE	024	010	002	010	R	EW	IN	IN
005	N50W	70NE	021	008	011	008	R	NW	IN	IN
005	N50W	70NE	026	015	007	019	R	NW	IN	IN
005	N50W	70NE	045	024	012	024	R	NW	IN	IN
005	N40E	15SE	025	024	033	024	R	NE	IN	IN
005	N40E	15SE	027	030	039	024	R	NE	IN	IN
005	N60W	70NE	032	016	003	010	R		IN	IN
005	N55W	73NE	022	010	008	010	R	NW	IN	IN
005	N40E	15SE	018	020	005	005	R	NE	IN	IN
006	N45W	82NE	007	012	015	012	R	NW	IN	IN
006	N45W	82NE	018	014	020	012	R	NW	IN	IN
006	N45W	82NE	009	020	015	010	R	NW	IN	IN
006	N45W	82NE	009	020	022	010	R	NW	IN	IN
006	N45W	82NE	007	017	012	010	R	NW	IN	IN
006	N45W	82NE	006	021	023	010	R	NW	IN	IN
006	N45W	82NE	035	021	016	011	R	NW	IN	IN
006	N45W	82NE	012	050	009	011	R	NW	IN	IN
006	N45W	82NE	005	020	007	011	R	NW	IN	IN
006	N45W	82NE	050	033	023	033	R	NW	IN	IN
006	N45W	82NE	022	006	010	006	R	NW	IN	IN
006	N45W	82NE	030	006	013	006	R	NW	IN	IN
006	N45W	82NE	031	006	012	006	R	NW	IN	IN
006	N45W	82NE	012	006	011	006	R	NW	IN	IN
006	N40E	56SE	010	006	010	006	R	NE	IN	IN

STA	STRI	DIP	LNG	DTH	SPA	BED	EX	ST	LO	GR
006	N40E	56SE	011	006	023	006	R	NE	IN	IN
006	N40E	56SE	010	010	011	010	R	NE	IN	IN
006	N40E	56SE	033	014	003	014	R	NE	IN	IN
007	N23W	90SW	104	019	023	019	R		IN	IN
007	N23W	90SW	033	019	022	019	R		IN	IN
007	N23W	90SW	016	019	017	019	R		IN	IN
007	N23W	90SW	001	019	010	019	R		IN	IN
007	N23W	90SW	018	019	011	019	R		IN	IN
007	N23W	90SW	012	019	022	019	R		IN	IN
007	N23W	90SW	022	019	017	019	R		IN	IN
007	N69E	90NW	260	090	048	025	R		IN	IN
007	N69E	90NW	250	048	017	017	R		IN	IN
007	N23W	90SW	010	005	012	005	R		IN	IN
007	N23W	90SW	008	005	014	003	R		IN	IN
007	N23W	90SW	001	008	002	003	R		IN	IN
007	N23W	90SW	001	020	005	005	R		IN	IN
007	N69E	90NW	043	021	011	021	R		IN	IN
007	N69E	90SE	001	034	015	034	R		IN	IN
007	N69E	90NW	015	007	040	007	R		IN	IN
007	N69E	90NW	007	007	041	007	R		IN	IN
007	N69E	90NW	002	007	060	007	R		IN	IN
007	N69E	90NW	002	007	065	007	R		IN	IN
007	N69E	90NW	032	010	010	010	R		IN	IN
007	N69E	90NW	010	010	009	010	R		IN	IN
008	N35E	90NW	010	011	010	011	R	NE	IN	IN
008	N75W	90SW	600	070	055	038	R		IN	IN
008	N35E	90NW	011	011	028	011	R	NE	IN	IN
008	N35E	90NW	011	011	015	011	R	NE	IN	IN
008	N35E	90NW	012	011	035	011	R	NE	IN	IN
008	N35E	90NW	009	011	021	011	R	NE	IN	IN
008	N85W	56NE	038	020	048	020	R	EW	IN	IN
008	N85W	56NE	165	011	050	011	R	EW	IN	IN
008	N35E	90NW	015	004	013	004	R	NE	IN	IN
008	N35E	90NW	001	004	013	004	R	NE	IN	IN
008	N35E	90NW	001	004	010	004	R	NE	IN	IN
008	N35E	90NW	017	007	014	007	R	NE	IN	IN
008	N35E	90NW	016	007	007	007	R	NE	IN	IN
008	N35E	90NW	014	015	020	015	R	NE	IN	IN
008	N53W	90SW	500	115		060	R	NW	IN	IN
008	N53W	90SW	500	233		085	R	NW	IN	IN
009	N74E	90NW	060	013	008	013	S		IN	IN
009	N74E	90NW	080	013	034	013	S		IN	IN
009	N74E	90NW	080	013	017	013	S		IN	IN
009	N74E	90NW	065	013	020	013	S		IN	IN
009	N74E	90NW	070	013	010	013	S		IN	IN
009	N74E	90NW	051	013	007	013	S		IN	IN
009	N74E	90NW	040	013	020	013	S		IN	IN

<u>STA</u>	<u>STRI</u>	<u>DIP</u>	<u>LNG</u>	<u>DTH</u>	<u>SPA</u>	<u>BED</u>	<u>EX</u>	<u>ST</u>	<u>LO</u>	<u>GR</u>
009	N74E	90NW	041	013	030	013	S		IN	IN
009	N74E	90NW	007	008	020	008	S		IN	IN
009	N35W	90SW	040	008	030	008	S	NW	IN	IN
009	N35W	90SW	063	013	037	013	S	NW	IN	IN
009	N35W	90SW	042	013	013	013	S	NW	IN	IN
009	N35W	90SW	043	013	021	013	S	NW	IN	IN
009	N35W	90SW	070	013	021	013	S	NW	IN	IN
010	N52W	90SW	105	007	010	007	R	NW	IN	IN
010	N52W	90SW	125	007	002	007	R	NW	IN	IN
010	N52W	90SW	029	007	009	007	R	NW	IN	IN
010	N52W	90SW	040	011	006	011	R	NW	IN	IN
010	N52W	90SW	022	011	010	011	R	NW	IN	IN
010	N52W	90SW	228	070	003	011	R	NW	IN	IN
010	N52E	90NW	001	007	043	007	R		IN	IN
010	N52E	90NW	001	007	011	007	R		IN	IN
010	N52E	90NW	001	007	023	007	R		IN	IN
010	N52E	90NW	010	007	026	007	R		IN	IN
010	N52E	90NW	001	007	043	007	R		IN	IN
010	N52E	90NW	005	007	024	007	R		IN	IN
010	N52E	90NW	009	007	046	007	R		IN	IN
010	N52E	90NW	001	007	038	007	R		IN	IN
010	N52E	90NW	001	007	031	007	R		IN	IN
010	N52E	90NW	001	007	030	007	R		IN	IN
010	N52E	90NW	001	010	021	010	R		IN	IN
010	N52E	90NW	001	010	020	010	R		IN	IN
010	N52E	90NW	001	010	024	010	R		IN	IN
011	N46W	87SW	057	018	030	018	R	NW	IN	IN
011	N46W	87SW	161	030	028	030	R	NW	IN	IN
011	N46W	87SW	022	009	028	009	R	NW	IN	IN
011	N46W	87SW	022	009	018	009	R	NW	IN	IN
011	N46W	87SW	105	030	025	030	R	NW	IN	IN
011	N46W	87SW	098	023	054	023	R	NW	IN	IN
011	N46W	87SW	050	023	020	023	R	NW	IN	IN
012	N48W	90SW	025	105	012	012	R	NW	IN	IN
012	N48W	90SW	020	057	012	012	R	NW	IN	IN
012	N48W	90SW	020	012	030	012	R	NW	IN	IN
012	N48W	90SW	120	130	080	012	R	NW	IN	IN
012	N65E	90NW	075	012	035	012	R		IN	IN
012	N65E	90NW	016	013	014	013	R		IN	IN
012	N21E	86SE	045	037		012	R		IN	IN
012	N46E	73NW	047	024	009	017	R		IN	IN
012	N46E	73NW	088	017	011	017	R		IN	IN
012	N48W	90SW	160	060	018	030	R	NW	IN	IN
012	N48W	90SW	015	028	022	011	R	NW	IN	IN
012	N48W	90SW	002	030		010	R	NW	IN	IN
012	N30E	90NW	057	020	004	008	R	NE	IN	IN
012	N28E	84NW	023	027	030	012	R	NE	IN	IN

STA	STRI	DIP	LNG	DTH	SPA	BED	EX	ST	LO	GR
012	N88W	90SW	030	002	005	002	R	EW	IN	IN
012	N88W	90SW	013	007	010	007	R	EW	IN	IN
012	N88W	90SW	014	007	025	007	R	EW	IN	IN
012	N55E	90NW	180	040		040	R		IN	IN
012	N55W	90SW	079	112		040	R	NW	IN	IN
012	N55W	90SW	150	040		040	R	NW	IN	IN
012	N55W	90SW	200	080	060	040	R	NW	IN	IN
013	N68W	90SW	039	058	023	047	R		IN	IN
013	N86W	90SW	038	038	043	038	R	EW	IN	IN
013	N68W	90SW	001	027	003	027	R		IN	IN
013	N68W	90SW	001	047	046	047	R		IN	IN
013	N68W	90SW	003	055	012	055	R		IN	IN
013	N68W	90SW	001	055	023	055	R		IN	IN
013	N68W	90SW	042	018	043	018	R		IN	IN
013	N68W	90SW	027	018	040	018	R		IN	IN
013	N68W	90SW	010	027	037	018	R		IN	IN
013	N68W	90SW	030	018	020	018	R		IN	IN
013	N68W	90SW	005	018	022	018	R		IN	IN
013	N78W	90SW	023	026	028	007	R		IN	IN
013	N78W	90SW	014	005	020	005	R		IN	IN
013	N78W	90SW	010	005	016	005	R		IN	IN
013	N20W	81SW	052	010		010	R		IN	IN
014	N75W	85NE					R		IN	IN
015	N73W	55NE	096	015	029	003	R		IN	IN
015	N73W	55NE	040	006		003	R		IN	IN
015	N73W	55NE	020	007	012	003	R		IN	IN
015	N73W	55NE	012	007	013	003	R		IN	IN
015	N73W	55NE	020	007	022	003	R		IN	IN
015	N73W	55NE	045	007	011	003	R		IN	IN
015	N73W	55NE	045	010	028	003	R		IN	IN
015	N73W	55NE	045	010	038	003	R		IN	IN
015	N73W	55NE	037	010	040	003	R		IN	IN
015	N73W	55NE	035	010	033	003	R		IN	IN
015	N73W	55NE	029	010	025	003	R		IN	IN
016	N49W	76SW	060	050	074	050	R	NW	IN	IN
016	N46W	75SW	138	120	052	065	R	NW	IN	IN
016	N46W	75SW	092	055	049	055	R	NW	IN	IN
016	N46W	75SW	061	040	037	040	R	NW	IN	IN
016	N46W	74SW	064	065	024	060	R	NW	IN	IN
016	N46W	75SW	034	051	026	051	R	NW	IN	IN
016	N46W	75SW	071	035	033	035	R	NW	IN	IN
016	N46W	75SW	045	022	035	022	R	NW	IN	IN
016	N46W	75SW	070	054	078	054	R	NW	IN	IN
016	N46W	75SW	101	075	116	045	R	NW	IN	IN
016	N46W	75SW	083	052	077	052	R	NW	IN	IN
016	N46W	75SW	105	038	045	038	P	NW	IN	IN
016	N46W	75SW	095	038	029	038	R	NW	IN	IN

STA	STRI	DIP	LNG	DTH	SPA	BED	EX	ST	LO	GR
016	N46W	75SW	010	038	045	045	R	NW	IN	IN
016	N60E	78SE	014	008	021	008	R		IN	IN
016	N60E	72SE	003	008	028	008	R		IN	IN
017	N62E	78SE	006	008	041	008	R		BR	OT
017	N62E	78SE	018	008	057	008	R		BR	OT
017	N62E	78SE	018	012	039	010	R		BR	OT
017	N62E	78SE	001	012	026	010	R		BR	OT
017	N62E	78SE	014	010	046	010	R		BR	OT
017	N62E	78SE	008	010	030	010	R		BR	OT
017	N62E	78SE	014	006	038	003	R		BR	OT
017	N62E	78SE	014	006	035	006	R		BR	OT
017	N62E	78SE	002	006	040	006	R		BR	OT
017	N62E	78SE	001	006	035	006	R		BR	OT
018	N42W	75SW	061	004	055	004	R	NW	BR	OT
018	N42W	75SW	024	004	028	004	R	NW	BR	OT
018	N42W	75SW	034	012	045	012	R	NW	BR	OT
018	N42W	75SW	012	010	030	010	R	NW	BR	OT
018	N13E	90NW	043	004	018	004	R		BR	OT
018	N42W	75SW	020	014	014	004	R	NW	BR	OT
018	N42W	75SW	075	004	024	004	R	NW	BR	OT
018	N42W	75SW	028	008	028	008	R	NW	BR	OT
018	N42W	75SW	102	016	044	016	R	NW	BR	OT
018	N13E	90NW	058	016		016	R		BR	OT
018	N87E	90NW	015	001	007	001	R	EW	BR	OT
018	N87E	90NW	012	001		001	R	EW	BR	OT
018	N25E	90NW	087	005	052	005	R	NE	BR	OT
018	N45W	74SW	065	010	060	010	R	NW	BR	OT
018	N45W	75SW	059	049	040	005	R	NW	BR	OT
018	N45W	74SW	030	005	067	005	R	NW	BR	OT
018	N45W	74SW	050	005	059	005	R	NW	BR	OT
019	N33E	73NW	026	005	012	005	R	NE	BR	OT
019	N33E	73NW	013	005	010	005	R	NE	BR	OT
019	N33E	73NW	014	005	010	005	R	NE	BR	OT
019	N33E	73NW	026	005	013	005	R	NE	BR	OT
019	N33E	73NW	019	005	010	005	R	NE	BR	OT
019	N33E	73NW	015	004	005	004	R	NE	BR	OT
019	N33E	73NW	016	004	007	004	R	NE	BR	OT
019	N33E	73NW	016	004	010	004	R	NE	BR	OT
019	N33E	73NW	012	004	007	004	R	NE	BR	OT
019	N33E	73NW	012	003	008	003	R	NE	BR	OT
019	N33E	73NW	001	003	005	003	R	NE	BR	OT
019	N33E	73NW	015	005	012	005	R	NE	BR	OT
019	N33E	73NW	018	005	005	005	R	NE	BR	OT
019	N50W	88SW	005	004	023	004	R	NW	BR	OT
019	N50W	88SW	007	005	015	005	R	NW	BR	OT
019	N50W	88SW	001	005	015	005	R	NW	BR	OT
019	N50W	88SW	001	006	016	006	R	NW	BR	OT

STA	STRI	DIP	LNG	DTH	SPA	BED	EX	ST	LO	GR
019	N50W	88SW	001	006	014	006	R	NW	BR	OT
019	N50W	88SW	006	002	015	002	R	NW	BR	OT
019	N50W	88SW	007	002	011	002	R	NW	BR	OT
019	N50W	88SW	009	003	010	003	R	NW	BR	OT
019	N50W	88SW	006	003	007	003	R	NW	BR	OT
020	N24E	68SE	048	004	007	004	R		BR	OT
020	N35E	67SE	075	009		009	R	NE	BR	OT
020	N35E	66SE	010	007	003	007	R	NE	BR	OT
020	N49W	75SW	007	023	030	004	R	NW	BR	OT
020	N49W	75SW	017	011	065	004	R	NW	BR	OT
020	N49W	75SW	001	013	048	008	R	NW	BR	OT
020	N49W	75SW	001	013	050	008	R	NW	BR	OT
020	N24E	68SE	183	013	003	008	R		BR	OT
020	N24E	68SE	103	008		008	R		BR	OT
020	N05E	58NW	089	026		015	R		BR	OT
020	N05E	58NW	089	014	008	005	R		BR	OT
020	N05E	58NW	035	019	007	008	R		BR	OT
020	N05E	58NW	053	054	019	008	R		BR	OT
020	N05E	58NW	057	041		005	R		BR	OT
020	N05E	58NW	024	007	005	007	R		BR	OT
021	N37W	85SW	048	024	025	024	R	NW	BR	OT
021	N12E	67NW	066	026	023	026	R		BR	OT
021	N12E	67NW	064	023	004	023	R		BR	OT
021	N12E	67NW	119	023		023	R		BR	OT
021	N12E	67NW	078	023	030	023	R		BR	OT
021	N12E	67NW	045	023	004	023	R		BR	OT
021	N12E	67NW	078	023		023	R		BR	OT
021	N37W	85SW	035	010	024	010	R	NW	BR	OT
021	N37W	85SW	032	012	032	012	R	NW	BR	OT
021	N37W	85SW	006	011	016	001	R	NW	BR	OT
021	N37W	85SW	032	019	031	019	R	NW	BR	OT
021	N37W	85SW	070	023	030	023	R	NW	BR	OT
021	N37W	85SW	037	011	029	011	R	NW	BR	OT
021	N37W	85SW	037	022	026	022	R	NW	BR	OT
021	N37W	85SW	034	022	019	022	R	NW	BR	OT
021	N70W	90SW	007	021	006	021	R		BR	OT
021	N70W	90SW	001	024	004	024	R		BR	OT
021	N70W	90SW	001	024	003	024	R		BR	OT
021	N70W	90SW	001	024	007	024	R		BR	OT
021	N70W	90SW	001	024	008	024	R		BR	OT
021	N70W	90SW	001	024	009	024	R		BR	OT
021	N70W	90SW	001	024	008	024	R		BR	OT
021	N70W	90SW	001	024	026	024	R		BR	OT
022	N57E	78NW	062	039	029	039	R		SO	OT
022	N16E	77SE	040	039	084	039	R		SO	OT
022	N57E	78NW	050	039		039	R		SO	OT
022	N57E	78NW	125	028	025	028	R		SO	OT

<u>STA</u>	<u>STRI</u>	<u>DIP</u>	<u>LNG</u>	<u>DTH</u>	<u>SPA</u>	<u>BED</u>	<u>EX</u>	<u>ST</u>	<u>LO</u>	<u>GR</u>
022	N57E	78NW	012	037	044	037	R		SO	OT
022	N57E	78NW	027	037	057	037	R		SO	OT
022	N57E	78NW	038	037	018	037	R		SO	OT
022	N16E	77SE	003	007	029	007	R		SO	OT
022	N16E	77SE	030	007	018	007	R		SO	OT
022	N57E	78NW	055	025		025	R		SO	OT
022	N16E	77SE	045	025	075	025	R		SO	OT
022	N16E	77SE	080	025	052	025	R		SO	OT
023	N10E	90NW	025	005	018	005	R		SO	OT
023	N10E	90NW	014	005	028	005	R		SO	OT
023	N10E	90NW	012	005	028	005	R		SO	OT
023	N10E	90NW	009	005	014	005	R		SO	OT
023	N40E	90NW	017	005	023	005	R	NE	SO	OT
023	N40E	90NW	019	005	024	005	R	NE	SO	OT
023	N40E	90NW	014	005	030	005	R	NE	SO	OT
023	N45W	73SW	071	012		012	R	NW	SO	OT
023	N45W	73SW	087	009		009	R	NW	SO	OT
023	N13W	75SW	030	006	013	006	R		SO	OT
023	N13W	75SW	005	006	015	006	R		SO	OT
023	N40E	90NW	017	007	023	007	R	NE	SO	OT
023	N40E	90NW	007	007	005	007	R	NE	SO	OT
023	N40E	90NW	017	007	015	007	R	NE	SO	OT
023	N40E	90NW	010	007	015	007	R	NE	SO	OT
023	N45W	73SW	200	050	025	007	R	NW	SO	OT
024	N08W	70SW	020	007	022	007	R		SO	OT
024	N08W	70SW	021	007	022	007	R		SO	OT
024	N08W	70SW	020	010	022	010	R		SO	OT
024	N08W	70SW	020	002	020	002	R		SO	OT
024	N08W	72SW	044	009	043	009	R		SO	OT
024	N28E	90NW	015	003	025	003	R	NE	SO	OT
024	N28E	90NW	007	005	027	005	R	NE	SO	OT
024	N08W	72SW	010	006	014	006	R		SO	OT
024	N08W	72SW	017	008		008	R		SO	OT
024	N08W	72SW	049	014	022	014	R		SO	OT
024	N08W	72SW	026	014	018	004	R		SO	OT
024	N10E	65NW	014	005	023	005	R		SO	OT
024	N20E	77NW	007	007	002	007	R		SO	OT
024	N20E	77NW	010	008	008	008	R		SO	OT
025	N10W	69SW	012	017	008	017	R		SO	OT
025	N02E	69SE	006	017	005	017	R		SO	OT
025	N07W	69SW	002	017	008	017	R		SO	OT
025	N07W	69SW	010	017	013	017	R		SO	OT
025	N07W	69SW	010	010	023	010	R		SO	OT
025	N07W	69SW	017	010	014	010	R		SO	OT
025	N07W	69SW	040	025	052	025	R		SO	OT
025	N07W	69SW	057	025	018	025	R		SO	OT
025	N07W	69SW	047	110	026	025	R		SO	OT

STA	STRI	DIP	LNG	DTH	SPA	BED	EX	ST	LO	GR
025	N07W	69SW	023	004	008	004	R		SO	OT
025	N07W	69SW	009	004	018	004	R		SO	OT
025	N18E	61NW	027	006	006	006	R		SO	OT
025	N18E	61NW	010	006	004	006	R		SO	OT
025	N18E	61NW	017	006	007	006	R		SO	OT
025	N18E	61NW	010	006	004	006	R		SO	OT
025	N18E	61NW	020	008	004	008	R		SO	OT
025	N18E	61NW	007	008	005	008	R		SO	OT
025	N18E	61NW	001	008	008	008	R		SO	OT
025	N18E	61NW	001	008	009	008	R		SO	OT
025	N18E	61NW	001	008	009	008	R		SO	OT
026	N38W	90SW	413	018	010	018	R	NW	IN	IN
026	N80E	60SE	001	018	042	018	R	EW	IN	IN
026	N80E	60SE	001	018	057	018	R	EW	IN	IN
026	N80E	60SE	001	018	029	018	R	EW	IN	IN
026	N80E	60SE	001	018	059	018	R	EW	IN	IN
026	N35W	90SW	057	019	023	029	R	NW	IN	IN
026	N35W	90SW	048	019	013	019	R	NW	IN	IN
026	N35W	90SW	099	019	013	019	R	NW	IN	IN
026	N35W	90SW	099	019	012	019	R	NW	IN	IN
026	N35W	90SW	090	019	014	019	R	NW	IN	IN
026	N35W	90SW	057	019	010	019	R	NW	IN	IN
026	N35W	90SW	056	019	018	019	R	NW	IN	IN
026	N35W	90SW	120	019	024	019	R	NW	IN	IN
026	N80E	60SE	009	009	028	009	R	EW	IN	IN
026	N80E	60SE	003	009	026	009	R	EW	IN	IN
026	N80E	60SE	003	009	015	009	R	EW	IN	IN
026	N80E	60SE	001	009	012	009	R	EW	IN	IN
026	N80E	60SE	003	009	035	009	R	EW	IN	IN
026	N80E	60SE	016	009	013	009	R	EW	IN	IN
026	N80E	60SE	003	009	032	009	R	EW	IN	IN
026	N80E	60SE	003	009	035	009	R	EW	IN	IN
026	N38W	90SW	014	006	019	006	R	NW	IN	IN
026	N38W	90SW	008	103	015	006	R	NW	IN	IN
026	N38W	90SW	005	006	015	006	R	NW	IN	IN
027	N71W	90SW	114	012		012	R		IN	IN
027	N06W	90SW	127	010		010	R		IN	IN
027	N71W	90SW	022	007		007	R		IN	IN
027	N71W	90SW	032	011		011	R		IN	IN
027	N45E	90NW	038	013		013	R	NE	IN	IN
028	N50W	90SW	075	015	009	015	R	NW	IN	IN
028	N50W	90SW	078	017	014	017	R	NW	IN	IN
028	N50W	90SW	075	013		013	R	NW	IN	IN
028	N50W	90SW	091	008		008	R	NW	IN	IN
028	N50W	90SW	020	010	015	010	R	NW	IN	IN
028	N50W	90SW	025	008		008	R	NW	IN	IN
028	N50W	90SW	129	006		006	R	NW	IN	IN

STA	STRI	DIP	LNG	DTH	SPA	BED	EX	ST	LO	GR
028	N77W	74NE	050	013	027	013	R		IN	IN
028	N75W	75NE	072	014	011	014	R		IN	IN
028	N77W	78NE	025	009	011	009	R		IN	IN
028	N77W	78NE	001	009	005	009	R		IN	IN
028	N77W	78NE	030	009	003	009	R		IN	IN
028	N77W	78NE	022	004	011	004	R		IN	IN
028	N77W	78NE	048	004	016	004	R		IN	IN
028	N77W	78NE	020	004	008	004	R		IN	IN
028	N77W	78NE	015	004	006	004	R		IN	IN
028	N77W	78NE	015	003	009	003	R		IN	IN
028	N77W	78NE	028	015	022	004	R		IN	IN
029	N85E	85NW	139	021		021	R	EW	IN	IN
029	N45W	78SW	094	011		011	R	NW	IN	IN
029	N40W	80SW	083	032	008	032	R	NW	IN	IN
029	N40W	80SW	036	032	010	032	R	NW	IN	IN
029	N40W	80SW	042	032	031	032	R	NW	IN	IN
029	N40W	80SW	037	025	005	025	R	NW	IN	IN
029	N40W	80SW	154	025		025	R	NW	IN	IN
029	N40W	80SW	041	012	009	012	R	NW	IN	IN
029	N40W	80SW	047	012	013	012	R	NW	IN	IN
029	N40W	80SW	070	018	020	018	R	NW	IN	IN
029	N40W	80SW	015	012	008	012	R	NW	IN	IN
029	N40W	80SW	074	012		012	R	NW	IN	IN
029	N85E	85NW	052	019	011	007	R	EW	IN	IN
029	N85E	85NW	100	018	004	018	R	EW	IN	IN
029	N85E	85NW	195	030		030	R	EW	IN	IN
030	N59W	90SW	017	003	020	003	R		IN	IN
030	N59W	90SW	019	002	012	002	R		IN	IN
030	N59W	90SW	021	002	027	002	R		IN	IN
030	N59W	90SW	020	003	020	003	R		IN	IN
031	N42W	83SW	058	046	103	046	R	NW	IN	IN
031	N87W	85SW	045	069		033	R	EW	IN	IN
031	N65W	89NE	054	028	016	028	R		IN	IN
031	N65W	89NE	012	028		028	R		IN	IN
031	N87W	85SW	030	036	057	036	R	EW	IN	IN
031	N87W	85SW	010	050		050	R	EW	IN	IN
031	N87W	85SW	010	022	045	022	R	EW	IN	IN
031	N87W	85SW	017	024	022	024	R	EW	IN	IN
031	N87W	85SW	005	050		050	R	EW	IN	IN
031	N87W	85SW	017	101	044	050	R	EW	IN	IN
031	N38W	88SW	102	078	058	078	R	NW	IN	IN
031	N42W	83NE	120	078	076	078	R	NW	IN	IN
031	N42W	83NE	078	043	037	043	R	NW	IN	IN
031	N42W	83NE	045	042	044	042	R	NW	IN	IN
031	N42W	83NE	047	026	050	026	R	NW	IN	IN
032	N89E	83NW	024	020	028	020	R	EW	IN	IN
032	N89E	83NW	011	019		019	R	EW	IN	IN

STA	STRI	DIP	LNG	DTH	SPA	BED	EX	ST	LO	GR
032	N89E	83NW	011	008	017	008	R	EW	IN	IN
032	N89E	83NW	010	002	017	002	R	EW	IN	IN
032	N89E	83NW	005	005	013	005	R	EW	IN	IN
032	N89E	83NW	012	003	007	003	R	EW	IN	IN
032	N89E	83NW	022	013	034	013	R	EW	IN	IN
032	N89E	83NW	010	022	075	022	R	EW	IN	IN
032	N89E	83NW	015	022	048	022	R	EW	IN	IN
033	N83W	90SW	037	018	025	018	R	EW	IN	IN
033	N83W	90SW	012	018	020	018	R	EW	IN	IN
033	N83W	90SW	021	014	014	014	R	EW	IN	IN
033	N83W	90SW	007	006	011	006	R	EW	IN	IN
033	N83W	90SW	021	006	012	006	R	EW	IN	IN
033	N83W	90SW	006	010	008	010	R	EW	IN	IN
033	N83W	90SW	027	016	018	016	R	EW	IN	IN
033	N83W	90SW	087	019	024	019	R	EW	IN	IN
033	N83W	90SW	053	018	024	018	R	EW	IN	IN
033	N83W	90SW	056	025	032	025	R	EW	IN	IN
035	N47W	90SW	300				SC	NW	IN	IN
035	N24E	45SE	200		090		SC		IN	IN
035	N24E	45SE	200		059		SC		IN	IN
035	N24E	45SE	040		029		SC		IN	IN
035	N02E	45SE	040		021		SC		IN	IN
035	N02E	45SE	016		031		SC		IN	IN
035	N02E	45SE	023		011		SC		IN	IN
035	N55W	90SW	048	017	047	010	SC	NW	IN	IN
035	N55W	90SW	017	010	009	010	SC	NW	IN	IN
035	N55W	90SW	030	010	025	010	SC	NW	IN	IN
035	N55W	90SW	039	010	035	010	SC	NW	IN	IN
035	N85W	90SW	020	010	036	010	SC	EW	IN	IN
035	N85W	90SW	047	010	029	010	SC	EW	IN	IN
035	N85W	90SW	036	010	016	010	SC	EW	IN	IN
035	N85W	90SW	036	010	037	010	SC	EW	IN	IN
035	N68W		077				SC		IN	IN
036	N48W	84SW	029	018	010	007	R	NW	IN	IN
036	N81E	82SE	002	007	011	007	R	EW	IN	IN
036	N43E	57NW	012	007	017	007	R	NE	IN	IN
036	N48W	84SW	001	018	020	007	R	NW	IN	IN
036	N48W	84SW	029	018	016	007	R	NW	IN	IN
036	N48W	84SW	021	007		007	R	NW	IN	IN
036	N81E	82SE	012	007	010	007	R	EW	IN	IN
036	N81E	82SE	017	007	055	007	R	EW	IN	IN
036	N48W	84SW	086	019	022	007	R	NW	IN	IN
036	N48W	84SW	035	007	008	007	R	NW	IN	IN
036	N48W	84SW	001	007	008	007	R	NW	IN	IN
036	N48W	84SW	001	007	008	007	R	NW	IN	IN
036	N81E	82SE	010	007		007	R	EW	IN	IN
036	N43E	57NW	001	007	037	007	R	NE	IN	IN

STA	STRI	DIP	LNG	DTH	SPA	BED	EX	ST	LO	GR
036	N43E	57NW	001	007	005	007	R	NE	IN	IN
036	N43E	57NW	001	007	018	007	R	NE	IN	IN
036	N48W	84SW	015	003	009	003	R	NW	IN	IN
036	N48W	84SW	003	003	005	003	R	NW	IN	IN
036	N48W	84SW	001	003	010	003	R	NW	IN	IN
036	N48W	84SW	001	003	003	003	R	NW	IN	IN
036	N43E	57NW	019	005	013	005	R	NE	IN	IN
036	N43W	57NW	015	005	014	005	R	NW	IN	IN
036	N81E	82SE	014	005	021	005	R	EW	IN	IN
036	N81E	82SE	018	016	009	005	R	EW	IN	IN
037	N65W	90SW					R		IN	IN
037	N18E	90NW					R		IN	IN
038	N57W	90SW	500	019		019	R		IN	IN
038	N57W	90SW	043	006	012	006	R		IN	IN
038	N57W	90SW	014	006	015	006	R		IN	IN
038	N57W	90SW	007	006	012	006	R		IN	IN
038	N57W	90SW	019	006	010	006	R		IN	IN
038	N57W	90SW	052	006	006	006	R		IN	IN
038	N57W	90SW	250	008	023	008	R		IN	IN
038	N57W	90SW	117	016	020	016	R		IN	IN
039							R		IN	IN
040	N53W	90SW					R	NW	IN	IN
040	N46W	90SW					R	NW	IN	IN
040	N45W	90SW					R	NW	IN	IN
040	N72W	88NE		150			R		IN	IN
040	N51W	90SW					R	NW	IN	IN
040	N80W	90SW					R	EW	IN	IN
040	N73W	90SW					R		IN	IN
040	N74W	90SW					R		IN	IN
040	N80W	90SW		150	015		R	EW	IN	IN
041	N80W	88NE		150			R	EW	IN	IN
041	N25E	90NW					R	NE	IN	IN
041	N25E	90NW	180	090		090	R	NE	IN	IN
041	N25E	90NW		200			R	NE	IN	IN
042	N53W	90SW	035	006	020	006	R	NW	IN	IN
042	N55W	90SW	010	025	028	012	R	NW	IN	IN
042	N53W	90SW	020	150		012	R	NW	IN	IN
042	N53W	90SW	029	048		012	R	NW	IN	IN
042	N53W	90SW	015	012	020	012	R	NW	IN	IN
042	N53W	90SW	050	120	057	020	R	NW	IN	IN
042	N53W	90SW	020	110	040	020	R	NW	IN	IN
042	N53W	90SW	015	050	040	020	R	NW	IN	IN
043	N46W	90SW	005	064	020	020	R	NW	IN	IN
043	N46W	90SW	005	065	050	020	R	NW	IN	IN
043	N46W	90SW	012	063	027	020	R	NW	IN	IN
043	N46W	90SW	063	051		051	R	NW	IN	IN
043	N46W	90SW	012	006	016	006	R	NW	IN	IN

STA	STRI	DIP	LNG	DTH	SPA	BED	EX	ST	LO	GR
043	N46W	90SW	009	006	018	006	R	NW	IN	IN
043	N46W	90SW	004	058	029	058	R	NW	IN	IN
043	N46W	90SW	029	019	023	019	R	NW	IN	IN
044	N48W	90SW	210	185		025	R	NW	IN	IN
044	N48W	90SW	104	100		025	R	NW	IN	IN
044	N48W	90SW	200	101		050	R	NW	IN	IN
044	N48W	90SW	500	050		030	R	NW	IN	IN
044	N48W	90SW	001	062	005	026	R	NW	IN	IN
044	N48W	90SW	001	062	075	026	R	NW	IN	IN
045	N65W	90SW	125	092	030	015	R		IN	IN
045	N65W	90SW	025	149		015	R		IN	IN
045	N65W	90SW	003	010	006	003	R		IN	IN
045	N65W	90SW	003	010	005	003	R		IN	IN
045	N65W	90SW	001	010	007	003	R		IN	IN
045	N65W	90SW	001	010	010	003	R		IN	IN
045	N65W	90SW	001	010	006	003	R		IN	IN
046	N85W	90SW	012	182	052	020	R	EW	IN	IN
046	N85W	90SW	007	190	028	020	R	EW	IN	IN
046	N85W	90SW	015	146	007	020	R	EW	IN	IN
046	N85W	90SW	001	097	007	020	R	EW	IN	IN
046	N85W	90SW	002	097	002	020	R	EW	IN	IN
046	N85W	90SW	003	096	002	020	R	EW	IN	IN
046	N85W	90SW	002	092	003	020	R	EW	IN	IN
046	N85W	90SW	002	093	005	020	R	EW	IN	IN
047	N26E	83SE	083	057	065	001	R	NE	NO	OT
047	N26E	83SE	041	059	020	001	R	NE	NO	OT
047	N85W	86SW	014	007	020	007	R	EW	NO	OT
047	N85W	86SW	006	010	013	007	R	EW	NO	OT
047	N85W	86SW	007	006	006	006	R	EW	NO	OT
047	N85W	86SW	010	011	029	011	R	EW	NO	OT
047	N85W	86SW	014	015	017	009	R	EW	NO	OT
047	N85E	86SW	023	009	026	009	R	EW	NO	OT
047	N85E	86SE	009	010	014	010	R	EW	NO	OT
048	N33W	55SW	146	070		003	R		NO	OT
048	N83E	90NW	006	004	007	004	R	EW	NO	OT
048	N83E	90NW	006	004	005	004	R	EW	NO	OT
048	N83E	90NW	001	004	011	004	R	EW	NO	OT
048	N30W	62SW	012	004		004	R		NO	OT
048	N30W	62SW	009	004		004	R		NO	OT
048	N45W	62SW	010	004	005	004	R	NW	NO	OT
049	N46W	71SW	165	027		027	R	NW	NO	OT
049	N88W	76NE	121	028		028	R	EW	NO	OT
049	N88W	76NE	034	004	008	004	R	EW	NO	OT
049	N46W	71SW	066	016	028	016	R	NW	NO	OT
049	N46W	71SW	050	016	011	016	R	NW	NO	OT
049	N46W	71SW	035	010	011	010	R	NW	NO	OT
049	N88W	76NE	028	018	030	018	R	EW	NO	OT

<u>STA</u>	<u>STRI</u>	<u>DIP</u>	<u>LNG</u>	<u>DTH</u>	<u>SPA</u>	<u>BED</u>	<u>EX</u>	<u>ST</u>	<u>LO</u>	<u>GR</u>
049	N88W	76NE	036	013	015	013	R	EW	NO	OT
049	N46W	71SW	015	016	014	016	R	NW	NO	OT
049	N12W	28SW	010	022	019	022	R		NO	OT
049	N12W	28SW	012	017		017	R		NO	OT
049	N12W	28SW	005	007	005	007	R		NO	OT
049	N12W	28SW	001	006	006	006	R		NO	OT
049	N12W	28SW	012	027	040	027	R		NO	OT
049	N46W	71SW	028	027	021	027	R	NW	NO	OT
049	N46W	71SW	025	027	013	027	R	NW	NO	OT
049	N46W	71SW	065	027	014	027	R	NW	NO	OT
049	N12W	28SW	010	015	013	015	R		NO	OT
049	N12W	28SW	003	015	020	015	R		NO	OT
049	N88W	76NE	033	017	021	017	R	EW	NO	OT
049	N88W	76NE	023	025	012	025	R	EW	NO	OT
050	N21W	90SW	500		096	001	S		NO	OT
050	N21W	90SW	500				S		NO	OT
050	N05W	90SW	386		122	001	S		NO	OT
050	N05W	90SW	238			001	S		NO	OT
050	N05W	90SW	120		025	001	S		NO	OT
050	N05W	90SW	293		036	001	S		NO	OT
050	N05W	90SW	251		037	001	S		NO	OT
050	N03W	90SW	450		150		SC		NO	OT
050	N03W	90SW	223				SC		NO	OT
050	N45W	90SW	048	007	015	007	SC	NW	NO	OT
050	N45W	90SW	061	007	018	007	SC	NW	NO	OT
050	N45W	90SW	081	007	025	007	SC	NW	NO	OT
050	N45W	90SW	105	007	018	007	SC	NW	NO	OT
050	N45W	90SW	014	007	017	007	SC	NW	NO	OT
050	N45W	90SW	015	007	015	007	SC	NW	NO	OT
050	N45W	90SW	028	007	036	007	SC	NW	NO	OT
051	N48W	88SW	081	029	027	029	SC	NW	NO	OT
051	N48W	88SW	081	029	025	029	SC	NW	NO	OT
051	N48W	88SW	078	029	021	029	SC	NW	NO	OT
051	N48W	88SW	066	029	005	029	SC	NW	NO	OT
051	N48W	88SW	048	029	032	029	SC	NW	NO	OT
051	N48W	88SW	049	029	015	029	SC	NW	NO	OT
051	N83W	90SW	130	025	038	025	SC	EW	NO	OT
051	N43W	90SW	072	025	030	025	SC	NW	NO	OT
051	N43W	90SW	086	025	062	025	SC	NW	NO	OT
051	N43W	90SW	090	025	034	025	SC	NW	NO	OT
051	N48W	88SW	035	025		025	SC	NW	NO	OT
051	N48W	88SW	056	005	015	005	SC	NW	NO	OT
051	N48W	88SW	085	005	006	005	SC	NW	NO	OT
051	N48W	88SW	056	005	006	005	SC	NW	NO	OT
051	N48W	88SW	061	005	015	005	SC	NW	NO	OT
051	N48W	88SW	046	005	010	005	SC	NW	NO	OT
051	N48W	88SW	067	005	055	005	SC	NW	NO	OT

STA	STRI	DIP	LNG	DTH	SPA	BED	EX	ST	LO	GR
052	N58W	75SW	150	080			R		NO	OT
053							R		NO	OT
054	N66W	90SW			032	013	R		IN	IN
054	N66W	90SW			027	013	R		IN	IN
054	N66W	90SW			021	013	R		IN	IN
054	N66W	90SW			028	013	R		IN	IN
054	N66W	90SW			016	013	R		IN	IN
054	N66W	90SW			015	013	R		IN	IN
054	N66W	90SW			028	013	R		IN	IN
054	N66W	90SW			022	013	R		IN	IN
054	N42E	45NW			059		R	NE	IN	IN
054	N42E	45NW			053		R	NE	IN	IN
054	N42E	45NW			081		R	NE	IN	IN
054	N42E	45NW			068		R	NE	IN	IN
054	N42E	45NW			016		R	NE	IN	IN
054	N42E	45NW			027		R	NE	IN	IN
054	N42E	45NW			038		R	NE	IN	IN
054	N42E	45NW			021		R	NE	IN	IN
054	N88W	90SW			067		R	EW	IN	IN
054	N88W	90SW			030		R	EW	IN	IN
054	N88W	90SW			020		R	EW	IN	IN
054	N88W	90SW			071		R	EW	IN	IN
054	N88W	90SW			027		R	EW	IN	IN
054	N88W	90SW			026		R	EW	IN	IN
054	N88W	90SW			030		R	EW	IN	IN
054	N88W	90SW			009		R	EW	IN	IN
055	N46W	89SW	109	047	019	047	R	NW	NO	OT
055	N87W	89NE	075	034	038	047	R	EW	NO	OT
055	N87W	89NE	138	028	069	028	R	EW	NO	OT
055	N42E	85NW	010	056		001	R	NE	NO	OT
055	N36E	90NW	050	028	130	028	R	NE	NO	OT
055	N46W	89SW	013	019		028	R	NW	NO	OT
055	N25E	90NW	012	006	009	001	R	NE	NO	OT
055	N25E	90NW	001	006	019	001	R	NE	NO	OT
055	N25E	90NW	001	006	020	001	R	NE	NO	OT
055	N36E	90NW	050	027	092	027	R	NE	NO	OT
055	N46W	89SW	048	027		027	R	NW	NO	OT
055	N87W	89NE	030	008	015	008	R	EW	NO	OT
055	N87W	89NE	010	008		008	R	EW	NO	OT
056	N45W	90SW	034	043	036	043	R	NW	NO	OT
056	N45W	90SW	010	043	062	043	R	NW	NO	OT
056	N45W	90SW	120	134		100	R	NW	NO	OT
056	N45W	90SW	038	123	015	100	R	NW	NO	OT
056	N45W	90SW	146	200		200	R	NW	NO	OT
056	N45W	90SW	180	220		200	R	NW	NO	OT
057	N83W	83NE	073	026	018	026	R	EW	NO	OT
057	N83W	84NE	001	026	018	026	R	EW	NO	OT

<u>STA</u>	<u>STRI</u>	<u>DIP</u>	<u>LNG</u>	<u>DTH</u>	<u>SPA</u>	<u>BED</u>	<u>EX</u>	<u>ST</u>	<u>LO</u>	<u>GR</u>
057	N83W	83NE	020	026	054	026	R	EW	NO	OT
057	N36W	83SW	041	021	016	021	R	NW	NO	OT
057	N36W	83SW	028	021	025	021	R	NW	NO	OT
057	N36W	83SW	033	021	024	021	R	NW	NO	OT
057	N38E	33NW	016	021	046	021	R	NE	NO	OT
057	N38E	33NW	025	021	029	021	R	NE	NO	OT
057	N38E	33NW	024	021	029	021	R	NE	NO	OT
058	N83E	49SE	057	067	006	001	R	EW	NO	OT
058	N73W	75SW	173	049		058	R		NO	OT
058	N83E	49SE	007	075	006	010	R	EW	NO	OT
058	N83E	49SE	008	069	019	010	R	EW	NO	OT
058	N83E	49SE	020	180	063	010	R	EW	NO	OT
058	N83E	49SE	015	250		010	R	EW	NO	OT
058	N83E	49SE	012	053	009	010	R	EW	NO	OT
058	N83E	49SE	006	041	010	010	R	EW	NO	OT
059	N20E	90NW					R		NO	OT
059	N80W	90SW					R	EW	NO	OT
060	N49W	90SW	042	030	025	030	R	NW	NO	OT
060	N49W	90SW	031	030	036	030	R	NW	NO	OT
060	N49W	90SW	029	030	006	030	R	NW	NO	OT
061	N41W	77SW	019	061	051	061	R	NW	NO	OT
061	N41W	77SW	038	061	041	061	R	NW	NO	OT
061	N41W	77SW	049	061	058	061	R	NW	NO	OT
061	N41W	77SW	033	038	024	038	R	NW	NO	OT
061	N41W	77SW	028	038	023	038	R	NW	NO	OT
061	N41W	77SW	021	038	037	038	R	NW	NO	OT
062	N75W	90SW	300	104		083	R		NO	OT
062	N45E	48NW					R	NE	NO	OT
063	N47W	84NE	091	058	068	058	S	NW	NO	OT
063	N75W	72NE	027	058		058	S		NO	OT
063	N47W	84NE	050	058	064	058	S	NW	NO	OT
063	N47W	84NE	080	047	021	044	S	NW	NO	OT
063	N47W	84NE	087	047	060	044	S	NW	NO	OT
063	N47W	84NE	020	058	037	058	S	NW	NO	OT
063	N47W	84NE	008	058	035	058	S	NW	NO	OT
063	N75W	72NE	001	078	088	058	S		NO	OT
063	N75W	72NE	003	163	100	058	S		NO	OT
063	N75W	72NE	008	080	025	020	S		NO	OT
063	N47W	84NE	031	018	023	018	S	NW	NO	OT
063	N47W	84NE	037	018	019	018	S	NW	NO	OT
063	N75W	72NE	045	018	085	018	S		NO	OT
063	N75W	72NE	060	018	031	018	S		NO	OT
063	N75W	72NE	027	018	051	018	S		NO	OT
064	N75W	80NE	029	005	014	005	R		NO	OT
064	N45W	78SW	025	019	015	012	R	NW	NO	OT
064	N45W	78SW	052	010	012	010	R	NW	NO	OT
064	N75W	80NE	026	005	011	005	R		NO	OT

STA	STRI	DIP	LNG	DTH	SPA	BED	EX	ST	LO	GR
064	N45W	78SW	022	012	020	012	R	NW	NO	OT
064	N75W	80NE	046	010	007	010	R		NO	OT
064	N45W	78SW	035	019	028	019	R	NW	NO	OT
064	N45W	78SW	007	019	013	019	R	NW	NO	OT
064	N45W	78SW	018	019	014	019	R	NW	NO	OT
064	N45W	78SW	057	012	020	012	R	NW	NO	OT
064	N87E	76NW	021	017	014	017	R	EW	NO	OT
064	N87E	76NW	007	017	015	017	R	EW	NO	OT
064	N87E	76NW	015	017	014	017	R	EW	NO	OT
065	N44W	89SW	058	025	042	025	S	NW	NO	OT
065	N44W	89SW	043	025	010	025	S	NW	NO	OT
065	N44W	89SW	039	025	025	025	S	NW	NO	OT
065	N44W	89SW	037	025	036	025	S	NW	NO	OT
065	N44W	89SW	054	025	027	025	S	NW	NO	OT
065	N44W	89SW	032	012	010	025	S	NW	NO	OT
065	N44W	89SW	028	012	008	025	S	NW	NO	OT
065	N44W	89SW	027	012	013	025	S	NW	NO	OT
065	N44W	89SW	025	012	012	025	S	NW	NO	OT
065	N89W	90SW	053	025	018	025	S	EW	NO	OT
065	N89W	90SW	029	025	009	025	S	EW	NO	OT
066	N72W	66SW	031	007	032	007	R		NO	OT
066	N72W	66SW	011	012	026	012	R		NO	OT
066	N58W	63SW	010	009	011	009	R		NO	OT
066	N58W	63SW	025	009	014	009	R		NO	OT
066	N58W	63SW	029	009	015	009	R		NO	OT
066	N58W	63SW	020	009	012	009	R		NO	OT
066	N49W	76SW	014	010	066	024	R	NW	NO	OT
066	N49W	76SW	031	012	013	012	R	NW	NO	OT
066	N49W	76SW	026	012	017	012	R	NW	NO	OT
067	N78W	69SW	026	019			R		NO	OT
067	N78W	69SW	035	019			R		NO	OT
068	N40W	90NW	016		065		S	NW	NO	OT
068	N45W	90SW	067	017	020	007	S	NW	NO	OT
068	N45W	90SW	040	027	024	007	S	NW	NO	OT
068	N45W	90SW	058	009	011	009	S	NW	NO	OT
068	N45W	90SW	060	009	026	009	S	NW	NO	OT
068	N45W	90SW	055	009	022	009	S	NW	NO	OT
068	N45W	90SW	072	009	042	009	S	NW	NO	OT
068	N78W	69SW	250				S		NO	OT
068	N78W	69SW	005	006	023	006	S		NO	OT
068	N78W	69SW	008	007	009	006	S		NO	OT
068	N78W	69SW	003	007	020	006	S		NO	OT
068	N78W	69SW	002	009	010	006	S		NO	OT
069	N46W	90SW	121	050	035	050	R	NW	NO	OT
069	N46W	90SW	093	042		042	R	NW	NO	OT
069	N46W	90SW	105	017		020	R	NW	NO	OT
069	N46W	90SW	135	060	021	042	R	NW	NO	OT

STA	STRI	DIP	LNG	DTH	SPA	BED	EX	ST	LO	GR
069	N46W	90SW	098	043		043	R	NW	NO	OT
069	N46W	90SW	080	035		035	R	NW	NO	OT
069	N34E	90NW	080	035		035	R	NE	NO	OT
069	N64W	90SW	094	046		039	R		NO	OT
069	N46W	90SW	109	053		053	R	NW	NO	OT
069	N46W	90SW	068	025	034	025	R	NW	NO	OT
069	N46W	90SW	055	025		025	R	NW	NO	OT
069	N46W	90SW	025	012	005	012	R	NW	NO	OT
069	N46W	90SW	012	012	007	012	R	NW	NO	OT
069	N46W	90SW	013	012	009	012	R	NW	NO	OT
070	N32E	81NW	461	020	000	032	R	NE	NO	OT
070	N36E	82NW	479	012	000	032	R	NE	NO	OT
070	N41W	90SW	015	006	000	006	R	NW	NO	OT
070	N48E	65NW	025	006	000	006	R		NO	OT
070	N46W	90SW	016	008	009	008	R	NW	NO	OT
070	N41W	90SW	004	008	013	008	R	NW	NO	OT
070	N41W	90SW	022	010	018	010	R	NW	NO	OT
070	N41W	90SW	023	010	000	010	R	NW	NO	OT
070	N43W	90SW	006	013	006	013	R	NW	NO	OT
070	N41W	90SW	005	013	006	013	R	NW	NO	OT
070	N41W	90SW	015	013	009	013	R	NW	NO	OT
070	N41W	90SW	006	010	010	010	R	NW	NO	OT
070	N41W	90SW	007	010	011	010	R	NW	NO	OT
070	N41W	90SW	019	010	007	010	R	NW	NO	OT
070	N41W	90SW	011	017	060	017	R	NW	NO	OT
070	N41W	90SW	011	017	015	017	R	NW	NO	OT
071	N71W	84SW	005	008	011	008	R		NO	OT
071	N71W	84SW	008	008	016	008	R		NO	OT
071	N71W	84SW	001	008	010	008	R		NO	OT
071	N71W	84SW	019	008	013	008	R		NO	OT
071	N71W	84SW	022	008	010	008	R		NO	OT
071	N71W	84SW	004	009	001	009	R		NO	OT
071	N71W	84SW	001	009	012	009	R		NO	OT
071	N71W	84SW	008	009	015	009	R		NO	OT
071	N71W	84SW	003	009	014	009	R		NO	OT
071	N71W	84SW	003	009	002	009	P		NO	OT
071	N11E	59NW	033	010	006	010	R		NO	OT
071	N11E	59NW	028	010	000	010	R		NO	OT
071	N42W	77SW	033	023	017	017	R	NW	NO	OT
071	N42W	77SW	027	027	009	018	R	NW	NO	OT
071	N42W	77SW	010	017	000	022	R	NW	NO	OT
071	N78W	81SW	007	013	008	013	R		NO	OT
071	N78W	81SW	008	013	010	013	R		NO	OT
071	N78W	81SW	027	013	011	013	R		NO	OT
071	N42W	77SW	025	030	032	030	R	NW	NO	OT
071	N42W	77SW	039	055	032	030	R	NW	NO	OT
072	N60W	90SW	055	018	000	023	R		NO	OT

STA	STRI	DIP	LNG	DTH	SPA	BFD	EX	ST	LO	GR
072	N25E	90NW	039	010	000	010	R	NE	NO	OT
072	N55W	90SW	020	028	000	021	R	NW	NO	OT
072	N60W	90SW	032	032	000	030	R		NO	OT
072	N60W	90SW	027	020	026	020	R		NO	OT
072	N85E	90NW	020	042	000	003	R	EW	NO	OT
072	N70W	83SW	020	083	000	007	R		NO	OT
072	N55W	90SW	038	080	000	015	R	NW	NO	OT
073	N85W	84SW	093	041	000	041	R	EW	NO	OT
073	N31W	79SW	045	036	099	036	R		NO	OT
073	N31W	79SW	039	036	099	036	R		NO	OT
073	N31W	79SW	010	036	000	036	R		NO	OT
073	N85W	84SW	044	020	000	020	R	EW	NO	OT
073	N41W	69SW	036	053	023	029	R	NW	NO	OT
073	N41W	69SW	043	060	000	020	R	NW	NO	OT
074	N87W	76SW	122	134	000	134	R	EW	NO	OT
074	N87W	76SW	070	027	000	023	R	EW	NO	OT
074	N87W	76SW	037	007	018	007	R	EW	NO	OT
074	N87W	76SW	031	007	010	007	R	EW	NO	OT
074	N87W	76SW	053	033	000	007	R	EW	NO	OT
074	N05E	79NW	046	007	000	007	R		NO	OT
075	N70E	60NW	165	010	000	005	R		NO	OT
075	N82E	90NW	135	015	035	015	R	EW	NO	OT
075	N82E	90NW	058	015	000	015	R	EW	NO	OT
076	N15E	90NW	076	012	076	012	S		NO	OT
076	N15E	90NW	050	012	037	012	S		NO	OT
076	N15E	90NW	086	012	047	012	S		NO	OT
076	N15E	90NW	094	012	049	012	S		NO	OT
076	N15E	90NW	080	012	000	012	S		NO	OT
076	N85E	90NW	157	012	000	012	S	EW	NO	OT
077	N22E	90NW	048	019	016	019	S		NO	OT
077	N45E	85NW	071	018	064	018	S	NE	NO	OT
077	N46W	90SW	051	025	019	019	S	NW	NO	OT
077	N87W	90SW	082	000	010	009	S	EW	NO	OT
077	N22E	90NW	037	019	016	019	S		NO	OT
077	N46W	90SW	053	019	014	019	S	NW	NO	OT
077	N45E	85NW	109	034	000	019	S	NE	NO	OT
077	N87W	90SW	110	009	011	009	S	EW	NO	OT
077	N87W	90SW	049	009	011	009	S	EW	NO	OT
078	N63W	90SW	206	034	065	034	R		NO	OT
078	N63W	90SW	101	015	080	015	R		NO	OT
078	N63W	90SW	080	015	000	015	R		NO	OT
078	N63W	90SW	278	034	000	034	R		NO	OT
078	N48W	90SW	050	008	017	008	R	NW	NO	OT
078	N55W	90SW	045	001	008	008	R	NW	NO	OT
078	N55W	90SW	086	001	008	008	R	NW	NO	OT
078	N55W	90SW	088	003	006	008	R	NW	NO	OT
078	N55W	90SW	098	002	005	008	R	NW	NO	OT

<u>STA</u>	<u>STRI</u>	<u>DIP</u>	<u>LNG</u>	<u>DTH</u>	<u>SPA</u>	<u>BED</u>	<u>EX</u>	<u>ST</u>	<u>LO</u>	<u>GR</u>
078	N55W	90SW	068	001	011	008	R	NW	NO	OT
078	N55W	90SW	062	004	013	008	R	NW	NO	OT
079	N47W	82SW	013	016	014	016	R	NW	NO	OT
079	N47W	82SW	039	019	000	019	R	NW	NO	OT
079	N47W	82SW	008	006	015	006	R	NW	NO	OT
079	N82W	87SW	020	016	038	016	R	EW	NO	OT
079	N82W	87SW	010	014	011	014	R	EW	NO	OT
079	N82W	87SW	015	014	003	014	R	EW	NO	OT
079	N82W	87SW	018	014	012	014	R	EW	NO	OT
079	N82W	87SW	017	014	024	014	R	EW	NO	OT
079	N47W	82SW	003	017	018	017	R	NW	NO	OT
079	N47W	82SW	018	018	013	018	R	NW	NO	OT
079	N47W	82SW	018	014	015	014	R	NW	NO	OT
079	N82W	87SW	009	014	017	014	R	EW	NO	OT
079	N82W	87SW	032	014	019	014	R	EW	NO	OT
079	N47W	82SW	017	018	012	018	R	NW	NO	OT
079	N47W	82SW	027	020	018	017	R	NW	NO	OT
079	N12W	70SW	043	013	000	013	R		NO	OT
079	N07E	59NW	018	018	001	018	R		NO	OT
079	N12E	48NW	033	013	014	013	R		NO	OT
080	N72W	84SW	033	008	008	008	R		NO	OT
080	N21E	84NW	017	008	018	008	R		NO	OT
080	N72W	84SW	007	008	013	008	R		NO	OT
080	N72W	84SW	024	008	018	008	R		NO	OT
080	N72W	84SW	044	009	015	009	R		NO	OT
080	N72W	84SW	018	009	009	009	R		NO	OT
080	N72W	84SW	018	009	018	009	R		NO	OT
080	N72W	84SW	018	009	011	009	R		NO	OT
080	N21E	84NW	017	008	029	008	R		NO	OT
080	N21E	84NW	001	009	013	009	R		NO	OT
080	N21E	84NW	015	009	012	009	R		NO	OT
080	N21E	84NW	024	009	025	009	R		NO	OT
080	N21E	84NW	010	009	018	009	R		NO	OT
080	N21E	84NW	019	010	017	010	R		NO	OT
082	N23E	74NW	049	026	080	026	R		IN	IN
082	N48W	88SW	064	027	065	027	R	NW	IN	IN
082	N48W	88SW	100	026	000	026	R	NW	IN	IN
082	N48W	88SW	020	036	039	036	R	NW	IN	IN
082	N48W	88SW	060	040	050	040	R	NW	IN	IN
082	N48W	88SW	062	046	067	046	R	NW	IN	IN
082	N84W	87SW	053	040	025	033	R	EW	IN	IN
082	N84W	87SW	005	040	020	033	R	EW	IN	IN
082	N84W	87SW	027	026	000	026	R	EW	IN	IN
082	N23E	74NW	058	030	063	030	R		IN	IN
082	N23E	74NW	072	033	000	033	R		IN	IN
083	N70W	87SW	020	015	000	013	R		IN	IN
083	N46W	88SW	012	004	010	008	R	NW	IN	IN

<u>STA</u>	<u>STRI</u>	<u>DIP</u>	<u>LNG</u>	<u>DTH</u>	<u>SPA</u>	<u>BED</u>	<u>EX</u>	<u>ST</u>	<u>LO</u>	<u>GR</u>
083	N46W	88SW	003	003	013	008	R	NW	IN	IN
083	N46W	88SW	005	004	010	008	R	NW	IN	IN
083	N70W	87SW	014	009	007	009	R		IN	IN
083	N21E	73NW	129	022	011	007	R		IN	IN
083	N21E	73NW	063	018	012	009	R		IN	IN
084	N85W	88SW	075	142	030	020	R	EW	IN	IN
084	N89W	90SW	034	034	044	034	R	EW	IN	IN
084	N89W	88SW	028	029	021	022	R	EW	IN	IN
084	N89W	88SW	035	056	041	022	R	EW	IN	IN
084	N89W	88SW	015	018	013	006	R	EW	IN	IN
084	N89W	88SW	012	026	014	006	R	EW	IN	IN
084	N89W	88SW	005	005	008	005	R	EW	IN	IN
084	N35E	84NW	015	019	006	019	R	NE	IN	IN
084	N35E	84NW	024	019	023	019	R	NE	IN	IN
084	N42W	71SW	024	014	000	014	R	NW	IN	IN
084	N89W	88SW	010	014	021	014	R	EW	IN	IN
084	N89W	88SW	010	014	022	014	R	EW	IN	IN
084	N89W	88SW	019	017	016	017	R	EW	IN	IN
084	N45W	84SW	146	018	015	018	R	NW	IN	IN
084	N42W	71SW	105	020	000	020	R	NW	IN	IN
084	N89W	88SW	216	020	015	012	R	EW	IN	IN
085	N54W	90SW	205	013	000	013	R	NW	IN	IN
085	N30E	51NW	005	036	030	036	R	NE	IN	IN
085	N30E	51NW	047	036	042	036	R	NE	IN	IN
085	N30E	51NW	012	036	023	036	R	NE	IN	IN
085	N30E	51NW	107	048	000	036	R	NE	IN	IN
085	N54W	90SW	102	013	000	013	R	NW	IN	IN
085	N54W	90SW	056	013	000	013	R	NW	IN	IN
086	N33E	90NW	046	005	000	005	S	NE	IN	IN
086	N47E	67NW	034	010	000	010	S		IN	IN
086	N47E	67NW	029	008	000	008	S		IN	IN
086	N33E	90NW	026	006	015	006	S	NE	IN	IN
086	N40W	90SW	030	007	000	007	S	NW	IN	IN
086	N40W	90SW	019	007	016	007	S	NW	IN	IN
086	N40W	90SW	013	007	000	007	S	NW	IN	IN
087	N87W	90SW	008	020	018	010	SC	EW	IN	IN
087	N51W	90SW	034	033	000	013	SC	NW	IN	IN
087	N87W	90SW	022	005	008	005	SC	EW	IN	IN
087	N87W	90SW	015	007	012	007	SC	EW	IN	IN
087	N87W	90SW	015	009	024	009	SC	EW	IN	IN
087	N87W	90SW	005	010	038	011	SC	EW	IN	IN
087	N87W	90SW	014	010	009	010	SC	EW	IN	IN
087	N87W	90SW	007	005	017	007	SC	EW	IN	IN
087	N87W	90SW	010	007	017	007	SC	EW	IN	IN
087	N87W	90SW	015	013	034	007	SC	EW	IN	IN
087	N87W	90SW	018	003	000	007	SC	EW	IN	IN
087	N51W	90SW	010	070	000	010	SC	NW	IN	IN

STA	STRI	DIP	LNG	DTH	SPA	BED	EX	ST	LO	GR
087	N51W	90SW	010	056	000	010	SC	NW	IN	IN
087	N43W	90SW	070	061	000	010	SC	NW	IN	IN
087	N51W	90SW	197	050	007	015	SC	NW	IN	IN
087	N51W	90SW	040	012	026	012	SC	NW	IN	IN
087	N84E	90NW	182	057	011	007	SC	EW	IN	IN
087	N84E	90NW	085	043	011	007	SC	EW	IN	IN
087	N84E	90NW	063	038	000	007	SC	EW	IN	IN
087	N87W	90SW	047	067	006	007	SC	EW	IN	IN
087	N73W	90SW	124	073	032	006	SC		IN	IN
087	N73W	90SW	117	060	031	006	SC		IN	IN
088	N45W	90SW	050	019	030	019	S	NW	IN	IN
088	N45W	90SW	043	019	033	019	S	NW	IN	IN
088	N45W	90SW	047	019	000	019	S	NW	IN	IN
088	N86W	75SW	142	022	039	022	S	EW	IN	IN
088	N86W	75SW	062	022	031	022	S	EW	IN	IN
088	N86W	75SW	032	020	000	022	S	EW	IN	IN
089	N62W	72SW	060	039	038	039	SC		IN	IN
089	N62W	72SW	077	039	009	039	SC		IN	IN
089	N62W	72SW	045	039	005	039	SC		IN	IN
089	N62W	72SW	035	039	011	039	SC		IN	IN
089	N62W	72SW	064	039	007	039	SC		IN	IN
089	N03E	52NW	060	019	008	019	SC		IN	IN
089	N03E	52NW	043	014	004	007	SC		IN	IN
089	N28E	44NW	025	010	000	007	SC	NE	IN	IN
089	N62W	72SW	040	039	007	039	SC		IN	IN
089	N62W	72SW	038	039	006	039	SC		IN	IN
089	N28E	44NW	015	014	011	014	SC	NE	IN	IN
089	N28E	44NW	010	008	008	008	SC	NE	IN	IN
089	N28E	44NW	020	005	001	005	SC	NE	IN	IN
090	N43W	90SW	020	009	003	009	SC	NW	IN	IN
090	N43W	90SW	016	009	009	009	SC	NW	IN	IN
090	N43W	90SW	011	009	003	009	SC	NW	IN	IN
090	N43W	90SW	012	009	010	009	SC	NW	IN	IN
090	N43W	90SW	018	017	005	009	SC	NW	IN	IN
090	N43W	90SW	018	013	006	009	SC	NW	IN	IN
090	N43W	90SW	018	017	010	009	SC	NW	IN	IN
090	N43W	90SW	018	013	014	009	SC	NW	IN	IN
090	N43W	90SW	010	017	007	009	SC	NW	IN	IN
090	N43W	90SW	012	017	015	009	SC	NW	IN	IN
090	N43W	90SW	010	017	013	009	SC	NW	IN	IN
090	N43W	90SW	010	017	010	009	SC	NW	IN	IN
091	N36W	87SW	180	025	068	025	S	NW	IN	IN
091	N36W	87SW	130	025	025	025	S	NW	IN	IN
091	N36W	87SW	103	025	012	025	S	NW	IN	IN
091	N36W	87SW	090	025	039	025	S	NW	IN	IN
091	N36W	87SW	087	025	014	025	S	NW	IN	IN
091	N36W	87SW	085	025	040	025	S	NW	IN	IN

<u>STA</u>	<u>STRI</u>	<u>DIP</u>	<u>LNG</u>	<u>DTH</u>	<u>SPA</u>	<u>BED</u>	<u>EX</u>	<u>ST</u>	<u>LO</u>	<u>GR</u>
091	N36W	87SW	080	025	055	025	S	NW	IN	IN
092	N55W	74SW	017	007	016	007	SC	NW	IN	IN
092	N55W	74SW	020	007	000	007	SC	NW	IN	IN
092	N55W	74SW	005	002	022	002	SC	NW	IN	IN
092	N55W	74SW	005	002	000	002	SC	NW	IN	IN
092	N87E	90NW	051	030	004	004	SC	EW	IN	IN
093	N25E	90NW	206	005	029	005	SC	NE	IN	IN
093	N25E	90NW	174	005	043	005	SC	NE	IN	IN
093	N25E	90NW	355	012	000	005	SC	NE	IN	IN
093	N25E	90NW	089	015	020	010	SC	NE	IN	IN
093	N49W	88SW	039	013	000	013	SC	NW	IN	IN
093	N40W	72SW	043	012	000	012	SC	NW	IN	IN
093	N40W	72SW	031	012	005	012	SC	NW	IN	IN
093	N40W	72SW	011	012	013	012	SC	NW	IN	IN
093	N85W	84SW	021	006	000	006	SC	EW	IN	IN
093	N85W	84SW	043	015	023	015	SC	EW	IN	IN
093	N40W	72SW	010	005	017	005	SC	NW	IN	IN
093	N40W	72SW	014	007	015	008	SC	NW	IN	IN
093	N40W	72SW	011	007	010	008	SC	NW	IN	IN
093	N40W	72SW	008	007	008	009	SC	NW	IN	IN
093	N40W	72SW	004	007	016	010	SC	NW	IN	IN
094	N76W	80SW	020	010	043	010	S		IN	IN
094	N76W	80SW	015	010	050	010	S		IN	IN
094	N76W	80SW	020	010	055	010	S		IN	IN
094	N76W	80SW	022	009	017	009	S		IN	IN
094	N35E	78NW	050	010	015	010	S	NE	IN	IN
095	N36W	84SW	320	014	006	014	R	NW	IN	IN
095	N36W	84SW	340	015	000	015	R	NW	IN	IN
095	N36W	84SW	310	008	000	008	R	NW	IN	IN
095	N36W	84SW	010	010	040	010	R	NW	IN	IN
096	N43W	88SW	073	005	000	005	R	NW	IN	IN
096	N25E	90NW	015	008	026	008	R	NE	IN	IN
096	N25E	90NW	024	008	021	008	R	NE	IN	IN
096	N43W	88SW	050	007	000	007	R	NW	IN	IN
097	N76E	74NW	242	102	008	102	R		IN	IN
097	N76E	74NW	171	102	000	102	R		IN	IN
097	N76E	74NW	190	039	004	039	R		IN	IN
097	N76E	74NW	187	015	000	015	R		IN	IN
098	N84E	75NW	078	026	003	016	R	EW	IN	IN
098	N84E	75NW	196	021	000	011	R	EW	IN	IN
098	N84E	75NW	132	007	000	007	R	EW	IN	IN
098	N84E	75NW	106	007	000	007	R	EW	IN	IN
098	N40E	68NW	053	013	008	013	R	NE	IN	IN
098	N40E	68NW	045	013	007	013	R	NE	IN	IN
099	N10W	69SW	110	046	014	046	R		IN	IN
099	N10W	69SW	040	046	000	046	R		IN	IN
099	N45W	90SW	055	072	000	072	R	NW	IN	IN

STA	STRI	DIP	LNG	DTH	SPA	BED	EX	ST	LO	GR
099	N45W	90SW	016	046	048	046	R	NW	IN	IN
100	N72W	76SW	224	011	000	011	R		IN	IN
100	N72W	76SW	133	017	000	017	R		IN	IN
101	N33W	70SW	019	006	012	006	R		IN	IN
101	N33W	70SW	021	006	000	006	R		IN	IN
101	N42E	86NW	031	006	023	006	R	NE	IN	IN
101	N42E	86NW	041	010	000	010	R	NE	IN	IN
101	N77E	90NW	051	008	000	008	R		IN	IN
101	N65W	87SW	094	023	004	023	R		IN	IN
101	N65W	87SW	096	043	000	023	R		IN	IN
102	N41W	85SW	084	014	032	005	S	NW	IN	IN
102	N41W	85SW	109	013	052	005	S	NW	IN	IN
102	N41W	85SW	045	005	008	005	S	NW	IN	IN
102	N41W	85SW	109	005	013	007	S	NW	IN	IN
102	N41W	85SW	034	012	036	007	S	NW	IN	IN
102	N41W	85SW	108	015	000	015	S	NW	IN	IN
102	N87W	84SW	142	023	042	023	S	EW	IN	IN
102	N87W	84SW	035	012	012	012	S	EW	IN	IN
102	N87W	84SW	024	012	019	012	S	EW	IN	IN
102	N87W	84SW	048	014	054	014	S	EW	IN	IN
102	N87W	84SW	092	021	000	021	S	EW	IN	IN
102	N41W	85SW	174	011	025	006	S	NW	IN	IN
102	N41W	85SW	153	013	012	006	S	NW	IN	IN
102	N41W	85SW	085	009	032	006	S	NW	IN	IN
102	N41W	85SW	174	013	038	006	S	NW	IN	IN
102	N87W	84SW	092	010	051	010	S	EW	IN	IN
102	N87W	84SW	095	009	040	009	S	EW	IN	IN
102	N87W	84SW	057	005	034	009	S	EW	IN	IN
103	N38W	84SW	014	008	007	008	S	NW	IN	IN
103	N38W	84SW	013	008	012	008	S	NW	IN	IN
103	N38W	84SW	023	007	009	007	S	NW	IN	IN
103	N38W	84SW	017	007	011	007	S	NW	IN	IN
103	N38W	84SW	013	008	000	008	S	NW	IN	IN
103	N38W	84SW	010	010	009	010	S	NW	IN	IN
103	N38W	84SW	012	010	008	010	S	NW	IN	IN
103	N38W	84SW	016	010	010	010	S	NW	IN	IN
103	N85E	58NW	022	006	008	006	S	EW	IN	IN
103	N85E	58NW	015	014	006	006	S	EW	IN	IN
103	N85E	58NW	011	007	003	003	S	EW	IN	IN
103	N85E	58NW	005	004	009	006	S	EW	IN	IN
104	N42W	86SW	057	012	012	012	S	NW	IN	IN
104	N42W	86SW	030	012	014	012	S	NW	IN	IN
104	N42W	86SW	039	009	007	009	S	NW	IN	IN
104	N42W	86SW	053	009	010	009	S	NW	IN	IN
104	N42W	86SW	058	009	007	009	S	NW	IN	IN
104	N42W	86SW	115	007	032	007	S	NW	IN	IN
104	N42W	86SW	042	008	004	008	S	NW	IN	IN

STA	STRI	DIP	LNG	DTH	SPA	BED	EX	ST	LO	GR
104	N42W	86SW	021	008	006	008	S	NW	IN	IN
105	N77W	75SW	045	023	015	023	S		IN	IN
105	N77W	75SW	016	023	000	023	S		IN	IN
105	N44W	85SW	023	022	040	022	S	NW	IN	IN
105	N44W	85SW	020	022	040	022	S	NW	IN	IN
105	N44W	85SW	010	014	025	014	S	NW	IN	IN
105	N44W	85SW	023	012	016	012	S	NW	IN	IN
105	N44W	85SW	012	012	012	012	S	NW	IN	IN
105	N44W	85SW	015	022	029	022	S	NW	IN	IN
105	N44W	85SW	016	018	023	018	S	NW	IN	IN
105	N44W	85SW	030	016	009	016	S	NW	IN	IN
105	N44W	85SW	038	023	019	012	S	NW	IN	IN
105	N44W	85SW	035	023	016	012	S	NW	IN	IN
105	N44W	85SW	015	020	000	012	S	NW	IN	IN
106	N51W	82SW	050	025	011	025	S	NW	IN	IN
106	N51W	82SW	101	025	010	025	S	NW	IN	IN
106	N51W	82SW	240	025	019	025	S	NW	IN	IN
106	N51W	82SW	111	015	014	015	S	NW	IN	IN
106	N51W	82SW	099	007	005	007	S	NW	IN	IN
106	N51W	82SW	097	007	004	007	S	NW	IN	IN
106	N51W	82SW	089	007	015	007	S	NW	IN	IN
106	N51W	82SW	078	007	011	007	S	NW	IN	IN
106	N32E	58NW	130	025	000	025	S	NE	IN	IN
106	N32E	58NW	050	015	000	015	S	NE	IN	IN
106	N01E	58NW	026	007	000	007	S		IN	IN
106	N01E	58NW	019	015	000	015	S		IN	IN
107	N82E	70NW	053	004	006	004	S	EW	IN	IN
107	N82E	70NW	058	015	012	015	S	EW	IN	IN
107	N82E	70NW	030	015	020	015	S	EW	IN	IN
107	N46W	90SW	100	019	034	025	S	NW	IN	IN
107	N46W	90SW	101	007	000	025	S	NW	IN	IN
108	N88W	77SW	055	005	035	005	SC	EW	IN	IN
108	N88W	77SW	047	005	027	005	SC	EW	IN	IN
108	N88W	77SW	055	005	036	005	SC	EW	IN	IN
108	N18W	80SW	033	045	006	045	SC		IN	IN
108	N18W	80SW	073	045	030	045	SC		IN	IN
108	N18W	80SW	065	045	000	045	SC		IN	IN
108	N18W	80SW	075	007	006	007	SC		IN	IN
108	N18W	80SW	052	008	000	008	SC		IN	IN
108	N18W	80SW	062	045	037	045	SC		IN	IN
108	N35E	90NW	044	045	038	045	SC	NE	IN	IN
108	N35E	90NW	010	045	000	045	SC	NE	IN	IN
109	N43W	83SW	044	012	012	012	SC	NW	IN	IN
109	N43W	83SW	058	014	021	014	SC	NW	IN	IN
109	N43W	83SW	055	021	014	021	SC	NW	IN	IN
109	N43W	83SW	042	020	012	020	SC	NW	IN	IN
109	N43W	83SW	020	020	012	020	SC	NW	IN	IN

STA	STRI	DIP	LNG	DTH	SPA	BED	EX	ST	LO	GR
109	N43W	83SW	023	009	003	009	SC	NW	IN	IN
109	N43W	83SW	023	009	009	009	SC	NW	IN	IN
109	N43W	83SW	023	009	003	009	SC	NW	IN	IN
109	N43W	83SW	025	009	007	009	SC	NW	IN	IN
109	N43W	83SW	054	039	008	067	SC	NW	IN	IN
110	N48W	90SW	020	053	020	007	S	NW	IN	IN
110	N48W	90SW	021	054	029	007	S	NW	IN	IN
110	N48W	90SW	005	008	009	008	S	NW	IN	IN
110	N48W	90SW	006	008	004	008	S	NW	IN	IN
110	N48W	90SW	005	008	004	008	S	NW	IN	IN
110	N48W	90SW	005	008	010	008	S	NW	IN	IN
110	N48W	90SW	002	008	008	008	S	NW	IN	IN
110	N48W	90SW	002	008	007	008	S	NW	IN	IN
111	N87W	85SW	144	012	025	012	SC	EW	IN	IN
111	N87W	85SW	152	012	019	012	SC	EW	IN	IN
111	N87W	85SW	178	014	024	014	SC	EW	IN	IN
111	N87W	85SW	195	014	016	014	SC	EW	IN	IN
111	N87W	85SW	117	014	013	014	SC	EW	IN	IN
111	N87W	85SW	025	010	019	010	SC	EW	IN	IN
111	N87W	85SW	057	010	020	010	SC	EW	IN	IN
111	N87W	85SW	049	010	020	01	SC	EW	IN	IN
111	N87W	85SW	070	010	010	010	SC	EW	IN	IN
111	N08E	72NW	020	010	030	010	SC		IN	IN
111	N08E	72NW	020	010	047	010	SC		IN	IN
111	N08E	72NW	010	010	027	010	SC		IN	IN
111	N08E	72NW	022	015	047	015	SC		IN	IN
111	N08E	72NW	013	015	025	015	SC		IN	IN
112	N84W	87SW	728	020	085	020	S	EW	IN	IN
112	N84W	87SW	720	020	123	020	S	EW	IN	IN
112	N84W	87SW	320	022	076	022	S	EW	IN	IN
112	N34W	57SW	085	020	046	020	S		IN	IN
112	N34W	57SW	085	020	053	020	S		IN	IN
112	N34W	57SW	085	020	085	020	S		IN	IN
112	N34W	57SW	123	020	088	020	S		IN	IN
112	N34W	57SW	123	020	164	020	S		IN	IN
112	N84W	87SW	007	022	062	022	S	EW	IN	IN
112	N84W	87SW	340	022	106	022	S	EW	IN	IN
112	N84W	87SW	320	022	052	022	S	EW	IN	IN
112	N84W	87SW	750	022	069	022	S	EW	IN	IN
112	N84W	87SW	720	042	083	042	S	EW	IN	IN
112	N84W	87SW	715	020	177	020	S	EW	IN	IN
113	N50W	90SW	082	010	000	003	S	NW	IN	IN
113	N45W	87SW	180	010	000	010	S	NW	IN	IN
113	N50W	90SW	017	008	007	008	S	NW	IN	IN
113	N50W	90SW	019	008	004	008	S	NW	IN	IN
113	N50W	90SW	034	008	007	008	S	NW	IN	IN
113	N50W	90SW	040	008	003	008	S	NW	IN	IN

<u>STA</u>	<u>STRI</u>	<u>DIP</u>	<u>LNG</u>	<u>DTH</u>	<u>SPA</u>	<u>BED</u>	<u>EX</u>	<u>ST</u>	<u>LO</u>	<u>GR</u>
113	N50W	90SW	009	005	008	003	S	NW	IN	IN
113	N50W	90SW	020	005	006	003	S	NW	IN	IN
114	N87W	85SW	130	010	035	010	S	EW	IN	IN
114	N87W	85SW	063	010	016	010	S	EW	IN	IN
114	N87W	85SW	174	010	021	010	S	EW	IN	IN
114	N87W	85SW	040	010	012	010	S	EW	IN	IN
114	N87W	85SW	102	010	031	010	S	EW	IN	IN
115	N83W	89SW	032	012	025	012	S	EW	IN	IN
115	N83W	89SW	015	012	019	012	S	EW	IN	IN
115	N83W	89SW	015	012	020	012	S	EW	IN	IN
115	N83W	89SW	023	012	010	012	S	EW	IN	IN
115	N83W	89SW	019	012	006	012	S	EW	IN	IN
115	N83W	89SW	017	012	013	012	S	EW	IN	IN
116	N44W	88SW	158	061	029	061	SC	NW	NO	OT
116	N44W	88SW	132	030	058	030	SC	NW	NO	OT
116	N44W	88SW	061	030	000	030	SC	NW	NO	OT
116	N38W	85SW	049	031	018	031	SC	NW	NO	OT
116	N38W	85SW	058	005	000	005	SC	NW	NO	OT
116	N38W	85SW	057	026	044	026	SC	NW	NO	OT
116	N38W	85SW	045	026	000	026	SC	NW	NO	OT
117	N55W	87SW	025	040	010	040	R	NW	NO	OT
117	N55W	87SW	024	040	009	040	R	NW	NO	OT
117	N01W	86SW	020	009	000	009	R		NO	OT
117	N01W	86SW	021	016	000	016	R		NO	OT
117	N55W	87SW	015	012	010	012	R	NW	NO	OT
117	N55W	87SW	019	012	009	012	R	NW	NO	OT
117	N55W	87SW	017	012	008	012	R	NW	NO	OT
117	N55W	87SW	023	012	007	012	R	NW	NO	OT
117	N55W	87SW	015	012	010	012	R	NW	NO	OT
117	N55W	87SW	007	014	017	012	R	NW	NO	OT
117	N55W	87SW	015	042	015	025	R	NW	NO	OT
117	N55W	87SW	012	025	019	025	R	NW	NO	OT
118	N41W	77SW	020	006	016	006	SC	NW	NO	OT
118	N41W	77SW	010	006	011	006	SC	NW	NO	OT
118	N41W	77SW	021	006	008	006	SC	NW	NO	OT
118	N41W	77SW	022	006	004	006	SC	NW	NO	OT
118	N41W	77SW	023	006	003	006	SC	NW	NO	OT
118	N41W	77SW	026	006	004	006	SC	NW	NO	OT
118	N41W	77SW	013	006	009	006	SC	NW	NO	OT
118	N41W	77SW	022	006	007	006	SC	NW	NO	OT
118	N41W	77SW	015	006	008	006	SC	NW	NO	OT
118	N41W	77SW	027	006	004	006	SC	NW	NO	OT
119	N80E	76NW	040	014	006	014	SC	EW	NO	OT
119	N80E	76NW	084	014	018	014	SC	EW	NO	OT
119	N80E	76NW	095	014	018	014	SC	EW	NO	OT
119	N80E	76NW	067	014	024	014	SC	EW	NO	OT
119	N80E	76NW	079	014	017	014	SC	EW	NO	OT

<u>STA</u>	<u>STRI</u>	<u>DIP</u>	<u>LNG</u>	<u>DTH</u>	<u>SPA</u>	<u>BED</u>	<u>EX</u>	<u>ST</u>	<u>LO</u>	<u>GR</u>
119	N80E	76NW	069	014	030	014	SC	EW	NO	OT
119	N80E	76NW	077	014	011	014	SC	EW	NO	OT
119	N80E	76NW	075	014	021	014	SC	EW	NO	OT
119	N44E	44NW	079	014	016	014	SC	NE	NO	OT
119	N44E	44NW	091	014	009	014	SC	NE	NO	OT
119	N44E	44NW	138	014	014	014	SC	NE	NO	OT
119	N44E	44NW	179	014	008	014	SC	NE	NO	OT
119	N44E	44NW	202	014	005	014	SC	NE	NO	OT
119	N44E	44NW	203	014	030	014	SC	NE	NO	OT
120	N83E	90NW	083	016	026	016	S	EW	NO	OT
120	N83E	90NW	058	016	028	016	S	EW	NO	OT
120	N83E	90NW	053	016	048	016	S	EW	NO	OT
120	N83E	90NW	046	016	015	016	S	EW	NO	OT
120	N83E	90NW	046	025	028	025	S	EW	NO	OT
120	N83E	90NW	062	025	039	025	S	EW	NO	OT
120	N83E	90NW	032	025	003	025	S	EW	NO	OT
120	N83E	90NW	019	025	022	025	S	EW	NO	OT
120	N83E	90NW	044	025	036	025	S	EW	NO	OT
120	N32W	87SW	054	012	030	012	S		NO	OT
120	N32W	87SW	058	012	013	012	S		NO	OT
120	N32W	87SW	065	012	026	012	S		NO	OT
120	N32W	87SW	057	012	018	012	S		NO	OT
120	N32W	87SW	025	012	027	012	S		NO	OT
120	N32W	87SW	030	012	015	012	S		NO	OT
121	N85W	80SW	005	012	036	012	R	EW	NO	OT
121	N85W	80SW	047	012	025	012	R	EW	NO	OT
121	N85W	80SW	003	014	010	014	R	EW	NO	OT
121	N85W	80SW	010	014	024	014	R	EW	NO	OT
121	N85W	80SW	019	014	035	014	R	EW	NO	OT
121	N35E	80NW	015	019	020	019	R	NE	NO	OT
121	N35E	80NW	013	019	008	019	R	NE	NO	OT
121	N35E	80NW	012	015	012	015	R	NE	NO	OT
123	N80E	90NW	035	022	033	022	S	EW	NO	OT
123	N80E	90NW	050	022	038	022	S	EW	NO	OT
123	N80E	90NW	028	022	058	022	S	EW	NO	OT
123	N03E	90NW	033	022	035	022	S		NO	OT
123	N03E	90NW	038	022	050	022	S		NO	OT
123	N03E	90NW	058	022	028	022	S		NO	OT
123	N47W	90SW	070	012	038	012	S	NW	NO	OT
123	N47W	90SW	034	012	041	012	S	NW	NO	OT
123	N47W	90SW	057	012	008	012	S	NW	NO	OT
123	N27E	90NW	021	012	038	012	S	NE	NO	OT
123	N27E	90NW	016	012	017	012	S	NE	NO	OT
123	N27E	90NW	018	012	027	012	S	NE	NO	OT
124	N42W	87SW	115	014	025	014	S	NW	NO	OT
124	N42W	87SW	106	014	036	014	S	NW	NO	OT
124	N4E	90NW	190	020	025	007	S		NO	OT

<u>STA</u>	<u>STRI</u>	<u>DIP</u>	<u>LNG</u>	<u>DTH</u>	<u>SPA</u>	<u>BED</u>	<u>EX</u>	<u>ST</u>	<u>LO</u>	<u>GR</u>
124	N42W	87SW	075	007	000	007	S	NW	NO	OT
124	N42W	87SW	078	010	015	010	S	NW	NO	OT
124	N42W	87SW	055	010	047	010	S	NW	NO	OT
124	N42W	87SW	038	019	035	019	S	NW	NO	OT
124	N42W	87SW	042	019	031	019	S	NW	NO	OT
124	N42W	87SW	065	019	042	019	S	NW	NO	OT
124	N42W	87SW	069	019	028	019	S	NW	NO	OT
124	N42W	87SW	070	019	025	019	S	NW	NO	OT
124	N42W	87SW	350	035	018	020	S	NW	NO	OT
125	N87E	90NW	196	007	036	007	S	EW	NO	OT
125	N87E	90NW	134	007	024	007	S	EW	NO	OT
125	N87E	90NW	158	007	020	007	S	EW	NO	OT
125	N87E	90NW	152	007	022	007	S	EW	NO	OT
125	N87E	90NW	152	007	021	007	S	EW	NO	OT
125	N87E	90NW	127	073	047	025	S	EW	NO	OT
125	N87E	90NW	097	077	042	025	S	EW	NO	OT
125	N87E	90NW	180	074	032	025	S	EW	NO	OT
126	N87W	85SW	546	270	030	020	SC	EW	NO	OT
126	N87W	85SW	584	240	029	020	SC	EW	NO	OT
126	N87W	85SW	042	020	023	020	SC	EW	NO	OT
126	N35E	85NW	020	035	025	007	SC	NE	NO	OT
126	N35E	85NW	005	007	027	007	SC	NE	NO	OT
126	N35E	85NW	004	007	009	007	SC	NE	NO	OT
126	N35E	85NW	003	007	016	007	SC	NE	NO	OT
126	N35E	85NW	005	007	010	007	SC	NE	NO	OT
127	N85W	90SW	063	007	033	007	S	EW	NO	OT
127	N85W	90SW	030	007	040	007	S	EW	NO	OT
127	N85W	90SW	033	007	020	007	S	EW	NO	OT
127	N85W	90SW	028	007	026	007	S	EW	NO	OT
128	N05E	90NW	074	024	012	024	SC		NO	OT
128	N05E	90NW	055	024	010	024	SC		NO	OT
128	N05E	90NW	012	024	038	024	SC		NO	OT
128	N63W	90SW	035	024	001	024	SC		NO	OT
128	N63W	90SW	014	024	075	024	SC		NO	OT
128	N63W	90SW	023	024	018	024	SC		NO	OT
128	N63W	90SW	022	024	072	024	SC		NO	OT
128	N63W	90SW	015	011	023	007	SC		NO	OT
128	N63W	90SW	013	011	030	007	SC		NO	OT
128	N63W	90SW	021	011	027	007	SC		NO	OT
128	N69W	90SW	106	033	059	033	SC		NO	OT
128	N69W	90SW	074	033	071	033	SC		NO	OT
128	N69W	90SW	150	036	058	033	SC		NO	OT
128	N69W	90SW	135	036	081	033	SC		NO	OT
128	N69W	90SW	150	033	069	033	SC		NO	OT
128	N69W	90SW	083	033	043	033	SC		NO	OT
128	N37W	85SW	030	035	009	019	SC	NW	NO	OT
128	N37W	85SW	027	035	005	019	SC	NW	NO	OT

STA	STRI	DIP	LNG	DTH	SPA	BED	EX	ST	LO	GR
128	N37W	85SW	007	016	026	016	SC	NW	NO	OT
128	N37W	85SW	018	016	019	016	SC	NW	NO	OT
128	N37W	85SW	027	020	030	020	SC	NW	NO	OT
128	N37E	79NW	147	093	120	004	SC	NE	NO	OT
128	N37E	79NW	180	112	072	004	SC	NE	NO	OT
128	N37E	79NW	130	110	000	004	SC	NE	NO	OT
128	N37E	79NW					SC	NE	NO	OT
129	N73W	60SW	020	017	016	017	S		NO	OT
129	N73W	60SW	010	017	016	017	S		NO	OT
129	N73W	60SW	010	017	000	017	S		NO	OT
129	N73W	60SW	010	029	005	029	S		NO	OT
129	N73W	60SW	001	029	013	029	S		NO	OT
129	N73W	60SW	006	029	018	029	S		NO	OT
130	N35W	90SW	075	008	020	008	S	NW	NO	OT
130	N35W	90SW	089	008	007	008	S	NW	NO	OT
130	N35W	90SW	120	008	023	008	S	NW	NO	OT
130	N35W	90SW	099	008	012	008	S	NW	NO	OT
130	N35W	90SW	039	008	016	008	S	NW	NO	OT
130	N35W	90SW	104	008	018	008	S	NW	NO	OT
130	N35W	90SW	109	008	008	008	S	NW	NO	OT
130	N35W	90SW	121	008	023	008	S	NW	NO	OT
130	N35W	90SW	083	008	028	008	S	NW	NO	OT
130	N40E	88NW	182	008	033	008	S	NE	NO	OT
130	N40E	88NW	197	008	034	008	S	NE	NO	OT
130	N40E	88NW	184	008	031	008	S	NE	NO	OT
130	N40E	88NW	098	008	000	008	S	NE	NO	OT
131	N53W	90SW	118	055	032	001	SC	NW	NO	OT
131	N53W	90SW	079	055	000	001	SC	NW	NO	OT
131	N53W	90SW	101	012	024	012	SC	NW	NO	OT
131	N53W	90SW	027	012	032	012	SC	NW	NO	OT
131	N53W	90SW	043	012	016	012	SC	NW	NO	OT
131	N53W	90SW	041	012	044	012	SC	NW	NO	OT
131	N53W	90SW	050	012	029	012	SC	NW	NO	OT
131	N53W	90SW	041	012	025	012	SC	NW	NO	OT
131	N53W	90SW	037	012	036	012	SC	NW	NO	OT
131	N53W	90SW	064	012	034	012	SC	NW	NO	OT
131	N53W	90SW	081	012	032	012	SC	NW	NO	OT
131	N53W	90SW	090	012	028	012	SC	NW	NO	OT
131	N53W	90SW	210	156	021	012	SC	NW	NO	OT
131	N53W	90SW	075	075	054	012	SC	NW	NO	OT
131	N53W	90SW	052	063	019	012	SC	NW	NO	OT
131	N53W	90SW	116	056	090	012	SC	NW	NO	OT
131	N53W	90SW	210	124	019	012	SC	NW	NO	OT
131	N53W	90SW	055	052	018	012	SC	NW	NO	OT
131	N53W	90SW	035	061	008	012	SC	NW	NO	OT
131	N53W	90SW	426	170	000	012	SC	NW	NO	OT
132	N58W	83SW	035	027	073	027	SC		NO	OT

<u>STA</u>	<u>STRI</u>	<u>DIP</u>	<u>LNG</u>	<u>DTH</u>	<u>SPA</u>	<u>BED</u>	<u>EX</u>	<u>ST</u>	<u>LO</u>	<u>GR</u>
132	N58W	83SW	023	027	070	027	SC		NO	OT
132	N58W	83SW	036	027	060	027	SC		NO	OT
132	N58W	83SW	056	027	014	027	SC		NO	OT
132	N58W	83SW	020	027	065	027	SC		NO	OT
132	N58W	83SW	029	027	020	027	SC		NO	OT
132	N58W	83SW	036	027	062	027	SC		NO	OT
132	N58W	83SW	009	040	033	027	SC		NO	OT
132	N58W	83SW	001	027	024	027	SC		NO	OT
132	N58W	83SW	007	027	026	027	SC		NO	OT
132	N58W	83SW	001	027	021	027	SC		NO	OT
132	N58W	83SW	001	027	032	027	SC		NO	OT
132	N40E	79NW	027	016	017	016	SC	NE	NO	OT
132	N40E	79NW	039	016	037	016	SC	NE	NO	OT
132	N40E	79NW	018	016	016	016	SC	NE	NO	OT
132	N40E	79NW	016	017	025	017	SC	NE	NO	OT
132	N40E	79NW	054	017	027	017	SC	NE	NO	OT
133	N84W	82SW	064	012	004	004	S	EW	NO	OT
133	N84W	82SW	030	004	019	004	S	EW	NO	OT
133	N61W	90SW	194	016	040	016	S		NO	OT
133	N61W	90SW	182	016	007	016	S		NO	OT
133	N61W	90SW	085	020	027	016	S		NO	OT
133	N61W	90SW	084	020	029	016	S		NO	OT
133	N61W	90SW	050	016	033	016	S		NO	OT
133	N61W	90SW	174	016	053	016	S		NO	OT
134	N48W	88SW	065	007	014	007	S	NW	NO	OT
134	N48W	88SW	063	007	055	007	S	NW	NO	OT
134	N48W	88SW	031	007	026	007	S	NW	NO	OT
134	N48W	88SW	053	007	026	007	S	NW	NO	OT
134	N48W	88SW	032	007	029	007	S	NW	NO	OT
134	N48W	88SW	043	007	041	007	S	NW	NO	OT
135	N80E	86NW	054	109	019	005	SC	EW	NO	OT
135	N80E	86NW	025	095	002	009	SC	EW	NO	OT
135	N80E	86NW	077	234	013	009	SC	EW	NO	OT
135	N80E	86NW	033	126	012	009	SC	EW	NO	OT
135	N80E	86NW	035	049	011	006	SC	EW	NO	OT
135	N80E	86NW	022	073	010	006	SC	EW	NO	OT
135	N80E	86NW	042	104	021	008	SC	EW	NO	OT
135	N80E	86NW	012	041	015	005	SC	EW	NO	OT
135	N04W	79SW	067	010	005	001	SC		NO	OT
135	N45W	88SW	059	016	036	016	SC	NW	NO	OT
135	N45W	88SW	049	016	005	016	SC	NW	NO	OT
135	N45W	88SW	040	015	031	015	SC	NW	NO	OT
135	N45W	88SW	032	014	076	014	SC	NW	NO	OT
135	N45W	88SW	050	011	006	011	SC	NW	NO	OT
135	N45W	88SW	084	013	048	013	SC	NW	NO	OT
135	N25W	87SW	068	006		001	SC		NO	OT
135	N06E	75NW	155	012	020	012	SC		NO	OT

STA	STRI	DIP	LNG	DTH	SPA	BED	EX	ST	LO	GP
135	N06E	75NW	071	015	023	015	SC		NO	OT
135	N06E	75NW	065	017		017	SC		NO	OT
135	N80E	86NW	110	030	038	001	SC	EW	NO	OT
135	N80E	86NW	104	027	013	001	SC	EW	NO	OT
135	N80E	86NW	057	018	023	001	SC	EW	NO	OT
135	N80E	86NW	074	084	011	001	SC	EW	NO	OT
135	N80E	86NW	213	096	015	001	SC	EW	NO	OT
135	N80E	86NW	179	075	025	001	SC	EW	NO	OT
136	N70W	75NE	146	020	022	009	S		NO	OT
136	N70W	75NE	023	003	017	003	S		NO	OT
136	N70W	75NE	176	013	035	003	S		NO	OT
136	N70W	75NE	123	023	036	007	S		NO	OT
136	N70W	75NE	079	006	029	006	S		NO	OT
136	N70W	75NE	065	009	028	006	S		NO	OT
137	N78W	90SW	103	014	007	014	S		NO	OT
137	N78W	90SW	126	024	021	024	S		NO	OT
137	N78W	90SW	043	032	014	012	S		NO	OT
137	N78W	90SW	103	023	016	013	S		NO	OT
137	N78W	90SW	001	015	016	016	S		NO	OT
137	N78W	90SW	031	043	013	020	S		NO	OT
138	N80E	82NW	087	111	057	111	S	EW	SO	OT
138	N80E	82NW	079	062	012	062	S	EW	SO	OT
138	N80E	82NW	030	025	021	062	S	EW	SO	OT
138	N80E	82NW	128	083		083	S	EW	SO	OT
138	N46W	86NE	052	060		060	S	NW	SO	OT
138	N04W	67SW	056	064	038	112	S		SO	OT
138	N15W	78SW	029	063	020	063	S		SO	OT
138	N15W	78SW	072	053	032	053	S		SO	OT
138	N80E	82NW	020	033	010	001	S	EW	SO	OT
138	N80E	82NW	008	030	003	001	S	EW	SO	OT
138	N80E	82NW	010	025	010	001	S	EW	SO	OT
139	N55W	80SW	294	011	064	001	S	NW	SO	OT
139	N55W	80SW	183	005	032	001	S	NW	SO	OT
139	N55W	80SW	031	002	032	001	S	NW	SO	OT
139	N55W	80SW	037	003	022	001	S	NW	SO	OT
139	N55W	80SW	030	018	029	018	S	NW	SO	OT
139	N55W	80SW	045	008	008	008	S	NW	SO	OT
139	N55W	80SW	063	018	008	018	S	NW	SO	OT
139	N55W	80SW	104	008	043	008	S	NW	SO	OT
139	N55W	80SW	091	015	034	015	S	NW	SO	OT
139	N72E	85SE	062	024	030	024	S		SO	OT
139	N72E	85SE	062	021	019	018	S		SO	OT
139	N72E	85SE	082	023	010	005	S		SO	OT
140	N87E	85NW	540	010	068	001	S	EW	SO	OT
140	N87E	85NW	429	010	012	001	S	EW	SO	OT
140	N87E	85NW	092	012	127	001	S	EW	SO	OT
140	N87E	85NW	364	016	087	001	S	EW	SO	OT

<u>STA</u>	<u>STRI</u>	<u>DIP</u>	<u>LNG</u>	<u>DTH</u>	<u>SPA</u>	<u>BED</u>	<u>EX</u>	<u>ST</u>	<u>LO</u>	<u>GR</u>
140	N87E	85NW	134	001	007	001	S	EW	SO	OT
140	N87E	85NW	182	003	024	001	S	EW	SO	OT
140	N87E	85NW	163	005		001	S	EW	SO	OT
140	N03E	84SE	084	012	028	001	S		SO	OT
140	N03E	84SE	070	007	050	001	S		SO	OT
140	N03E	84SE	136	006	014	001	S		SO	OT
140	N87E	85NW	268	025	003	001	S	EW	SO	OT
140	N87E	85NW	182	019	008	001	S	EW	SO	OT
140	N87E	85NW	204	022	027	001	S	EW	SO	OT
140	N87E	85NW	255	027	095	001	S	EW	SO	OT
140	N87E	85NW	246	025	083	001	S	EW	SO	OT
140	N87E	85NW	217	024	008	001	S	EW	SO	OT
140	N87E	85NW	229	025	010	001	S	EW	SO	OT
140	N87E	85NW	242	025	114	001	S	EW	SO	OT
141	N67W	90SW	180	009	027	009	S		SO	OT
141	N67W	90SW	214	009	030	009	S		SO	OT
141	N67W	90SW	131	009	043	009	S		SO	OT
141	N67W	90SW	108	009	026	009	S		SO	OT
141	N67W	90SW	224	009	015	009	S		SO	OT
141	N67W	90SW	224	009	027	009	S		SO	OT
141	N67W	90SW	182	009	017	009	S		SO	OT
141	N67W	90SW	156	009	016	009	S		SO	OT
141	N67W	90SW	130	009	014	009	S		SO	OT
141	N67W	90SW	100	009	019	009	S		SO	OT
141	N67W	90SW	077	009	009	009	S		SO	OT
141	N67W	90SW	069	009	011	009	S		SO	OT
141	N67W	90SW	065	009	013	009	S		SO	OT
141	N30E	90NW	071	005	048	005	S	NE	SO	OT
141	N30E	90NW	073	005	044	005	S	NE	SO	OT
141	N30E	90NW	302	012	052	012	S	NE	SO	OT
141	N30E	90NW	352	012	030	012	S	NE	SO	OT
141	N30E	90NW	260	012	021	012	S	NE	SO	OT
141	N30E	90NW	134	012	042	012	S	NE	SO	OT
141	N30E	90NW	093	012		012	S	NE	SO	OT
142	N83E	83SE	073	005	012	005	S	EW	SO	OT
142	N83E	83SE	067	005	062	005	S	EW	SO	OT
142	N83E	83SE	107		072		S	EW	SO	OT
142	N83E	83SE	093		015		S	EW	SO	OT
142	N83E	83SE	134		043		S	EW	SO	OT
142	N83E	83SE	087		049		S	EW	SO	OT
142	N83E	83SE	088		084		S	EW	SO	OT
142	N83E	83SE	102		042		S	EW	SO	OT
142	N83E	83SE	080		051		S	EW	SO	OT
142	N83E	83SE	131		031		S	EW	SO	OT
142	N83E	83SE	112		039		S	EW	SO	OT
142	N83E	83SE	111		039		S	EW	SO	OT
142	N83E	83SE	103		058		S	EW	SO	OT

STA	STRI	DIP	LNG	DTH	SPA	BED	EX	ST	LO	GR
142	N83E	83SE	094		060		S	EW	SO	OT
142	N83E	83SE	110		045		S	EW	SO	OT
142	N83E	83SE	125		039		S	EW	SO	OT
142	N13W	73SW	063		010		S		SO	OT
142	N13W	73SW	029		013		S		SO	OT
142	N13W	73SW	109		013		S		SO	OT
142	N13W	73SW	141	012	026	012	S		SO	OT
142	N13W	73SW	095		013		S		SO	OT
142	N13W	73SW	064	007	003	007	S		SO	OT
142	N12E	70NW	072	014	019	014	S		SO	OT
142	N12E	70NW	284	011	014	011	S		SO	OT
142	N12E	70NW	141	012	031	012	S		SO	OT
142	N75W	84NE	013	007	031	007	S		SO	OT
142	N75W	84NE	010	010	072	010	S		SO	OT
142	N75W	84NE	030	009	036	009	S		SO	OT
142	N75W	84NE	017	009	029	009	S		SO	OT
142	N75W	84NE	011	009	036	009	S		SO	OT
143	N45W	64SW	030	007	012	007	S	NW	SO	OT
143	N45W	64SW	027	007	011	007	S	NW	SO	OT
143	N45W	64SW	041	007	016	007	S	NW	SO	OT
143	N45W	64SW	029	007	006	007	S	NW	SO	OT
143	N45W	64SW	057	011	037	011	S	NW	SO	OT
143	N45W	64SW	023	011	013	011	S	NW	SO	OT
143	N45W	64SW	025	011	027	011	S	NW	SO	OT
143	N45W	64SW	056	020	042	020	S	NW	SO	OT
143	N68E	75NW	042	007	028	007	S		SO	OT
143	N68E	75NW	018	007	029	007	S		SO	OT
143	N68E	75NW	052	007	023	007	S		SO	OT
143	N68E	75NW	032	020	011	020	S		SO	OT
143	N65W	84SW	034	011	026	011	S		SO	OT
143	N65W	84SW	016	011	012	011	S		SO	OT
143	N65W	84SW	042	007	017	007	S		SO	OT
143	N65W	84SW	031	005	034	005	S		SO	OT
143	N65W	84SW	057	007	025	007	S		SO	OT
143	N65W	84SW	025	017	023	017	S		SO	OT
143	N65W	84SW	038	017	010	017	S		SO	OT
143	N65W	84SW	036	015	012	015	S		SO	OT
144	N28E	90NW	120		018		S	NE	BR	OT
144	N28E	90NW	134		019		S	NE	BR	OT
144	N28E	90NW	172		024		S	NE	BR	OT
144	N28E	90NW	234		023		S	NE	BR	OT
144	N28E	90NW	186		023		S	NE	BR	OT
144	N28E	90NW	100		016		S	NE	BR	OT
144	N28E	90NW	089		014		S	NE	BR	OT
144	N28E	90NW	115		012		S	NE	BR	OT
144	N28E	90NW	140		013		S	NE	BR	OT
144	N46W	90SW	045		082		S	NW	BR	OT

STA	STRI	DIP	LNG	DTH	SPA	BED	EX	ST	LO	GR
144	N46W	90SW	130		017		S	NW	BR	OT
144	N46W	90SW	090		017		S	NW	BR	OT
144	N46W	90SW	090		024		S	NW	BR	OT
145	N25E	65SE					S	NE	NO	OT
145	N72W	87NE					S		NO	OT
145	N10E	70SE					S		NO	OT
145	N80E	90NW					S	EW	NO	OT
145	N25E	65SE			070		S	NE	NO	OT
145	N25E	65SE			092		S	NE	NO	OT
145	N25E	65SE			060		S	NE	NO	OT
145	N25E	65SE			035		S	NE	NO	OT
145	N25E	65SE			024		S	NE	NO	OT
145	N25E	65SE			031		S	NE	NO	OT
145	N45W	88SW	058	022	128	022	S	NW	NO	OT
145	N45W	88SW	088	022	103	022	S	NW	NO	OT
145	N45W	88SW	020	020	032	020	S	NW	NO	OT
145	N45W	88SW	030	020	090	020	S	NW	NO	OT
145	N45W	88SW	012	020	071	020	S	NW	NO	OT
146	N70W	86SW	070	048	027	012	S		NO	OT
146	N70W	86SW	016	010	042	010	S		NO	OT
146	N70W	86SW	089	010	010	010	S		NO	OT
146	N70W	86SW	083	010		010	S		NO	OT
146	N70W	86SW	045	020	015	005	S		NO	OT
146	N70W	86SW	040	016	067	003	S		NO	OT
146	N70W	86SW	059	014	036	003	S		NO	OT
146	N70W	86SW	065	012	038	003	S		NO	OT
146	N84W	80NE	052	020	068	020	S	EW	NO	OT
146	N84W	80NE	076	041	049	020	S	EW	NO	OT
146	N84W	80NE	063	015	019	015	S	EW	NO	OT
146	N70W	86SW	068	014	035	014	S		NO	OT
146	N70W	86SW	057	014	074	014	S		NO	OT
146	N84W	80NE	080	022	028	022	S	EW	NO	OT
146	N84W	86NE	070	012	014	012	S	EW	NO	OT
146	N84W	80NE	061	012	019	012	S	EW	NO	OT
146	N84W	86NE	073	006	021	006	S	EW	NO	OT
146	N84W	86NE	062	012	048	012	S	EW	NO	OT
146	N70W	86SW	098	022	089	022	S		NO	OT
147	N85W	78NE	070	030	037	030	S	EW	NO	OT
147	N85W	78NE	061	030	043	030	S	EW	NO	OT
147	N85W	78NE	052	030	038	030	S	EW	NO	OT
147	N85W	78NE	032	030	033	030	S	EW	NO	OT
147	N85W	78NE	028	030	031	030	S	EW	NO	OT
147	N85W	78NE	044	030	028	030	S	EW	NO	OT
147	N85W	78NE	056	030	032	030	S	EW	NO	OT
147	N85W	78NE	083	030	043	030	S	EW	NO	OT
147	N85W	78NE	079	030	055	030	S	EW	NO	OT
147	N85W	78NE	075	030	027	030	S	EW	NO	OT

STA	STRI	DIP	LNG	DTH	SPA	BED	EX	ST	LO	GR
147	N85W	78NE	082	030	027	030	S	EW	NO	OT
147	N65W	90SW	013	022	013	022	S		NO	OT
147	N65W	90SW	032	022	013	022	S		NO	OT
148	N80E	90NW	039	025	027	007	S	EW	NO	OT
148	N80E	90NW	079	045	021	009	S	EW	NO	OT
148	N80E	90NW	029	028	016	009	S	EW	NO	OT
148	N80E	90NW	025	015	007	009	S	EW	NO	OT
148	N80E	90NW	039	012	020	009	S	EW	NO	OT
148	N80E	90NW	007	007	020	007	S	EW	NO	OT
148	N80E	90NW	031	007	019	007	S	EW	NO	OT
148	N43W	87SW	024	006	006	006	S	NW	NO	OT
148	N43W	87SW	021	006	009	006	S	NW	NO	OT
148	N43W	87SW	030	006	015	006	S	NW	NO	OT
148	N43W	87SW	069	022	012	022	S	NW	NO	OT
148	N43W	87SW	061	012	013	012	S	NW	NO	OT
148	N43W	87SW	050	012	012	012	S	NW	NO	OT
149	N44W	85NE	025	012	009	012	S	NW	NO	OT
149	N44W	85NE	022	012	018	012	S	NW	NO	OT
149	N44W	85NE	016	012	014	012	S	NW	NO	OT
149	N44W	85NE	032	012	013	012	S	NW	NO	OT
149	N44W	85NE	033	012	011	012	S	NW	NO	OT
149	N44W	85NE	023	012	015	012	S	NW	NO	OT
149	N44W	85NE	029	012	016	012	S	NW	NO	OT
149	N44W	85NE	035	012	007	012	S	NW	NO	OT
149	N44W	85NE	028	012	013	012	S	NW	NO	OT
149	N44W	85NE	025	012		012	S	NW	NO	OT
149	N60W	41SW	027	020	016	007	S		NO	OT
149	N60W	41SW	024	020	010	020	S		NO	OT
149	N60W	41SW	018	007	017	007	S		NO	OT
149	N60W	41SW	035	027	036	007	S		NO	OT
149	N60W	41SW	016	037	017	012	S		NO	OT
149	N60W	41SW	021	040	032	012	S		NO	OT

APPENDIX C

STATION LOCATIONS AT THE ALLEGHENY FRONT
(in UTM Grid Coordinates)Key to Abbreviations:

STA - station number

<u>STA</u>	<u>LATITUDE</u>	<u>LONGITUDE</u>
001	4317.020	646.880
002	4317.090	647.220
003	4316.590	647.850
004	4316.560	648.050
005	4324.310	648.460
006	4324.360	648.690
007	4324.870	649.130
008	4318.570	646.500
009	4318.720	647.550
010	4318.660	647.870
011	4318.510	648.280
012	4313.750	645.430
013	4313.470	646.070
014	4313.320	646.300
015	4313.120	646.420
016	4314.670	645.500
017	4314.740	645.640
018	4314.610	646.050
019	4314.460	646.420
020	4314.280	646.640
021	4309.770	644.080
022	4309.550	643.560
023	4309.130	644.310
024	4310.800	646.980
025	4307.000	642.710
026	4313.210	647.910
027	4313.760	648.230
028	4318.500	650.010
029	4314.090	645.800

APPENDIX D

ALLEGHENY FRONT DATA

Key to Abbreviations:

STA - station number

STRI- joint strike

DIP - joint dip

SPA - joint spacing (in. cm)

LTH - unit: MPO = Pocono, DCK = Catskill,
DCH = Chemung, DBS = black shales

LO - location with respect to the Petersburg
lineament: IN = within, NO = north,
SO = south

GR - group with respect to the Petersburg
lineament: IN = within, OT = outside

STA	STRI	DIP	SPA	LTH	LO	GR
001	N70W	86SW	170	MPO	IN	IN
001	N65W	90SW	165	MPO	IN	IN
001	N71W	82SW	044	MPO	IN	IN
001	N70W	86SW	105	MPO	IN	IN
001	N69E	90SE	112	MPO	IN	IN
001	N75E	87SE	023	MPO	IN	IN
001	N75E	83SE	053	MPO	IN	IN
001	N69E	90SE	350	MPO	IN	IN
001	N12E	67SE		MPO	IN	IN
001	N30E	72SE	019	MPO	IN	IN
001	N25E	71SE	049	MPO	IN	IN
002	N78E	57SE	103	DCK	IN	IN
002	N68E	67SE	093	DCK	IN	IN
002	N78E	57SE	105	DCK	IN	IN
002	N68E	67SE	320	DCK	IN	IN
003	N63W	88NE	050	DCK	IN	IN
003	N69W	90SW	085	DCK	IN	IN
003	N73W	85SW	130	DCK	IN	IN
003	N63W	88NE	038	DCK	IN	IN
003	N69W	90SW	058	DCK	IN	IN
003	N73W	85SW	056	DCK	IN	IN
003	N88W	78SW	200	DCK	IN	IN
003	N86W	64SW	075	DCK	IN	IN
003	N88W	78SW	090	DCK	IN	IN
003	N27E	37SE	092	DCK	IN	IN
003	N37E	30SE	097	DCK	IN	IN
003	N28E	33SE	060	DCK	IN	IN
003	N27E	37SE	057	DCK	IN	IN
003	N37E	30SE	029	DCK	IN	IN
003	N28E	33SE	021	DCK	IN	IN
003	N27E	37SE	034	DCK	IN	IN
003	N37E	30SE	046	DCK	IN	IN
003	N28E	33SE	031	DCK	IN	IN
003	N27E	37SE	061	DCK	IN	IN
003	N37E	30SE	030	DCK	IN	IN
003	N28E	33SE	070	DCK	IN	IN
003	N27E	37SE	085	DCK	IN	IN
003	N37E	30SE	065	DCK	IN	IN
003	N28E	33SE	031	DCK	IN	IN
003	N27E	37SE	026	DCK	IN	IN
003	N28E	33SE	032	DCK	IN	IN
003	N27E	37SE	095	DCK	IN	IN
003	N37E	30SE	094	DCK	IN	IN
004	N86W	43SW	240	DCH	IN	IN
004	N86W	43SW	190	DCH	IN	IN
004	N86W	43SW	130	DCH	IN	IN
004	N86W	43SW	055	DCH	IN	IN

<u>STA</u>	<u>STRI</u>	<u>DIP</u>	<u>SPA</u>	<u>LTH</u>	<u>LO</u>	<u>GR</u>
004	N86W	43SW	030	DCH	IN	IN
004	N86W	43SW	238	DCH	IN	IN
004	N86W	43SW	157	DCH	IN	IN
004	N86W	43SW	100	DCH	IN	IN
004	N86W	43SW	050	DCH	IN	IN
004	N11W	39NE	028	DCH	IN	IN
004	N11W	39NE	033	DCH	IN	IN
004	N11W	39NE	035	DCH	IN	IN
004	N11W	39NE	056	DCH	IN	IN
004	N70W	69SW	024	DCH	IN	IN
004	N70W	71SW	026	DCH	IN	IN
004	N70W	69SW	015	DCH	IN	IN
004	N70W	71SW	083	DCH	IN	IN
004	N70W	69SW	055	DCH	IN	IN
004	N70W	71SW	067	DCH	IN	IN
004	N70W	69SW	044	DCH	IN	IN
004	N70W	71SW	036	DCH	IN	IN
004	N70W	69SW	045	DCH	IN	IN
004	N70W	71SW	047	DCH	IN	IN
004	N70W	69SW	075	DCH	IN	IN
004	N70W	71SW	066	DCH	IN	IN
005	N15E	87SW	132	MPO	NO	OT
005	N14E	83SE	370	MPO	NO	OT
005	N19E	76SE	022	MPO	NO	OT
005	N15E	87SE	230	MPO	NO	OT
005	N14E	83SE	050	MPO	NO	OT
005	N52W	89SW	066	MPO	NO	OT
005	N58W	89NE	045	MPO	NO	OT
005	N51W	90SW	042	MPO	NO	OT
005	N52W	89SW	113	MPO	NO	OT
005	N58W	89NE	310	MPO	NO	OT
005	N51W	90SW	195	MPO	NO	OT
005	N52W	89SW	110	MPO	NO	OT
005	N58W	89NE	054	MPO	NO	OT
005	N51W	90SW	020	MPO	NO	OT
005	N52W	89SW	092	MPO	NO	OT
005	N58W	89NE	078	MPO	NO	OT
005	N51W	90SW	030	MPO	NO	OT
005	N52W	89SW	115	MPO	NO	OT
005	N85W	84SW	048	MPO	NO	OT
005	N85W	84SW	035	MPO	NO	OT
005	N85W	84SW	030	MPO	NO	OT
005	N85W	84SW	070	MPO	NO	OT
005	N85W	84SW	050	MPO	NO	OT
005	N85W	84SW	085	MPO	NO	OT
006	N12E	58SE	086	DCK	NO	OT
006	N12E	61SE	300	DCK	NO	OT

<u>STA</u>	<u>STRI</u>	<u>DIP</u>	<u>SPA</u>	<u>LTH</u>	<u>LO</u>	<u>GR</u>
006	N19E	54SE	065	DCK	NO	OT
006	N12E	58AQ	380	DCK	NO	OT
006	N44W	90NE	250	DCK	NO	OT
006	N43W	90NE	084	DCK	NO	OT
006	N48W	88NE	068	DCK	NO	OT
006	N40W	90NE	089	DCK	NO	OT
006	N44W	90NE	086	DCK	NO	OT
006	N43W	90NE	178	DCK	NO	OT
006	N48W	88NE	361	DCK	NO	OT
006	N85E	75NW	030	DCK	NO	OT
006	N85W	80NE	028	DCK	NO	OT
006	N85E	75NW	250	DCK	NO	OT
006	N85W	80NE	125	DCK	NO	OT
006	N85E	75NW	222	DCK	NO	OT
006	N85W	80NE	180	DCK	NO	OT
006	N85E	75NW	030	DCK	NO	OT
006	N85W	80NE	221	DCK	NO	OT
007	N84E	87SE	120	DCK	NO	OT
007	N85E	82SE	043	DCK	NO	OT
007	N84E	87SE	148	DCK	NO	OT
007	N85E	82SE	050	DCK	NO	OT
007	N84E	87SE	100	DCK	NO	OT
007	N85E	82SE	150	DCK	NO	OT
007	N84E	82SE	110	DCK	NO	OT
007	N35W	80NE	134	DCK	NO	OT
007	N40W	85NE	110	DCK	NO	OT
007	N35W	80NE	115	DCK	NO	OT
007	N40W	85NE	180	DCK	NO	OT
007	N35W	80NE	114	DCK	NO	OT
007	N40W	85NE	128	DCK	NO	OT
007	N12E	50SE	092	DCK	NO	OT
007	N13E	50SE	150	DCK	NO	OT
007	N09E	60SE	180	DCK	NO	OT
007	N12E	50SE	212	DCK	NO	OT
007	N13E	50SE	250	DCK	NO	OT
008	N52W	90NE	053	MPO	NO	OT
008	N50W	90NE	080	MPO	NO	OT
008	N52W	90NE	075	MPO	NO	OT
008	N50W	90NE	200	MPO	NO	OT
008	N10E	70SE	105	MPO	NO	OT
008	N10E	70SE	180	MPO	NO	OT
008	N10E	70SE	085	MPO	NO	OT
008	N10E	70SE	075	MPO	NO	OT
008	N10E	70SE	040	MPO	NO	OT
008	N83E	90NW	150	MPO	NO	OT
008	N84E	90NW	055	MPO	NO	OT
008	N83E	90NW	064	MPO	NO	OT

<u>STA</u>	<u>STRI</u>	<u>DIP</u>	<u>SPA</u>	<u>LTH</u>	<u>LO</u>	<u>GR</u>
008	N84E	90NW	175	MPO	NO	OT
008	N83E	89NW	150	MPO	NO	OT
008	N35W	90NE	060	MPO	NO	OT
008	N41W	90NE	045	MPO	NO	OT
008	N36W	90NE	070	MPO	NO	OT
008	N41W	90NE	035	MPO	NO	OT
008	N36W	90NE	060	MPO	NO	OT
009	N82W	88NE		DCK	NO	OT
009	N88E	88NW	050	DCK	NO	OT
009	N88E	88NW	600	DCK	NO	OT
009	N88E	88NW	350	DCK	NO	OT
009	N88E	88NW	160	DCK	NO	OT
009	N88E	88NW	150	DCK	NO	OT
009	N05W	88SW	180	DCK	NO	OT
009	N00W	88SW	250	DCK	NO	OT
009	N05W	88SW	180	DCK	NO	OT
009	N00W	88SW	065	DCK	NO	OT
009	N05W	88SW	200	DCK	NO	OT
009	N00W	88SW	025	DCK	NO	OT
009	N05W	88SW	072	DCK	NO	OT
009	N00W	88SW	098	DCK	NO	OT
010	N40E	79SE	073	DCK	NO	OT
010	N32E	80SE	200	DCK	NO	OT
010	N40E	79SE	150	DCK	NO	OT
010	N28E	72NW	180	DCK	NO	OT
010	N25E	56SE	073	DCK	NO	OT
010	N25E	67SE	030	DCK	NO	OT
010	N28E	72NW	078	DCK	NO	OT
010	N25E	56SE	055	DCK	NO	OT
010	N25E	67SE	054	DCK	NO	OT
010	N28E	72NW	044	DCK	NO	OT
010	N78W	80NE	027	DCK	NO	OT
010	N83W	88SW	100	DCK	NO	OT
010	N78W	77NE	079	DCK	NO	OT
010	N80W	88NE	200	DCK	NO	OT
010	N78W	80NE	230	DCK	NO	OT
010	N83W	88SW	100	DCK	NO	OT
010	N78W	77NE	054	DCK	NO	OT
010	N80W	88NE	288	DCK	NO	OT
010	N78W	80NE	070	DCK	NO	OT
010	N50W	72NE	200	DCK	NO	OT
010	N50W	72NE	260	DCK	NO	OT
011	N32E	53SE	100	DCH	NO	OT
011	N32E	53SE	200	DCH	NO	OT
011	N32E	53SE	180	DCH	NO	OT
011	N32E	53SE	060	DCH	NO	OT
011	N32E	53SE	150	DCH	NO	OT

<u>STA</u>	<u>STRI</u>	<u>DIP</u>	<u>SPA</u>	<u>LTH</u>	<u>LO</u>	<u>GR</u>
011	N83W	90SW	050	DCH	NO	OT
011	N77W	90SW	070	DCH	NO	OT
011	N83W	90SW	050	DCH	NO	OT
011	N77W	90SW	095	DCH	NO	OT
011	N83W	90SW	040	DCH	NO	OT
011	N77W	90SW	110	DCH	NO	OT
011	N83W	90SW	150	DCH	NO	OT
011	N77W	90SW	110	DCH	NO	OT
011	N83W	90SW	080	DCH	NO	OT
011	N16E	70SE	170	DCH	NO	OT
011	N16E	70SE	120	DCH	NO	OT
012	N42W	89SW	062	MPO	IN	IN
012	N45W	88SW	055	MPO	IN	IN
012	N39W	90SW	088	MPO	IN	IN
012	N50W	85SW	043	MPO	IN	IN
012	N42W	89SW	110	MPO	IN	IN
012	N45W	88SW	085	MPO	IN	IN
012	N39W	90SW	120	MPO	IN	IN
012	N50W	85SW	075	MPO	IN	IN
012	N42W	89SW	130	MPO	IN	IN
012	N45W	88SW	068	MPO	IN	IN
012	N39W	90SW	049	MPO	IN	IN
012	N28E	90SE	080	MPO	IN	IN
012	N28E	80SE	060	MPO	IN	IN
012	N24E	85SE	110	MPO	IN	IN
012	N28E	90SE	074	MPO	IN	IN
012	N28E	80SE	096	MPO	IN	IN
012	N24E	85SE	060	MPO	IN	IN
012	N10E	75SE	042	MPO	IN	IN
012	N15E	90SE	055	MPO	IN	IN
012	N10E	75SE	040	MPO	IN	IN
012	N15E	90SE	027	MPO	IN	IN
012	N10E	75SE	080	MPO	IN	IN
012	N15E	90SE	060	MPO	IN	IN
013	N75W	86NE	058	DCK	IN	IN
013	N75W	86NE	095	DCK	IN	IN
013	N75W	86NE	105	DCK	IN	IN
013	N74W	86NE	047	DCK	IN	IN
013	N30E	53SE	057	DCK	IN	IN
013	N30E	53SE	052	DCK	IN	IN
013	N30E	53SE	045	DCK	IN	IN
013	N30E	53SE	049	DCK	IN	IN
013	N30E	53SE	059	DCK	IN	IN
013	N30E	53SE	083	DCK	IN	IN
013	N30E	53SE	048	DCK	IN	IN
013	N30E	53SE	045	DCK	IN	IN
014	N65W	86SW	150	DCK	IN	IN

<u>STA</u>	<u>STRI</u>	<u>DIP</u>	<u>SPA</u>	<u>LTH</u>	<u>LO</u>	<u>GR</u>
014	N65W	90SW	240	DCK	IN	IN
014	N65W	86SW	090	DCK	IN	IN
014	N64W	90SW	100	DCK	IN	IN
014	N65W	86SW	030	DCK	IN	IN
014	N65W	86SW	030	DCK	IN	IN
014	N65W	90SW	080	DCK	IN	IN
014	N65W	86SW	120	DCK	IN	IN
014	N08E	78NW	040	DCK	IN	IN
014	N08E	78NW	040	DCK	IN	IN
014	N08E	78NW	100	DCK	IN	IN
014	N08E	78NW	100	DCK	IN	IN
014	N08E	78NW	090	DCK	IN	IN
014	N35E	55SE	039	DCK	IN	IN
014	N35E	55SW	045	DCK	IN	IN
014	N35E	55SW	030	DCK	IN	IN
014	N35E	55SW	050	DCK	IN	IN
014	N35E	55SW	040	DCK	IN	IN
014	N35E	55SW	050	DCK	IN	IN
014	N35E	55SW	063	DCK	IN	IN
014	N35E	55SW	049	DCK	IN	IN
014	N88W	60SW	039	DCK	IN	IN
014	N88W	60SW	022	DCK	IN	IN
014	N88W	60SW	030	DCK	IN	IN
015	N85W	88SW	026	DCH	IN	IN
015	N85W	88SW	034	DCH	IN	IN
015	N85W	88SW	026	DCH	IN	IN
015	N85W	88SW	033	DCH	IN	IN
015	N85W	88SW	080	DCH	IN	IN
015	N02E	27SE	020	DCH	IN	IN
015	N02E	27SE	030	DCH	IN	IN
015	N02E	27SE	038	DCH	IN	IN
015	N02E	27SE	055	DCH	IN	IN
015	N02E	27SE	038	DCH	IN	IN
015	N02E	27SE	024	DCH	IN	IN
015	N02E	27SE	025	DCH	IN	IN
015	N02E	27SE	050	DCH	IN	IN
016	N18E	78SE	081	DCK	IN	IN
016	N20E	70SE	008	DCK	IN	IN
016	N18E	78SE	016	DCK	IN	IN
016	N20E	70SE	040	DCK	IN	IN
016	N18E	78SE	045	DCK	IN	IN
016	N20E	70SE	040	DCK	IN	IN
016	N18E	78SE	035	DCK	IN	IN
016	N20E	70SE	080	DCK	IN	IN
016	N18E	70SE	045	DCK	IN	IN
016	N20E	70SE	110	DCK	IN	IN
016	N26W	74NE	068	DCK	IN	IN

STA	STRI	DIP	SPA	LTH	LO	GR
016	N26W	74NE	074	DCK	IN	IN
016	N26W	74NE	050	DCK	IN	IN
016	N26W	74NE	022	DCK	IN	IN
016	N85W	90SW	025	DCK	IN	IN
016	N85W	90SW	015	DCK	IN	IN
016	N85W	90SW	043	DCK	IN	IN
016	N85E	75SE	030	DCK	IN	IN
016	N85W	90SW	027	DCK	IN	IN
016	N85W	90SW	016	DCK	IN	IN
016	N85W	90SW	012	DCK	IN	IN
016	N85W	90SW	023	DCK	IN	IN
016	N85W	90SW	026	DCK	IN	IN
016	N85W	90SW	038	DCK	IN	IN
016	N85W	90SW	032	DCK	IN	IN
016	N85W	90SW	052	DCK	IN	IN
016	N85W	90SW	033	DCK	IN	IN
016	N85W	90SW	041	DCK	IN	IN
016	N85W	90SW	075	DCK	IN	IN
016	N85W	90SW	053	DCK	IN	IN
016	N85W	90SW	035	DCK	IN	IN
016	N85W	90SW	025	DCK	IN	IN
016	N85W	90SW	030	DCK	IN	IN
016	N85W	90SW	120	DCK	IN	IN
017	N82E	90SE		DCK	IN	IN
017	N10E	75SE	070	DCK	IN	IN
017	N10E	75SE	036	DCK	IN	IN
017	N10E	75SE	073	DCK	IN	IN
017	N10E	75SE	045	DCK	IN	IN
017	N10E	75SE	073	DCK	IN	IN
017	N45W	90SW	090	DCK	IN	IN
017	N45W	90SW	110	DCK	IN	IN
017	N45W	90SW	080	DCK	IN	IN
018	N80W	86NE	020	DCK	IN	IN
018	N80W	86NE	053	DCK	IN	IN
018	N80W	86NE	040	DCK	IN	IN
018	N80W	86NE	045	DCK	IN	IN
018	N80W	86NE	042	DCK	IN	IN
018	N80W	86NE	023	DCK	IN	IN
018	N80W	86NE	080	DCK	IN	IN
018	N50E	62SE	076	DCK	IN	IN
018	N50E	62SE	023	DCK	IN	IN
018	N50E	62SE	029	DCK	IN	IN
018	N50E	62SE	040	DCK	IN	IN
018	N50E	62SE	078	DCK	IN	IN
018	N50E	62SE	058	DCK	IN	IN
018	N50E	62SE	060	DCK	IN	IN
018	N50E	62SE	100	DCK	IN	IN

<u>STA</u>	<u>STRI</u>	<u>DIP</u>	<u>SPA</u>	<u>LTH</u>	<u>LO</u>	<u>GR</u>
019	N85W	83SW	060	DCK	IN	IN
019	N85W	83SW	082	DCK	IN	IN
019	N85W	83SW	060	DCK	IN	IN
019	N85W	83SW	040	DCK	IN	IN
019	N85W	83SW	023	DCK	IN	IN
019	N85W	83SW	040	DCK	IN	IN
019	N85W	83SW	150	DCK	IN	IN
019	N85W	83SW	150	DCK	IN	IN
019	N85W	83SW	040	DCK	IN	IN
019	N85W	83SW	018	DCK	IN	IN
019	N85W	83SW	028	DCK	IN	IN
019	N85W	83SW	032	DCK	IN	IN
020	N80W	90SW	070	DCH	IN	IN
020	N80W	90SW	050	DCH	IN	IN
020	N80W	90SW	040	DCH	IN	IN
020	N80W	90SW	020	DCH	IN	IN
020	N80W	90SW	050	DCH	IN	IN
020	N80W	90SW	040	DCH	IN	IN
020	N80W	90SW	080	DCH	IN	IN
020	N80W	90SW	020	DCH	IN	IN
020	N80W	90SW	040	DCH	IN	IN
020	N10E	50SE	020	DCH	IN	IN
020	N10E	50SE	020	DCH	IN	IN
020	N10E	50SE	020	DCH	IN	IN
020	N10E	50SE	040	DCH	IN	IN
021	N15E	66SE	110	MPO	SO	OT
021	N15E	66SE	175	MPO	SO	OT
021	N15E	66SE	080	MPO	SO	OT
021	N50W	80NE	150	MPO	SO	OT
021	N50W	80NE	120	MPO	SO	OT
021	N50W	80NE	120	MPO	SO	OT
021	N50W	80NE	070	MPO	SO	OT
021	N50W	80NE	050	MPO	SO	OT
021	N50W	80NE	070	MPO	SO	OT
021	N50W	80NE	200	MPO	SO	OT
021	N50W	80NE	175	MPO	SO	OT
021	N50W	80NE	075	MPO	SO	OT
021	N50W	80NE	250	MPO	SO	OT
022	N40E	70SE	300	DCK	SO	OT
022	N40E	70SE	175	DCK	SO	OT
022	N45W	88NE	070	DCK	SO	OT
022	N45W	88NE	300	DCK	SO	OT
022	N45W	88NE	250	DCK	SO	OT
022	N45W	88NE	150	DCK	SO	OT
023	N50E	21NW	070	DCK	SO	OT
023	N50E	21NW	075	DCK	SO	OT
023	N50E	21NW	090	DCK	SO	OT

STA	STRI	DIP	SPA	LTH	LO	GR
023	N50E	21NW	200	DCK	SO	OT
023	N50E	21NW	040	DCK	SO	OT
023	N50E	21NW	060	DCK	SO	OT
023	N51W	90SW	160	DCK	SO	OT
023	N51W	90SW	060	DCK	SO	OT
023	N51W	90SW	075	DCK	SO	OT
023	N51W	90SW	100	DCK	SO	OT
023	N51W	90SW	070	DCK	SO	OT
023	N51W	90SW	080	DCK	SO	OT
023	N51W	90SW	030	DCK	SO	OT
023	N51W	90SW	150	DCK	SO	OT
023	N51W	90SW	300	DCK	SO	OT
023	N34E	53NW		DCK	SO	OT
024	N81W	89NE	057	DCH	SO	OT
024	N81W	89NE	060	DCH	SO	OT
024	N81W	89NE	054	DCH	SO	OT
024	N81W	89NE	035	DCH	SO	OT
024	N81W	89NE	067	DCH	SO	OT
024	N81W	89NE	115	DCH	SO	OT
024	N81W	89NE	100	DCH	SO	OT
024	N81W	89NE	037	DCH	SO	OT
024	N81W	89NE	150	DCH	SO	OT
024	N81W	89NE	115	DCH	SO	OT
024	N81W	89NE	075	DCH	SO	OT
024	N81W	89NE	105	DCH	SO	OT
024	N16E	76NW	160	DCH	SO	OT
024	N16E	76NW	075	DCH	SO	OT
024	N16E	76NW	169	DCH	SO	OT
024	N16E	76NW	065	DCH	SO	OT
024	N16E	76NW	175	DCH	SO	OT
024	N16E	76NW	160	DCH	SO	OT
024	N16E	76NW	120	DCH	SO	OT
024	N16E	76NW	070	DCH	SO	OT
024	N16E	76NW	070	DCH	SO	OT
024	N16E	76NW	100	DCH	SO	OT
025	N50W	54SW	018	DBS	SO	OT
025	N50W	54SW	018	DBS	SO	OT
025	N50W	54SW	016	DBS	SO	OT
025	N50W	54SW	019	DBS	SO	OT
025	N50W	54SW	017	DBS	SO	OT
025	N50W	54SW	017	DBS	SO	OT
025	N50W	54SW	022	DBS	SO	OT
025	N50W	54SW	017	DBS	SO	OT
025	N50W	54SW	015	DBS	SO	OT
025	N50W	54SW	014	DBS	SO	OT
025	N50W	54SW	013	DBS	SO	OT
025	N50W	54SW	009	DBS	SO	OT

<u>STA</u>	<u>STRI</u>	<u>DIP</u>	<u>SPA</u>	<u>LTH</u>	<u>LO</u>	<u>GR</u>
025	N85W	30NE	030	DBS	SO	OT
025	N85W	30NE	017	DBS	SO	OT
025	N85W	30NE	025	DBS	SO	OT
025	N85W	30NE	040	DBS	SO	OT
025	N85W	30NE	030	DBS	SO	OT
025	N85W	30NE	040	DBS	SO	OT
025	N85W	30NE	020	DBS	SO	OT
025	N85W	30NE	052	DBS	SO	OT
025	N85W	30NE	016	DBS	SO	OT
025	N85W	30NE	050	DBS	SO	OT
026	N83E	71NW	045	DBS	IN	IN
026	N83E	71NW	007	DBS	IN	IN
026	N83E	71NW	007	DBS	IN	IN
026	N83E	71NW	013	DBS	IN	IN
026	N83E	71NW	015	DBS	IN	IN
026	N83E	71NW	008	DBS	IN	IN
026	N83E	71NW	009	DBS	IN	IN
026	N83E	71NW	015	DBS	IN	IN
026	N83E	71NW	010	DBS	IN	IN
026	N83E	71NW	028	DBS	IN	IN
026	N83E	71NW	013	DBS	IN	IN
026	N83E	71NW	015	DBS	IN	IN
026	N83E	71NW	018	DBS	IN	IN
026	N83E	71NW	025	DBS	IN	IN
026	N83E	71NW	007	DBS	IN	IN
026	N14E	34SE	028	DBS	IN	IN
026	N14E	34SE	028	DBS	IN	IN
026	N14E	34SE	019	DBS	IN	IN
026	N14E	34SE	011	DBS	IN	IN
027	N50E	45SE	016	DBS	IN	IN
027	N50E	45SE	010	DBS	IN	IN
027	N50E	45SE	020	DBS	IN	IN
027	N50E	45SE	020	DBS	IN	IN
027	N50E	45SE	009	DBS	IN	IN
027	N50E	45SE	010	DBS	IN	IN
027	N50E	45SE	030	DBS	IN	IN
027	N50E	45SE	019	DBS	IN	IN
027	N55W	86NE	013	DBS	IN	IN
027	N55W	86NE	012	DBS	IN	IN
027	N55W	86NE	007	DBS	IN	IN
027	N55W	86NE	007	DBS	IN	IN
027	N55W	86NE	012	DBS	IN	IN
027	N55W	86NE	030	DBS	IN	IN
028	N35E	55NW	020	DBS	NO	OT
028	N35E	55NW	016	DBS	NO	OT
028	N35E	55NW	009	DBS	NO	OT

<u>STA</u>	<u>STRI</u>	<u>DIP</u>	<u>SPA</u>	<u>LTH</u>	<u>LO</u>	<u>GR</u>
028	N35E	55NW	023	DBS	NO	OT
028	N35E	55NW	017	DBS	NO	OT
028	N35E	55NW	023	DBS	NO	OT
028	N35E	55NW	034	DBS	NO	OT
028	N35E	55NW	025	DBS	NO	OT
028	N50W	60SW	040	DBS	NO	OT
028	N50W	60SW	026	DBS	NO	OT
028	N50W	60SW	038	DBS	NO	OT
028	N50W	60SW	041	DBS	NO	OT
028	N50W	60SW	033	DBS	NO	OT
029			058	MPO	IN	IN
029			059	MPO	IN	IN
029			090	MPO	IN	IN
029			052	MPO	IN	IN
029			049	MPO	IN	IN
029			042	MPO	IN	IN
029			033	MPO	IN	IN
029			034	MPO	IN	IN
029			076	MPO	IN	IN
029			075	MPO	IN	IN
029			057	MPO	IN	IN
029			082	MPO	IN	IN

APPENDIX E

STATION LOCATIONS OF THE WESTWARD EXTENSIONS
PARSONS AND PETERSBURG LINEAMENTS
(in UTM Grid Coordinates)

Key to Abbreviations:

STA - station number

<u>STA</u>	<u>LATITUDE</u>	<u>LONGITUDE</u>	<u>STA</u>	<u>LATITUDE</u>	<u>LONGITUDE</u>
038	4340.470	592.200	81A	4311.470	580.210
042	4330.820	586.670	082	4313.780	578.540
043	4338.920	585.530	083	4314.000	578.020
044	4340.010	589.220	084	4308.180	576.310
045	4341.180	591.640	085	4307.770	576.620
046	4341.700	591.610	087	4304.660	586.050
047	4341.900	591.450	088	4304.510	586.690
048	4341.960	591.270	089	4305.600	588.780
049	4342.500	591.740	090	4313.450	589.900
050	4353.810	592.840	091	4311.540	589.900
051	4355.000	591.780	092	4306.030	585.600
052	4355.360	591.260	093	4305.130	583.910
053	4354.980	588.700	094	4321.510	581.100
054	4359.300	593.310	095	4303.280	588.650
055	4362.350	595.450	096	4300.280	588.170
056	4363.770	596.120	097	4299.210	587.180
057	4360.580	595.570	098	4296.560	582.920
058	4356.220	592.020	099	4296.800	582.100
059	4349.870	591.830	100	4294.590	578.900
060	4342.910	592.070	101	4302.330	575.710
061	4343.110	592.010	102	4344.770	584.380
062	4367.310	580.420	103	4322.850	589.800
063	4367.070	581.080	104	4331.470	586.340
064	4359.870	578.640	105	4326.170	578.380
065	4349.260	594.170	106	4326.480	578.480
066	4350.070	591.320	107	4302.250	570.990
068	4361.550	577.800	108	4302.720	571.330
069	4361.340	577.910	109	4303.100	571.520
070	4360.840	578.170	110	4332.110	587.660
071	4360.630	578.380	111	4334.280	589.070
072	4370.410	579.710	112	4334.550	590.570
078	4359.160	587.580	113	4337.390	588.710
079	4355.410	586.060	114	4339.020	588.090
080	4354.770	582.400	115	4339.940	587.960
081	4354.320	580.710			

APPENDIX F

WESTWARD EXTENSIONS DATA

Key to Abbreviations:

STA - station number

STRI- joint strike

DIP - joint dip

SPA - joint spacing (in cm)

LTH - unit: PAL = Allegheny, PPV = Pottsville

LOC - location with respect to lineaments.
See Figure 14 for sub-area locations

GR - group with respect to lineaments: IN =
within, OT = outside

<u>STA</u>	<u>STRI</u>	<u>DIP</u>	<u>SPA</u>	<u>LTH</u>	<u>LOC</u>	<u>GR</u>
038	N22E		0367	PPV	I-2	IN
038	N22E		0202	PPV	I-2	IN
038	N22E		0220	PPV	I-2	IN
038	N22E		0200	PPV	I-2	IN
038	N22E		0900	PPV	I-2	IN
038	N22E		0760	PPV	I-2	IN
038	N22E		0280	PPV	I-2	IN
038	N22E		0400	PPV	I-2	IN
038	N22E		0260	PPV	I-2	IN
038	N22E		0297	PPV	I-2	IN
038	N80E		0220	PPV	I-2	IN
038	N80E		0360	PPV	I-2	IN
038	N80E		0227	PPV	I-2	IN
042	N85E	77NE	0900	PAL	O-5	OT
042	N85E	77NE	1500	PAL	O-5	OT
042	N14E	82SE	0300	PAL	O-5	OT
042	N14E	82SE	0560	PAL	O-5	OT
042	N14E	82SE	0750	PAL	O-5	OT
042	N14E	82SE	0280	PAL	O-5	OT
042	N49W	86NE	0550	PAL	O-5	OT
042	N49W	86NE	1500	PAL	O-5	OT
042	N49W	86NE	1450	PAL	O-5	OT
043	N34E	85SE	0450	PAL	O-5	OT
043	N34E	85SE	0800	PAL	O-5	OT
043	N34E	85SE	0520	PAL	O-5	OT
043	N34E	85SE	1080	PAL	O-5	OT
043	N34E	85SE	0630	PAL	O-5	OT
043	N76E	88SE	0490	PAL	O-5	OT
043	N76E	88SE	0104	PAL	O-5	OT
043	N76E	88SE	0295	PAL	O-5	OT
043	N76E	88SE	0310	PAL	O-5	OT
043	N76E	88SE	0276	PAL	O-5	OT
043	N76E	88SE	0130	PPV	O-5	OT
043	N75E	88SE	0100	PPV	O-5	OT
044	N70W	90SW	0340	PPV	O-5	OT
044	N70W	90SW	0190	PPV	O-5	OT
044	N70W	90SW	0210	PPV	O-5	OT
044	N70W	90SW	0710	PPV	O-5	OT
044	N70W	90SW	0580	PPV	O-5	OT
044	N70W	90SW	0238	PPV	O-5	OT
044	N70W	90SW	0320	PPV	O-5	OT
044	N10E	90NW	1390	PPV	O-5	OT
044	N10E	90NW	0400	PPV	O-5	OT
044	N10E	90NW	1120	PPV	O-5	OT
044	N10E	90NW	0205	PPV	O-5	OT
044	N10E	90NW	0605	PPV	O-5	OT
044	N10E	90NW	0505	PPV	O-5	OT

<u>STA</u>	<u>STRI</u>	<u>DIP</u>	<u>SPA</u>	<u>LTH</u>	<u>LOC</u>	<u>GR</u>
045	N13E	81NW	0170	PPV	I-2	IN
045	N13E	81NW	0150	PPV	I-2	IN
045	N13E	81NW	0230	PPV	I-2	IN
045	N13E	81NW	0095	PPV	I-2	IN
045	N13E	81NW	0180	PPV	I-2	IN
045	N13E	81NW	0370	PPV	I-2	IN
045	N87E	75SE	0940	PPV	I-2	IN
045	N87E	75SE	0190	PPV	I-2	IN
045	N87E	75SE	0380	PPV	I-2	IN
045	N87E	75SE	0370	PPV	I-2	IN
046	N30W	77SW	0230	PPV	I-2	IN
046	N30W	77SW	0220	PPV	I-2	IN
046	N30W	77SW	0250	PPV	I-2	IN
047	N72E	87SE	0150	PAL	I-2	IN
047	N72E	87SE	0150	PAL	I-2	IN
047	N72E	87SE	0100	PAL	I-2	IN
047	N72E	87SE	0200	PAL	I-2	IN
047	N72E	87SE	0115	PAL	I-2	IN
047	N72E	87SE	0100	PAL	I-2	IN
047	N72E	87SE	0130	PAL	I-2	IN
047	N72E	87SE	0110	PAL	I-2	IN
047	N72E	87SE	0120	PAL	I-2	IN
047	N72E	87SE	0200	PAL	I-2	IN
047	N72E	87SE	0300	PAL	I-2	IN
047	N72E	87SE	0170	PAL	I-2	IN
048	N70E	90NW	0380	PAL	I-2	IN
048	N70E	90NW	0440	PAL	I-2	IN
048	N70E	90SW	0730	PAL	I-2	IN
048	N70E	90NW	0570	PAL	I-2	IN
048	N70E	90NW	0770	PAL	I-2	IN
048	N35E	90NW	0300	PAL	I-2	IN
048	N35E	90NW	0280	PAL	I-2	IN
048	N35E	90NW	0410	PAL	I-2	IN
048	N35E	90NW	0240	PAL	I-2	IN
048	N35E	90NW	0150	PAL	I-2	IN
048	N35E	90NW	0200	PAL	I-2	IN
049	N85W	70NE	0150	PAL	I-2	IN
049	N85W	70NE	0125	PAL	I-2	IN
049	N85W	70NE	0200	PAL	I-2	IN
049	N85W	70NE	0150	PAL	I-2	IN
049	N85W	70NE	0180	PAL	I-2	IN
049	N35E	90NW	0200	PAL	I-2	IN
049	N35E	90NW	0250	PAL	I-2	IN
050	N88E	88NW	0020	PST	I-1	IN
050	N88E	88NW	0055	PST	I-1	IN
050	N88E	88NW	0280	PST	I-1	IN
050	N88E	88NW	0200	PST	I-1	IN

<u>STA</u>	<u>STRI</u>	<u>DIP</u>	<u>SPA</u>	<u>LTH</u>	<u>LOC</u>	<u>GR</u>
050	N22E	90NW	0200	PST	I-1	IN
050	N22E	90NW	0220	PST	I-1	IN
051	N19E	72SE	0300	PAL	I-1	IN
051	N19E	72SE	0180	PAL	I-1	IN
051	N19E	72SE	0150	PAL	I-1	IN
051	N19E	72SE	0150	PAL	I-1	IN
051	N19E	72SE	0180	PAL	I-1	IN
051	N19E	72SE	0275	PAL	I-1	IN
051	N75E	90NW	0300	PAL	I-1	IN
051	N75E	90NW	0300	PAL	I-1	IN
051	N75E	90NW	0180	PAL	I-1	IN
051	N75E	90NW	0250	PAL	I-1	IN
051	N75E	90NW	0270	PAL	I-1	IN
051	N75E	90NW	0200	PAL	I-1	IN
051	N75E	90NW	0200	PAL	I-1	IN
051	N75E	90NW	0350	PAL	I-1	IN
052	N24E	90NW	0270	PAL	I-1	IN
052	N24E	90NW	0690	PAL	I-1	IN
052	N24E	90NW	1020	PAL	I-1	IN
052	N83E	75NW	0140	PAL	I-1	IN
052	N83E	75NW	0040	PAL	I-1	IN
052	N83E	75NW	0940	PAL	I-1	IN
052	N83E	75NW	0100	PAL	I-1	IN
052	N83E	75NW	0400	PAL	I-1	IN
052	N36W	75NW	0350	PAL	I-1	IN
052	N35W	75NW	0150	PAL	I-1	IN
053	N85W	90NE	0200	PAL	I-1	IN
053	N86W	90NE	0300	PAL	I-1	IN
053	N86W	90NE	0220	PAL	I-1	IN
053	N30W	89NE	0220	PAL	I-1	IN
053	N30W	89NE	0350	PAL	I-1	IN
053	N30W	89NE	0180	PAL	I-1	IN
054	N50W		0300	PAL	O-1	OT
054	N50W		0500	PAL	O-1	OT
054	N24E		0210	PAL	O-1	OT
054	N24E		0310	PAL	O-1	OT
054	N24E		0380	PAL	O-1	OT
054	N24E		0300	PAL	O-1	OT
054	N24E		0530	PAL	O-1	OT
055	N25E		0620	PAL	O-1	OT
055	N25E		0530	PAL	O-1	OT
055	N25E		0400	PAL	O-1	OT
055	N25E		0850	PAL	O-1	OT
055	N55W		0425	PAL	O-1	OT
055	N55W		0280	PAL	O-1	OT
055	N55W		0240	PAL	O-1	OT
055	N55W		0590	PAL	O-1	OT

<u>STA</u>	<u>STRI</u>	<u>DIP</u>	<u>SPA</u>	<u>LTH</u>	<u>LOC</u>	<u>GR</u>
055	N55W		0370	PAL	0-1	OT
055	N55W		0340	PAL	0-1	OT
056	N52W		0330	PAL	0-1	OT
056	N52W		1150	PAL	0-1	OT
056	N52W		0800	PAL	0-1	OT
056	N52W		0940	PAL	0-1	OT
057	N15E	88SE	1060	PAL	0-1	OT
057	N15E	88SE	0580	PAL	0-1	OT
057	N15E	88SE	0330	PAL	0-1	OT
057	N54W	80SW	0290	PAL	0-1	OT
057	N54W	80SW	0300	PAL	0-1	OT
057	N54W	80SW	0340	PAL	0-1	OT
057	N15E	88SE	0270	PAL	0-1	OT
058	N54W	90SW	0870	PAL	0-1	OT
058	N54W	90SW	0900	PAL	0-1	OT
058	N54W	90SW	0840	PAL	0-1	OT
058	N54W	90SW	0590	PAL	0-1	OT
058	N54W	90SW	0500	PAL	0-1	OT
058	N54W	90SW	0450	PAL	0-1	OT
058	N54W	90SW	0470	PAL	0-1	OT
058	N54W	90SW	0560	PAL	0-1	OT
058	N33E	75NW	0340	PAL	0-1	OT
058	N33E	75NW	0340	PAL	0-1	OT
058	N33E	75NW	0350	PAL	0-1	OT
058	N33E	75NW	0360	PAL	0-1	OT
059	N02W	75SW	0510	PAL	0-4	OT
059	N02W	75SW	2000	PAL	0-4	OT
059	N02W	75SW	0510	PAL	0-4	OT
059	N02W	75SW	1070	PAL	0-4	OT
059	N20E	75SW	0330	PAL	0-4	OT
060	N80W	80NE	0570	PPV	0-4	OT
060	N80W	80NE	0720	PPV	0-4	OT
060	N80W	80NE	1110	PPV	0-4	OT
060	N80W	80NE	0840	PPV	0-4	OT
060	N80W	80NE	0245	PPV	0-4	OT
060	N80W	80NE	0955	PPV	0-4	OT
060	N80W	80NE	0815	PPV	0-4	OT
060	N80W	80NE	0160	PPV	0-4	OT
060	N80W	80NE	0420	PPV	0-4	OT
060	N80W	80NE	0295	PPV	0-4	OT
060	N80W	80NE	0170	PPV	0-4	OT
060	N80W	80NE	0460	PPV	0-4	OT
060	N80W	80NE	0210	PPV	0-4	OT
060	N80W	80NE	0170	PPV	0-4	OT
060	N80W	80NE	0270	PPV	0-4	OT
061	N25E			PPV	0-4	OT
061	N04W	80SW	0480	PPV	0-4	OT

STA	STRI	DIP	SPA	LTH	LOC	GR
061	N04W	80SW	0400	PPV	O-4	OT
061	N85E		0500	PPV	O-4	OT
061	N85E		0500	PPV	O-4	OT
061	N85E		0800	PPV	O-4	OT
061	N85E		0740	PPV	O-4	OT
062	N11E		0350	PPV	O-2	OT
062	N11E		0200	PPV	O-2	OT
063	N56W	90SW	0380	PAL	O-2	OT
063	N56W	90SW	0360	PAL	O-2	OT
064	N75W	90SW	0184	PAL	O-3	OT
064	N75W	90SW	0227	PAL	O-3	OT
064	N75W	90SW	0250	PAL	O-3	OT
064	N75W	90SW	0530	PAL	O-3	OT
064	N75W	90SW	0445	PAL	O-3	OT
064	N75W	90SW	0320	PAL	O-3	OT
064	N75W	90SW	0100	PAL	O-3	OT
064	N75W	90SW	0180	PAL	O-3	OT
064	N75W	90SW	0100	PAL	O-3	OT
064	N75W	90SW	0200	PAL	O-3	OT
064	N75W	90SW	0210	PAL	O-3	OT
064	N75W	90SW	0240	PAL	O-3	OT
064	N75W	90SW	0310	PAL	O-3	OT
064	N75W		0440	PAL	O-3	OT
064	N75W		0610	PAL	O-3	OT
065	N45E		0250	PAL	I-1	IN
065	N45E		0325	PAL	I-1	IN
065	N45E		0200	PAL	I-1	IN
065	N45E		0225	PAL	I-1	IN
065	N45E		0325	PAL	I-1	IN
065	N38W		0280	PAL	I-1	IN
065	N38W		0350	PAL	I-1	IN
065	N38W		0350	PAL	I-1	IN
065	N38W		0300	PAL	I-1	IN
065	N38W		0150	PAL	I-1	IN
065	N38W		0175	PAL	I-1	IN
065	N38W		0275	PAL	I-1	IN
065	N38W		0275	PAL	I-1	IN
066	N15W		1117	PAL	O-4	OT
066	N15W		0420	PAL	O-4	OT
066	N15W		0640	PAL	O-4	OT
066	N37W		0260	PAL	O-4	OT
066	N37W		0330	PAL	O-4	OT
066	N37W		0220	PAL	O-4	OT
066	N37W		0240	PAL	O-4	OT
066	N37W		0140	PAL	O-4	OT
066	N37W		0310	PAL	O-4	OT

<u>STA</u>	<u>STRI</u>	<u>DIP</u>	<u>SPA</u>	<u>LTH</u>	<u>LOC</u>	<u>GR</u>
068	N75W		0200	PAL	0-3	OT
068	N75W		0190	PAL	0-3	OT
068	N75W		0460	PAL	0-3	OT
068	N75W		0350	PAL	0-3	OT
068	N75W		0260	PAL	0-3	OT
069	N70W		0560	PAL	0-3	OT
069	N70W		0560	PAL	0-3	OT
069	N70W		0700	PAL	0-3	OT
070	N18E	88NW	0675	PAL	0-3	OT
070	N18E	88NW	0475	PAL	0-3	OT
070	N75W	86NE	0775	PAL	0-3	OT
070	N75W	86NE	0690	PAL	0-3	OT
070	N75W	86NE	1090	PAL	0-3	OT
070	N75W	86NE	1030	PAL	0-3	OT
070	N75W	86NE	0530	PAL	0-3	OT
071	N69W	89NE	0330	PAL	0-3	OT
071	N69W	89NE	0520	PAL	0-3	OT
071	N69W	89NE	0230	PAL	0-3	OT
071	N69W	89NE	0450	PAL	0-3	OT
072	N07E		0530	PAL	0-2	OT
072	N07E		0340	PAL	0-2	OT
072	N07E		0280	PAL	0-2	OT
072	N80E		0790	PAL	0-2	OT
078	N01E	89NW		PAL	I-1	IN
078	N45W	79SW	0490	PAL	I-1	IN
078	N45W	79SW	0410	PAL	I-1	IN
078	N80W	85SW	0220	PAL	I-1	IN
079	N87W	90SW	0350	PAL	0-4	OT
080	N25E	90NW	0540	PAL	0-3	OT
080	N25E	90NW	0190	PAL	0-3	OT
080	N25W	90SW	0430	PAL	0-3	OT
081	N15E	90NW	0570	PAL	0-3	OT
081	N15E	90NW	0480	PAL	0-3	OT
081	N15E	90NW	0840	PAL	0-3	OT
081	N15E	90NW	0430	PAL	0-3	OT
081	N85W	74SW	1200	PAL	0-3	OT
81A	N20E	90NW	1810	PPV	0-6	OT
81A	N20E	90NW	1270	PPV	0-6	OT
81A	N20E	90NW	1950	PPV	0-6	OT
81A	N20E	90NW	1410	PPV	0-6	OT
81A	N45W	80NE	0230	PPV	0-6	OT
81A	N45W	80NE	0760	PPV	0-6	OT
81A	N45W	80NE	1730	PPV	0-6	OT
81A	N45W	80NE	1200	PPV	0-6	OT
082	N40E	90NW	1030	PAL	0-6	OT
082	N40E	90NW	0830	PAL	0-6	OT
082	N40E	90NW	0670	PAL	0-6	OT

<u>STA</u>	<u>STRI</u>	<u>DIP</u>	<u>SPA</u>	<u>LTH</u>	<u>LOC</u>	<u>GR</u>
082	N80E	75SE	0070	PAL	0-6	OT
082	N80E	75SE	0220	PAL	0-6	OT
082	N80E	75SE	0400	PAL	0-6	OT
083				PAL	0-6	OT
084	N80W	88SW	1220	PAL	0-6	OT
084	N03E	87SE			0-6	OT
086	N75E	89SE	0130	PPV	0-6	OT
086	N75E	89SE	0110	PPV	0-6	OT
086	N75E	89SE	0230	PPV	0-6	OT
087	N73E	87SE	1000	PAL	I-3	IN
087	N73E	87SE	0460	PAL	I-3	IN
087	N01E	77NW	0740	PAL	I-3	IN
088	N81E	90NW	0330	PPV	I-3	IN
088	N81E	90NW	0330	PPV	I-3	IN
088	N81E	90NW	0340	PPV	I-3	IN
088	N81E	90NW	0380	PPV	I-3	IN
088	N81E	90NW	0440	PPV	I-3	IN
088	N81E	90NW	0490	PPV	I-3	IN
088	N81E	90NW	0240	PPV	I-3	IN
088	N81E	90NW	0190	PPV	I-3	IN
088	N60W	90SW	0270	PPV	I-3	IN
088	N60W	90SW	0260	PPV	I-3	IN
089	N25E	83SE	0450	PPV	I-3	IN
089	N65W	90SW	0275	PPV	I-3	IN
090	N55E	78NW	0620	PAL	0-6	OT
090	N55E	78NW	0710	PAL	0-6	OT
090	N85E	85NW	0800	PAL	0-6	OT
091	N75E	78SE	0810	PAL	0-6	OT
091	N75E	78SE	1900	PAL	0-6	OT
091	N75E	78SE	0650	PAL	0-6	OT
091	N75E	78SE	0260	PAL	0-6	OT
091	N75E	78SE	1130	PAL	0-6	OT
091	N75E	78SE	0520	PAL	0-6	OT
092	N10E	90NW	0160	PAL	I-3	IN
092	N10E	90NW	0110	PAL	I-3	IN
092	N10E	90NW	1320	PAL	I-3	IN
092	N10E	90NW	0840	PAL	I-3	IN
092	N85E	90NW	1140	PAL	I-3	IN
092	N27E	75NW	0160	PAL	I-3	IN
093	N22W	82SW	0120	PPV	I-3	IN
093	N22W	82SW	0100	PPV	I-3	IN
093	N22W	82SW	0080	PPV	I-3	IN
093	N45W	90SW		PPV	I-3	IN
094	N35E	90NW		PAL	0-6	OT
095	N65W	90SW	0150	PPV	I-3	IN
095	N89W	90SW	0480	PPV	I-3	IN
096	N75E	78NW	0180	PPV	I-3	IN

STA	STRI	DIP	SPA	LTH	LOC	GR
096	N75E	78NW	0300	PPV	I-3	IN
096	N75E	78NW	0190	PPV	I-3	IN
096	N75E	78NW	0080	PPV	I-3	IN
096	N75E	78NW	0210	PPV	I-3	IN
096	N75E	78NW	0210	PPV	I-3	IN
096	N75E	78NW	0140	PPV	I-3	IN
096	N75E	78NW	0140	PPV	I-3	IN
096	N75E	78NW	0510	PPV	I-3	IN
096	N75E	78NW	0490	PPV	I-3	IN
096	N05W	77NE	0190	PPV	I-3	IN
096	N05W	77NE	0780	PPV	I-3	IN
096	N05W	77NE	0250	PPV	I-3	IN
096	N05W	77NE	0340	PPV	I-3	IN
097	N72E	83SE	0440	PAL	O-7	OT
097	N72E	83SE	1070	PAL	O-7	OT
097	N10W	90SW	1500	PAL	O-7	OT
097	N10W	90SW	0580	PAL	O-7	OT
097	N10W	90SW	0450	PAL	O-7	OT
098	N75E	78NW	0870	PPV	O-7	OT
098	N75E	78NW	1230	PPV	O-7	OT
098	N75E	78NW	1430	PPV	O-7	OT
099	N55E	90NW		PPV	O-7	OT
100				PPV	O-7	OT
101	N52E	80SE		PAL	O-8	OT
102	N53W	65SW	0950	PAL	O-5	OT
102	N55W	65SW	1910	PAL	O-5	OT
102	N34E	80SE	0510	PAL	O-5	OT
103	N12E	80SE		PAL	O-6	OT
104	N30W	85SW	0640	PAL	O-5	OT
104	N30W	85SW	0700	PAL	O-5	OT
104	N70W	90SW	0850	PAL	O-5	OT
105				PAL	O-5	OT
106	N05W	78NE	1000	PAL	O-5	OT
106	N67E	90NW	1060	PAL	O-5	OT
106	N67E	90NW	0850	PAL	O-5	OT
107	N37E	85SE	0850	PAL	O-8	OT
107	N37E	85SE	0480	PAL	O-8	OT
107	N85W	90SW	0750	PAL	O-8	OT
108	N20W	80SW	0700	PAL	O-8	OT
108	N20W	80SW	0600	PAL	O-8	OT
108	N20W	80SW	0800	PAL	O-8	OT
108	N20W	80SW	0600	PAL	O-8	OT
108	N20W	80SW	0900	PAL	O-8	OT
108	N75E	90NW	0700	PAL	O-8	OT
109	N70W	90SW		PAL	O-8	OT
110	N56E	87NW		PAL	O-5	OT
110	N25W	77NE	0410	PAL	O-5	OT
111	N81E	89NW	0670	PAL	O-5	OT
111	N81E	89NW	2100	PAL	O-5	OT
112	N22E	80SE		PAL	O-5	OT
113	N10W	79NE	0970	PPV	O-5	OT

<u>STA</u>	<u>STRI</u>	<u>DIP</u>	<u>SPA</u>	<u>LTH</u>	<u>LOC</u>	<u>GR</u>
113	N62E	90NW	1700	PPV	0-5	OT
114	N21E	88SE	0400	PPV	0-5	OT
115	N87W	90SW	0800	PPV	0-5	OT
115	N87W	90SW	0600	PPV	0-5	OT
115	N87W	90SW	1000	PPV	0-5	OT
115	N87W	90SW	1000	PPV	0-5	OT

APPENDIX G

OPERATOR VARIANCE DATA

Key to Abbreviations:

OPR - operator

STRI- joint strike

SP - joint spacing (in cm)

ST - joint set: EW = east-west, 7W = N 70-79°W, 6W = N 60-69°W, NE = northeast, NN = N 05°W to N 05°E, NW = northwest

STA - station number. See Appendix A, Station Locations in Tucker County

<u>OPR</u>	<u>STRI</u>	<u>SP</u>	<u>ST</u>	<u>STA</u>
BRI	N74W	06	EW	33
BRI	N83W	08	EW	33
BRI	N87W	13	EW	33
BRI	N53W	07	NW	33
BRI	N18E	03	NE	33
BRI	N25E	10	NE	33
BRI	N83W	22	EW	33
BRI	N82W	26	EW	33
BRI	N86W	11	EW	33
BRI	N86E	28	EW	33
BRI	N10E	28	NN	33
BRI	N14E	29	NN	33
BRI	N75W	31	7W	87
BRI	N77W	32	7W	87
BRI	N73W	12	7W	87
BRI	N23E	27	NE	87
BRI	N83E	31	EW	87
BRI	N80E	20	FW	87
BRI	N15E	21	NN	87
BRI	N45W		NW	87
BRI	N85E	45	EW	87
BRI	N87W	15	EW	87
BRI	N82W	13	EW	87
BRI	N80E	05	EW	87
BRI	N18E	55	NN	87
BRI	N53W		NW	87
BRI	N58W	32	NW	35
BRI	N64W	13	6W	35
BRI	N60W	07	6W	35
BRI	N61W	06	6W	35
BRI	N57W	08	6W	35
BRI	N71W	10	6W	35
BRI	N26E	04	NE	35
BRI	N25E	03	NE	35
BRI	N12E	19	NE	35
BRI	N62W	12	6W	35
BRI	N63W	09	6W	35
BRI	N58W	39	6W	35
BRI	N60E	23	6E	35
BRI	N62E	28	6E	35
BRI	N89W	16	EW	35
BRI	N28E	45	NE	35
BRI	N32E	99	NE	35
TOM	N86W	29	EW	33
TOM	N87W	24	EW	33
TOM	N84W	35	EW	33
TOM	N86W	34	EW	33

<u>OPR</u>	<u>STRI</u>	<u>SP</u>	<u>ST</u>	<u>STA</u>
TOM	N87W	55	EW	33
TOM	N84W	66	EW	33
TOM	N86W	68	EW	33
TOM	N87W	12	EW	33
TOM	N84W	34	EW	33
TOM	N86W	40	EW	33
TOM	N19E	19	NE	33
TOM	N21E	02	NE	33
TOM	N42E	19	NE	33
TOM	N19E	23	NE	33
TOM	N21E	08	NE	33
TOM	N42E	16	NE	33
TOM	N19E	23	NE	33
TOM	N21E	10	NE	33
TOM	N42E	16	NE	33
TOM	N19E	17	NE	33
TOM	N21E	22	NE	33
TOM	N42E	32	NE	33
TOM	N19E	30	NE	33
TOM	N21E	03	NE	33
TOM	N42E	27	NE	33
TOM	N19E	34	NE	33
TOM	N21E	17	NE	33
TOM	N42E	08	NE	33
TOM	N19E	13	NE	33
TOM	N21E	21	NE	33
TOM	N42E	23	NE	33
TOM	N19E	39	NE	33
TOM	N83E	30	EW	87
TOM	N85E	32	EW	87
TOM	N79W	37	EW	87
TOM	N83E	14	EW	87
TOM	N85E	11	EW	87
TOM	N79W	18	EW	87
TOM	N83E	25	EW	87
TOM	N85E	46	EW	87
TOM	N79W	13	EW	87
TOM	N83E	62	EW	87
TOM	N85E	18	EW	87
TOM	N79W	06	EW	87
TOM	N83E	15	EW	87
TOM	N85E	16	EW	87
TOM	N79W	03	EW	87
TOM	N83E	17	EW	87
TOM	N85E	10	EW	87
TOM	N79W	12	EW	87
TOM	N83E	09	EW	87

<u>OPR</u>	<u>STRI</u>	<u>SP</u>	<u>ST</u>	<u>STA</u>
TOM	N85E	06	EW	87
TOM	N79W	30	EW	87
TOM	N83E	10	EW	87
TOM	N85E	10	EW	87
TOM	N79W	16	EW	87
TOM	N83E	07	EW	87
TOM	N85E	17	EW	87
TOM	N40W		NW	87
TOM	N20E	15	NE	87
TOM	N26E	28	NE	87
TOM	N24E	13	NE	87
TOM	N20E	08	NE	87
TOM	N26E	06	NE	87
TOM	N44E	42	NE	35
TOM	N25E	35	NE	35
TOM	N29E	07	NE	35
TOM	N25E	46	NE	35
TOM	N61W	13	NW	35
TOM	N51W	23	NW	35
TOM	N51W	34	NW	35
TOM	N53W	35	NW	35
TOM	N53W	11	NW	35
TOM	N51W	32	NW	35
TOM	N53W	28	NW	35
TOM	N51W	15	NW	35
TOM	N53W	08	NW	35
TOM	N51W	39	NW	35
TOM	N53W	79	NW	35
TOM	N51W	39	NW	35
TOM	N73E	27	7E	35
TOM	N73E	23	7E	35
TOM	N52W	14	NW	35
TOM	N53W	15	NW	35
TOM	N51W	26	NW	35
TOM	N02E	12	NN	35
TOM	N02E	11	NN	35
TOM	N51W	32	NW	35
TOM	N53W	08	NW	35
TOM	N51W	07	NW	35
TOM	N53W	17	NW	35
TOM	N51W	24	NW	35
TOM	N25E	99	NE	35
TOM	N29E	37	NE	35
TOM	N25E	35	NE	35
TOM	N29E	14	NE	35
RUS	N87W	19	EW	33
RUS	N84W	12	EW	33

<u>OPR</u>	<u>STRI</u>	<u>SP</u>	<u>ST</u>	<u>STA</u>
RUS	N82W	10	EW	33
RUS	N84W	18	EW	33
RUS	N87W	31	EW	33
RUS	N84W	07	EW	33
RUS	N83W	12	EW	33
RUS	N39W	16	NW	33
RUS	N46W	18	NW	33
RUS	N47W	24	NW	33
RUS	N47W	27	NW	33
RUS	N39W	13	NW	33
RUS	N46W	18	NW	33
RUS	N47W	70	NW	33
RUS	N47W	36	NW	33
RUS	N39W	29	NW	33
RUS	N67W	17	6W	33
RUS	N63W	04	6W	33
RUS	N67W	08	6W	33
RUS	N21E	43	NE	33
RUS	N14E	26	NE	33
RUS	N14E	29	NE	33
RUS	N17E	53	NE	33
RUS	N21E	34	NE	33
RUS	N14E	33	NE	33
RUS	N14E	23	NE	33
RUS	N21E	59	NE	33
RUS	N14E	71	NE	33
RUS	N87E	70	EW	87
RUS	N85E	05	EW	87
RUS	N89E	99	EW	87
RUS	N85E	38	EW	87
RUS	N87E	06	EW	87
RUS	N85E	07	EW	87
RUS	N89E	03	EW	87
RUS	N85E	72	EW	87
RUS	N87E	70	EW	87
RUS	N85E	28	EW	87
RUS	N70W	30	7W	87
RUS	N72W	99	7W	87
RUS	N71W	32	7W	87
RUS	N72W	48	7W	87
RUS	N70W	43	7W	87
RUS	N72W	48	7W	87
RUS	N71W	47	7W	87
RUS	N58W	12	NW	35
RUS	N57W	11	NW	35
RUS	N57W	13	NW	35
RUS	N62W	09	NW	35

<u>OPR</u>	<u>STRI</u>	<u>SP</u>	<u>ST</u>	<u>STA</u>
RUS	N58W	24	NW	35
RUS	N57W	36	NW	35
RUS	N62W	38	NW	35
RUS	N74W	22	7W	35
RUS	N70W	12	7W	35
RUS	N70W	05	7W	35
RUS	N74W	08	7W	35
RUS	N70W	21	7W	35
RUS	N70W	16	7W	35
RUS	N70W	11	7W	35
RUS	N74W	02	7W	35
RUS	N70W	05	7W	35
RUS	N70W	24	7W	35
RUS	N70W	13	7W	35
RUS	N70W	13	7W	35
RUS	N70W	39	7W	35
RUS	N70W	32	7W	35
RUS	N70W	12	7W	35
RUS	N70W	16	7W	35
RUS	N70W	28	7W	35
RUS	N70W	30	7W	35
RUS	N57W	06	NW	35
RUS	N55W	09	NW	35
RUS	N57W	09	NW	35
RUS	N55W	08	NW	35
RUS	N57W	19	NW	35
RUS	N27E	28	NE	35
RUS	N17E	25	NE	35
RUS	N27E	32	NE	35
RUS	N17E	45	NE	35
RUS	N27E	03	NE	35
JAN	N80W	25	EW	33
JAN	N83W	20	EW	33
JAN	N80W	14	EW	33
JAN	N80W	11	EW	33
JAN	N83W	12	EW	33
JAN	N83W	08	EW	33
JAN	N80W	18	EW	33
JAN	N83W	24	EW	33
JAN	N80W	24	EW	33
JAN	N83W	32	EW	33
JAN	N50W	16	NW	33
JAN	N45W	20	NW	33
JAN	N48W	19	NW	33
JAN	N50W	12	NW	33
JAN	N87W	18	EW	87
JAN	N87W	08	EW	87

<u>OPR</u>	<u>STRI</u>	<u>SP</u>	<u>ST</u>	<u>STA</u>
JAN	N87W	12	EW	87
JAN	N87W	24	EW	87
JAN	N87W	38	EW	87
JAN	N87W	09	EW	87
JAN	N87W	17	EW	87
JAN	N87W	17	EW	87
JAN	N87W	34	EW	87
JAN	N51W	07	NW	87
JAN	N51W	26	NW	87
JAN	N84E	11	EW	87
JAN	N84E	11	EW	87
JAN	N73W	32	7W	87
JAN	N73W	31	7W	87
JAN	N24E	90	NE	35
JAN	N24E	59	NE	35
JAN	N24E	29	NE	35
JAN	N02E	21	NN	35
JAN	N02E	31	NN	35
JAN	N02E	11	NN	35
JAN	N55W	47	NW	35
JAN	N55W	09	NW	35
JAN	N55W	25	NW	35
JAN	N54W	35	NW	35
JAN	N85W	36	EW	35
JAN	N85W	29	EW	35
JAN	N85W	12	EW	35
JAN	N85W	16	EW	35
JAN	N85W	37	EW	35

APPENDIX H

COAL CLEAT INTENSITY DATA

Key to Abbreviations:

STA - station number

STRI - joint strike

DIP - joint dip

CLEAT- type of cleat: FACE, BUTT

SPA - cleat spacing (in cm)

BT - bed thickness (in cm)

<u>STA</u>	<u>STRI</u>	<u>DIP</u>	<u>CLEAT</u>	<u>SPA</u>	<u>BT</u>
001	N75W	90SW	FACE	02.5	40
001	N75W	90SW	FACE	02.0	40
001	N75W	90SW	FACE	04.5	40
001	N75W	90SW	FACE	03.0	40
001	N75W	90SW	FACE	01.0	40
001	N75W	90SW	FACE	02.5	40
001	N75W	90SW	FACE	03.0	40
001	N75W	90SW	FACE	01.0	40
001	N75W	90SW	FACE	02.5	40
001	N75W	90SW	FACE	02.0	40
001	N11E	75SE	BUTT	03.5	40
001	N11E	75SE	BUTT	05.0	40
001	N11E	75SE	BUTT	03.0	40
001	N11E	75SE	BUTT	07.0	40
001	N11E	75SE	BUTT	04.0	40
001	N11E	75SE	BUTT	08.0	40
001	N11E	75SE	BUTT	04.0	40
001	N11E	75SE	BUTT	10.0	40
001	N11E	75SE	BUTT	04.0	40
001	N11E	75SE	BUTT	05.5	40
002	N70W	90SW	FACE	03.0	38
002	N70W	90SW	FACE	04.0	38
002	N70W	90SW	FACE	06.0	38
002	N70W	90SW	FACE	02.5	38
002	N70W	90SW	FACE	02.5	38
002	N70W	90SW	FACE	03.0	38
002	N70W	90SW	FACE	03.0	38
002	N70W	90SW	FACE	03.0	38
002	N70W	90SW	FACE	03.0	38
002	N70W	90SW	FACE	02.5	38
002	N05E	70SE	BUTT	02.5	38
002	N05E	70SE	BUTT	02.0	38
002	N05E	70SE	BUTT	03.0	38
002	N05E	70SE	BUTT	02.0	38
002	N05E	70SE	BUTT	04.0	38
002	N05E	70SE	BUTT	01.5	38
002	N05E	70SE	BUTT	02.0	38
002	N05E	70SE	BUTT	03.5	38
002	N05E	70SE	BUTT	04.0	38
002	N05E	70SE	BUTT	01.5	38
004	N74W	90SW	FACE	02.0	35
004	N74W	90SW	FACE	02.0	35
004	N74W	90SW	FACE	02.5	35
004	N74W	90SW	FACE	01.0	35
004	N74W	90SW	FACE	02.5	35
004	N74W	90SW	FACE	02.5	35
004	N74W	90SW	FACE	02.0	35

<u>STA</u>	<u>STRI</u>	<u>DIP</u>	<u>CLEAT</u>	<u>SPA</u>	<u>BT</u>
004	N74W	90SW	FACE	01.5	35
004	N74W	90SW	FACE	02.5	35
004	N74W	90SW	FACE	03.0	35
004	N15E	83SE	BUTT	09.0	35
004	N15E	83SE	BUTT	05.0	35
004	N15E	83SE	BUTT	04.0	35
004	N15E	83SE	BUTT	05.0	35
004	N15E	83SE	BUTT	05.0	35
004	N15E	83SE	BUTT	04.0	35
004	N15E	83SE	BUTT	04.0	35
004	N15E	83SE	BUTT	06.0	35
004	N15E	83SE	BUTT	05.0	35
004	N15E	83SE	BUTT	08.5	35
006	N78W	90SW	FACE	03.5	20
006	N78W	90SW	FACE	03.0	20
006	N78W	90SW	FACE	03.0	20
006	N78W	90SW	FACE	02.0	20
006	N78W	90SW	FACE	02.0	20
006	N78W	90SW	FACE	01.5	20
006	N78W	90SW	FACE	02.0	20
006	N78W	90SW	FACE	04.0	20
006	N78W	90SW	FACE	04.0	20
006	N78W	90SW	FACE	02.5	20
006	N22E	87NW	BUTT	03.0	20
006	N22E	87NW	BUTT	02.0	20
006	N22E	87NW	BUTT	03.5	20
006	N22E	87NW	BUTT	02.5	20
006	N22E	87NW	BUTT	04.0	20
006	N22E	87NW	BUTT	04.0	20
006	N22E	87NW	BUTT	07.0	20
006	N22E	87NW	BUTT	03.0	20
006	N22E	87NW	BUTT	03.0	20
006	N22E	87NW	BUTT	03.5	20
007	N75W	90SW	FACE	07.0	35
007	N75W	90SW	FACE	08.5	35
007	N75W	90SW	FACE	07.0	35
007	N75W	90SW	FACE	08.0	35
007	N75W	90SW	FACE	09.5	35
007	N75W	90SW	FACE	06.5	35
007	N75W	90SW	FACE	07.5	35
007	N75W	90SW	FACE	06.5	35
007	N75W	90SW	FACE	09.0	35
007	N75W	90SW	FACE	07.5	35
007	N15E	80NW	BUTT	08.5	35
007	N15E	80NW	BUTT	09.0	35
007	N15E	80NW	BUTT	10.5	35
007	N15E	80NW	BUTT	12.0	35

<u>STA</u>	<u>STRI</u>	<u>DIP</u>	<u>CLEAT</u>	<u>SPA</u>	<u>BT</u>
007	N15E	80NW	BUTT	10.5	35
007	N15E	80NW	BUTT	08.0	35
007	N15E	80NW	BUTT	08.0	35
007	N15E	80NW	BUTT	09.5	35
007	N15E	80NW	BUTT	08.0	35
007	N15E	80NW	BUTT	10.0	35
008	N75W	89SW	FACE	02.0	40
008	N75W	89SW	FACE	03.0	40
008	N75W	89SW	FACE	03.5	40
008	N75W	89SW	FACE	03.0	40
008	N75W	89SW	FACE	05.5	40
008	N75W	89SW	FACE	03.5	40
008	N75W	89SW	FACE	02.5	40
008	N75W	89SW	FACE	02.5	40
008	N75W	89SW	FACE	02.5	40
008	N75W	89SW	FACE	02.0	40
008	N11E	73SE	BUTT	08.0	40
008	N113	73SE	BUTT	10.0	40
008	N11E	73SE	BUTT	06.0	40
008	N11E	73SE	BUTT	05.0	40
008	N11E	73SE	BUTT	11.0	40
008	N11E	73SE	BUTT	13.0	40
008	N11E	73SE	BUTT	06.0	40
008	N113	73SE	BUTT	06.5	40
008	N11E	73SE	BUTT	13.0	40
008	N11E	73SE	BUTT	05.0	40
011	N77W	89NE	FACE	02.0	40
011	N77W	89NE	FACE	02.0	40
011	N77W	89NE	FACE	02.0	40
011	N77W	89NE	FACE	03.0	40
011	N77W	89NE	FACE	02.0	40
011	N77W	89NE	FACE	02.0	40
011	N77W	89NE	FACE	02.0	40
011	N77W	89NE	FACE	01.0	40
011	N77W	89NE	FACE	03.0	40
011	N77W	89NE	FACE	01.0	40
011	N15E	77SE	BUTT	06.0	40
011	N15E	77SE	BUTT	09.0	40
011	N15E	77SE	BUTT	07.0	40
011	N15E	77SE	BUTT	05.0	40
011	N15E	77SE	BUTT	07.0	40
011	N15E	77SE	BUTT	05.0	40
011	N15E	77SE	BUTT	07.0	40
011	N15E	77SE	BUTT	12.0	40
011	N15E	77SE	BUTT	10.0	40
011	N15E	77SE	BUTT	10.0	40
012	N73W	86SW	FACE	04.0	40

<u>STA</u>	<u>STRI</u>	<u>DIP</u>	<u>CLEAT</u>	<u>SPA</u>	<u>BT</u>
012	N73W	86SW	FACE	02.5	40
012	N73W	86SW	FACE	06.0	40
012	N73W	86SW	FACE	04.0	40
012	N73W	86SW	FACE	05.0	40
012	N73W	86SW	FACE	03.0	40
012	N73W	86SW	FACE	06.0	40
012	N73W	86SW	FACE	05.0	40
012	N73W	86SW	FACE	03.0	40
012	N73W	86SW	FACE	02.0	40
012	N18E	90NW	BUTT	08.0	40
012	N18E	90NW	BUTT	04.0	40
012	N18E	90NW	BUTT	04.5	40
012	N18E	90NW	BUTT	03.0	40
012	N18E	90NW	BUTT	04.0	40
012	N18E	90NW	BUTT	05.0	40
012	N18E	90NW	BUTT	06.0	40
012	N18E	90NW	BUTT	06.0	40
012	N18E	90NW	BUTT	07.0	40
012	N18E	90NW	BUTT	06.0	40
013	N76W	90SW	FACE	03.0	40
013	N76W	90SW	FACE	03.0	40
013	N76W	90SW	FACE	03.0	40
013	N76W	90SW	FACE	03.5	40
013	N76W	90SW	FACE	02.5	40
013	N76W	90SW	FACE	03.0	40
013	N76W	90SW	FACE	03.0	40
013	N76W	90SW	FACE	04.0	40
013	N76W	90SW	FACE	03.0	40
013	N76W	90SW	FACE	02.5	40
013	N25E	75SE	BUTT	11.0	40
013	N25E	75SE	BUTT	09.0	40
013	N25E	75SE	BUTT	04.0	40
013	N25E	75SE	BUTT	14.0	40
013	N25E	75SE	BUTT	09.0	40
013	N25E	75SE	BUTT	10.0	40
013	N25E	75SE	BUTT	11.0	40
013	N25E	75SE	BUTT	12.0	40
013	N25E	75SE	BUTT	08.0	40
013	N25E	75SE	BUTT	11.0	40
014	N74W	85SW	FACE	05.0	35
014	N74W	85SW	FACE	03.5	35
014	N74W	85SW	FACE	06.0	35
014	N74W	85SW	FACE	05.0	35
014	N74W	85SW	FACE	05.5	35
014	N74W	85SW	FACE	06.5	35
014	N74W	85SW	FACE	06.0	35
014	N74W	85SW	FACE	05.0	35

<u>STA</u>	<u>STRI</u>	<u>DIP</u>	<u>CLEAT</u>	<u>SPA</u>	<u>BT</u>
014	N74W	85SW	FACE	04.0	35
014	N74W	85SW	FACE	06.0	35
014	N10E	83SE	BUTT	07.5	35
014	N10E	83SE	BUTT	12.0	35
014	N10E	83SE	BUTT	12.5	35
014	N10E	83SE	BUTT	13.0	35
014	N10E	83SE	BUTT	13.0	35
014	N10E	83SE	BUTT	13.0	35
014	N10E	83SE	BUTT	17.0	35
014	N10E	83SE	BUTT	16.0	35
014	N10E	83SE	BUTT	10.0	35
014	N10E	83SE	BUTT	09.0	35
015	N72W	90SW	FACE	08.0	35
015	N72W	90SW	FACE	07.0	35
015	N72W	90SW	FACE	04.0	35
015	N72W	90SW	FACE	05.0	35
015	N72W	90SW	FACE	10.0	35
015	N72W	90SW	FACE	07.0	35
015	N72W	90SW	FACE	10.0	35
015	N72W	90SW	FACE	11.0	35
015	N72W	90SW	FACE	11.0	35
015	N72W	90SW	FACE	11.0	35
015	N12E	80NW	BUTT	14.0	35
015	N12E	80NW	BUTT	18.0	35
015	N12E	80NW	BUTT	16.0	35
015	N12E	80NW	BUTT	05.0	35
015	N12E	80NW	BUTT	07.0	35
015	N12E	80NW	BUTT	18.0	35
015	N12E	80NW	BUTT	11.0	35
015	N12E	80NW	BUTT	17.0	35
015	N12E	80NW	BUTT	14.0	35
015	N12E	80NW	BUTT	13.0	35

APPENDIX I

FIELD METHODS FOR MEASURING JOINT INTENSITY

FIELD METHODS FOR MEASURING JOINT INTENSITY

This handbook is meant to assist people who are about to engage in a joint intensity study, perhaps for the first time. Certain procedures need to be strictly adhered to, regardless of the study; others will vary. Within a study, consistency is most important.

Ideally, the area to be studied should be previewed. Some rocks lend themselves to this type of study better than others. A preliminary investigation of rock type, number of exposures, and a few sample measurements could save time, trouble, and retracing of steps.

Joint strike, dip, and spacing are the only necessary measurements. However, bed thickness is a useful measurement. If the joints are very regular and consistent, only one strike and dip measurement per set per exposure may be necessary; two or three measurements may be useful where joints are less consistent.

Spacing is the perpendicular distance to the next adjacent joint in the same set. In an exposure, one should measure spacing consistently in one direction so as not to repeat a spacing measurement. If part of the exposure has been washed out, covered by vegetation, covered by talus, or in any way covered, spacing should not be measured across the area; a joint may be hidden and the spacing measurement would be erroneous. Wherever possible, at least three spacings per set should be meas-

ured. The number of joint spacings one should measure at each exposure will vary according to the number of joint sets and the regularity or irregularity of the spacing. If joint spacing in a set is fairly consistent across the exposure, only three to five measurements are necessary; if spacing is variable, 10 to 20 measurements may be necessary. The key to measuring spacings is to choose a representative sample. The exception to the rule is massive sandstone where joint spacing may be many meters. If the exposure is large, and yet has only one or two joints or one or two spacings, then the intensity value may be considered equal to or less than the calculated value. For example, if an outcrop is 25 meters long and two joints at a high angle to the face of the outcrop are found at one end ten meters apart and the next joint spacing is greater than 15 meters, then no other joint from that set will be found in the remaining 15 meters of the outcrop. The average spacing of that set can be considered equal to or greater than 12.5 meters. It is important to note when an outcrop has no joints, particularly if the outcrop is of fair size.

Field equipment is often a personal choice. However, two measuring instruments are found to be useful: a six-foot folding, metric/English carpenter's ruler and a 30 meter fiberglass tape. The carpenter's ruler is good when spacings are less than a few meters. It is invaluable

when measuring steep cuts where joints are a few feet above your reach. The ruler can be unfolded into an upside down L shape, using the long end for extension and the short end for measuring spacings. The 30 meter fiberglass tape, used when spacings are large, is flexible and will not rust when used in streams or other wet areas.

One should beware of blasting fractures, weathering cracks, or other breaks which are not joints. As a general rule, when in doubt, don't! If you are unsure whether or not a fracture is a systematic joint, do not measure it for spacing. When you have completed the study, any differences in joint intensities will be detected from spacings you are sure are real.

Processing of the data will vary from study to study. In areas where a great number of intensity measurements were taken a simple contour map may best illustrate intensity variances. Mean spacings of individual sets can assist in interpreting causes of joint intensity. However, it is only the joint intensity measurement that estimates the total surface area of fractured rock per unit volume. An individual set may show close spacing in a area, which would suggest increased intensity, but that may be counteracted by wide spacings of other sets.

APPENDIX J

SUGGESTIONS FOR FUTURE WORK

SUGGESTIONS FOR FUTURE WORK

1. Two preliminary studies suggest that gas production decreases inside the Parsons and Petersburg lineaments. Because intense fracturing is being considered as one criterion for locating drilling sites, additional detailed studies should be done to compare gas production with the Parsons and Petersburg lineaments.
2. Joint orientations seem to be affected by the Parsons and Petersburg lineaments. A study of the area where these lineaments appear to intersect may better define the area of intersection, and determine time and structural relationships between them.
3. A study of surface joint orientations and intensities around gas fields known to be producing from fractured reservoirs may determine if any relationship exists between surface and subsurface fractures.
4. Joint intensity studies along lineaments associated with known basement structures may characterize those lineaments and give an indication as to the origins of the Parsons and Petersburg lineaments.
5. Rocks between the test areas in this study could be examined to determine if the Parsons and Petersburg lineaments are more intensely fractured all along their lengths. Permian rocks of the Dunkard Group could be studied to determine whether the lineaments are disrupted or terminated in northwestern West Virginia.

6. Surface rocks above coal mine roof falls should be examined to determine if any relationship exists between roof falls and surface joint intensities. If a correlation exists, surface joint intensity studies may be used to assist in predicting roof falls.
7. Studies on coal cleat intensities could be used to determine relationships between cleating and pillar strengths. Stream channels, faults, folds, and other stratigraphic and tectonic structures located around coal seams could be examined to determine their effects on cleat intensities.

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THE PARSONS CROSS STRIKE STRUCTURAL DISCONTINUITY
AS AN EXPLORATION AREA FOR FRACTURED GAS RESERVOIRS

by

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ABSTRACT

The Parsons cross-strike structural discontinuity of the Plateau, and Valley and Ridge provinces in the Central Appalachians is defined as a cross-strike alignment of noses, bends and saddles of major folds. Structural shortening in the lineament is generally taken up by smaller folds and more abundant thrust faults. In the Plateau, Upper Devonian shale, mudstone and siltstone, and Lower and Middle Pennsylvanian sandstone are more intensely jointed. In the Middle Mountain syncline of the Valley and Ridge Province, the Middle Devonian shales exposed within the structural lineament are characterized by larger and more numerous deformation domains. These deformation domains are areas of disrupted bedding associated with faulting and folding of the shales and the underlying Lower Devonian Oriskany Sandstone. These deformation domains also define areas of more intensely jointed shale so that information about Devonian Oriskany structure can be used to predict the locations of intensely fractured gas producing Devonian shales. Future exploration for fractured gas reservoirs can then be optimized by concentrating surface and subsurface studies along cross-strike structural discontinuities, and determining their westward extent into the Appalachian Plateau.

INTRODUCTION

Much of the current research in the D.O.E.'s Eastern Gas Shales Project is directed toward predicting the locations of fractured reservoirs in the gas producing Devonian shales. The Middle Devonian shales that outcrop in the Valley and Ridge Province are the mechanical equivalent of the Upper Devonian Brown shale beneath the Allegheny Plateau Province. The current work in the Middle Mountain syncline and on the Allegheny Plateau is aimed at determining the effects of cross-strike structural discontinuities (in this case the Parsons structural lineament) on the organic-rich Middle Devonian shales exposed in this area, and to suggest an exploration rationale for locating fractured gas reservoirs associated with structural discontinuities in the Allegheny Plateau.

Previous studies have indicated that the Parsons structural lineament (cross-strike structural discontinuity) is a zone of anomalously intense jointing (Wheeler and Holland, 1978; Henderson, 1973; Mullenex, 1975; Trumbo, 1976). Increased jointing and deformation has often been cited as a reason for some gas production in fractured reservoirs. Thus, the Parsons structural lineament has been suggested as a possible area for gas exploration (Wheeler, 1978a, 1978b; Wheeler and others, 1974). In order to recommend specific areas for drilling, detailed mapping, and joint intensity included in detailed mapping studies have been conducted along parts of the Parsons structural lineament (Figure 1).

The Parsons structural lineament is a northwest trending zone up to 10 km wide, of cross-strike alignment of noses, bends and saddles of major folds in the Valley and Ridge and Plateau provinces (Gwinn, 1964; Wheeler and others, 1974). It extends at least 55 km in length. More recently, the lineament is also defined as an area of anomalously intense jointing (Wheeler and Holland, 1978; Dixon, 1979a, 1979b).

JOINT INTENSITY

A method to identify and quantify zones of intense jointing has been described by Dixon (1979a, 1979b), by Wheeler and Dixon (in review), and by Wheeler (1979). It was determined that joint orientation and spacing were the only necessary measurements needed to determine joint intensity or joint surface area per unit volume of rock. For a specific exposure, a measurement of intensity was made by using the sum of inverses of average spacings for each systematic joint set (Vialon and others, 1976; Dixon, 1979a, 1979b; and Wheeler, 1979). In the first part of this study, joints were measured in the Upper Devonian Chemung siltstone, mudstone, and shale exposed in western Tucker County. A SYMAP (computer generated contour map) map shows areas of more intense jointing within the lineament (Figure 2). Of the three dominant joint sets measured (N 35-55° W, N 25-45° E, and N 80° E - N 80° W) the northeast set contributes most to the increase in joint intensity by a marked increase in abundance and closer spacing of that set. Average spacings of all joints measured in the Chemung is approximately 25 cm.

Northwest, along the trend of the lineament in southeast Taylor County, the Parsons structural lineament is manifest in Lower and Middle Pennsylvanian sandstone as two narrow zones of intense jointing; the lineament is disrupted or terminates in northeast Taylor County (Figure 1). Joint intensity inside the lineament in the Plateau is approximately twice as great as outside the lineament. Four dominant sets were measured in the sandstone: (1) N 10-40° E, (2) N 45-55° W, (3) N 65-85° W, and (4) N 70-90° E. Spacings commonly range from 2 to 10 meters. Neither the Tucker County nor the Taylor County segments of the lineament shows any apparent correlation between the trend of the lineament and the trends of the joint sets.

A joint intensity study of Middle Devonian shales exposed in the Middle Mountain syncline (Figure 1) similarly shows that the intensity of systematic jointing is greater within the Parsons structural lineament (see Deformation Domains).

DEFORMATION DOMAINS

During the mapping and structural analysis of the Middle Mountain syncline in the Valley and Ridge (Figure 1), methods were developed which permit the interpretation of bedding orientation contours in terms of fold

geometry and internal structure (Wilson, 1979a, 1979b). The resulting maps are particularly useful as a tool in mapping the poorly exposed, mechanically less competent, organic-rich Middle Devonian shales exposed in this syncline.

Bedding orientation contours are constructed from detailed measurements of bedding strike and dip. The map area is divided into a regularly spaced square grid. The contoured values of strike or dip are the mean of the measurements contained in each square division of the map area. The center of each square grid represents a control point. The standard deviations of the samples within each cell were also contoured. Areas of high standard deviation in bedding dip defined the extent of fault related deformation within the shale mass. These areas have been defined as deformation domains (Wilson, 1979b).

Structural shortening within the Parsons structural lineament in the Middle Mountain syncline is generally taken up by smaller folds and more abundant thrust faults than outside the lineament. The increase in minor folding and particularly the increased number of thrust faults in the Middle Devonian shale result in an increase in the size and number of deformation domains. A joint intensity study (Wilson, 1979b) has shown that the intensity of systematic jointing is greater within deformation domains. Thus the Parsons structural lineament in the Middle Mountain syncline is a zone of greater fracture intensity because it is also a zone of more intensely faulted and folded shales. A thrust fault is more likely to flatten out as it propagates into a weak layer, although high angle faulting is possible (Rodgers and Rizer, 1979a, 1979b). As the fault propagates into the weak layer, secondary structures and fractures will remain in the region initially near the fault tip after the fault tip has propagated out of that region (Rodgers, oral communication, 1979). Relic secondary faults observed in the Upper Devonian Lower Huron Shale Member of the Ohio Shale Formation were used to identify the interval of detachment in the Pine Mountain thrust sheet (Wilson and others, 1979). An increased intensity of jointing was also observed in the interval of detachment (Wilson and others, 1979). Secondary faulting will also deform the area in advance of the leading edge of a thrust fault (Anderson, 1951; Hafner, 1951; Chinnery, 1966; Rodgers and Rizer, 1979b). Northwest trending slickenlines observed in the Brown shales of the Nicholas Combs #7239 core (Kulander and others, 1977) and slickenlines observed in the Martin County core were explained in this way (Wilson and others, 1979) and were suggested to represent the porous fracture facies discussed by Shumaker (1978).

Bedding-transverse thrust faults cut across the Devonian Oriskany Sandstone on the northwest limb of the Elkhorn Mountain anticline (adjacent to the southeast of the Middle Mountain syncline) and probably represents secondary splay thrusts off a major splay that rises from a decollement in the Ordovician Reedsville Formation and above which the Elkhorn Mountain anticline is formed. The deformation domains on both limbs of the Middle Mountain syncline are interpreted as a direct result of the thrust faults and associated folding in the underlying Devonian Oriskany Sandstone.

RECOMMENDATIONS FOR FUTURE EXPLORATION EFFORTS

The association of deformation domains with mapped faults and more intensely jointed shales suggests that the deformation domain is a small analogue of the fracture facies. Although the presence of shear surfaces may act to decrease the porosity of these shales (Bagnell and Ryan, 1976), the presence of more intense jointing in these shales may increase the porosity and permeability producing a fractured gas reservoir.

Brown shale gas production is in part related to the quantity of open fractures that intersect the well bore (Shumaker, 1978; Schaefer, 1979). In the Midway-Extra Field, Putnam County, West Virginia, the "highest production potential and thus, the most intense fracturing is located on the west flank of the Midway anticline, just east of the syncline" (Schaefer, 1979). The Midway anticline is associated with basement faulting along the Rome Trough (Shumaker, 1978). Originally vertical faults are known to flatten up section producing reverse movement above the downthrown blocks (Sanford, 1959). Although the presence of faulting is not indicated, the increased fracturing on the west limb of the Midway anticline may be the result of similar but smaller horizontally directed stresses arising from vertical basement movements.

Shallowest drilling depths to the base of the Devonian shales within the Parsons structural lineament occur near central western Tucker County, West Virginia, (Figure 3) along the southwest plunging nose of the Deer Park anticline. Structure contours on the Onondaga Limestone (Cardwell, 1973) show that the plunging nose of the Deer Park anticline is faulted by a strike-trending, detachment-related, normal fault with the upthrown block to the southeast. The presence of increased joint intensity in faulted volumes of rock make this area an excellent test site in the effort to extend shale gas production into the eastern Plateau.

CONCLUSIONS

1. Rocks in the Parsons structural lineament are more intensely jointed than rocks outside. This increase in intensity is manifest in rocks from the Middle Devonian of the Valley and Ridge to the Middle Pennsylvanian in the Plateau.
2. Joint intensity inside the lineament in the Plateau is approximately twice as great as outside the lineament.
3. Contour maps of standard deviations in bedding dip are of considerable value in mapping structures in poorly exposed, mechanically incompetent shales and in defining deformation domains.

4. The relationship between joint intensity and deformation domains to structural lineaments like the Parsons lineament may represent an important factor to consider in developing an exploration rationale to locate fractured gas reservoirs.

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Figure 1

Figure 2. Parsons structural lineament, Tucker County, West Virginia, located between solid lines.

Figure 3 Isopach of drilling depth to the base of the Devonian shales - T. H. Wilson, 1979

APPENDIX C

SURFACE FRACTURE DATA

1979 - 1980

Mark A. Evans

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FRACTURES IN ORIENTED DEVONIAN SHALE CORES
FROM THE APPALACHIAN BASIN

VOLUME I

by

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January 1980

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ABSTRACT

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, Genesee Shale, West Falls Formation, and the Lower Huron Member of the Ohio Shale. Slickensided fractures occur most frequently in the Marcellus Shale, Tully Limestone, Genesee 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.

INTRODUCTION

Purpose

Fractures in the Middle and Upper Devonian shale sequence of the Appalachian Basin are believed to provide the permeability needed for commercial gas production. If the nature, orientation, and intensity of the fractures can be determined, then the extent and location of potentially productive permeable zones can be predicted and better exploration programs planned for greater gas production.

Most studies of reservoirs with fracture permeability rely on surface joint data, photolineament data, and production studies to predict subsurface fracture patterns. However, the availability of numerous oriented cores from the Devonian shale sequence of the Appalachian Plateau province has allowed the characterization of subsurface fractures for parts of that sequence cored. The rock has not been exposed to weathering or long-term, near-surface tensile stresses which may add fracture patterns not found at depth. The cores present a unique opportunity to study natural fractures from a fractured reservoir and demonstrate that open fractures do exist at considerable depth in the earth's crust.

The purpose of this study is threefold: first, to document subsurface fractures in the Devonian shale by examining oriented cores; second, to determine relationships of subsurface fracture patterns to regional structure and stresses; and finally, to provide a basis for the evaluation of the utility of subsurface fracture patterns and possible highly fractured zones as an aid in gas exploration. Ultimately, the data collected in this study will be used by others for comparison

with additional production and geologic information.

Location

The study area comprises a large part of the Appalachian Plateau province, extending from eastern Ohio and southwestern Pennsylvania through West Virginia and into eastern Kentucky and western Virginia. Thirteen cores were examined from wells located throughout this area (figure 1, table 1).

Regional Structure

The Appalachian Plateau province lies between the relatively undisturbed rocks of the Central Stable Interior on the west and folded sedimentary rocks of the western Valley and Ridge province on the east. Surface rocks in the Plateau region appear to be flat-lying, but low-amplitude folds can be defined by detailed surface and subsurface mapping (figure 2). Décollement zones often separate undeformed or mildly deformed shallow rocks from those deformed by basement structures below. These décollement zones are the westward extensions of larger thrust zones in the adjacent Valley and Ridge Province. The Pine Mountain thrust, a large sheet detached in the Devonian shales, is found at the southeast boundary of the Plateau, at the common borders Kentucky, Virginia, and Tennessee. The Rome Trough, a large basement graben which formed during the early Cambrian, extends northeastward from eastern Kentucky through western West Virginia and possibly into Pennsylvania (figure 2). The Rome Trough is believed to be an extension of the Eastern Interior aulacogen (Harris, 1978), but it may be a back-arc or basin complex that formed at the inception of subduction

Figure 1. Location of core wells

EGSF Well No.	Company Well No.	State Well No. (if any)	Location	Latitude Longitude Carter Coordinates in KY & OH	Year Cored	Contractor	Cored Interval	Amt. of Core (in feet)	Total Depth	Elevation of KB (above sealevel)
OH #1	Gien Gery S-745	Permit No. 835	Carroll Co., OH	600 FSLX x 760 FWL SW 1/4 sec. 29, T. 16N., R. 7W	1974	Belden and Blake, Inc.	2080 - 2200 3080 - 3200	240	5187	1045
YY #1	Nicholas- Combs 7239	Permit No. 28982	Perry Co., KY	1960 FNLX x 325 FWL 19-K-76	1975	Kentucky-West Virginia Gas Co.	2369 - 2700	330	2710	1090
WV #2	W.D. Pinnell 12041	Jac-1371	Jackson Co., WV	0.77 mi. W 2.97 mi. S of of 81° 50' 00"W 38° 55' 00"N	1975	Consolidated Gas Co.	3220 - 3690	470	3742	673
WV #3	20403 Fee	LIN-1637	Lincoln Co., WV	3.1 mi. W 4.5 mi. S of of 82° 10' 00" 38° 10' 00"	1976	Columbia Gas Corp.	2720 - 4028	1308	4073	1222
WV #4	20402 Fee	LIN-1636	Lincoln Co., WV	3.94 mi. W 4.83 mi. S of of 82° 10' 00" 38° 10' 00"	1976	Columbia Gas Corp.	2654 - 2770 3000 - 3118 3290 - 3588 3886 - 3968	614	4066	1152
OH #2	Florence L. House R-109	Permit No. 3521	Washington Co. OH	6200 ft. W 8400 ft. S of of 81° 32' 30" 39° 25' 00"	1976	River Gas Co.	3490 - 3714	224	6262	825
KY #3	20336 Fee	Permit No. 31020	Martin Co., KY	2750 FNL x 1650 FWL 16-P-85	1976	Columbia Gas Corp.	2429 - 3411	982	3456	831
VA #1	Penra.- Virginia Corp. 20338	Permit No. 253	Wise Co., VA	82° 41' 14"W 37° 00' 37"N	1977	Columbia Gas Corp.	4870 - 4985 5210 - 5475	380	5734	245.5
WV #5	#3 D/K Farm	MAS-146	Mason Co. WV	82° 03' 45"W 38° 55' 30"N	1977	Reel Energy, Inc.	2673 - 3420	747	3422	875
WV #6	MERC #1		Monongalia Co. WV	79° 58' 44"W 39° 40' 14"N	1978	U.S. Dept. of Energy	7168 - 7509	350	7520	573
WV #7	Emch-Fyles UNIT #1	WET-645	Wetzel Co., WV	80° 49' 20"W 39° 40' 37"N	1978	Mobay Chemical Co.	6100 - 6650	550	6694	1355
WV #8	Skaggs- Kelly UNIT #1 #3 R-S	Permit No.	Johnson Co., KY	82° 56' 20"W 37° 57' 40"N	1978	Ashland Exploration, Inc.	950 - 1500	550	1505	972
PA #2	C.E.P.S. #1	ALL-20980	Allegheny Co., PA	79° 53' 30"W 40° 11' 30"N	1978	C.E. Power Systems	6950 - 7505	555	7520	760

Table 1. Core well data

Figure 2. Tectonic map of the study area.

(Avalonian) along the Paleozoic North American continent (Shumaker, 1979). Low folds that are only visible in the subsurface in southwestern West Virginia and eastern Kentucky may be the result of reactivated Rome Trough faults which also affected sedimentation during the Devonian (Schaefer, 1979).

Stratigraphy

Surface rocks in the study area, which are primarily of Permian and Pennsylvanian age, consist of deltaic sequences of shale, sandstone, minor limestone, and coal. In the subsurface, the Mississippian system includes shales, sandstones, and a limestone which extends over most of the study area. Rocks of the Middle and Upper Devonian consist of siltstones, grey, brown, and black shales, and a few thin limestones. The rocks of the Lower Devonian are mainly limestones. Figure 3 shows the stratigraphic nomenclature for Middle and Upper Devonian rocks in the Appalachian Basin. More detailed discussions of the stratigraphy and structure in the vicinity of individual core wells are presented in the core well reports in the appendices.

Previous Investigations

One of the first studies of subsurface fractures in cores was made by Wilkinson (1953) who studied subsurface fractures in the Spraberry Field of west Texas and compared them with production trends. Friedman (1967) conducted a structural analysis of both macrofractures and microfractures in cores from the Santicoy Field in Ventura County, California. Stearns and Friedman (1972) present a method for core orientation and fracture measurement. They also give an identification

OHIO	VIRGINIA	PENNSYLVANIA WEST VIRGINIA	NEW YORK		
BEREA SANDSTONE	POCONO FORMATION	POCONO FORMATION		MISSISSIPPIAN	
BEDFORD SHALE					
OHIO SHALE	HAMPSHIRE FORMATION	HAMPSHIRE FORMATION	CONEWANGO GROUP	DEVONIAN	UPPER
	CHEMUNG FORMATION	CHEMUNG FORMATION	CONNEAUT GROUP		
			CANADAWAY GROUP		
UPPER OLENTANGY SHALE	BRALLIER FORMATION	BRALLIER FORMATION	JAVA FORMATION		MIDDLE
			WEST FALLS FORMATION		
			SONYEA FORMATION		
		HARRELL SHALE	GENESEE FORMATION		
		TULLY LIMESTONE	TULLY LIMESTONE		
LOWER OLENTANGY SHALE	MILLBORO SHALE	MAHANTANGO FORMATION	MOSCOW FORMATION		
			LUDLOWVILLE FORMATION		
			SKANEATELES FORMATION		
		MARCELLUS SHALE	MARCELLUS SHALE		
DELAWARE LIMESTONE	ONONDAGA LIMESTONE / HUNTERSVILLE CHERT / NEEDMORE SHALE /	ONONDAGA FORMATION	ONONDAGA LIMESTONE		

Figure 3. Stratigraphic nomenclature for Middle and Upper Devonian rocks in the Appalachian Basin (from Neal, 1979).

system for distinguishing pre-core and core-induced fractures.

Two studies, Kulander, Dean, and Barton (1977) and Kulander, Barton, and Dean (1978), present an exhaustive treatment of core fractures and fracture characteristics as well as a system for classifying fracture types. It is this classification and the distinguishing characteristics of several fracture types described by Kulander et. al. (1977; 1978) that the author used in this study to distinguish natural (Kulander's pre-core fractures) and core-induced fractures.

The first studies of subsurface fracturing in the Appalachian Plateau province were conducted by the U. S. Bureau of Mines. Results of these studies are given by Overbey and Rough (1968), Overbey (1969), and Overbey and Rough (1971). Surface and subsurface fractures were investigated in the Bradford and Allegheny oilfields in northern Pennsylvania, southern New York state, and in Hocking County, Ohio.

A report by Wilson, Dixon, Shumaker, and Wheeler (1978) discusses fracture patterns observed in five cores from the Devonian shale of the Appalachian Basin. The cores: WV #3 (20403), WV #4 (20402), OH #2 (R-109), KY #3 (20336), and VA #1 (20338), were also investigated in this study.

Each well in this investigation has been previously logged and studied by personnel or representatives of the U. S. Department of Energy, including the author (Evans, 1978; 1979). However, this is the first comprehensive report that compiles, integrates, and analyzes all the data.

METHODS OF ANALYSIS

Data Acquisition

Each of the thirteen cores studied was oriented by one of three organizations: the U. S. Department of Energy - Morgantown Energy Technology Center (METC) (KY #1, OH #1, WV #2, WV #3, and WV #4); the West Virginia Geologic and Economic Survey (KY #3, OH #2, VA #1, WV #5, and WV #6); and Cliffs Minerals (PA #2, KY #4, and WV #7). Personnel of METC supplied core-induced fracture data to the author for four cores (WV #4, WV #5, VA #1, and KY #3) and undifferentiated fracture data for two cores (OH #1 and OH #2). Dr. Byron Kulander supplied fracture data for the KY #1 core. Thomas Wilson supplied fracture data for the KY #3 core. Nine cores were examined personally by the author (WV #2, WV #3, WV #4, WV #5, WV #6, WV #7, KY #4, PA #2, and VA #1) at the METC Core Lab and the Cliffs Minerals Core Lab.

Fractures in the cores were measured by using a 360° protractor and a ruler, or a goniometer (when available). The data recorded for each observed fracture includes (see table 2 for definitions):

- 1) Depth at which the fracture occurs (below Kelly bushing).
- 2) Strike.
- 3) Dip.
- 4) Upper extent.
- 5) Lower extent.
- 6) Total length.
- 7) Fracture type.
- 8) Whether the fracture is slickensided or not.

- 9, 10) If slickensided, trend and plunge of slickenlines (striations).
- 11) Slickenline intensity (based on arbitrary scale).
- 12) Type and amount of fracture mineralization (if any).
- 13) Type and extent of face markings, and fracture propagation direction (if determinable) (see fractography section below).
- 14) Lithology in which the fracture occurs.
- 15) Other comments.

A sample fracture data sheet is shown in table 2. Unsatisfactory core condition many times restricted the amount of data that could be collected. Either the core had been sampled to the extent that it was useless to collect quantitative data or the shale had disintegrated to a rubble. For example, the WV #2 and WV #3 cores were so badly broken and sampled to the extent that very few fractures could be measured, the author was forced to sample only five core-induced fractures per box. Accurate fracture lengths, and upper and lower extents of the fractures could not be determined for these two cores.

Fractography

During the study certain structural and surface features were observed on fractures, and these were used to interpret the type and origin of the fractures. For example, core-induced fractures possess a unique combination of fracture surface characteristics which distinguish them from natural fractures.

Kulander, Dean, and Barton (1977) and Kulander, Barton, and Dean (1978) have classified fracture surface characteristics into two groups:

transient features, which are structures on fracture surfaces, and tendential features, which are fracture trace changes (figure 4).

Transient features are short range irregularities and perturbations of a fracture surface which can be attributed to:

- 1) Material inhomogeneities (fossils, pyrite nodules, pore space, etc.).
- 2) Sonic wave interference.
- 3) Local changes in stress directions and stress gradients in the dominant stress field.
- 4) Fracture velocity variations.

Among more common transient features are arrest lines or "rib marks" (figures 4A, 6, and 10), inclusion hackle (figure 4A), twist hackle (figures 4A, 10, and 13), and hackle plume or "feather fracture" (figures 4A, 9, 10, and 13).

Arrest lines record an instantaneous picture of the fracture front configuration at a particular time during fracture propagation. Inclusion hackle results from the interference with an advancing fracture front of an inclusion (pore space, weakly cemented area, grain of different composition or size, etc.) in its path. Twist hackle is generated at the fracture front when the direction of principle tension rotates in the plane containing the fracture front. Hackle plume is made up of twist hackle and inclusion hackle. It consists of a central axis that starts at the point of fracture origin and faint ridges that diverge outward from the axis in a plumose fashion toward the edge of the fracture plane (Kulander, Barton, and Dean, 1978). The presence of plumose markings on a fracture surface indicates that the

FEATURES OF NATURAL FRACTURES

Figure 4. Features of natural fractures: A) transient features B) tendency features

Figure 5. Idealized diagram of: A) petal-centerline fracture, B) torsion fracture, and C) disc fracture.

Figure 6. Petal-centerline fracture. Note symmetrical arrest lines downcore. From WV #5 (#3 D/K) core.

Figure 7. Three petal fractures, all with same strike and dip. From WV #5 (#3 D/K) core.

Figure 8. Two connected petal fractures forming a "scallop" fracture. Fracture C formed after A and B. From WV #5 (#3 D/K) core.

Figure 9. Disc fracture, and two petal fractures with same strike but opposing dips. Note hackle plume spreading from its origin, a fossil fragment, to meet the core boundary orthogonally. From WV #5 (#3 D/K) core.

Figure 10. Natural fracture termination, exhibiting: A) hackle plume, B) twist hackle, C) arrest line, and D) dolomite mineralization diminishing toward edge of fracture. From WV #5 (#3 D/K) core.

Figure 11. Three parallel subvertical natural fractures. From WV #5 (#3 D/K) core.

Figure 12. Natural fracture mineralized with calcite and pyrite.
From WV #6 (MERC #1) core.

Figure 13. Two intersecting fractures of different strike and dip.
Note: A) calcite mineralization, B) twist hackle, and
C) hackle plume. From WV #4 (20402) core.

fracture walls have not ground against each other. However, high fluid pressure can permit preservation of plumes during relative slip of the walls.

Tendential features arise from long range changes in the stress field and are recorded as undulations in the fracture profile or trace line, generally at right angles to transient features. There are two basic types of tendential features; hooking and forking (figure 4B). The criteria used by the author to distinguish pre-core or natural fractures from core-induced fractures were set forth by Kulander, et. al. (1977; 1978) and are presented below.

Core-induced fractures have one or more of the following characteristics:

- 1) A fracture origin at the core boundary or within the core itself.
- 2) Hackle marks diverging and attempting to meet the core boundary or a pre-existing fracture surface orthogonally.
- 3) Hackle marks becoming coarse, the hackle steps increasing in relief in the immediate vicinity of the core boundary or pre-existing fracture surface.
- 4) Twist hackle originating near the core boundary or pre-existing fracture surfaces.
- 5) Hackle plumes on subhorizontal fractures that diverge from the central core area in a spiral pattern indicating a torque stress.
- 6) Closely spaced arrest lines on vertical and inclined fractures; arrest lines are convex downcore and symmet-

rical about the imaginary line down the fracture surface center.

- 7) Hackle marks on vertical or inclined fractures that diverge downcore symmetrically about an imaginary line down the fracture surface center.
- 8) Fractures that hook abruptly towards the core boundary or a pre-core (natural) fracture surface.

Natural fractures have one or more of the following characteristics:

- 1) Polished and slickensided fracture faces (almost always smooth and planar).
- 2) Fractures filled by fibrous or non-fibrous minerals.
- 3) Smooth fractures extending entirely across the core and against which later fractures usually terminate.
- 4) Inclines or vertical fracture faces displaying small, often conchoidal chips at the fracture-drilled core boundary intersection. The chips hook to meet the fracture orthogonally.
- 5) Conchoidal chips originating at the scribe marks on the core and curving to meet a pre-existing fracture face orthogonally.
- 6) Outsize transient markings or twist and inclusion hackle that do not curve to meet the core boundary orthogonally.
- 7) Several parallel to subparallel vertical or inclined fractures passing completely through the core.
- 8) General lack of any diagnostic symmetrical association

between fractographic markings, coring methods, and core geometry.

Fracture types

In the preceeding section on fractography we have been able to differentiate core-induced fractures and natural fractures. Core-induced fractures can be further subdivided. The common types include petal-centerline fractures, torsion fractures, and disc fractures.

Petal-centerline fractures (figures 5A, 6, 7, 8, and 9) form in response to a core-induced principal tension that rotates downward in a vertical plane from an inclined orientation to horizontal. The petal section of these fractures is that portion that curves in a downcore direction from a dip angle generally between 30° and 70° at the core boundary to a vertical dip within the core. A petal fracture may form without the vertical centerline portion (figures 7, 8, and 9). Very often these fractures show a remarkably consistent strike orientation throughout a core even though they may have opposing dips (figure 9). This strike consistency indicates that these fractures follow a stress or rock fabric anisotropy throughout the drilled section (Kulander et. al., 1978).

Torsion fractures (figure 5B) are formed by a torsion induced stress generated behind the drill bit. They are distinguished by a helical fracture trace on the core surface.

Disc fractures (figures 5C and 9) are horizontal to subhorizontal and form in response to vertically acting principal tensile stress. This stress is attributed to unloading and bit pressure along with vibrations and torques inherent to the drilling process.

The orientation or frequency of torsion fractures and disc fractures were not measured, and these fractures will not be discussed further, except to indicate their presence or absence in a particular core.

Natural or pre-core fractures are formed as a result of the failure of the rock under natural stresses in the earth's crust. Natural fractures are subdivided into unmineralized fractures, mineralized fractures, and slickensides. In this study, natural fractures, exclusive of slickensides, are referred to simply as "natural fractures" and they are joints. Natural fractures in the cores are generally subvertical to vertical (figure 11).

Natural tension fractures may form near the earth's surface where tensile total principal stresses are possible or they may form at depth where only effective tension is possible and where pore fluid is important in fracture genesis. The coring process samples those natural fractures which, in most cases, formed at depth and thus probably in a different stress system than did fractures near the surface.

According to Secor (1969, p. 41):

When natural tension fracturing occurs at depth in the earth's crust, in the presence of high pore pressures, macroscopic fracture growth is a slow process consisting in detail of numerous short, quick episodes of fracture propagation interspersed with longer periods of quiescence during which pore fluid from the surrounding rock percolates into the crack and wedges it open.

The formation of these fractures requires a ratio of fluid pressure to overburden weight which approaches one (Secor, 1965).

Natural fractures often occur as two or more distinct sets intersec-

ting acutely or orthogonally. These sets may have originated at different times under different stress conditions.

Many of the natural fractures in the shale cores are mineralized (figures 10, 12, and 13). The most common fillings are calcite, dolomite, barite, pyrite, anhydrite, or some combination of these. The fillings may be massive, crystalline, or fibrous. The fibrous fillings consist of mineral fibers, usually calcite, that are perpendicular to, or at a slight angle to, the fracture walls. The fibers grew parallel to the principal acting tension as the fracture opened (Durney and Ramsay, 1973).

Slickensides are small faults which are distinguished and studied separately from other natural fractures. The orientations of the striations or slickenlines on the slickensides were measured. These striae form when the fracture surfaces are forced past one another during slippage. It is presumed that the slickenlines are oriented in the direction of movement. Figure 14 illustrates the use of the terms slickenside and slickenline, for the common case of slickenlines trending up- or down-dip on the slickenside.

Slickensides are divided into two classes: subhorizontal to horizontal ($\text{dip} < 10^\circ$) (figures 15 and 16), and inclined ($\text{dip} \geq 10^\circ$) (figures 17 and 18). This distinction was made to separate low dipping fracture surfaces that generally are slickensided bedding planes from more inclined shear fractures. The strike orientations of subhorizontal to horizontal slickensides were not measured because strike lines are too difficult to determine on fractures dipping less than 10° . It was felt that measuring only slickenline trends on the low

SLICKENSIDE TERMINOLOGY

Figure 14.

Figure 15. Horizontal bedding plane slickenside. Note irregular surface. From WV #6 (MERC #1) core.

Figure 16. Horizontal bedding plane slickenside mineralized with fibrous calcite, fibers are perpendicular to the fracture walls. From WV #6 (MERC #1) core.

Figure 17. Inclined slickenside. From WV #4 (20402) core.

Figure 18. Inclined slickensides in tendential view. From base of VA #1 (20338) core.

dipping fractures would be more accurate and meaningful. Slickensides were found to be mineralized with either calcite, dolomite, barite, pyrite, or some combination of these. The fillings are usually fibrous and found on horizontal and low dipping slickensides (figure 16). This indicates that the fracture was open, and that fluid under high pressure was passing along the bedding planes separating the fracture.

Data Analysis

Core fracture data were analyzed by several methods: 1) composite rose diagrams and lower hemisphere equal area projections for all fractures of each fracture type (core-induced, natural, and slickensided) and slickenlines in each core, 2) rose diagrams and equal area projections for each fracture type and slickenlines in approximately equal core-length intervals in each core, 3) fracture frequency vs. depth plots for each fracture type in each core, 4) statistical testing to determine peaks in composite rose plots, and 5) statistical comparisons of core-length interval core-induced fracture orientation distributions.

To further aid in data analysis the core-length interval rose diagrams and equal area projections were plotted next to a gamma-ray log of the cored interval. This was done so that changes in fracture orientation with depth and stratigraphy could be observed. Composite fracture data sheets of all fracture types and slickenlines were made for each core to compare differences in fracture orientation and frequency with fracture type, depth, and stratigraphy. The composite rose diagrams for each core were plotted on maps to determine regional

subsurface fracture trends. Histograms of strikes of core-induced fractures, in approximately equal core-length intervals of each core, were plotted so that subtle differences in strike could be observed. The Upper and Middle Devonian units of each core well were correlated across the study area. Fracture frequencies in each shale unit were then compared between wells. This was done for each fracture type in order to determine if certain units are characteristically more fractured.

Plotting of fracture strikes and slickenline trends as rose diagrams was accomplished using a CALCOMP plotter and program (Werner, Program to plot orientation data, unpublished manuscript) on the IBM 360/75-370/148 of West Virginia Network for Educational Telecomputing. Except where noted, a 5° class interval was used in all rose diagrams and histograms. Plotting of fracture strikes and dips, and slickenline trends and plunges was accomplished using a computer program (Wheeler, unpublished program) which plots a Mellis-contoured equal area projection of fracture strike and dip or slickenline trend and plunge.

Data analysis was accomplished by visual inspection and interpretation. This analysis involved choosing peaks from the rose diagrams and clusters from the equal area projections as well as trends from regional maps. Also, visual comparisons of fracture frequencies were made between cores by examining the cross sections. Since personal bias tends to color this form of interpretation, statistical testing has also been performed to provide an impartial assessment of the data.

A statistical test discussed by Abdel-Rahman and Hay (1978) was

used to determine if individual peaks and troughs found visually on the composite rose plots are significant statistically. Identification of peaks and troughs uses the Poisson method for calculating the minimum and maximum numbers of fractures, respectively, needed to fill in any one orientational class in order to reject the assumption of random distribution of the data.

The differences between core-length interval core-induced fracture orientation distributions were determined by using a modification of the Kolmogorov-Smirnov (K-S) test. This modification, suggested by Kuiper (1960), takes into consideration the circular nature of the data. The hypothesis tested was that the two distributions compared were equal. The test was accomplished using a computer program (Werner, Program to plot orientation data, unpublished manuscript). Statistics generated by the program include; N (number of fractures) in each interval; VN, the test statistic; and alpha (α), the significance level. The test results are in the appendices.

A bias, introduced by the coring method, exists in the sampling of natural fractures at depth by the core bit. Two factors are involved. These are the spacing of the fractures relative to the diameter of the core and the orientation of the fractures relative to the core axis. For example, natural vertical fractures which are spaced one foot apart are poorly sampled by a six inch core bit in a vertical hole. The sampling improves, however, as the angle between the fractures and the core axis increases. According to Stearns and Friedman (1972) the distribution of dip angles between the fracture

and the core axis follows a Gaussian distribution. They present a method to weight observed fracture frequencies of differently dipping fracture sets in cores in order to determine their relative order of abundance. The weighting procedure was not used in this study, because the author felt that, in most cases, the natural fracture and slicken-side orientations did not show enough variability to warrant its use.

FRACTURE ANALYSIS

Reports on Fractures in Each Core

Individual reports on each of the cored wells studied are presented in the appendices. Each report discusses, in detail, the fractures and fracture patterns in that particular core and their relationships to local structures and regional tectonics. A brief discussion of gas production from the shale section of the well is also included in these reports. The reader may wish to refer to these reports for detailed information to evaluate conclusions drawn by the author. However, for easy reference the dominant fracture peaks and their statistical significance, for each core, are summarized in table 3.

Regional Fracture Patterns

Distinct, statistically significant fracture orientation peaks, dominant fracture trends, or both, were found in all of the cores studied. Certain of these trends are unique to a particular core and show little or no relationship to trends in other cores. Such unique trends are probably related to stresses associated with local structures or local stress anomalies. Certain other fracture trends, however, can be found in several cores throughout the Appalachian Plateau province with only minor, and usually predictable, variations in trend between cores. Because of their regional extent, these trends seem related to stresses associated with regional deformation. Of course, some variation in regional fracture trends are found which resulted from the interaction of both local and regional stresses. Fracture trends resulting from local influences are discussed primarily

Well No.	Natural Fracture Peaks				Silicified Peaks				Silicified Peaks				Core-Induced Fracture Peaks			
OH #1	Undiff. K20°-30°E K25°E 0.05	Undiff. K65°W not sig.	—	—	—	—	—	—	—	—	—	—	—	—	—	—
KT #1	Undiff. K5°-15°W K10°W 0.05	Undiff. K3°E 0.05	Undiff. K77°W 0.10	Undiff. K33°E 0.10	K7°E 0.01	—	—	—	K87°W 0.01	K83°E 0.01	K27°E 0.01	K33°W 0.05	—	—	—	—
WT #2	K57°E 0.01	—	—	—	K5°-20°W K7°W 0.01	—	—	—	K70°-85°E K77°E 0.01	—	—	—	K50°-70°E K60°E 0.01	K17°W 0.05	—	—
WT #3	K60°-70°E K65°E 0.01	K27°W 0.01	K83°E 0.01	—	K70°-85°E K77°E 0.01	K75°W not sig.	K27°E not sig.	K63°E not sig.	K5°-20°W K13°W 0.01	K65°W not sig.	—	—	K55°-75°E K65°E 0.01	K83°E 0.01	—	—
WT #4	K20°-35°E K27°E 0.01	K65°E not sig.	K63°W not sig.	K7°W not sig.	K33°-45°E K40°E 0.01	—	—	—	K40°-50°W K45°W 0.01	K33°E not sig.	K27°W not sig.	—	K20°-45°E K33°E 0.01	—	—	—
OH #2	Undiff. K5°-75°E K67°E 0.01	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
KT #3	K57°W not sig.	K47°W not sig.	K37°E not sig.	—	K17°W 0.05	K47°E 0.05	K83°E 0.05	—	K3°W 0.05	K73°E 0.10	K63°W not sig.	—	K40°-55°E K47°E 0.01	K63°E 0.01	K13°E 0.01	—
TA #1	K7°W 0.01	K37°W 0.01	K83°W not sig.	K13°E not sig.	K40°-55°E K47°E 0.01	K27°E not sig.	—	—	K35°-55°W K45°W 0.01	—	—	—	K65°-70°E K57°E 0.01	—	—	—
WT #5	K70°-80°E K75°E 0.01	K33°E 0.05	K65°-60°W 0.05	—	K17°W 0.01	—	—	—	K67°E 0.01	—	—	—	K65°-85°E K75°E 0.01	—	—	—
WT #6	K83°E 0.01	K67°W 0.05	K47°W not sig.	—	K0°-30°E K15°E 0.05	K20°-30°W K25°W 0.05	—	—	K65°-75°W K70°W 0.01	—	—	—	—	—	—	—
WT #7	K57°W 0.01	K47°W 0.05	—	—	K15°-30°E K23°E 0.05	K43°W 0.10	—	—	K67°W 0.05	—	—	—	K67°E 0.01	—	—	—
KT #4	K60°-70°E K65°E 0.01	K47°E 0.10	—	—	K7°W not sig.	K33°E not sig.	K83°E not sig.	—	K43°W not sig.	K3°W not sig.	K65°E not sig.	K55°W not sig.	K55°-65°E K60°E 0.01	K73°E 0.01	—	—
TA #2	K17°E not sig.	K37°E not sig.	K65°E not sig.	K47°W not sig.	K47°E 0.01	—	—	—	K40°-60°W K50°W 0.01	—	—	—	—	—	—	—

Key
 K5°-15°W --- peak range
 K13°W --- average peak orientation
 0.01 --- value, significance

Table 3. Fracture orientation peaks for all fracture types for each core

in the individual core reports. This analysis will concentrate on coherent regional patterns of each structure studied: Core-induced fractures; natural fractures; slickensided fractures, and their associated slickenlines.

Core-induced Fractures

Composite rose diagrams of core-induced fractures for each core were plotted on a map of the study area to evaluate the consistency of trends from well to well. Core-induced fracture orientations show a remarkable preference for a northeast trend in nearly all cores in which they occur (figure 19). Minor, yet significant, variations in trend do exist locally. The consistent orientation indicates the presence of a stress or rock fabric anisotropy in the rocks throughout the Appalachian Plateau province. This anisotropy probably relates to the present day horizontal maximum compressive stress which exists in eastern North America (Sbar and Sykes, 1973). The present day stress was delimited from a combination of fault plane solutions of earthquakes, in-situ stress measurements, and observations of postglacial deformation (pop-ups). Voight (1969) suggests that the stress relates to convective flow in the mantle associated with the spreading of the crust, including North America, away from the Mid-Atlantic Ridge. This stress would be Mesozoic in origin, and it would probably have nullified any previous residual stress in the crust. Figure 20 shows dominant core-induced fracture orientations along with postulated maximum compressive stress trajectories, based on data in table 4. The core-induced fracture trends closely follow the stress trajectories.

The anisotropy may also be related to the rock fabric. Peng and

TABLE 4
COMPRESSIVE STRESS MEASUREMENTS IN THE APPALACHIAN PLATEAU

<u>Location</u>	<u>Trend of</u>	<u>Method</u>	<u>Reference</u>
1) Alma Twp., N.Y.	N77°E	HYDRO	2
2) Falls Twp., Ohio	N64°E	HYDRO	4
3) Falls Twp., Ohio	N63°E	HYDRO	4
4) Bradford, Pa.	N70°E	HYDRO	5
5) Barberton, Ohio	N90°E	SR	3
6) Gibsonville, Ohio	N78°E	SR	7
7) Logan, Ohio	N75°E	BHD	6
8) Laural Twp., Hocking Co., Oh.	N73°E	BHD & IP	6
9) Scherrodsville, Ohio	N88°E	BHD	6
10) Loudenville, Ohio	N83°W	BHD	6
11) Allegheny Co., N.Y.	N62°E	IP	6
12) Logan Co., W.Va.	N87°W	BHD	6
13) Lincoln Co., W.Va.	N37°E	IP	6
14) Roan Co., W.Va.	N87°W	TS	6
15) Roan Co., W.Va.	N83°E	TS	6
16) Jackson Co., W.Va.	N82°W	BHD	6
17) Doddridge Co., W.Va.	N87°E	TS	6
18) Monongalia Co., W.Va.	N84°W	IP	6
19) Monongalia Co., W.Va.	N66°E	BHD	6
20) Buchanan, Va.	N71°E	BHD	6
21) Perry Co., Ky.	N67°E	BHD	6
22) Wetzel Co., W.Va.	N40°E ?	BHD	6
23) Lincoln Co., W.Va.	N40°-50°E	IP	1

References: 1- Brechtel, Abou-Sayed, and Clifton (1977); 2- Hamison and Stahl (1969); 3- Obert (1962); 4- Overbey and Rough (1968); 5- Overbey and Rough (1971); 6- Overbey (1976); 7- Rough and Lambert (1971)

HYDRO - Hydrofracture
SR - Strain Relief
BHD - Borehole deformation gauge
IP - Impression packer survey
TS - Televiewer survey

Figure 19. Regional core-induced fracture patterns.

Figure 20.

Okubo (1978) propose that the Devonian shale in the WV #3 (20403) core contains lenticular microcracks lying in the horizontal plane with their long axes predominatly parallel to $N60^{\circ}E$ (the core-induced fracture trend), intermediate axes parallel to $N30^{\circ}W$, and their short axes vertical. However in a petrographic study, Vinopal, Nuhfer, and Klanderman (1979) found no evidence for a microcrack system in the WV #3 (20403) core. Microcracks in an oriented core from Hocking County, Ohio, were found to strike $N67^{\circ}E$, nearly paralleling the measured in-situ stress of $N73^{\circ}E$ (Overbey and Rough, 1971). If a microcrack system exists, it probably formed as an extension feature under the influence of the post-Paleozoic east to northeast trending maximum compressive stress. If microcracks are present throughout the entire Plateau they may serve as Griffith cracks in the formation of the core-induced fractures, as well as planes of weakness in which the fractures propagate. Microcracks may also serve as the origins of northeast striking natural fractures which parallel the core-induced fractures.

Local fracture trends in the Appalachian Plateau province which do not follow the dominant northeast trend, may be the result of stress distributions which are modified by remnant stress, uplift, movement associated with decollement zones, and basement structures. One large basement structure which modifies the stress system is the Rome Trough, over which stress trajectories change abruptly (figure 20) and fracture patterns become quite variable. Advani, et. al. (1977) has shown through finite element analysis that stress distributions are altered over the Rome Trough basement fault zones. Core-induced fracture orientations were found to differ by 30° between the WV #3 (20403) and WV #4 (20402)

cores which are located over the Rome Trough in Lincoln County, West Virginia. These core wells are only 0.9 miles apart and have average core-induced fracture orientations of $N63^{\circ}E$ and $N33^{\circ}E$, respectively. To the southwest, just south of a Rome Trough fault, The KY #3 (20336) core has core-induced fracture orientations ranging from $N33^{\circ}E$ to $N63^{\circ}E$, with a large peak at $N47^{\circ}E$. The KY #1 (7239) core, which is also just south of a Rome Trough fault, and near other proposed basement faults, has several undifferentiated fracture trends: $N33^{\circ}E$, $N3^{\circ}E$, $N5^{\circ}-15^{\circ}W$, and $N37^{\circ}W$. Throughout the rest of the Appalachian Plateau province, core-induced fracture strikes range from $N50^{\circ}E$ to $N85^{\circ}E$.

Natural Fractures

Composite rose diagrams of natural fracture orientations for each core were plotted on a map of the study area so that regional relationships could be observed. Natural fracturea are positively identified in most of the cores studied, and they probably constitute a portion of the undifferentiated fractures logged in the OH #1 (S-745), OH #2 (R-109), and KY #1 (7239) cores. Natural fracture trends throughout the Appalachian Plateau province are the result of regional and local stress conditions. Two regional natural fracture systems predominate (figure 21). One system consists of northwest striking extension fractures. These fractures are orthogonal to central Appalachian trends in West Virginia, southeastern Ohio, and southwestern Pennsylvania, and probably formed under compressive stresses during Alleghenian deformation. Natural fractures of this system strike more northerly, and are orthogonal to the southern Appalachian trend, in southern West Virginia, eastern Kentucky, and western Virginia. Dolomite mineral-

Figure 21. Regional natural fracture patterns.

ization found primarily within the northwest set in the WV #3 (20403) and WV #5 (#3 D/K) cores, suggests a preferential mineralization of this system.

The second natural fracture system found in the cores from the Appalachian Plateau province is one that generally strikes northeast, paralleling the core-induced fractures and maximum compressive stress present in most of eastern North America (Sbar and Sykes, 1973). This system may have originated from stress created during post-Paleozoic plate spreading. It is possible that these natural fractures formed when the stress was considerably greater than the present day in-situ stress, or that they are presently in the process of forming. If the former is true, an early Mesozoic age seems likely. The fractures of this system are often mineralized with calcite.

Local structures many times affect fracture trends in an area. In eastern Kentucky and southwestern West Virginia, for example, numerous surface faults of the eastern Kentucky fault system and subsurface faults of the Rome Trough, probably contributed to the formation of a wide variety of natural fracture patterns. Natural fractures in this area formed by the several stress fields described above, that is local faulting, regional stress, and the interaction of these stress fields. The chaotically fractured nature of this area probably contributes to the success of the Eastern Kentucky Gas Field. Long (1979) found that surface fracture patterns in eastern Kentucky are also more complex than in surrounding areas.

Fractures in the PA #2 (C.E.P.S. #1) core from Allegheny County, Pennsylvania, exhibit a great diversity in trend. The core well is

located on the perimeter of a line of structural discontinuity (Wagner and Lytle, 1976), upon which structural strike and folds of the Appalachian trend are interrupted or terminated. This zone may be one of several that have been interpreted as basement transcurrent faults (Cardwell, Erwin, and Woodward, 1968). The variety in fracture orientation cannot be explained by a simple northwest directed compressive stress, as during Alleghenian deformation, and probably relates to movement or stress along the discontinuity. Wagner and Lytle (1976) have found that oil and gas fields in southwestern Pennsylvania terminate against lines of structural discontinuity. Possibly, the highly fractures nature of these zones allows the hydrocarbon to escape.

The well is also located near the proposed Lat. 40°N basement fault zone (Root and Hoskins, 1977). Altered stress fields above this zone may have also contributed to the chaotic fracture pattern.

Slickensides and Slickenlines

Composite rose diagrams of slickenside strikes and slickenline trends, and equal area projections of poles to slickensided surfaces, were plotted on maps of the study area so that regional relationships could be observed. Slickensides are found in all but one of the cores investigated (figures 22 and 23). Their presence throughout the Appalachian Plateau province can be related to décollement tectonics, local faulting, and compaction. One dominant slickenside strike and the associated slickenlines (figure 24) have formed as a result of Alleghenian compressive stresses. The slickenside strikes parallel the Appalachian trend whereas the slickenlines are orthogonal to it. During Alleghenian deformation, large blocks of the detached sedimentary section

Figure 23. Regional slickenside patterns.

Figure 24. Regional slickenline patterns.

were moved to the west along several décollements in the Silurian Salina salt and Devonian shales. Several of the cores investigated in this study pass through the décollement zones in the Devonian shales.

Décollement zones are characterized by intense deformation in the form of numerous slickensides and natural fractures throughout. They are usually found in the lowest viscosity (softest, least competent) strata, the black high organic shales, but may extend into higher viscosity (stiffer, more competent) rock. Décollement zones result from deformation, primarily simple (rectilinear) shear, being distributed across infinitely narrow faults. Distributing the shear markedly reduces the stresses associated with moving thrusts and the work expended in the process. This distributed shear is a natural consequence of the loading process thought to be responsible for gravity sliding and subhorizontal orogenic transport (Kehle, 1970). Deformation interpreted to be décollement zones was identified in southwestern Pennsylvania (PA #2), northern West Virginia (WV #6, WV #7), southwestern West Virginia (WV #3, WV #4), on the Pine Mountain overthrust sheet (VA #1), and possibly in eastern Kentucky (KY #4).

A model which seems to best describe the shear fracture (slickenside) orientations found in the décollement zones of the cores in this study is presented by Skempton (1966). It is the classic shear zone model that he describes which allows for three types of shear fractures: displacement shears, Riedel shears, and thrust shears. Displacement shears (D in figure 25) lie parallel or subparallel to the ab plane (figure 25). Riedel shears (R in figure 25) lie en echelon, and are inclined 10° to 30° to the ab plane, with the acute angle

Figure 25. Shear zones

always pointing against the direction of relative movement. Ideally these shears are accompanied by a conjugate set R' (R' in figure 25) which should make an acute dihedral angle with the main R shears. Thrust shears (P in figure 25) have a dip opposite to the Riedel shears. The acute angle with the ab plane points in the direction of relative movement. The slickensided fractures, as they would appear in a vertical core cutting through a décollement zone, are shown in figure 25b. An equal area projection of poles to slickensided surfaces in a décollement zone would ideally exhibit four clusters (figure 25c). The sense of displacement in both illustrations is to the northwest. After formation, and with continuous shearing, the slip planes may rotate, altering the geometric relationships accordingly.

In several of the décollement zones, subhorizontal to horizontal slickensides, and at times inclined slickensides, were found to be mineralized with fibrous calcite. This is indicative of a very high fluid pressure in the shales and a vertical principal effective tension during mineralization (Durney and Ramsay, 1973). Such abnormally pressured rocks are preferred sites for décollement because they are probably less viscous than their normally pressured counterparts (Kehle, 1970). Fiber growth may have occurred during or after décollement movement. The fibers are usually vertical, but they may be curved indicating movement during fiber growth.

As with natural fractures, slickensides and slickenlines exhibit a wide variety of orientations in eastern Kentucky. Most of the orientations can be related to fault movements in the area, either directly or through adjustment and compaction of the rocks after

faulting. Slickensides in the WV #2 (12041) and WV #5 (#3 D/K) cores from Jackson and Mason Counties, West Virginia, respectively, strike approximately $N20^{\circ}W$. Slickenlines trend approximately $N70^{\circ}E$. These trends may be related to the detached Burning Springs Anticline which is northeast of the wells.

The Lincoln County, West Virginia, Cores

The WV #3 (20403) and WV #4 (20402) core wells in Lincoln County, West Virginia, require a special discussion as they exhibit dramatic differences in orientations of all fracture types and slickenlines. This is true even though the wells are only 0.9 miles apart. Dominant fracture and slickenline patterns differ by approximately 30° between cores. There are, however, some fracture sets in each core that are unique to that core. The differences between the two cores may be the result of one or more of the following:

- 1) One, or both of the cores may not be oriented correctly. A problem in alignment could have arisen through misalignment of the orienting camera with the scribe marks on the core. The author checked core orientations, as marked after coring, and they agreed with the orientation logs. The alignment is therefore assumed to be correct.

- 2) One, or both of the cores may overlies a basement fault of the Rome Trough. The difference in fracture and slickenline patterns between the two cores may be related to altered stress distributions over a fault zone (Advani, 1977). In adjoining Mingo, Logan, Boone, and Kanawha Counties Kulander and Dean (1978a; 1978b) found chaotic fracturing in coals over a basement fault zone. Altered stress fields also could have affected the sense of movement in décollement zones

(Kulander and Dean, 1978).

3) Slickensides present in both cores suggest that the Devonian shales contain décollement zones. Movement within the décollement zones may have altered stress distributions in the shales, resulting in the formation of spatially variable fracture orientations.

4) The area in which the two wells are located is in the transition zone between the central and southern Appalachians. The intersection of the stress fields of both provinces may have resulted in altered stress distributions in the shales and, consequently, spatially variable fracture orientations. However, Dean and Kulander (1978) found no change in regional fracture trends from the southern Appalachians to the central Appalachians in southeastern West Virginia.

The second explanation in itself is most likely. However, the others may have contributed to some extent and should not be ignored, but checked in future investigations.

FRACTURE FREQUENCY

During the course of this study it was found that the occurrence and frequency of fractures in the cores is, in many cases, dependent on stratigraphy. This is true of all fracture types, but certain fracture types reflect this more so than others. Spacing changes from one lithology to another are expected. However, the occurrence of natural vertical unmineralized fractures, mineralized fractures, and slickensides together may create a permeability that is important to shale gas production. The occurrence of associated porosity within a highly fractured lithology has been called a porous fracture facies (Shumaker, 1978).

In order to investigate the stratigraphic position of the zones of intense fracturing in the 13 core wells, several stratigraphic cross sections were constructed in which the Middle and Upper Devonian units are correlated across the study area (plates 1 and 2). The Middle and Upper Devonian constitutes that portion of the Devonian between the Mississippian Berea Sandstone and the Devonian Onondaga Limestone. By examining the cross sections, one notices that the Middle and Upper Devonian section has its greatest thickness (nearly 6000 feet) in the PA #2 (C.E.P.S. #1) core well which is located near the center of the Appalachian Basin. To the south and to the west the thickness decreases, until, in eastern Kentucky, the section is only 600 feet thick. An unconformity on top of the Onondaga Limestone extends throughout the study area. Several units of the Middle Devonian are terminated against this unconformity just west of the center of the basin.

After correlating stratigraphic units, fracture frequency plots from the composite data sheets were placed on the cross sections. Three separate correlations were made, one each for core-induced fractures, natural fractures, and slickensides. Visual comparisons of the fracture frequencies were then made to determine which units had an abundance of, or lacked fractures.

Core-induced Fractures

Core-induced fracture frequencies remain quite consistent throughout the cored intervals and show very little similarity from core to core (plates 3 and 4). However, a general lack of core-induced fractures was found to be characteristic of the Java Formation and the West Falls Formation, particularly the Rhinestreet Member. It is also worth noting that it is near the base of the Java Formation that the core-induced fracture orientations generally deviate. The Sonyea Formation in the WV #7 (E-P #1) core and the Upper Huron Member in the KY #4 (#3 R-S) core are the only units in those cores in which core-induced fractures are found.

Natural Fractures

Unlike the core-induced fractures, natural fracture frequencies show distinct relationships to stratigraphic units (plates 5 and 6). The units which usually contain an abundance of natural fractures are the Marcellus Shale, Tully Limestone, Genesee Shale, West Falls Formation, and the Lower Huron Member. Other units in the cores have natural fractures, but not in as great abundance. The Java Formation, on the other hand, generally lacks natural fractures.

Slickensides

Slickensides are generally found most frequently in those units which also have a high frequency of natural fractures (plates 7 and 8). The units which usually contain an abundance of slickensides are the Marcellus Shale, Tully Limestone, Genesee Shale, West Falls Formation, base of the Java Formation, Lower Huron Member and Cleveland Member. Presumably, several of these units act as décollement zones in the Appalachian Plateau province.

This study has found the Lower Huron Member to be most important in that at least one slickenside has been found near the base of the Lower Huron Member in all cores which have sampled that interval (WV #3, WV #4, WV #5, KY #1, KY #3, and VA #1). The trend of the slickenlines on the slickensides are usually northeast-southwest. The slickensides are all very low dipping. The author has termed this the "Lower Huron slip plane" as it seems to be of regional extent throughout southwestern West Virginia and eastern Kentucky.

With exception of the Tully Limestone, the highly fractured units are in the softer, less competent organic shales. This is probably because the less competent strata absorbed a great proportion of the stresses associated with local and regional deformation and faulting.

The porous fracture facies concept is generally supported by this study. Units which are highly fractured may serve as conduits for the flow of gas in the subsurface, in which case, if an appropriate seal is present, these intervals may prove to be excellent producers. If, however, no seal is present, these highly fractured units may allow the gas to escape and abnormally low production would result.

- CONCLUSIONS

Subsurface fractures in the Appalachian Plateau province can be related to Alleghenian deformation, local faulting, and crustal spreading along the Mid-Atlantic Ridge. Northwest directed tectonic compressive stresses present during Alleghenian deformation have resulted in a system of vertical, northwest striking natural fractures, and a system of northeast striking slickensides with northwest trending slickenlines. Anomalous fracture patterns have resulted from altered stress fields within the Rome Trough area, above basement fault zones in eastern Kentucky, southwestern West Virginia, and possibly southwestern Pennsylvania. Crustal spreading along the Mid-Atlantic Ridge is believed to result in an east to northeast trending maximum compressive stress throughout most of eastern North America. This stress is interpreted to have created a regional system of northeast striking natural fractures and an in-situ stress or rock fabric anisotropy which causes the formation of northeast striking core-induced fractures. The stress probably originated during the Mesozoic. In two of the cores studied, calcite mineralization was found primarily on the northeast striking natural fractures, and dolomite mineralization was found on the northwest striking fractures. This preferential mineralization suggests that the fractures of each trend formed, or were open, at different times.

Several of the cores investigated in this study pass through décollement zones in the Devonian shales. These zones are characterized by intense deformation in the form of numerous natural fractures and slickensides. The zones are found primarily in the lowest vis-

cosity strata and result from shear being distributed across the interval. Décollement zones are noted in cores from southwestern Pennsylvania, northern West Virginia, southwestern West Virginia, within the Pine Mountain thrust sheet in western Virginia, and possibly in eastern Kentucky, suggesting several detachments of regional extent.

Slickensides in several of the décollement zones are mineralized with fibrous calcite, indicating the existence of a high fluid pressure in the shales. A model which seems to best describe the slickenside orientations found in décollement zones is the classic shear zone model.

Increased frequency of natural fractures and slickensides within less competent, and primarily shale units such as the Marcellus Shale, Tully Limestone, Genesee Shale, West River Shale, West Falls Formation, base of the Java Formation, Lower Huron Member, and Cleveland Member support the concept of porous fracture facies for shale gas production (Shumaker, 1978). A porous fracture facies serves as a passageway for the gas in the subsurface. If a seal is present, the zone may prove to be an excellent producer. However, without a seal, the fractures may serve as escape routes for the gas. Several of the aforementioned units served as décollement zones. At least one slickenside is found at the base of the Lower Huron Member in each of the cores which intersect that unit. This is the most extensive slip plane found in the section studied.

The Devonian shale sequence in the western half of the Appalachian Basin contains large amounts of natural gas, but commercial gas production is limited to areas where natural fracture systems increase

the otherwise insignificant permeability. Delineation of zones of more intense fracturing, especially mineralized fractures, and understanding the nature of the fractures in the shale in terms of origin, orientation, and frequency, is crucial to an accurate appraisal of shale gas potential.

SUGGESTIONS FOR FUTURE WORK

1. Surface fracture orientation data for the Appalachian Plateau province needs to be examined to determine relationships with subsurface natural and core-induced fracture patterns. In some areas surface fracture patterns may be useful in predicting subsurface fracture patterns, and thus help in determining well stimulation strategies.

2. Linear features (lineaments) picked on high and low altitude photographs, and satellite images of areas around oriented-core wells may prove useful in predicting both subsurface and surface fracture patterns.

3. The regional subsurface fracture patterns found in this study may extend throughout the entire Appalachian Plateau province. The study area needs to be extended into eastern Tennessee, central West Virginia, northern Pennsylvania, and southern New York state. Oriented cores are available from eastern Tennessee, northern Pennsylvania, and southern New York state.

4. Four of the cores used in this study were not examined personally by the author. The cores (KY #1, KY #3, OH #1, and OH #2), which are in very poor condition, need to be examined in detail to differentiate fracture types, fracture orientations, and mineral fillings.

5. The two cores from Lincoln County, West Virginia, are only 0.9 miles apart and yet have such different fracture patterns. More work needs to be done to determine why these cores are so different.

6. Very little is known about conditions in decollement zones

during décollement movement. Since several of the cores investigated in this study intersect décollement zones, a unique opportunity is presented to study their formation and effects. Among the structures which may be used are slickenside and slickenline orientations, natural fracture orientations, shale microfabric, microstructures, mineral filling types, and mineral fibers.

7. The consistent core-induced fracture orientations found in the cores may be related to some type of stress or rock fabric anisotropy. An extensive petrographic study of all shale types could determine whether or not a microcrack system, or other type of rock fabric anisotropy, exists.

8. The three cored wells in eastern Kentucky indicate that the area is chaotically fractured. More work needs to be done to determine the cause for this, and if it is related to basement faulting and resultant stresses. Also, the chaotic fracturing should be examined in relation to the high shale gas production in the area.

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UPPER AND MIDDLE DEVONIAN

A

Key
Cored Interval

1" = 10 miles
except where noted

Huron Member of Ohio Shale
Berea Bedford
Cleveland Member of Ohio Shale
Three Lick Bed
Upper and Middle Huron
Lower Huron
Java Formation
Angola Shale Formation
Rhinestreet Shale Member
Gasconade Shale Member of Sycamore Formation
Middlesex Shale Member of Sycamore Formation
West River Shale Member of Genesee Formation
Genesee Shale Member of Genesee Formation
Tully Limestone
Mahanango Formation
Marcellus Shale
Hamilton Group

UNDIFFERENTIATED SHALE

UNCONFORMITY

PA-2 (F.P.S.)

WV-5 (F.P.S.)

OH-2 (R. 101)

WV-7 (E. P. 1)

WV-4 (20402)

WV-3 (21403)

KY-3 (20336)

VA-1 (20338)

PLATE 2.

UPPER AND MIDDLE
DEVONIAN

Sheet 2

PLATE 3.

UPPER AND MIDDLE DEVONIAN
CORE-INDUCED FRACTURES

Sheet 1

UPPER AND MIDDLE DEVONIAN CORE-INDUCED FRACTURES

Sheet 2

Cored Interval

PLATE 4.

UPPER AND MIDDLE DEVONIAN NATURAL FRACTURES

UPPER AND MIDDLE DEVONIAN NATURAL FRACTURES

PLATE 6.

UPPER AND MIDDLE DEVONIAN SLICKENSIDES

Sheet 1

PLATE 7.

UPPER AND MIDDLE DEVONIAN SLICKENSIDES

Sheet 2

PLATE 8

FRACTURES IN ORIENTED DEVONIAN SHALE CORES
FROM THE APPALACHIAN BASIN

VOLUME II (Appendices)

by

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January 1980

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INTRODUCTION TO APPENDICES

Thirteen cores from wells located throughout the Appalachian Basin were examined (figure 1, table 1). The following are separate, self-contained reports summarizing fracture data obtained on each of the cores. Each report discusses, in detail, the fracture types and fracture patterns described in that particular core, and it relates the fractures to local structure and regional tectonics. A brief discussion of gas production from the Devonian shale in the well is also included in each report.

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APPENDIX A: WV #2 (12041) CORE WELL

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WV #2 (12041) CORE WELL

Location

The WV #2 (12041) core well is located in Jackson County, West Virginia, approximately three miles west of the town of Cottageville (figures 1 and A-1, table 1). The wellsite is on the western flank of the N60°E trending Parkersburg Syncline. Regional structure of the Devonian shales shows a monoclinial dip of less than 1° to the southeast. A total of 490 feet of the Devonian was cored, from 3220'-3690' (figure A-2).

Production Data

One interval of the well (3400'-3560') was stimulated by foam fracturing resulting in an initial open flow of 180 mcf/day (Komar, Frone, and Yost, 1978).

Core-induced fractures

Core-induced fractures are the most common fracture type in the core. The lower portion of the Lower Huron Member of the Ohio Shale and the Java Formation tend to have a greater abundance of core-induced fractures than the other units (figure A-12). The orientations of only a portion of the core-induced fractures were measured due to the poor condition of the core. The frequency distribution diagram does, however, indicate the presence of all core-induced fractures. The composite rose diagram of core-induced fracture strikes (figure A-3) has two peaks. There is a 1.0% chance that the peak at N50°-70°E does not exist, and a 5.0% chance that the peak at N17°W does not exist. The equal area projection of poles to core-induced fracture surfaces

(figure A-3) has four clusters corresponding to the opposing dips of the two fracture sets. Core-induced fracture orientations change dramatically from a $N50^{\circ}-70^{\circ}E$ trend to a $N17^{\circ}W$ trend at 3679', which is 10 feet above the top of the Java Formation (figures A-4 and A-5, table A-1). Two subhorizontal slickensides are also found at this point. This change in orientation indicates an almost 90° swing in a stress or rock fabric anisotropy. The swing may be the effect of altered stress fields in the Java Formation caused by differential movement below the slip plane, which has also been noted in other wells. The consistent $N50^{\circ}-70^{\circ}E$ orientation may be related to the general east to northeast trending maximum compressive stress present in most of eastern North America (Sbar and Sykes, 1973).

Natural Fractures

Natural fractures are found only in the Lower Huron Member of the Ohio Shale, above the slickenside zone. Below that point, in the Java Formation, no natural fractures were found (figure A-12), again probably resulting from altered stress fields in the Java Formation. The natural fracture composite rose diagram (figure A-6) has a single peak at $N57^{\circ}E$. There is a 1.0% chance that this peak does not exist. The equal area projection of poles to natural fracture surfaces (figure A-6) has two peripheral clusters corresponding to the subvertical to vertical fracture dips. There is very little scatter in natural fracture orientation (figure A-7). None of the natural fractures in the WV #2 (12041) core are mineralized.

The $N57^{\circ}E$ natural fracture set parallels the dominant core-induced fracture trend and may have formed under the same stress

conditions which formed the core-induced fractures. The fractures in this set are also subparallel to slickenline trends in this core and may have formed as extension fractures under compression from the northeast during formation of the Buring Springs Anticline.

Slickensides and Slickenlines

Slickensides are found in only two distinct zones, both of which are located near viscosity boundaries in the shale (figure A-12). The upper zone, at 3544', is in a thin high-organic shale layer immediately below a harder shale layer. The lower zone, at 3641', is in a high organic shale near the base of the Lower Huron Member of the Ohio Shale, immediately above the harder grey shales of the Java Formation. The slickenside composite rose diagram (figure A-8) has a single peak at $N5^{\circ}-20^{\circ}W$. There is a 1.0% chance that this peak does not exist. The equal area projection of poles to slickensided surfaces (figure A-8) has two clusters; one, dipping $10^{\circ}SW$, another, dipping $30^{\circ}SW$. Slickenside orientations do not change with depth or stratigraphy (figure A-9). None of the slickensides in this core are mineralized.

The slickenline composite rose diagram (figure A-10) has a single peak at $N77^{\circ}E$. There is a 1.0% chance that this peak does not exist. The equal area projection of slickenlines (figure A-10) has two low-dipping clusters corresponding to the $N77^{\circ}E$ trend. Slickenline orientations do not change with depth or stratigraphy (figure A-11).

The two slickenside occurrences, because of their limited number and extent, cannot be considered décollement zones. However, they may be slip planes which formed as the rock absorbed the remaining stresses of dying out detachments to the east. The $N77^{\circ}E$ displacement trend

suggests a relationship to the detached Burning Springs Anticline to the northeast.

Figure A-1. Index map for the WV #2 (12041) core well

Figure A-2. Gamma-ray log, Middle and Upper Devonian

INDUCED FRACTURES

WV*2 (12041)

Figure A-3. (A) composite rose diagram of core-induced fracture strikes, and (B) equal area projection of poles to core-induced fracture surfaces

Figure A-4. Equal area projections of poles to core-induced fracture surfaces and rose diagrams of core-induced fracture strikes for approximately equal length intervals of the WV #2 (12041) core.

WV*2 (12041)
CORE-INDUCED FRACTURES

Figure A-5. Histograms of core-induced fracture orientations.

TABLE A-1

WV #2 (12041) INDUCED FRACTURES

<u>Interval</u>	<u>N</u>	<u>VN</u>	<u>α</u>
3220-3280	69	2.2395	≤ 1.00
3281-3330	83	2.5886	≤ 0.05
3331-3380	84	2.3425	≤ 0.10
3381-3430	71	1.5828	≤ 1.00
3431-3480	89	1.9002	≤ 1.00
3481-3540	84	4.6540	≤ 0.01
3541-3590	87	2.5095	≤ 0.05
3591-3640	84	7.6401	≤ 0.01
3641-3690	86

NATURAL FRACTURES

WV*2 (12041)

Figure A-6. (A) composite rose diagram of natural fracture strikes, and (B) equal area projection of poles to natural fracture surfaces

WV#2(12041) Natural Fractures

Figure A-7. Equal area projections of poles to natural fracture surfaces and rose diagrams of natural fracture strikes for approximately equal length intervals of the WV #2 (12041) core.

SLICKENSIDES
(Inclined- $\geq 10^\circ$ Dip)

WV*2 (12041)

Figure A-8. (A) composite rose diagram of slickenside strikes, and
(B) equal area projection of poles to slickensided
surfaces

Figure A-9. Equal area projections of poles to slickensided surfaces and rose diagrams of slickenside strikes for approximately equal length intervals of the WV #2 (12041) core.

WV*2 (12041)

Figure A-10. (A) composite rose diagram of slickenline trends, and (B) equal area projection of slickenlines

**WV# 2(12041)
Slickenlines**

Figure A-11. Equal area projections of slickenlines and rose diagrams of slickenline trends for approximately equal length intervals of the WV #2 (12041) core.

Figure A-12. Composite data sheet of fracture frequencies and orientations for all fracture types.

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APPENDIX B: WV #3 (20403) CORE WELL

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WV #3 (20403) CORE WELL

Location

The WV #3 (20403) core well is located in Lincoln County, West Virginia, three miles southwest of the town of Ranger (figures 1 and B-1, table 1). The wellsite is directly over the Rome Trough, 15 miles north of the northeast trending Warfield Fault. Fold axes in the area generally trend $N65^{\circ}E$. Regional structure of the Devonian shales is a monoclinal dip of less than 1° to the east. This is the longest core studied with 1308 feet of the Devonian cored, from 2720'-4025' (figure B-2).

Production Data

Four intervals of the well had gas shows: 2775'-2825' (381 mcf/day, 160 mcf/day after fracturing), 2950'-3225' (103 mcf/day, 107 mcf/day after fracturing), 3400'-3650' (95 mcf/day, 200 mcf/day after fracturing), and 3850'-4025' (show, 110 mcf/day after fracturing) (Komar, Frone, and Yost, 1978).

Core-induced Fractures

Core-induced fractures are the most common fracture type in the core and are well distributed throughout the cored interval (figure B-13). The orientations of only a portion of the core-induced fractures were measured due to the poor condition of the core. The frequency distribution diagram does, however, indicate the presence of all core-induced fractures. The core-induced fracture composite rose diagram (figure B-3) has two peaks, $N55^{\circ}-75^{\circ}E$ with an average strike of $N65^{\circ}E$,

and $N83^{\circ}E$. There is a 1.0% chance that each of these peaks do not exist. The equal area projection of poles to core-induced fracture surfaces (figure B-3) has two wide clusters corresponding to the merging of opposing dips of the two fracture sets. Core-induced fracture strikes are consistent down through the Lower Huron Member where they swing from an orientation at the base of the Java Formation (figures B-4 and B-5, table B-1). This swing may be the effect of altered stress fields in the Java Formation, resulting from the unit being bounded by slip planes.

The generally consistent fracture orientations suggest that a stress or fabric anisotropy exists in the rock. This anisotropy may be related to the general east to northeast trending maximum compressive stress present in most of eastern North America (Sbar and Sykes, 1973).

Natural Fractures

Natural fractures are found throughout the core except in the Java Formation. A concentration of fractures exists in the interval 3030'-3070' (figure B-13). The natural fracture composite rose diagram (figure B-6) has three peaks. There is a 1.0% chance that the peaks at $N60^{\circ}-70^{\circ}W$ and $N27^{\circ}W$ do not exist, and a 10% chance that the peak at $N83^{\circ}E$ does not exist. The equal area projection of poles to natural fracture surfaces (figure B-6) has six clusters: two wide clusters resulting from the merging subvertical to vertical northeast trending fracture sets; two smaller clusters which correspond to the vertical $N27^{\circ}E$ set; and two clusters dipping $35^{\circ}NW$ and $35^{\circ}SE$, resulting from inclined $N75^{\circ}E$ striking fractures.

The northeast striking natural fracture sets are found throughout the core and they parallel the core-induced fracture strikes to the point of swinging from $N65^{\circ}E$ to $N83^{\circ}E$ near the base of the Lower Huron Member of the Ohio Shale, and then back to $N65^{\circ}E$ at the base of the Java Formation (figure B-7). This also suggests that there may have been, and still may be, altered stress fields in the Java Formation and that these natural fractures formed in relation to the same stresses responsible for the core-induced fractures. The two trends also generally parallel fold axes in the area. This suggests the possibility that these fractures formed as release fractures when tectonic stresses were relaxed. Some of the fractures in the two northeast striking sets are mineralized, primarily with massive or crystalline calcite.

The $N27^{\circ}W$ fracture set is vertically limited, occurring only in the interval 3030'-3070'. This set is mineralized exclusively with massive or crystalline dolomite or barite (Laresse and Heald, 1977) (figure B-8). In this section of shale there are also several inclined $N75^{\circ}E$ striking dolomite filled fractures. This interval is one of the gas producing intervals of the well. The $N27^{\circ}W$ set is orthogonal to the southern Appalachian trend and probably formed as an extension fracture set under tectonic compressive stresses directed from the southeast. This is supported by the occurrence, in this interval, of a single slickenside having slickenlines trending $N7^{\circ}W$, and by the inclined $N75^{\circ}E$ striking fractures which are interpreted to be mineral filled shear fractures. This fracture zone may have formed in relation to slip movement.

The difference in mineralization between the northeast striking fractures and the northwest striking fractures may indicate different times of formation. Since the northeast striking sets parallel the core-induced fractures it seems likely that they formed later than the northwest set.

Slickensides and Slickenlines

Slickensides are confined to several distinct zones. One slickenside, as mentioned above, is at 3050' in the interval of N27°W striking natural fractures. Slickensides are also found at the base of the Lower Huron Member of the Ohio Shale (one horizontal slickenside), base of the Java Formation, and throughout the entire West Falls Formation (figure B-13). The Lower Huron and Java zones occur near viscosity boundaries, and the West Falls zone occurs in a low-viscosity dark shale unit immediately above the much stiffer Onondaga Limestone. Only the West Falls slickenside zone and the zone at the base of the Java Formation are vertically extensive enough to be considered décollement zones. The slickenside composite rose diagram (figure B-9) has a single statistically significant peak at N70°-85°E with an average strike of N77°E. There is a 1.0% chance that this peak does not exist. Three smaller peaks that are not statistically significant are N75°W, N27°E, and N63°E. Poles to slickensided surfaces form an incomplete girdle across the equal area projection (figure B-9). The pattern of clusters is close to that expected for a shear zone, but dips of the Riedel and thrust shear clusters exceed the 30° maximum. This may be explained by rotation of the slickensides during shearing. The 0° dipping cluster in the center is the

displacement shear cluster, the 40°NW dipping cluster is the Riedel shear cluster, and the 40°SE dipping cluster is the thrust shear cluster. R' shears may be present in the scatter in the southeast quadrant of the plot. Two small clusters corresponding to the vertical fractures of the $\text{N}75^{\circ}\text{W}$ set are found on the perimeter of the plot in the northeast and southwest quadrants. The slickensides of this set occur only in the Java Formation and in the Rhinestreet Member of the West Falls Formation (figure B-10).

The slickenline composite rose diagram (figure B-11) has a single significant peak at $\text{N}5^{\circ}\text{--}20^{\circ}\text{W}$ with an average trend of $\text{N}13^{\circ}\text{W}$. There is a 1.0% chance that this peak does not exist. Two peaks which are not statistically significant occur at $\text{N}27^{\circ}\text{W}$ and $\text{N}65^{\circ}\text{W}$. The equal area projection of slickenlines (figure B-11) has four clusters: two, at 30°SE and 30°NW which result from the merging of the $\text{N}5^{\circ}\text{--}20^{\circ}\text{W}$ set and the $\text{N}27^{\circ}\text{W}$ set; and two, on the perimeter of the plot, corresponding to the subhorizontal slickenlines of the $\text{N}65^{\circ}\text{W}$ set. The $\text{N}5^{\circ}\text{--}20^{\circ}\text{W}$ set occurs primarily in the Angola Shale Member of the West Falls Formation. The $\text{N}65^{\circ}\text{W}$ set occurs primarily in the Rhinestreet Shale Member of the West Falls Formation and consists of nearly horizontal slickenlines on the vertical $\text{N}75^{\circ}\text{W}$ striking slickensides. The $\text{N}27^{\circ}\text{W}$ set is found only in the Rhinestreet Member of the West Falls Formation and in the lower portion of the Java Formation (figure B-12). Very few slickensides in the core are mineralized. Massive calcite is the most common filling.

The $\text{N}5^{\circ}\text{--}20^{\circ}\text{W}$ and $\text{N}27^{\circ}\text{W}$ trending slickenlines parallel the $\text{N}27^{\circ}\text{W}$ natural fracture set and are orthogonal to the dominant slickenside

orientation. These three fracture sets are related in that they probably formed under the same tectonic compressive stresses that existed during the formation of the southern Appalachians. The $N75^{\circ}W$ slickenside set, with its $N65^{\circ}W$ trending slickenlines, shows no relationship to any known nearby structures.

Figure B-1. Index map of the WV #3 (20403) core well

Figure B-2. Gamma-ray log, Middle and Upper Devonian.

Figure B-3. (A) composite rose diagram of core-induced fracture strikes, and (B) equal area projection of poles to core-induced fracture surfaces

Figure B-4. Equal area projections of poles to core-induced fracture surfaces and rose diagrams of core-induced fracture strikes for approximately equal length intervals of the WV #3 (20403) core.

WV#3 (20403)

CORE-INDUCED FRACTURES

Figure B-5. Histograms of core-induced fracture orientations.

TABLE B-1

WV #3 (20403) INDUCED FRACTURES

<u>Interval</u>	<u>N</u>	<u>VN</u>	<u>α</u>
2720-2820	54	2.6938	≤ 0.05
2821-2920	88		
2921-3020	96	3.6866	≤ 0.01
3021-3120	89	1.3117	≤ 1.00
3121-3220	134	3.5455	≤ 0.01
3221-3320	61	2.8474	≤ 0.01
3321-3420	103	1.8808	≤ 1.00
3421-3520	96	1.4943	≤ 1.00
3521-3620	116	9.0201	≤ 0.01
3621-3720	134	1.4204	≤ 1.00
3721-3820	96	5.4656	≤ 0.01
3821-3920	88	3.5267	≤ 0.01
3921-4025	60	3.6265	≤ 0.01

WV*3 (20403)

Figure B-6. (A) composite rose diagram of natural fracture strikes, and (B) equal area projections of poles to natural fracture surfaces

Figure B-7. Equal area projections of poles to natural fracture surfaces and rose diagrams of natural fracture strikes for approximately equal length intervals of the WV #3 (20403) core.

Figure B-8. N30°W striking dolomite filled natural fracture from interval 3030'-3070' - WV #3 (20403) core.

WV*3 (20403)

Figure B-9. (A) composite rose diagram of slickenside strikes, and (B) equal area projection of poles to slickensided surfaces

Figure B-10. Equal area projections of poles to slickensided surfaces and rose diagrams of slickenside strikes for approximately equal length intervals of the WV #3 (20403) core.

WV*3 (20403)

Figure B-11. (A) composite rose diagram of slickenline trends, and (B) equal area projection of slickenlines

Figure B-12. Equal area projections of slickenlines and rose diagrams of slickenline trends for approximately equal length intervals of the WV #3 (20403) core.

Figure B-13. Composite data sheet of fracture frequencies and orientations for all fracture types.

APPENDIX C: WV #4 (20402) CORE WELL

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WV #4 (20402) CORE WELL

Location

The WV #4 (20402) core well is located 0.9 miles southwest of the WV #3 (20403) core well and approximately four miles southwest of the town of Ranger, Lincoln County, West Virginia (figures 1 and C-1, table 1). The wellsite is within the Rome Trough, 15 miles north of the northeast trending Warfield Fault. Fold axes in the area generally trend $N65^{\circ}E$. Regional structure of the Devonian shales is a monoclinical dip of less than 1° to the east. A total of 614 feet of the Devonian was cored from four separate intervals: 2654'-2770', 3000'-3118', 3280'-3588', and 3886'-3968' (figure C-2).

Production Data

No production data was available.

Core-induced Fractures

Core-induced fractures are the most common fracture type in the core and are well distributed throughout the cored intervals (figure C-12). There is, however, a notable drop off in frequency in the 2654'-2770' interval in the undifferentiated shales. The core-induced fracture composite rose diagram (figure C-3) has a single peak at $N20^{\circ}-45^{\circ}E$ with an average strike of $N33^{\circ}E$. There is a 1.0% chance that this peak does not exist. The equal area projection of poles to core-induced fracture surfaces (figure C-3) has four clusters corresponding to the petal and centerline portions of the fractures. Core-induced fracture orientation distributions show only minor variations throughout the core. The greatest amount of scatter occurs in the

undifferentiated shales (figures C-4 and C-5, table C-1).

The generally consistent fracture orientations suggest the presence of a stress or rock fabric anisotropy. The $N33^{\circ}E$ trending anisotropy may be related to the general east to northeast maximum compressive stress present in most of eastern North America (Sbar and Sykes, 1973). This trend is 30° more northerly than the dominant core-induced fracture trend in the nearby WV #3 (20403) core well.

Natural Fractures

Natural fractures occur throughout the cored intervals. A concentration of fractures is found in the interval 2723'-2733' (figure C-12). The natural fracture composite rose diagram (figure C-6) has a single statistically significant peak at $N20^{\circ}-35^{\circ}E$ with an average strike of $N27^{\circ}E$. There is a 1.0% chance that this peak does not exist. Four peaks that are not statistically significant occur at $N67^{\circ}E$, $N3^{\circ}W$, $N17^{\circ}W$, and $N63^{\circ}W$. The equal area projection of poles to natural fracture surfaces (figure C-6) has eight peripheral clusters corresponding to four of the five subvertical to vertical fracture sets. Natural fracture orientations are quite variable and show no pattern or systematic variation with depth or stratigraphy (figure C-7). Several of the natural fracture sets are mineralized, generally with massive or crystalline calcite. A greater proportion of natural fractures are mineralized in the West Falls Formation than in any other unit in the core.

The $N20^{\circ}-35^{\circ}E$ natural fracture set parallels the core-induced fractures and may have formed under the same stress conditions. The set also parallels the central Appalachian trend and may have formed

as a release fracture set when Alleghenian tectonic stresses were relaxed. The $N67^{\circ}E$ set parallels the southern Appalachian trend and also may have formed when tectonic stresses were relaxed. This set also parallels the core-induced fractures, natural fractures, and slickensides in the WV #3 (20403) core. The $N63^{\circ}W$ set is orthogonal to the central Appalachian trend and probably formed as extension fractures when tectonic compressive stresses were oriented $N60^{\circ}-70^{\circ}W$ during Alleghenian deformation. The $N3^{\circ}W$ and $N17^{\circ}W$ sets may actually be part of the same set. They are nearly orthogonal to the southern Appalachian trend and also probably formed as extension fractures. These two sets are subparallel to the $N27^{\circ}W$ natural fracture set in the WV #3 (20403) core.

Slickensides and Slickenlines

Slickensides are found in three zones: at 3400', in the Middle Huron Member of the Ohio Shale; at 3582', 10 feet above the base of the Lower Huron Member of the Ohio Shale; and throughout the entire cored portion of the West Falls Formation (figure C-12). The Lower Huron zone occurs in a soft dark shale unit immediately above the contact with the stiffer shales of the Java Formation. The West Falls zone occurs in a low-viscosity dark shale unit immediately above the much stiffer Onondaga Limestone. Only the West Falls zone is vertically extensive enough to be classified as a décollement zone. The Lower Huron zone correlates with a similar zone in the WV #3 (20403) core.

The slickenside composite rose diagram (figure C-8) has a single peak at $N35^{\circ}-45^{\circ}E$ with an average strike of $N40^{\circ}E$. There is a 1.0%

chance that this peak does not exist. A smaller peak which is not statistically significant occurs at $N55^{\circ}W$. The slickensided surfaces in this set are gouged and intensely slickenlined, more so than the dominant set. Also, this set only occurs in the West Falls Formation. The poles to slickensided surfaces form an incomplete girdle across the equal area projection (figure C-8). The cluster pattern follows that expected for a shear zone. The 0° dipping cluster in the center is the displacement shear cluster, the Riedel shear cluster dips $20^{\circ}NW$, and the thrust shear cluster dips $30^{\circ}SE$. R' shears are not present in this core. A $50^{\circ}SW$ dipping cluster results from the $N55^{\circ}W$ slickenside set. Very few of the slickensides in this core are mineralized, and those occur only in the West Falls Formation. Massive calcite is the dominant filling. Slickenside orientations show very little scatter or systematic variation with depth or stratigraphy (figure C-9).

The slickenline composite rose diagram (figure C-10) has a single statistically significant peak at $N40^{\circ}-50^{\circ}W$. There is a 1.0% chance that this peak does not exist. A smaller peak, at $N33^{\circ}E$, is not statistically significant. This orientation is found only on the $N55^{\circ}W$ slickenside set. The equal area projection of slickenlines (figure C-10) has three clusters: two of which correspond to the low-dipping $N40^{\circ}-50^{\circ}W$ trending slickenlines, and a $50^{\circ}SW$ dipping cluster resulting from the $N33^{\circ}E$ trending set. Slickenlines show very little variation from a northwest trend, except in the Lower Huron Member of the the Ohio Shale and West Falls Formation (figure C-11).

The $N40^{\circ}-50^{\circ}W$ slickenlines are subparallel to the $N63^{\circ}W$ natural fractures and are orthogonal to the $N35^{\circ}-45^{\circ}E$ slickenside set. These

three trends are related in that they all probably formed under the same tectonic compressive stresses. The N55°W slickenside set may indicate a splay off of a basement fault, or compaction and settling of the shales resulting from basin subsidence or movement along a Rome Trough fault.

Figure C-1. Index map for the WV #4 (20402) core well

Figure C-2. Gamma-ray log, Middle and Upper Devonian.

CORE-INDUCED FRACTURES

WV#4 (20402)

Figure C-3. (A) composite rose diagram of core-induced fracture strikes, and (B) equal area projection of poles to core-induced fracture surfaces

Figure C-4. Equal area projections of poles to core-induced fracture surfaces and rose diagrams of core-induced fracture strikes for approximately equal length intervals of the WV #4 (20402) core.

WV*4 (20402) CORE-INDUCED FRACTURES

Figure C-5. Histograms of core-induced fracture orientations.

TABLE C-1

WV #4 (20402) INDUCED FRACTURES

<u>Interval</u>	<u>N</u>	<u>VN</u>	<u>α</u>
2654-2712	26	2.0503	≤ 1.00
2713-2770	94		
3000-3060	206	4.5132	≤ 0.01
3061-3118	226	1.7621	≤ 1.00
3290-3340	207	3.2234	≤ 0.01
3341-3390	147	4.3534	≤ 0.01
3391-3440	94	2.5982	≤ 0.05
3441-3490	147	2.5579	≤ 0.05
3491-3540	141	3.1142	≤ 0.01
3541-3588	141	4.7160	≤ 0.01
3886-3927	114	4.3561	≤ 0.01
3928-3968	84	3.1239	≤ 0.01

WV*4 (20402)

Figure C-6. (A) composite rose diagram of natural fracture strikes, and (B) equal area projection of poles to natural fracture surfaces

Figure C-7. Equal area projections of poles to natural fracture surfaces and rose diagrams for approximately equal length intervals of the WV #4 (20402) core.

Figure C-8. (A) composite rose diagram of slickenside strikes, and (B) equal area projection of poles to slickensided surfaces

Figure C-9. Equal area projections of poles to slickensided surfaces and rose diagrams of slickenside strikes for approximately equal length intervals of the WV #4 (20402) core.

WV*4 (20402)

Figure C-10. (A) composite rose diagram of slickenline trends, and (B) equal area projection of slickenlines

Figure C-11. Equal area projections of slickenlines and rose diagrams of slickenline trends for approximately equal length intervals of the WV #4 (20402) core.

M. Evans 1979

Figure C-12. Composite data sheet of fracture frequencies and orientations for all fracture types.

APPENDIX D: WV #5 (#3 D/K) CORE WELL

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WV #5 (#3 D/K) CORE WELL

Location

The WV #5 (#3D/K) core well is located in Mason County, West Virginia, approximately five miles northeast of the town of Point Pleasant (figures 1 and D-1, table 1). The wellsite is on the western flank of the N60°E trending Parkersburg Syncline. Regional structure of the Devonian shales shows a monoclinal dip of less than 1° to the southeast. A total of 747 feet of the Devonian was cored, from 2673'-3420' (figure D-2). The first 38 feet of the core could not be oriented because it was severely broken during coring. This interval was not used in this study, and data collection began at 2711'.

Production Data

Two intervals of the WV #5 (#3 D/K) well were stimulated. Interval 2730'-3042' in the Huron Member of the Ohio Shale was stimulated with a cryogenic type treatment resulting in an initial open flow of 456 mcf/day. Interval 3348'-3374' in the Rhinestreet Member of the West Falls Formation was stimulated by foam fracturing and the resulting initial open flow was 50 mcf/day. This interval was immediately flooded out, presumably with salt water from the underlying Onondaga Limestone (Overbey, personal communication).

Core-induced fractures

Core-induced fractures are the most abundant fracture type in the core. The Huron Member of the Ohio Shale has the greatest frequency of core-induced fractures with abundance dropping off in the Java Formation and West Falls Formation (figure D-16). The composite

rose diagram of core-induced fracture strikes (figure D-3) has one peak at $N65^{\circ}-85^{\circ}E$ with an average orientation of $N75^{\circ}E$. There is a 1.0% chance that this peak does not exist. The equal area projection of poles to core-induced fracture surfaces (figure D-3) has two clusters corresponding to the opposing dips of the fractures. Core-induced fracture strike distributions change subtly downcore with the greatest difference occurring between intervals 3201'-3250' and 3251'-3300'. Average orientations for these intervals are $N71^{\circ}E$ and $N85^{\circ}E$ respectively (figures D-4, D-5, D-6, and D-7, table D-1). The change occurs near the base of the Angola Shale Member of the West Falls Formation.

The consistency in core-induced fracture strike indicates that a stress or rock fabric anisotropy may be present in the rock around this well. This anisotropy may be related to the east to northeast trending maximum compressive stress present in most of eastern North America (Sbar and Sykes, 1973).

Natural Fractures

Natural fractures are found primarily in the Huron Member of the Ohio Shale, but a few are also found in the West Falls Formation (figure D-16). The natural fracture composite rose diagram (figure D-8) has three peaks. There is a 1.0% chance that the peak at $N65^{\circ}-80^{\circ}E$ does not exist and a 5.0% chance that the peaks at $N45^{\circ}-60^{\circ}W$ and $N33^{\circ}E$ do not exist. The equal area projection of poles to natural fracture surfaces (figure D-8) has six peripheral clusters corresponding to the three subvertical to vertical fracture sets. Fractures of the $N65^{\circ}-80^{\circ}E$ set are found throughout the core, whereas

fractures of the $N45^{\circ}-60^{\circ}W$ set are restricted only to the lower portion of the Huron Member of the Ohio Shale (figures D-9, D-10, and D-11).

Over one third of the natural fractures in the core are mineralized, with either calcite, dolomite, anhydrite, or barite, in the crystallized form or as massive coatings sparsely covering the fracture surface (figure D-12). All of the mineralized fractures are found in the Huron Member of the Ohio Shale. The fractures with calcite mineralization generally strike $N65^{\circ}-80^{\circ}E$, whereas the fractures with dolomite mineralization (figure D-13) generally strike $N45^{\circ}-60^{\circ}W$ and are concentrated in a zone between 2870' and 2890'. The $N33^{\circ}E$ set is not mineralized. This preference in fracture mineralization suggests that one fracture set formed, or was open, at a time different from that of the other fracture set. If this is the case, each set would have been exposed to fluid pressure and temperature conditions, and groundwater chemistries different from that of the other set, resulting in the formation of different minerals. No abutting relationships were found in the core to confirm this idea.

The calcite mineralized $N65^{\circ}-80^{\circ}E$ set has nearly the same orientation as the core-induced fractures. Therefore, it is possible that these natural fractures formed under the same stress conditions responsible for the core-induced fractures. This would make the $N65^{\circ}-80^{\circ}E$ set the most recent because it follows the current stress or rock fabric anisotropy. The fractures in this set also parallel slickenline trends in this core, suggesting that they may have formed as extension fractures under compression from the northeast during formation of the Burning Springs Anticline. The $N45^{\circ}-60^{\circ}W$ natural

fracture set is nearly orthogonal to the trend of the central Appalachians and probably formed as an extension fracture set under tectonic compressive stresses during Alleghenian deformation. The $N33^{\circ}E$ set parallels the central Appalachians and may have formed as a release fracture set as Paleozoic tectonic stresses were relaxed.

Slickensides and Slickenlines

In the WV #5 (#3 D/K) core, slickensides are found in only two distinct zones, both of which are located near viscosity boundaries in the shales (figure D-16). The upper zone, at 3036', is the soft high-organic black shales of the Huron Member, 10 feet above the contact with the stiffer shales of the Java Formation. The lower zone, 3128'-3136', is in the Java Formation, 13 feet above the contact with the slightly softer shales in the Angola Shale Member. The slickenside composite rose diagram (figure D-14) has a single peak at $N17^{\circ}W$. There is a 1.0% chance that this peak does not exist. The equal area projection of poles to slickensided surfaces (figure D-14) has two clusters dipping $20^{\circ}SW$ and $20^{\circ}NE$. The slickensides in the Java Formation show more scatter in strike than those in the Huron Member and are less well developed.

The slickenline composite rose diagram (figure D-15) has a single peak trending $N67^{\circ}E$. There is a 1.0% chance that this peak does not exist. The equal area projection of slickenlines (figure D-15) has two peripheral clusters that correspond to the low dipping slickenlines. The two slickenside zones, because of their limited vertical extent and limited number of readings, cannot be considered décollement

zones. However they may be slip planes which formed as the rock absorbed the remaining stresses of dying out detachments to the east. The N67°E displacement trend suggests a relationship to the detached Burning Springs Anticline located forty miles to the northeast.

5 0 5 10 15

Miles
Contour Interval 100'

STRUCTURE
Top of the Onondaga
Limestone

(from Cardwell, 1974)

Figure D-1. Index map for the WV #5 (#3 D/K) core well

DEVONIAN SHALES

CORED INTERVAL

371.

Figure D-2. Gamma-ray log, Middle and Upper Devonian.

WV#5 (#3 D/K)

Figure D-3. (A) composite rose diagram of core-induced fracture strikes, and (B) equal area projection of poles to core-induced fracture surfaces

Core Induced Fractures

2710'-2950'

Figure D-4. Equal area projections of poles to core-induced fracture strikes for approximately equal length intervals of the WV #5 (#3 D/K) core. Also figures D-5 and D-6.

Core Induced Fractures

374.

2951'-3200'

Figure D-5.

Core Induced Fractures

3201'-3400'

GAMMA RAY
API Units

Figure D-6.

WV*5 (3 D/K)
CORE-INDUCED FRACTURES

M. Evans 1979

Figure D-7. Histograms of core-induced fracture orientations.

TABLE D-1

WV #5 (#3 D/K) INDUCED FRACTURES

<u>Interval</u>	<u>N</u>	<u>VN</u>	<u>α</u>
2710-2750	78	2.4324	≤ 0.10
2751-2800	87		
2801-2850	183	2.1600	≤ 1.00
2851-2900	217	4.3652	≤ 0.01
2901-2950	101	3.6275	≤ 0.01
2951-3000	112	3.1441	≤ 0.01
3001-3050	85	1.6144	≤ 1.00
3051-3100	29	2.1934	≤ 1.00
3101-3150	135	1.8817	≤ 1.00
3151-3200	72	3.8419	≤ 0.01
3201-3250	57	2.5387	≤ 0.05
3251-3300	47	6.2031	≤ 0.01
3301-3350	49	2.9292	≤ 0.01
3351-3400	16	2.1173	≤ 1.00

NATURAL FRACTURES

Figure D-8. (A) composite rose diagram of natural fracture strikes, and
(B) equal area projection of poles to natural fracture surfaces

M. Evans

Natural Fractures

2710'-2950'

Natural Fractures

2951'-3200'

Figure D-10.

Natural Fractures

3201'-3400'

GAMMA RAY
API Units

Figure D-11.

Figure D-12. Natural fracture mineralized with euhedral calcite crystals - WV #5 (#3 D/K) core.

Figure D-13. Natural fracture mineralized with massive dolomite - WV #5 (#3 D/K) core.

Figure D-14. (A) composite rose diagram of slickenside strikes, and
(B) equal area projection of poles to slickensided surfaces

M. Evans

M. Evans

Figure D-15. (A) composite rose diagram of slickenline trends, and
(B) equal area projection of slickenlines

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APPENDIX E: WV #6 (MERC #1) CORE WELL

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WV #6 (MERC #1) CORE WELL

Location

The WV #6 (MERC #1) core well is located in Monongalia County, West Virginia, approximately two miles north of the city of Morgantown (figures 1 and E-1, table 1). The wellsite is on the western flank of the Fayette Anticline, which is just west of the large N30°E trending Chestnut Ridge Anticline. A total of 352 feet of the Devonian was cored, from 7168'-7520' (figure E-2). Interval 7232'-7290' of the core could not be oriented because of a malfunction of the orienting camera. That interval was not used in this study to obtain fracture orientation data; however, fracture frequency data from this interval was recorded.

Production Data

The WV #6 (MERC #1) well had a show of gas from the Big Injun, Squaw, Gordon, 4th, 5th, Baynard, and Riley Sands, all of which are well above the cored interval. The only significant production from the Devonian shales was from the Burkett Member of the Harrell Shale, which produced 25 mcf/day after fracturing (Frone, 1978). This is immediately above the cored interval.

Core-induced Fractures

The only core-induced fractures in the core are torsion fractures and disc fractures. The lack of core-induced petal-centerline fractures may be related to the physical characteristics of the rock; which is generally a soft, fissile, black shale; or stress conditions present in the rock.

Natural Fractures

Unfortunately the Burkett Member was not cored. However, the Tully Limestone, just below the Burkett Member, was cored. The Tully Limestone and Marcellus Shale have the greatest number of natural fractures, while the Mahantango Formation has relatively few natural fractures (figure E-9). The natural fracture composite rose diagram (figure E-3) has two dominant peaks. There is a 1.0% chance that the peak at N83°E does not exist and a 5.0% chance that the peak at N67°W does not exist. One minor peak at N47°W is not statistically significant. The equal area projection of poles to natural fracture surfaces (figure E-3) has four peripheral clusters corresponding to the two dominant subvertical to vertical fracture sets. The natural fracture orientations show no pattern or systematic variation with depth or stratigraphy (figure E-4). Nearly all of the natural fractures are mineralized with calcite (crystalline or fibrous), barite, or pyrite. The mineral growth fibers are perpendicular to the fracture faces, implying that the principal acting tension during mineralization was horizontal. The type of mineralization shows no preference for fracture orientation, depth, or stratigraphy.

The N67°W fracture set is nearly orthogonal to the N30°E axial trend of the nearby Chestnut Ridge Anticline. The fractures in this set probably formed as extension fractures when tectonic compressive stresses were oriented approximately N60°-70°W during Alleghenian deformation. The N83°E set shows no relationship to any known nearby structures. However, these fractures may have formed as a result of the east to northeast trending maximum compressive stress present in

most of eastern North America (Sbar and Sykes, 1973).

Slickensides and Slickenlines

Slickensides are most abundant in the Tully Limestone and the lower portion of the Mahantango Formation through the base of the Marcellus Shale (figure E-9). The latter zone is vertically extensive, near a viscosity boundary (just above the Onondaga Limestone), and in a low viscosity unit; suggesting that it acted as a décollement zone. The slickenside composite rose diagram (figure E-5) has two significant peaks. There is a 5.0% chance that the peaks at $N0^{\circ}-30^{\circ}E$ and $N20^{\circ}-30^{\circ}W$ do not exist. The equal area projection of poles to slickensided surfaces (figure E-5) shows that slickensides are generally very low dipping ($0^{\circ}-30^{\circ}$) with an overall east to northeast dip. Although there is a great amount of scatter in slickenside orientations, a cluster pattern can be seen that matches that of the idealized shear zone model. The cluster in the center of the plot is the displacement shear cluster, the minor cluster dipping $20^{\circ}NW$ is the Riedel shear cluster, and the cluster dipping $20^{\circ}SE$ is the thrust shear cluster. R' shears are not present in this core. The wide scatter in slickenside orientations probably resulted strike measurements on low-dipping, undulating surfaces. Inclined slickenside orientations are quite variable but show no pattern or systematic variation with depth or stratigraphy (figure E-6).

The slickenline composite rose diagram (figure E-7) has one significant peak at $N65^{\circ}-75^{\circ}W$. There is a 1.0% chance that this peak does not exist. The equal area projection of slickenlines (figure E-7) has two peripheral clusters corresponding to the subhorizontal to

horizontal slickenlines. There is very little scatter in slickenline trend with depth or stratigraphy (figure E-8).

The $N65^{\circ}-75^{\circ}W$ slickenline trend parallels the $N67^{\circ}W$ natural fracture set and is orthogonal to the $N0^{\circ}-30^{\circ}E$ slickenside set. These three trends are related in that they all probably formed under the same $N60^{\circ}-70^{\circ}W$ directed Alleghenian tectonic compressive stresses.

Many of the slickensides in this core are mineralized, usually with fibrous calcite in a layer which separates the fracture surfaces. The mineralization is found primarily on subhorizontal to horizontal slickensides. This is indicative of a very high fluid pressure in the bedding planes of the shales and a vertical principal acting tension during mineralization (Durney and Ramsay, 1973). Such abnormally pressured rocks are preferred sites for decollement because these rocks are probably less viscous than their normally pressured counterparts (Kehle, 1970). Fiber growth may have occurred during or after decollement movement. The fibers are usually vertical but at times are curved indicating movement during fiber growth.

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STRUCTURE
Top of the Onondaga Limestone
 Modified from Cardwell, 1974

CI=100 ft, 500 ft in eastern folded areas

M. EVANS 1979

Figure E-1. Index map for the WV #6 (MERC #1) core well

Figure E-2. Gamma-ray log, Middle and Upper Devonian - WV #6 (MERC #1) core well.

Figure E-3. (a) composite rose diagram of natural fracture strikes, and
(b) equal area projection of poles to natural fracture surfaces

NATURAL FRACTURES

Figure E-4. Equal area projections of poles to natural fracture surfaces and rose diagrams of natural fracture strikes for approximately equal length intervals of the WV #6 (MERC #1) core.

WV #6 (MERC-1)

Figure E-5. (a) composite rose diagram of slickenside strikes, and
(b) equal area projection of poles to slickensided surfaces

Figure E-6. Equal area projections of poles to slickensided surfaces and rose diagrams of slickenside strikes for approximately equal length intervals of the WV #6 (MERC #1) core.

Figure E-7. (a) composite rose diagram of slickenline trends, and
(b) equal area projection of slickenlines

SLICKENLINES

Figure E-8. Equal area projections of slickenlines and rose diagrams of slickenline trends for approximately equal length intervals of the WV #6 (MERC #1) core.

Figure E-9. Composite data sheet of fracture frequencies and orientations for all fracture types in the WV #6 (MERC #1) core

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APPENDIX F: WV #7 (E-P #1) CORE WELL

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WV #7 (E-P #1) CORE WELL

Location

The WV #7 (E-P #1) core well is located in Wetzel County, West Virginia, one mile northeast of the town of New Martinsville (figures 1 and F-1, table 1). The wellsite is near the crest of the northeast trending New Martinsville Anticline. Regional structure of the Devonian shales shows a monoclinal dip of less than 1° to the southeast. A total of 550 feet of the Devonian was cored, from 6100'-6650' (figure F-2).

Production Data

No production data was available.

Core-induced Fractures

Core-induced fractures in the WV #7 (E-P #1) core are primarily of the torsion and disc type with several petal-centerline fractures occurring only in the Sonyea Formation (figure F-11). The composite rose diagram of core-induced fracture strikes (figure F-3) has a single peak at $N67^{\circ}E$. There is a 1.0% chance that this peak does not exist. The equal area projection of poles to core-induced fracture surfaces (figure F-3) has two clusters corresponding to the opposing dips of the petals. Fracture orientations remain constant with depth (figure F-4) with the preference for the $N67^{\circ}E$ trend probably resulting from a stress or rock fabric anisotropy. This anisotropy may be related to the east to northeast trending maximum compressive stress present in most of eastern North America (Sbar and Sykes, 1973). The harder shales of the Sonyea Formation seem to be

the rock type best suited for the development of the anisotropy in the cored interval.

Natural Fractures

Natural fractures occur primarily in the Rhinestreet Shale, West River Shale, Genesee Shale, and Marcellus Shale (figure F-11). The composite rose diagram (figure F-5) has two peaks. There is a 1.0% chance that the peak at N57°W does not exist and a 5.0% chance that the peak at N43°W does not exist. Fractures of both sets are found throughout the core. The equal area projection of poles to natural fracture surfaces (figure F-5) has four clusters corresponding to the two subvertical to vertical fracture sets. Natural fracture orientations are quite variable but show no pattern or systematic variation with depth or stratigraphy (figure F-6). Nearly all of the natural fractures in the WV #7 (E-P #1) core are mineralized with massive or crystalline calcite.

Both natural fracture sets are nearly orthogonal to the trend of local fold axes. They are probably extension fractures resulting from tectonic compressive stresses acting during Alleghenian deformation. The difference in strike between the two sets is probably a result of variable stresses in the décollement sheet.

Slickensides and Slickenlines

Slickensides are most abundant in the lower portion of the Rhinestreet Shale, Genesee Shale, and Marcellus Shale (figure F-11). Each of these zones is either near or within a low-viscosity unit, suggesting that they acted as décollement zones. The Rhinestreet Shale is

a soft shale unit above the slightly stiffer Sonyea Formation, the Genesee Shale is a soft shale unit above the stiffer Tully Limestone, and the Marcellus Shale is a soft shale unit above the Onondaga Limestone. The slickenside composite rose diagram (figure F-7) has two peaks. There is a 5.0% chance that the peak at $N15^{\circ}-30^{\circ}E$ does not exist and a 10.0% chance that the peak at $N43^{\circ}W$ does not exist. Poles to slickensided surfaces form a girdle across the equal area projection (figure F-7). The pattern closely resembles that which would be expected from a shear zone. The 0° dipping cluster in the center is the displacement shear cluster, the Riedel shears are represented by the $25^{\circ}NW$ dipping cluster, and the thrust shears are represented by the $25^{\circ}SE$ dipping cluster. R' shears are not present in this core. Slickenside strikes show very little variability except for some scatter in the lower portion of the Rhinestreet Shale (figure F-8).

The slickenline composite rose diagram (figure F-9) has a single peak at $N67^{\circ}W$. There is a 1.0% chance that this peak does not exist. The equal area projection of slickenlines (figure F-9) has two peripheral clusters which reflect the low-plunging slickenlines of the $N67^{\circ}W$ set. Two smaller clusters result from horizontal slickenlines trending $N43^{\circ}W$ and $N83^{\circ}W$. There is some scatter in slickenline trend, mainly in the Rhinestreet Shale (figure F-10).

The $N67^{\circ}W$ slickenline trend is subparallel to the natural fracture trends and is orthogonal to the dominant slickenside trend. These fracture sets are related in that they all probably formed under the same Alleghenian tectonic compressive stresses.

Many of the slickensides in the core are mineralized, particularly those in the Genesee Shale and Marcellus Shale. Calcite is the dominant mineral type and occurs as fibers between slickenside surfaces and as massive and crystalline coatings on the slickensided surfaces. The fibrous crystal growth is indicative of high fluid pressure in the bedding planes of the shales and a vertical principal acting tension during mineralization. Such abnormally pressured rocks are preferred sites for décollement because these rocks are probably less viscous than their normally pressured counterparts (Kehle, 1970).

5 0 5 10 15

Miles

Contour Interval: 100'

STRUCTURE
Top of the Onondaga
Limestone

(From Cardwell, 1974)

Figure F-1. Index map for the WV #7 (E-P #1) core well

Figure F-2. Gamma-ray log, Middle and Upper Devonian.

WV#7 (E-P#1)

Figure F-3. (A) composite rose diagram of core-induced fracture strikes, and
(B) equal area projection of poles to core-induced fracture surfaces

Figure F-4. Equal area projections of poles to core-induced fracture surfaces and rose diagrams of core-induced fracture strikes for approximately equal length intervals of the WV #7 (E-P #1) core.

WV#7 (E-P#1)

Figure F-5. (A) composite rose diagram of natural fracture strikes, and (B) equal area projection of poles to natural fracture surfaces

Figure F-6. Equal area projections of poles to natural fracture surfaces and rose diagrams of natural fracture strikes for approximately equal length intervals of the WV #7 (E-P #1) core.

WV#7 (E-P#1)

Figure F-7. (A) composite rose diagram of slickenside strikes, and (B) equal area projection of poles to slickensided surfaces

Figure F-8. Equal area projections of poles to slickensided surfaces and rose diagrams of slickenside strikes for approximately equal length intervals of the WV #7 (E-P #1) core.

WV#7 (E-P#1)

Figure F-9. (A) composite rose diagram of slickenline trends, and (B) equal area projection of slickenlines

Figure F-10. Equal area projections of slickenlines and rose diagrams of slickenline trends for approximately equal length intervals of the WV #7 (E-P #1) core.

Figure F-11. Composite data sheet of fracture frequencies and orientations for all fracture types.

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APPENDIX G: OH #1 (S-745) CORE WELL

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OH #1 (S-745) CORE WELL

Location

The OH #1 (S-745) core well is located in Carroll County, Ohio, ten miles southeast of the city of Canton (figures 1 and G-1, table 1). Regional structure of the Devonian shales shows a monoclinial dip of less than 1° to the southeast. A total of 240 feet of the Devonian was cored in two separate sections, from 2080'-2200' in the Lower Huron Member of the Ohio Shale, and 3080'-3200' in the West Falls Formation.

Production Data

No production data was available for this well.

Undifferentiated Fractures

The core was oriented by Morgantown Energy Technology Center personnel with no distinction being made between core-induced fractures, natural fractures, and slickensided fractures. In this study they are all grouped under the category of undifferentiated fractures. Also, only fracture strikes were measured, no fracture dips (Byrer and Rhoads, 1976).

The composite rose diagram of undifferentiated fracture strikes (figure G-2) has a single statistically significant peak at $N25^{\circ}E$. There is a 5.0% chance that this peak does not exist. A smaller peak which is not statistically significant occurs at $N63^{\circ}W$. Fracture orientations show a great amount of variability (figures G-3 and G-4, table G-1). The Upper Huron Member of the Ohio Shale tends to show the most distinct fracture sets whereas the fractures in the West

Falls Formation show more scatter. Due to the fact that the fracture types are not known, nor fracture dips, no reliable interpretations can be made.

Figure G-1. Index map for the OH #1 (S-745) core well

UNDIFFERENTIATED FRACTURES

OH*1 (S-745)

Figure G-2. Rose diagram of undifferentiated fracture strikes.

OH*1 (S-745) UNDIFFERENTIATED FRACTURES

Figure G-3. Histograms of undifferentiated fracture orientations.

TABLE G-1

OH #1 (S-745) UNDIFFERENTIATED FRACTURES

<u>Interval</u>	<u>N</u>	<u>VN</u>	<u>α</u>
2080-2109	63	3.9056	≤ 0.01
2110-2139	84		
2140-2169	44	4.8242	≤ 0.01
2170-2200	33		
3080-3109	7	1.2484	≤ 1.00
3110-3139	52		
3140-3169	31	2.5628	≤ 0.05
3170-3200	63

Figure G-4. Composite data sheet of undifferentiated fracture frequencies and orientations.

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APPENDIX H: OH #2 (R-109) CORE WELL

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OH #2 (R-109) CORE WELL

Location

The OH #2 (R-109) core well is located in Washington County, Ohio, along the Ohio River, approximately two miles northwest of the city of Parkersburg, West Virginia (figures 1 and H-1, table 1). The wellsite is on the northeast flank of the northwest trending Parkersburg-Lorain Syncline. Regional structure of the Devonian shales shows a monoclinal dip of less than 1° to the southeast. A total of 224 feet of the Devonian Lower Huron Member of the Ohio Shale was cored, from 3490'-3714' (figure H-2). The lower 59 feet of the core, interval 3655'-3714', could not be oriented due to a malfunction of the orienting camera. This interval was not used in this study.

Production Data

No production data was available for this well.

Undifferentiated Fractures

Core fracture orientations were measured by West Virginia Geologic and Economic Survey personnel with no distinction being made between core-induced fractures, natural fractures, and slickensided fractures. In this study they are all grouped together under the category of undifferentiated fractures. According to Vickers (1977, unpublished manuscript) a majority of the fractures logged in the core are core-induced fractures. He also states that slickensides are abundant below 3580' with none found above that point.

The rose diagram of undifferentiated fracture strikes (figure H-3) has a one statistically significant peak at $N60^{\circ}-75^{\circ}E$ with an average

strike of $N65^{\circ}E$. There is a 1.0% chance that this peak does not exist. A very minor peak which is not statistically significant occurs at $N20^{\circ}W$. Fractures in this set are found only in the interval 3574'-3601' (figures H-4 and H-6). The equal area projection of poles to undifferentiated fracture surfaces (figure H-3) has eight clusters; four corresponding to the inclined and vertical fractures of the $N60^{\circ}75^{\circ}E$ set, and four clusters corresponding to the inclined and vertical fractures of the $N20^{\circ}W$ set. Fracture orientations exhibit a great amount of scatter in the interval 3490'-3517' (figures H-4 and H-5, table H-1), but are very consistent throughout the rest of the core. The consistent fracture orientations suggest the presence of a stress or rock fabric anisotropy. The dominant $N60^{\circ}-75^{\circ}E$ strike may be related to the general east to northeast trending maximum compressive stress present in most of eastern North America (Sbar and Sykes, 1973). The $N20^{\circ}W$ set may be an anomalous core-induced fracture set caused by differential stresses in that particular interval, or possibly, a natural fracture set which formed as an extension fracture set under tectonic compressive stresses directed from the southeast during the formation of the southern Appalachians.

Figure H-1. Index map for the OH #2 (R-109) core well

Figure H-2. Gamma-ray log, Middle and Upper Devonian.

OH*2 (R-109)

Figure H-3. (A) composite rose diagram of undifferentiated fracture strikes, and (B) equal area projection of poles to undifferentiated fracture surfaces

Figure H-4. Equal area projections of poles to undifferentiated fracture surfaces and rose diagrams of undifferentiated fracture strikes for approximately equal length intervals of the OH #2 (R-109) core.

OH*2 (R-109) UNDIFFERENTIATED FRACTURES

Figure H-5. Histograms of undifferentiated fracture orientations.

TABLE H-1

OH #2 (R-109) UNDIFFERENTIATED FRACTURES

<u>Interval</u>	<u>N</u>	<u>VN</u>	<u>α</u>
3490-3517	61	3.0228	≤ 0.01
3518-3545	54		
3546-3573	61	4.6357	≤ 0.01
3574-3601	65	1.6783	≤ 1.00
3602-3629	109	2.0506	≤ 1.00
3630-3655	57	2.5118	≤ 0.05

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APPENDIX I: VA #1 (20338) CORE WELL

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VA #1 (20338) CORE WELL

Location

The VA #1 (20338) core well is located in Wise County, Virginia, approximately ten miles southeast of the town of Whitesburg, Kentucky (figures 1 and I-1, table 1). The wellsite is near the center of the Millsboro Basin on the Pine Mountain overthrust sheet. A total of 380 feet of the Devonian was cored from two separate intervals, 4870'-4985' and 5210'-5475' (figure I-2).

Production Data

Two intervals of the well were stimulated by a cryogenic type treatment (gelled water and liquid CO₂). After stimulation, interval 4890'-4910', in the Cleveland Member of the Ohio Shale, had an initial open flow fluctuating between 54 mcf/day and 107 mcf/day; and interval 5450'-5480', in the Lower Huron Member of the Ohio Shale, had an initial open flow of 40 mcf/day (Komar, Frone, and Yost, 1978).

Core-induced Fractures

Core-induced fractures are the most common fracture type in the core. The Cleveland Member and the Three Lick Bed have the highest frequency of core-induced fractures whereas the Lower Huron Member has the lowest frequency (figure I-12). The core-induced fracture composite rose diagram (figure I-3) has a peak at N45°-70°E with an average strike of N57°E. There is a 1.0% chance that this peak does not exist. The equal area projection of poles to core-induced fracture surfaces (figure I-3) has two large clusters corresponding to the opposing dips of the N57°E fracture set, and two smaller clusters

corresponding to the opposing dips of a fracture set striking approximately $N25^{\circ}W$. The $N25^{\circ}W$ set is not statistically significant. Core-induced fracture orientations show very little variability with depth. The greatest change occurs between the Cleveland Member, interval 4870'-4930', and the Three Lick Bed, interval 4931'-4985', where mean strikes are $N62^{\circ}E$ and $N43^{\circ}E$ respectively (figures I-4 and I-5, table I-1).

The dominant core-induced fracture orientation, $N45^{\circ}-70^{\circ}E$, may be related to the east to northeast trending maximum compressive stress which exists in most of eastern North America (Sbar and Sykes, 1973). The trend also parallels the Pine Mountain thrust. This suggests that the tectonic compressive stresses which formed the thrust and the resulting layer-parallel shortening, may have imposed a residual strain in the rocks in the form of an incipient cleavage (Engelder, 1979). This self-equilibrating recoverable strain may be responsible for the formation of the core-induced fractures, alone or in combination with the maximum compressive stress.

Natural Fractures

Natural fractures occur throughout the VA #1 (20338) core. The Lower Huron Member, however, has a greater frequency of natural fractures than other units in the core (figure I-12). The natural fracture composite rose diagram (figure I-6) has two significant peaks. There is a 1.0% chance that the peaks at $N7^{\circ}W$ and $N37^{\circ}W$ do not exist. Two peaks that are not statistically significant are found at $N13^{\circ}E$ and $N83^{\circ}W$. The equal area projection of poles to natural fracture surfaces (figure I-6) has two clusters which correspond to the two major

subvertical natural fracture sets. The two smaller sets do not form definite clusters on the plot. Natural fracture orientations are quite variable and show no pattern or systematic variation with depth or stratigraphy (figure I-7). Surfaces of nearly all of the natural fractures are polished to some degree. However, since twist hackle and hackle plume can be distinguished on most of these fracture surfaces, displacement along the fracture probably took place during or after fracture formation.

The N37°W natural fracture set is nearly orthogonal to the trace of the Pine Mountain thrust and probably formed as an extension fracture set under tectonic compressive stresses during formation of the thrust. The N7°W set and the two smaller fracture sets parallel faults and fold axes on the thrust sheet. The transcurrent movement within the thrust sheet which formed these structures may also be responsible for the three fracture sets.

Slickensides and Slickenlines

Slickensides are found to be concentrated in two zones: an upper zone at the contact of the Cleveland Member with the Three Lick Bed; and a lower zone which includes the entire Lower Huron Member, a soft black shale unit (figure I-12). Slickensides are also scattered throughout the rest of the core. The two slickenside zones are vertically extensive and can be considered décollement zones. Lack of data between the two cored intervals inhibits determining whether the two slickenside zones are actually part of a single, much wider, décollement. Contours on blowout zones in the area (Young, 1957) fall near the top of the Lower Huron Member in the vicinity of this core

well. This agrees with the top of the lower décollement zone. The slickenside composite rose diagram (figure I-8) has a single peak at $N40^{\circ}-55^{\circ}E$ with an average strike of $N47^{\circ}E$. There is a 1.0% chance that this peak does not exist. A small peak that is not statistically significant is found at $N27^{\circ}E$. Poles to slickensided surfaces form a girdle across the equal area projection (figure I-8). The pattern of clusters closely resembles the pattern of fracture dips which would be expected in a shear zone. The 0° dipping cluster in the center is the displacement shear cluster, the Riedel shear cluster dips $20^{\circ}NW$, and the thrust shear cluster dips $20^{\circ}SE$. R' shears may be present among the scatter in the southeast quadrant of the plot. In portions of the décollement zones the various sets of slip surfaces combine to divide the shear zone into numerous lenses. The lenses, usually bounded by Riedel and displacement shears, contain rock fragments so deformed as to be slickensided on all sides. Small fold and flow structures were also found in the lower décollement zone. Slickenside orientations show very little variability (figure I-9)

The slickenline composite rose diagram (figure I-10) has a single peak at $N35^{\circ}-55^{\circ}W$ with an average trend of $N45^{\circ}W$. There is a 1.0% chance that this peak does not exist. The equal area projection of slickenlines (figure I-10) has two peripheral clusters which correspond to the low dipping slickenlines. There is very little scatter in slickenline trend (figure I-11). Very few of the slickensides are mineralized. Massive barite on the slickensided surfaces is the most common type of mineralization.

The $N40^{\circ}-55^{\circ}E$ slickenside trend parallels the trace of the Pine

Mountain thrust and the $N35^{\circ}-55^{\circ}W$ trending slickenlines are orthogonal to it. Therefore, it can be assumed that these structures reflect movement of the Pine Mountain thrust sheet on décollement zones in the Devonian shales.

Figure I-1. Index map for the VA #1 (20338) core well showing surface structure on the Pine Mountain thrust sheet, and a cross section through the thrust sheet.

Figure I-2. Gamma -ray log, Upper and Middle Devonian.

VA*1 (20338)

Figure I-3. (A) composite rose diagram of core-induced fracture strikes, and
(B) equal area projection of poles to core-induced fracture
surfaces

Figure I-4. Equal area projections of poles to core-induced fracture surfaces and rose diagrams of core-induced fracture strikes for approximately equal length intervals of the VA #1 (20338) core.

VA*1 (20338) CORE-INDUCED FRACTURES

Figure I-5. Histograms of core-induced fracture orientations.

TABLE I-1

VA #1 (20338) INDUCED FRACTURES

<u>Interval</u>	<u>N</u>	<u>VN</u>	<u>α</u>
4870-4930	76	4.9886	≤ 0.01
4931-4985	98		
5210-5260	55	1.9194	≤ 1.00
5261-5310	22	1.8762	≤ 1.00
5311-5360	68	2.8030	≤ 0.01
5361-5410	15	1.9023	≤ 1.00
5411-5475	62	1.2952	≤ 1.00

VA*1 (20338)

Figure I-6. (A) composite rose diagram of natural fracture strikes, and (B) equal area projection of poles to natural fracture surfaces

Figure I-7. Equal area projections of poles to natural fracture surfaces and rose diagrams of natural fracture strikes for approximately equal length intervals of the VA #1 (20338) core.

VA*1 (20338)

Figure I-8. (A) composite rose diagram of slickenside strikes, and (B) equal area projection of poles to slickensided surfaces

Figure I-9. Equal area projections of poles to slickensided surfaces and rose diagrams of slickenside strikes for approximately equal length intervals of the VA #1 (20338) core.

VA*1 (20338)

Figure I-10. (A) composite rose diagram of slickenline trends, and (B) equal area projection of slickenlines

Figure I-11. Equal area projections of slickenlines and rose diagrams for approximately equal length intervals of the VA #1 (20338) core.

M. Evans 1979

Figure I-12. Composite data sheet of fracture frequencies and orientations for all fracture types.

APPENDIX J: PA #2 (C.E.P.S. #1) CORE WELL

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PA #2 (C.E.P.S. #1) CORE WELL

Location

The PA #2 (C.E.P.S. #1) core well is located in Allegheny County, Pennsylvania, one mile east of the town of Monongahela along the Monongahela River (figures 1 and J-1, table 1). The wellsite is on the southern border of a $N70^{\circ}W$ trending zone of structural discontinuity (Wagner and Lytle, 1976). It is also near what is believed to be a basement fault zone known as the Lat. $40^{\circ}N$ Fault or the Transylvania Fault (Root and Hoskins, 1977) (figure J-1). The fault zone trends $N70^{\circ}W$ and is evidenced in the Plateau by aeromagnetic anomalies as well as the aforementioned zone of structural discontinuity where folds of the Appalachian trend are interrupted or terminated. The structural discontinuity also controls the distribution of oil and gas fields in the area (Wagner and Lytle, 1976). A total of 550 feet of the Devonian was cored, from 6950'-7500' (figure J-2).

Production Data

No production data was available for this core well.

Core-induced Fractures

The only core-induced fractures in the core are torsion and disc fractures. The lack of core-induced petal-centerline fractures may be related to the physical characteristics of the rock; which is generally a soft, fissile, black shale; or stress conditions in the rock.

Natural Fractures

Natural fractures are only found in three stratigraphic intervals

in this core: the Genesee Shale, Tully Limestone, and Marcellus Shale (figure J-9). The West River Shale and the Mahantango Formation have no natural fractures. The natural fracture composite rose diagram has no statistically significant peaks (figure J-3). However, four dominant trends can be determined: $N17^{\circ}E$, $N37^{\circ}E$, $N85^{\circ}E$, and $N47^{\circ}W$. The equal area projection of poles to natural fracture surfaces (figure J-3) has six peripheral clusters which correspond to three of the four subvertical to vertical natural fracture sets. Natural fracture orientations are quite variable and show no pattern or systematic variation with depth or stratigraphy (figure J-4). Most of the natural fractures in the core are mineralized with fibrous or massive calcite. The mineral fibers are perpendicular to the fracture faces, implying that mineral growth has probably occurred parallel to the principal acting tension as the fracture opened (Durney and Ramsay, 1973). The mineral fibers also suggest the existence of a high pore fluid pressure to open the fractures.

The proximity of the wellsite to the zone of structural discontinuity and proposed basement fault zone may account for the diversity of fracture trends in the core. Similar situations are reported by Kulander and Dean (1978) who found chaotic fracturing in coals above a basement fault zone in southwestern West Virginia, and Dixon (1979) who found that Devonian shales within a cross strike discontinuity were more intensely fractured than those outside of it. The $N47^{\circ}W$ fracture set is nearly orthogonal to the Appalachian trend in this area and probably formed as an extension fracture set under tectonic compressive stresses during Alleghenian deformation. The $N17^{\circ}E$ and

and $N37^{\circ}E$ fracture sets parallel portions of nearby folds and may have formed as release fractures when tectonic stresses were relaxed. The $N85^{\circ}E$ fracture set may be related to the general east to northeast trending maximum compressive stress present in most of eastern North America (Sbar and Sykes, 1973).

Slickensides and Slickenlines

Slickensides in the core are found primarily in the West River Shale, Tully Limestone, and Marcellus Shale (figure J-9). A very few slickensides are also found in the upper portion of the Genesee Shale and Mahantango Formation. The West River slickenside zone occurs in a shale below the stiffer Sonyea Formation and above the Tully Limestone. The Marcellus Slickenside zone occurs in a soft shale unit above the much stiffer Onondaga Limestone. The West River and Marcellus zones are quite vertically extensive, suggesting that these two units acted as décollement zones. The slickenside composite rose diagram (figure J-5) has two peaks. There is a 1.0% chance that the peaks at $N23^{\circ}W$ and $N47^{\circ}E$ do not exist. Poles to slickensided surfaces form a girdle across the equal area projection (figure J-5). The pattern of clusters closely resembles the pattern of fracture dips which would be expected in a shear zone. The 0° dipping cluster in the center is the displacement shear cluster, the $30^{\circ}NW$ dipping cluster is the Riedel shear cluster, and the $30^{\circ}SE$ dipping cluster is the thrust shear cluster. R' shears are not present in this core. A $10^{\circ}NE$ dipping cluster results from the low-dipping $N23^{\circ}W$ slickenside set. Slickenside orientations show a great amount of variation with depth. The West River Shale has a majority of northwest striking

slickensides whereas in the rest of the core they strike northeast (figure J-6).

The slickenline composite rose diagram (figure J-7) has a single peak at $N40^{\circ}-60^{\circ}W$ with an average trend of $N50^{\circ}W$. There is a 5.0% chance that this peak does not exist. The equal area projection of slickenlines (figure J-7) has two large peripheral clusters corresponding to the wide range in trends of low plunging slickenlines. There is very little variability in slickenline trend, except for those slickenlines in the upper portion of the Marcellus Shale which trend more to the north than those in the rest of the core (figure J-8).

The $N40^{\circ}-60^{\circ}W$ slickenline trend parallels the $N47^{\circ}W$ natural fracture set and is nearly orthogonal to the $N47^{\circ}E$ slickenside set. These three sets are related in that they all probably formed under the same Alleghenian tectonic compressive stresses.

Several slickensides in the core are mineralized, particularly those in the West River Shale and in the lower portion of the Marcellus Shale. Mineralization generally consists of calcite fibers between slickensided surfaces, or massive or crystalline coatings on the slickensided surfaces. The fibrous crystal growth is indicative of high fluid pressure in the bedding planes of the shales, and a vertical principal acting tension during mineralization (Durney and Ramsay, 1973). Such abnormally pressured rocks are preferred sites for décollement because these rocks are probably less viscous than their normally pressured counterparts (Kehle, 1970).

Figure J-1. Index map for the PA #2 (C.E.P.S. #1) core well with major structures and lines of structural discontinuity in the Pittsburgh, Pennsylvania, region. Also, the location of the proposed Lat 40°N Fault Zone.

Figure J-2. Gamma-ray log, Middle and Upper Devonian

Figure J-3. (A) composite rose diagram of natural fracture strikes, and (B) equal area projection of poles to natural fracture surfaces

Figure J-4. Equal area projection of poles to natural fracture surfaces and rose diagrams of natural fracture strikes for approximately equal length intervals of the PA #2 (C.E.P.S. #1) core.

PA^{*}2 (C.E.P.S.^{*}1)

Figure J-5. (A) composite rose diagram of slickenside strikes, and (B) equal area projection of poles to slickensided surfaces

Figure J-6. Equal area projections of poles to slickensided surfaces and rose diagrams of slickenside strikes for approximately equal length intervals of the PA #2 (C.E.P.S. #1) core.

PA*2 (C.E.P.S.*1)

Figure J-7. (A) composite rose diagram of slickenline trends, and (B) equal area projection of slickenlines

Figure J-8. Equal area projections of slickenlines and rose diagrams of slickenline trends for approximately equal length intervals of the PA #2 (C.E.P.S. #1) core.

Figure J-9. Composite data sheet of fracture frequencies and orientations for all fracture types.

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APPENDIX K: KY #1 (7239) CORE WELL

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KY #1 (7239) CORE WELL

Location

The KY #1 (7239) core well is located in Perry County, Kentucky, twelve miles due north of the town of Hazard (figures 1 and K-1, table 1). The wellsite is between the Pine Mountain thrust, to the south, and the Irving-Paint Creek Fault, to the north. Regional structure of the Devonian shales shows a monoclinal dip of less than 1° to the southeast. A total of 339 feet of the Devonian was cored, from 2369'-2708'. In this study only two sections of the core were analyzed; a 52 foot section from 2374'-2426', and a 71 foot section from 2588'-2660' (figure K-2). This was done because the only reliable data available to the author for this core included only these sections. Within each of these two sections there is a small interval with no fracture data.

Production Data

Five intervals of the KY #1 (7239) well were stimulated by foam fracturing. After stimulation, interval 2326'-2675' had an initial open flow of 60 mcf/day, intervals 3174'-3180' and 3412'-3491' combined had an initial open flow of 450 mcf/day, and intervals 2560'-2580' and 2730'-2790' combined had an initial open flow of 103 mcf/day (Komar, Frone, and Yost, 1978).

Undifferentiated Fractures

The fractures in the two sections studied were previously logged and analyzed by, and the results presented in, Kulander, Dean, and Barton (1977). No natural fractures were logged by Kulander, et.al.

(1977), but they stated that there is a "remote possibility" that some of the fractures they classified as core-induced fractures are actually pre-core (natural) fractures. The author is therefore placing all core-induced fractures as logged by Kulander, et. al. (1977) in the category of undifferentiated fractures. Kulander, et. al. (1977), however, did differentiate slickensided fractures, slickenlines, and horizontal mineral filled fractures.

Undifferentiated fractures were found to be distributed throughout the sections studied (figure K-10). The composite rose diagram of undifferentiated fracture strikes (figure K-3) has four peaks. There is a 5.0% chance that the peaks at $N5^{\circ}-15^{\circ}W$ and $N3^{\circ}E$ do not exist, and a 10.0% chance that the peaks at $N37^{\circ}W$ and $N33^{\circ}E$ do not exist. The equal area projection of poles to undifferentiated fracture surfaces (figure K-3) has numerous clusters corresponding to the fractures which generally dip greater than 60° . Undifferentiated fracture orientations show significant changes with depth (figures K-4 and K-5, table K-1). Dominant orientations swing from $N33^{\circ}E$ in the Cleveland Member to $N5^{\circ}-15^{\circ}W$ at the base of the Middle Huron Member and top of the Lower Huron Member, back to $N33^{\circ}E$ in interval 2614'-2638' and then to $N37^{\circ}W$ in interval 2639'-2669'. The various fracture sets, and their preference for certain intervals of the core, may be the result of the interaction of several stress fields; tensile stresses associated with faulting in the area, southern Appalachian tectonic compressive stresses, and the general east to northeast trending maximum compressive stress present in most of eastern North America (Sbar and Sykes, 1973).

Slickensides and Slickenlines

Slickensides are found in both sections of the core studied (figure K-10), and most are subhorizontal to horizontal. The only inclined slickensides occur in the Lower Huron Member (figure K-7). The slickenside composite rose diagram (figure K-6) has a single peak at $N3^{\circ}E$. There is a 1.0% chance that this peak does not exist. The equal area projection of poles to slickensided surfaces (figure K-6) has two clusters; one, dipping 0° , corresponding to the numerous horizontal slickensides; and one, dipping $60^{\circ}W$ corresponding to the inclined $N3^{\circ}E$ striking slickensides.

The slickenline composite rose diagram (figure K-8) has four significant peaks. There is a 1.0% chance that the peaks at $N87^{\circ}W$, $N27^{\circ}E$, and $N83^{\circ}E$ do not exist, and a 5.0% chance that the peak at $N33^{\circ}W$ does not exist. The equal area projection of slickenlines (figure K-8) has several peripheral clusters corresponding to the horizontal slickenlines, and a cluster dipping $60^{\circ}W$, corresponding to the slickenlines on the $N3^{\circ}E$ striking slickensides. The $N33^{\circ}W$ set occurs primarily in the Cleveland Member, and the $N87^{\circ}W$ and $N83^{\circ}E$ sets occur primarily in the Lower Huron Member (figure K-9).

Tectonic compressive stress directed from the southeast may be responsible for the $N33^{\circ}W$ trending slickenlines. The $N27^{\circ}E$, $N83^{\circ}E$, and $N87^{\circ}W$ sets may be related directly to local fault movement, or to compaction and settling of the rock after fault movement. The $N83^{\circ}E$ trending, and $60^{\circ}W$ dipping slickenlines may indicate the presence of a north-south trending normal fault to the west. Some of the scatter in slickenline orientations may be due to local movements on the flanks

of low-amplitude, short-wavelength, discontinuous, shale folds (Kulander, et. al., 1977).

Numerous mineral filled fractures were found throughout the two sections studied; most of these are horizontal. Fibrous and non-fibrous calcite is the predominant mineral filling. The fibrous mineral growth is indicative of high fluid pressure in the bedding planes of the shales, and a vertical principal acting tension during mineralization (Durney and Ramsay, 1973). such abnormally pressured rocks are preferred sites for décollement because these rocks are probably less viscous than their normally pressured counterparts (Kehle, 1970). It is possible that the shales penetrated by this core acted as a poorly developed décollement zone.

Figure K-1. Index map for the KY #1 (7239) core well

Figure K-2. Gamma-ray log, Upper and Middle Devonian.

KY*1 (7239)

Figure K-3. (A) composite rose diagram of undifferentiated fracture strikes, and (B) equal area projection of poles to undifferentiated fracture surfaces.

Figure K-4. Equal area projections of poles to undifferentiated fracture surfaces and rose diagrams of undifferentiated fracture strikes for approximately equal length intervals of the KY #1 (7239) core.

KY*1 (7239) UNDIFFERENTIATED FRACTURES

Figure K-5. Histograms of undifferentiated fracture strikes.

TABLE K-1

KY #1 (7239) UNDIFFERENTIATED FRACTURES

<u>Interval</u>	<u>N</u>	<u>VN</u>	<u>σ</u>
2374-2400	19	1.8812	≤ 1.00
2401-2426	35		
2588-2613	74	2.9215	≤ 0.01
2614-2638	94	3.3860	≤ 0.01
2639-2664	76	2.1111	≤ 1.00

KY*1 (7239)

Figure K-6. (A) composite rose diagram of slickenside strikes, and (B) equal area projection of poles to slickensided surfaces.

KY#1(7239) Slickensides

Figure K-7. Equal area projections of poles to slickensided surfaces and rose diagrams of slickenside strikes for approximately equal length intervals of the KY #1 (7239) core.

KY*1 (7239)

Figure K-8. (A) composite rose diagram of slickenline trends, and (B) equal area projection of slickenlines.

Figure K-9. Equal area projections of slickenlines and rose diagrams of slickenline trends for approximately equal length intervals of the KY #1 (7239) core.

Figure K-10. Composite data sheet of fracture frequencies and orientations for all fracture types.

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APPENDIX L: KY #3 (20336) CORE WELL

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KY #3 (20336) CORE WELL

Location

The KY #3 (20336) core well is located in Martin County, Kentucky, approximately three miles south of the town of Warfield, near the Warfield Fault (figures 1 and L-1, table 1). A total of 982 feet of the Devonian was cored, from 2429'-3411' (figure L-2). Intervals 2429'-2486' and 3404'-3411' were not oriented, and are therefore not used in this study.

Production Data

Two intervals of the well were stimulated; 2666'-2712', in the Upper Huron Member, which produced an initial open flow of 250 mcf/day after stimulation; and 2968'-3122', in the Lower Huron Member, which had an initial open flow of 370 mcf/day after stimulation (Yost, 1979, written communication).

Core-induced Fractures

Core-induced fractures are the most common fracture type in the core and are well distributed throughout (figure L-12). The core-induced fracture composite rose diagram (figure L-3) has three peaks. There is a 1.0% chance that the peaks at $N40^{\circ}-55^{\circ}E$, $N63^{\circ}E$, and $N33^{\circ}E$ do not exist. The equal area projection of poles to core-induced fracture surfaces (figure L-3) has four large clusters corresponding to the vertical and inclined, opposite dipping fractures in the three merged sets. Scattered poles are also found in the northwest and southeast quadrants. Most of the scatter occurs in interval 2487'-2550'. In general, core-induced fracture orientations show a gradual

swing to the north down the core (figures L-4 and L-5, table L-1).

The $N33^{\circ}E$ and $N63^{\circ}E$ fracture sets parallel the core-induced fractures in the WV #4 (20402) and WV #3 (20403) cores, respectively, which are located to the northeast. The largest peak, $N40^{\circ}-55^{\circ}E$, bisects the two smaller peaks, and probably represents a merging of the two trends. The consistent core-induced fracture orientations suggest the presence of a stress or rock fabric anisotropy. This anisotropy may be related to the general east to northeast trending maximum compressive stress present in most of eastern North America (Sbar and Sykes, 1973).

Natural Fractures

Natural fractures are found throughout the core (figure L-12). The natural fracture composite rose diagram (figure L-6) shows the great variability in natural fracture orientations. There are no statistically significant peaks. However, three dominant trends are present: $N67^{\circ}W$, $N47^{\circ}W$, and $N37^{\circ}E$. The equal area projection of poles to natural fracture surfaces (figure L-6) has two clusters corresponding to the vertical fractures of the $N67^{\circ}W$ and $N47^{\circ}W$ sets, and two clusters corresponding to the subvertical to vertical fractures of the $N37^{\circ}E$ set. Natural fractures generally strike northeast in and above the Middle Huron Member, and northwest below (figure L-7).

The $N37^{\circ}E$ natural fracture set parallels the $N33^{\circ}E$ core-induced fracture set, and may be related to the same stress or rock fabric anisotropy responsible for the core-induced fractures. The two northwest striking natural fracture sets show no relationship to any known nearby structures. However, the great variation in fracture orientation may be the result of the interaction of stress fields associated

with nearby faulting.

Slickensides and Slickenlines

Slickensides are found in and below the Middle Huron Member, with a majority occurring in the West Falls Formation (figure L-12). The slickenside composite rose diagram (figure L-8) has three peaks. There is a 5.0% chance that the peaks at $N17^{\circ}W$, $N47^{\circ}E$, and $N83^{\circ}E$ do not exist. The equal area projection of poles to slickensided surfaces (figure L-8) has several clusters; one, dipping $25^{\circ}SW$, corresponds to the $N17^{\circ}W$ set; two clusters, dipping $40^{\circ}SE$ and $60^{\circ}SE$, correspond to the $N83^{\circ}E$ set; and one, dipping $30^{\circ}SE$, corresponds to the $N47^{\circ}E$ set. The $N83^{\circ}E$ set occurs only in the Lower Huron Member and below, whereas the other two sets are scattered throughout the core (figure L-9). Very few slickensides in the WV #3 (20336) core are mineralized.

The slickenline composite rose diagram (figure L-10) has two statistically significant peaks. There is a 1.0% chance that the peak at $N5^{\circ}W$ does not exist, and a 10.0% chance that the peak at $N73^{\circ}E$ does not exist. A smaller peak which is not statistically significant occurs at $N43^{\circ}W$. The equal area projection of slickenlines (figure L-10) has three clusters: $N73^{\circ}E/65^{\circ}SW$, $N5^{\circ}W/40^{\circ}SE$, and $N43^{\circ}W/0^{\circ}SE$. The $N43^{\circ}W$ trend is generally found in the Middle Huron Member, and the $N5^{\circ}W$ and $N73^{\circ}E$ sets are found in the Lower Huron Member and below (figure L-11).

All three slickenside sets parallel mapped or proposed normal faults in the area, suggesting that they developed through actual fault movement, or compaction and settling of the rock after fault movement.

Figure L-1. Index map for the KY #3 (20336) core well

Figure L-2. Gamma-ray log, Upper and Middle Devonian.

KY*3 (20336)

Figure L-3. (A) composite rose diagram of core-induced fracture strikes, and (B) equal area projection of poles to core-induced fracture surfaces.

Figure L-4. Equal area projections of poles to core-induced fracture surfaces and rose diagrams of core-induced fracture strikes for approximately equal length intervals of the KY #3 (20336) core.

KY*3 (20336) CORE-INDUCED FRACTURES

Figure L-5. Histograms of core-induced fracture orientations.

TABLE L-1

KY #3 (20336) INDUCED FRACTURES

<u>Interval</u>	<u>N</u>	<u>VN</u>	<u>α</u>
2487-2550	148	2.5078	≤ 0.05
2551-2600	112		
2601-2650	60	2.8125	≤ 0.01
2651-2700	68		
2701-2750	91	2.7931	≤ 0.05
2751-2800	98		
2801-2850	55	1.6649	≤ 1.00
2851-2900	102		
2901-2950	112	2.7600	≤ 0.05
2951-3000	51		
3001-3050	40	0.7906	≤ 1.00
3051-3100	76		
3101-3150	84	1.3983	≤ 1.00
3151-3200	100		
3201-3250	122	2.2127	≤ 1.00
3251-3300	137		
3301-3350	65	2.2098	≤ 1.00
3351-3403	52

KY*3 (20336)

Figure L-6. (A) composite rose diagram of natural fracture strikes, and (B) equal area projection of poles to natural fracture surfaces.

Figure L-7. Equal area projections of poles to natural fracture surfaces and rose diagrams of natural fracture strikes for approximately equal length intervals of the KY #3 (20336) core.

SLICKENSIDES
(Inclined $\geq 10^\circ$ Dip)

KY*3 (20336)

Figure L-8. (A) composite rose diagram of slickenside strikes, and (B) equal area projection of poles to slickensided surfaces.

Figure L-9. Equal area projections of poles to slickensided surfaces and rose diagrams of slickenside strikes for approximately equal length intervals of the KY #3 (20336) core.

KY*3 (20336)

Figure L-10. (A) composite rose diagram of slickenline trends, and (B) equal area projection of slickenlines.

Figure L-11. Equal area projections of slickenlines and rose diagrams of slickenlines trends for approximately equal length intervals of the KY #3 (20336) core.

M. Evans 1979

Figure L-12. Composite data sheet of fracture frequencies and orientations for all fracture types.

APPENDIX M: KY #4 (#3 R-S) CORE WELL

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KY #4 (#3 R-S) CORE WELL

Location

The KY #4 (#3 R-S) core well is located in Johnson County, Kentucky, approximately 13 miles northwest of the town of Paintsville (figures 1 and M-1, table 1). The wellsite is in the Eastern Kentucky Fault System, about seven miles north of the east-west trending Irving-Paint Creek Fault. A total of 550 feet of the Devonian was cored, from 950'-1500' (figure M-12).

Production Data

A gas show, illustrated by a deviation of the temperature log (figure M-12), occurs in a zone of inclined unmineralized fractures at 1307'-1310'. Two intervals of the well were stimulated; 1294'-1382', in the Lower Huron Member, which had an initial open flow of 33 mcf/day after stimulation; and 1010'-1120', in the Cleveland Member and Three Lick Bed, which had an initial open flow of 52 mcf/day after stimulation (Yost, 1979, written communication).

Core-induced Fractures

Core-induced fractures are not common in this core, with only three petal fractures recorded in the Upper Huron Member (figure M-12). Disc fractures and torsion fractures are present, but rare. The core-induced fracture composite rose diagram (figure M-2) has two peaks. There is a 1.0% chance that the peaks at $N55^{\circ}-65^{\circ}E$ and $N77^{\circ}E$ do not exist. The equal area projection of poles to core-induced fracture surfaces (figure M-2) has a single cluster corresponding to the northwest dipping petals. Although the sample is small (3) it

may still indicate the presence of a stress or rock fabric anisotropy in the rock around the KY #4 (#3R-S) well. This anisotropy may be related to the east to northeast trending maximum compressive stress present in most of eastern North America (Sbar and Sykes, 1973). The restriction of petal fractures to the Upper Huron Member may be related to the physical characteristics of the rock. No significant changes in orientation with depth can be determined (figure M-3).

Natural Fractures

Natural fractures in this core fall into two classes: 1) vertical, calcite filled fractures which probably formed before rock lithification, possibly as dessication cracks (figure M-4); and 2) inclined unmineralized fractures (figure M-5). Fractures of class 1 have a most unexpectedly consistent orientation, and occur only in the Cleveland Member and Middle Huron Member. Fractures in class 2 occur only in the Berea Sandstone and Lower Huron Member (figure M-12). Both fracture types have the same general northeast strike. The natural fracture composite rose diagram (figure M-6) has two peaks. There is a 1.0% chance that the peak at $N60^{\circ}-70^{\circ}E$ does not exist, and a 10.0% chance that the peak at $47^{\circ}E$ does not exist. The equal area projection of poles to natural fracture surfaces (figure M-6) has five clusters; four peripheral clusters corresponding to the vertical fractures in the two sets, and a cluster dipping $50^{\circ}SW$ corresponding to the inclined fractures in the $N60^{\circ}-70^{\circ}E$ set. Fracture orientations vary very little with depth or stratigraphy (figure M-7).

The two natural fracture sets parallel nearby faults. The pre-lithification (class 1) fractures may have formed in relation to

faulting in the area which stressed the sediments, thus producing oriented cracks that later filled with calcite. As lithification continued, the sediment and fractures were compacted, deforming the fracture and filling. The inclined fractures (class 2) may have also formed in relation to local faulting, or they may have formed under the same stresses which formed the core-induced fractures.

Slickensides and Slickenlines

Most of the slickensides in the core occur near the contact of the Berea Sandstone and the Cleveland Member (figure M-12); a few also occur near the base of the Lower Huron Member. The slickenside composite rose diagram (figure M-8) has no statistically significant peaks. A predominant $N50^{\circ}-90^{\circ}E$ strike can be determined, however. The equal area projection of poles to slickensided surfaces (figure M-8) has three questionable clusters dipping 0° , $45^{\circ}S$, and $45^{\circ}NW$. Poles to slickensided surfaces tend to form a girdle across the plot, suggesting that the contact of the Berea Sandstone and Cleveland Member may be a poorly developed shear zone. In general, slickenside orientations are quite variable with depth (figure M-9).

The slickenline composite rose diagram (figure M-10) also shows a wide variety of trends. However, clusters on the equal area projection of slickenlines (figure M-10) tends to show three dominant trends; $N40^{\circ}W$ (two clusters, dipping $40^{\circ}NW$ and $35^{\circ}SE$), $N85^{\circ}E$ (two clusters, dipping $0^{\circ}W$ and $0^{\circ}-50^{\circ}E$), and $N5^{\circ}W$ (cluster dipping $40^{\circ}SW$). The $N40^{\circ}W$ trending slickenlines are nearly orthogonal to the southern Appalachian trend and may have formed under tectonic compressive stresses directed from the southeast. The $N5^{\circ}W$ and $N85^{\circ}E$ sets are

orthogonal to nearby faults and probably formed as a result of compaction and adjustment of the rock after fault movement. The $N40^{\circ}W$ set occurs only in the Berea Sandstone and Cleveland Member, the $N5^{\circ}W$ set occurs only in the Berea Sandstone and Lower Huron Member, and the $N85^{\circ}E$ set occurs only in the Berea Sandstone (figure M-11).

Figure M-1. Index map for the KY #4 (#3 R-S) core well

KY#4 (3R-S)

Figure M-2. (A) composite rose diagram of core-induced fracture strikes, and
(B) equal area projection of poles to core-induced fracture surfaces

KY#4(3 R-S)

Induced Fractures

Figure M-3. Equal area projections of poles to core-induced fracture surfaces and rose diagrams of core-induced fracture strikes for approximately equal length intervals of the KY #4 (#3 R-S) core.

Figure M-4. Class 1 fracture - KY #4 (#3 R-S) core.

Figure M-5. Class 2 fracture - KY #4 (#3 R-S) core.

KY#4 (3R-S)

Figure M-6. (A) composite rose diagram of natural fracture strikes, and (B) equal area projection of poles to natural fracture surfaces

Figure M-7. Equal area projections of poles to natural fracture surfaces and rose diagrams of natural fracture strikes for approximately equal length intervals of the KY #4 (#3 R-S) core.

KY#4 (3R-S)

Figure M-8. (A) composite rose diagram of slickenside strikes, and (B) equal area projection of poles to slickensided surfaces.

Figure M-9. Equal area projections of poles to slickensided surfaces and rose diagrams of slickenside strikes for approximately equal length intervals of the KY #4 (#3 R-S) core.

KY*4 (3R-S)

Figure M-10. (A) composite rose diagram of slickenline trends, and (B) equal area projection of slickenlines.

Figure M-11. Equal area projection of slickenlines and rose diagrams of slickenline trends for approximately equal length intervals of the KY #4 (#3 R-S) core.

Figure M-12. Composite data sheet of fracture frequencies and orientations for all fracture types.

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SUBSURFACE STRUCTURE OF THE EASTERN (

KENTUCKY GAS FIELD

BY

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October 1980

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ABSTRACT

The Eastern Kentucky (or Big Sandy) gas field is a coalescence of many small gas fields. Parts of the field have produced continuously for more than 60 years. The Devonian Ohio Shale is the principal producing horizon, but production also comes from the Mississippian Newman Limestone, and several Pennsylvanian sandstones.

The purpose of this study is to locate subsurface structures that may affect shale gas production in the Eastern Kentucky field.

Detailed structure contour maps drawn on the top and bottom of the Ohio Shale, using 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.

INTRODUCTION

A. Purpose of the Investigation

The Eastern Kentucky gas field produces commercial quantities of natural gas from the Devonian Ohio Shale over a wide area. Discovering the variables which control production of natural gas from the Devonian shale in the eastern Kentucky area may lead to new production in surrounding areas, as the shale covers broad areas of the Appalachian basin. Aspects such as surface fractures (Long, 1979), subsurface fractures (Evans, 1979), and production (deWys, 1979) have been investigated by previous workers at West Virginia University and other institutions.

The purpose of this study is to define and interpret the subsurface structure of the Eastern Kentucky gas field, so that any faults or folds can later be compared to the production, stratigraphy, fractures, geochemistry, etc., of the Ohio Shale. The end goal of this research is to expand gas production from the Devonian Ohio Shale into other areas.

B. Location

The giant Eastern Kentucky gas field is located in the southeast corner of Kentucky. This field is a nearly continuous area of production, covering some 3,000 square miles (4,800 square kilometers) within part or all of the counties of Breathitt, Floyd, Johnson, Knott, Lawrence, Letcher, Magoffin, Martin, Perry, and Pike. (Figure 1)

C. Regional Structure

Plate 1 shows the geologic setting of the Eastern

Kentucky gas field, and all structures and cored wells mentioned or described in this study. The field is located between the eastern flank of the Cincinnati Arch and deeper parts of the Appalachian basin on the east.

Regional dip in southeastern Kentucky varies according to the stratigraphic level. Near the surface (Figure 2 and Plate 1), structural dip is to the northwest toward the eastern Kentucky syncline. The Mississippian-Devonian strata dip in the opposite direction, to the southeast (Figure 3). The basement has far more local structural relief and includes structures such as the Rome Trough, Pike and Perry County domes, and the Floyd County channel (Figure 4).

The northern border of the Eastern Kentucky field consists of a series of basement-related east-west faults, which are thought to be components of the Rome Trough fault system (Ammerman and Keller, 1979). The Rome Trough is an asymmetric graben structure thought to be associated with a Cambrian rift system (Harris, 1975). The larger faults are seen at the surface in Pennsylvanian and older rocks, indicating they have had additional movement during the Pennsylvanian and even later times.

The Eastern Kentucky field is bordered by Pine Mountain to the southeast. Pine Mountain is the surface expression of competent Carboniferous units dipping eastward above a major ramp of a detachment thrust. The thrust extends from the Devonian shale across more competent units to either the surface

FIGURE 3 - STRUCTURE CONTOUR MAP ON TOP OF THE OHIO SHALE

KEVIN LEE, 1980
MODIFIED FROM PROVO, 1977

FIGURE 4. BOUGUER GRAVITY MAP OF EASTERN KENTUCKY
MODIFIED FROM AMMERMAN AND KELLER, 1979

or to an incompetent horizon in the Pennsylvanian clastics (Harris and Milici, 1977).

D. Previous Investigations

There were no detailed regional subsurface structure maps available for eastern Kentucky at the onset of this study. The very high success ratio of shale wells drilled into the field negated the necessity and expense of producing detailed structural maps. Nearly 90% of all shale wells drilled within the Big Sandy area are economically productive (Hager, 1979).

Several workers have discussed the structure of the Big Sandy area, including Billingsley (1934), Hunter (1935), and McFarlan (1943). Hunter and Billingsley both showed production from within the field to be from fracture porosity. McFarlan included regional geologic structure maps of eastern Kentucky drawn on top of the Fire Clay Coal (Figure 2), and on top of the Ohio Shale (from an unstated number of data points). The Fire Clay Coal map established shallow regional dip to the northwest and outlines the general trend of the D'Inwilliers anticline. The Ohio Shale map showed regional dip at that level to be to the southeast.

The Kentucky Geological Survey published surface structural geology maps in the eastern Kentucky area by County, in series VI publications during the 1920's. Most of these maps were developed prior to intense drilling and are now out of print.

Subsequent workers, including Provo (1977), Fulton (1979) and deWys (1979) have drawn structural maps and cross

sections in the area, but they used only several hundred data points. Those maps show regional structure, but the wide spacing of the wells used makes definition of small scale and low relief structures impossible. Provo did show that regional dip at the Devonian shale level is to the southeast, just the opposite from the dip of the Fire Clay Coal. However, small structures not capable of being defined by Provo and de Wys may be extremely important to shale-gas production, and, therefore, detailed structural analysis is paramount to a critical evaluation of the causes of the shale production.

E. Regional Stratigraphy

The rocks that make up the regional stratigraphy for the eastern Kentucky field are illustrated in Figure 5.

The "Corniferous" Limestone is a thick, hard, grey limestone. "Corniferous" is a catch-all name for the Silurian Lockport Dolomite and Salina Formation and the Devonian Helderberg Formation and Onondaga Limestone. The contact between the "Corniferous" Limestone and the overlying West Falls Formation is erosional (Hunter, 1935).

The Rhinestreet member of the West Falls Formation is a dark, organic-rich shale that is present only in the eastern section of the field in Pike County.

The Olentangy Shale is 100 to 200 feet (30 to 61 meters) thick and is a hard, light-colored shale. It is not as friable as the shale at the base of the Ohio Shale.

The Ohio Shale, or driller's "Brown Shale," is a thick sequence of dark, organic-rich shale alternating with non-organic shale. The thickness of the unit increases from 350 feet

SYSTEM SERIES	FORMATION & MEMBER	LITHOLOGY	THICKNESS IN FEET
PENNSYLVANIAN	LOWER & MIDDLE PENNSYLVANIAN BREATHITT FORMATION	SILTSTONE SANDSTONE SHALE COAL	1,100- 3,000
	LOWER PENNSYLVANIAN LEE FORMATION	SANDSTONE SILTSTONE SHALE COAL	800-1,200
	PENNINGTON FORMATION	SILTSTONE SHALE SANDSTONE LIMESTONE	850-1,000
	STONY GAP SANDSTONE MEMBER	SANDSTONE SHALE	
MISSISSIPPIAN	UPPER MEMBER	SILTSTONE SHALE SANDSTONE LIMESTONE	400-800
	NEWMAN LIMESTONE	LIMESTONE & SHALE	
	LOWER MEMBER		
MISSISSIPPIAN & PENNSYLVANIAN	BORDEN (GRAINGER) FORMATION	SHALE & SILTSTONE	250-600
	SUNBURY SHALE	SHALE	0-140
	BEREA Sh. & BEDFORD Sh.	SANDSTONE & SHALE	0-200
	OHIO SHALE	LIGHT & DARK SHALE	350-700
DEVONIAN	OLENTANGY SHALE	LIGHT SHALE	100-200
	RHINESTREET MBR. WEST FALLS FORMATION	DARK SHALE	0-40
	ONONDAGA	LIMESTONE & SHALE	?
MIDDLE DEVONIAN			

FIGURE 5
GENERAL STRATIGRAPHIC
COLUMN
(MODIFIED FROM RICE & WOLCOTT, 1973)
KEVIN LEE, 1980

DRILLERS' TERMS

"BIG LIME"

"COFFEE SHALE"

"BROWN
SHALE"

"WHITE
SLATE"

CORNIFEROUS

(107 meters) in the western portion of the field in Perry County to over 700 feet (213 meters) in Martin and Pike Counties. The Ohio Shale is considered to be Devonian, while the Devonian-Mississippian boundary is near the base of the Bedford Shale.

The Berea Sandstone is a fine-to-medium-grained sandstone, and the Bedford Shale is a light-colored shale. They have been interpreted to be the prodelta and channel sands of a prograding delta (Pepper and others, 1954). The entire sedimentary sequence is 80-220 feet (24-61 meters) thick. The Berea Sandstone, however, is absent in the western portion of the field.

The Sunbury Shale, or driller's "Coffee Shale" is 0-140 feet thick (0-43 meters). It is an organic-rich, dark grey to black shale.

The Borden Formation is 300-600 feet (91-183 meters) of green to grey to red shales and siltstone.

The Mississippian Newman Limestone, or driller's "Big Lime," is 400-800 feet (122-244 meters) thick across the field, and is known to have an erosional basal contact in some places (Shumaker, 1979; Beardsley, 1980).

The Pennsylvanian-Mississippian boundary is not precisely known, but is within the Pennington Formation (Rice and others, 1979). This formation is 650-1,000 feet (213-305 meters) thick and is made up of sandstone, siltstone, shale, and minor limestone.

The Pennsylvanian Breathitt and Lee Formations are typical deltaic sequences of sandstone, shale, siltstone and coals. The coals are low sulphur/low ash/high B.T.U. and have great economic value (McFarlan, 1943). The sequence ranges from 1,900 to 4,300 feet (579 to 1311 meters) in thickness across the field.

Problems exist in recognizing the areal extent of the individual stratigraphic units of the field. Recognition of a specific shale unit in the Mississippian and Devonian section is complicated by the similarity of lithologies and because of interfingering of shale facies, especially in the Ohio Shale section. For a thorough discussion of the stratigraphy in the field, readers are referred to Provo (1977) and deWys (1979).

Map horizons had to be selected based on the reliability of driller's recognition of the units across the field. The base of the Ohio Shale is readily recognizable because of the macroscopic differences between it and the underlying Olentangy Shale and, therefore, found to be a suitable horizon to map. The top of the Ohio Shale was also selected, but was found to be unreliable in the western half of the field. Drillers were unable to differentiate between Ohio and the Sunbury Shales because of the similarities of the two units, primarily because the distinctive intervening Berea Sandstone is absent in that portion of the field. The uncertainty of drillers tops for the Ohio Shale in the western portion of the field necessitated selecting the top of the first dark-

colored, organic-rich shale which the drillers recognized in that area. The top of the Ohio Shale was found to be a reliable horizon in the eastern portion of the field because of the presence of the overlying Berea Sandstone.

F. Data Base and Limitations

This study is based on approximately 4,200 drillers' logs collected from data on file at Kentucky-West Virginia Gas Company in Prestonsburg, Kentucky. A driller's log includes such items as drilling progress, tools used, etc., and the driller notes changes in the color and lithology of the units being drilled. The driller will often indicate tops of geologic formations.

A data base of 4,200 wells is large but, in this case, does have limitations of accuracy which must be understood if valid maps are to be constructed. One of these limitations concerns the selection of tops in every well. Because the section under study is largely shale, there is extensive caving and mixing of chips in the drilling process, so change in the lithology as noted on a driller's log is approximate at best. The approximate nature of the log is especially true for the western portion of the field where overlying lithologies are very similar to those that were chosen to be mapped and where the distinctive Berea Sandstone is absent.

It is also important to remember that these data were collected by drillers who usually had no formal geologic train-

ing, and they did not always appreciate the importance of having a correct driller's log for geologic correlation and mapping.

Finally, company wells from Kentucky-West Virginia Gas Company were accurately surveyed, so a precise elevation of the drilling rig was usually known. However, approximately 1,800 "foreign" wells (drilled by independents or other companies) were included in the data set, and the locations of these were often spotted and elevations were estimated using topographic maps. These foreign wells could easily include errors of up to 50 feet or more. Although these data points can and do include information that is only very approximate, most wells that are significantly different can be easily detected. The density of wells is great, with up to 10 wells in a single square mile, and a single well that is anomalously high or low, when compared with many neighboring wells, can be excluded. A cut off of about 30 feet was typical for well exclusion. The detection of anomalous wells by comparison with neighboring wells was especially difficult in areas of complex structure, such as southern Floyd County, since an anomalous well was not necessarily wrong, but could be actual structure.

Although some of the data used here is approximate, the maps are considered valid because the great majority of the wells were not found to differ markedly from other

neighboring wells. Regional trends are adequately established to show which wells were probably in error. The contour interval of 50 feet was purposely chosen to eliminate any local errors in mapping which one or more incorrect data points, if not recognized as such, could infer.

The actual decision of whether or not to use any particular well was based on such things as density and amount of discrepancy with neighboring wells, whether the well was foreign or company, and how difficult certain tops would have been to pick because of the stratigraphy. Approximately 90% of the wells available were actually used (about 3,800 wells).

MAJOR STRUCTURAL FEATURES OF THE EASTERN KENTUCKY AREA

A. Introduction

The use of structural style in analysis of an area is based on the premise that certain types of deformation produce structures of predictable geometries. This type of analysis is important to the petroleum geologist because a limited amount of information on subsurface geology can be used to predict the geometry of a structure.

Once the structural style is identified, the origin and regional distribution of structures is often more easily attained. From regional relationships in well-studied areas, models can be developed and applied to areas under investigation. The exploration geologist who can analyze available structural information and make correct associations with known

areas should be able to better predict the geometry and distribution of structures.

Structural styles can be broadly subdivided into two categories: those associated with basement deformation and those associated with detached deformation. The division between basement and detached deformation is based on the practical question of whether or not a surface structure extends to the crystalline basement. Detached structure does not extend to the basement so the exploration rationale must change at the stratigraphic horizon where detachment occurs. For a thorough discussion of the applications of structural style to petroleum exploration, readers are referred to Harding and Lowell (1979).

The Eastern Kentucky field is located between structures that are clearly basement (the Rome Trough [Harris, 1975; Black and others, 1976; Ammerman and Keller, 1979] and Cincinnati Arch [McFarlan, 1943; Rodgers, 1970]) and detached (Pine Mountain Thrust [Rich, 1934; Harris, 1970; Harris and Milici, 1977]). If we presume that fracture permeability within the Ohio Shale accounts for shale production (Hunter, 1934; Billingsley, 1934; Difford, 1947; McFarlan, 1943; Shumaker, 1978; deWys, 1979), then the ultimate question becomes: Are the fractures related to local or regional structure that is basement or detached in origin?; and, if porosity develops on structure, will similar porosity form over similar structures elsewhere?

This has a very serious impact on the possible extent of shale production, for if the fracture porosity relates solely to detached structure, then it is difficult to imagine natural fracture permeability outside the rather narrow confines of the zone of detached deformation.

If production is related solely to basement structure, then production can be expected from areas far removed from the zone of detached structure, in areas of known basement induced structure.

Even though the scope of this report does not include comparing production with structure, it is the intent of this work to interpret, or suggest, as far as the data permit, which structures within eastern Kentucky relate to basement deformation and which are detached. Future work will evaluate the relationships of shale-gas production to the structures as defined here.

B. Basement Deformation in Eastern Kentucky

There are several presumed basement faults and fault zones north and west of the Big Sandy field which have been mapped at the surface, including the Warfield fault, Johnson Creek fault, Little Sandy fault, Blaine fault, the Kentucky River fault zone, and the Irvine-Paint Creek fault zone (McFarlan, 1943; Dever, et al, 1976; and Ammerman and Keller, 1979). These fault zones can be traced westward to the Cincinnati Arch which is outside (towards the craton) of the zone of orogenic detachment. Furthermore, these structures are

reflected in total magnetic intensity maps that respond primarily to basement lithology changes (Shumaker, 1980). Thus, the faults are presumed to be surface expressions of larger basement faults and one might expect similar, but smaller, basement faults to occur within the field area.

The northern boundary of the Rome Trough appears to be a series of faults known as the Kentucky River fault system (Figure 6). To the west, in central Kentucky, part of the trough abuts and turns south against the north-northeast and south-southwest trending Lexington fault zone (See Plate 1). The trough also connects with the Western Kentucky trough through the Cumberland saddle (Shumaker, 1975). The trough continues and deepens to the northeast into West Virginia (Ammerman and Keller, 1979).

According to Ammerman and Keller, the trough itself is an asymmetric graben structure with the Kentucky River fault zone to the north having a much greater total aggregate throw than do the faults which form the southern boundary. Since this study produces no new evidence for structural evaluation of the Rome Trough, it is impossible from available evidence to give a precise explanation to the formation of the trough. From the geometry of the trough, and the fact that it falls below the level of regional structure, it would appear to be part of a rift system.

The main growth of the Rome Trough occurred during

FIGURE 6 - REGIONAL EXTENT OF KENTUCKY RIVER FAULT SYSTEM
FROM DEVER ET.AL,1976

Cambrian time as evidenced by the greatly thickened sections of Cambrian strata (Harris, 1975), but intermittent growth along the trough zone continued through at least the Pennsylvanian period. There does not appear to be a large amount of horizontal, or strike-slip movement along the trough zone during the Phanerozoic (Black, 1976; Harris, 1975).

Some of the faults associated with the Rome Trough are interpreted to have been sporadically active throughout the Paleozoic (Shaefer, 1979; Dever, 1976). Basement deformation occurred within this area during deposition of the Devonian and Mississippian, producing abnormal sedimentary patterns in association with a structural feature. All detached structures of this area are considered to have been formed after the deposition of the sedimentary rock. Therefore, detached structures should not affect sediment distribution or thicknesses (Rodgers, 1970).

C. Detached Deformation

Detachment faults, or decollements, are formed on an incompetent stratigraphic unit acting as a glide plane for slip movement between more competent units above and below. Salt and organic-rich shale are units which are suitable detachment horizons, whereas sandstone, dolomite, and thick limestone often serve as competent units (Harris, 1970).

As detachment occurs, strength of the competent autochthonous unit is exceeded, causing the unit to break to form a tectonic ramp (Figure 7). Upward movement occurs and

continues along the ramp until another horizontal incompetent unit is intersected to form an upper-level decollement sheet. Movement can continue on the lower decollement and ramp, as well as within the new stratigraphically higher incompetent stratigraphic unit.

The migration of a horizontal fault plane from one incompetent unit up to another is tectonic ramping. Pine Mountain, the southern boundary of the Eastern Kentucky field, is one such ramp (Plate 1 and Figure 7).

Presumably the stress which created the Pine Mountain thrust extended into the area of the Big Sandy field (Shumaker, 1978), and the Devonian shale was a detachment horizon. If the stress and some minor movement did extend into the Devonian shales under the Eastern Kentucky field, then the stress could have created structures that effect fracture production. The deformation which created the Pine Mountain thrust and detached structure in eastern Kentucky occurred during the Alleghanian (Permian-Pennsylvanian age) orogeny.

STRUCTURE OF THE FIELD

A. Introduction

A basement structure is produced by stresses contained in the basement which effect overlying sediment. The resultant deformation will usually be similar on the top and bottom of any given stratigraphic unit or interval.

A detached structure is produced by stresses contained

within the sedimentary cover that do not involve the basement. A distinguishing characteristic of detached deformation is for a discordance of structure, such as anticlinal folds, to be present on top of a given stratigraphic unit or overlying units, but absent from the base of that unit.

The structure of the Eastern Kentucky gas field is shown by structure contour maps drawn on the top (Plate 2) and the bottom (Plate 3) of the Ohio Shale. In this study of the Ohio Shale, which is known to be a detachment horizon, (Harris and Milici, 1977), the differentiation of basement versus detached structure was based on such things as 1) whether the structure was present on top and bottom of the Ohio Shale; 2) do isopach maps show trends which correspond to structure; and, 3) is the structure near a known basement structure.

B. Paint Creek Uplift

By looking at the structure contour maps drawn on the top (Plate 2) and on the bottom (Plate 3) of the Ohio Shale, one sees the northwestern border of the field in Johnson, Floyd, and Knott Counties is against the nose of a north-south trending high called the Paint Creek Uplift. Figure 8 shows an outline of the Paint Creek Uplift.

McFarlan (1943) describes the Paint Creek Uplift as a large upwarp with north-south major axis and an associated structural closure of about 250 feet (76 meters) in Pennsylvanian rocks at the surface. An even greater closure in the

**FIGURE 8: SURFACE OUTLINE OF THE PAINT CREEK UPLIFT
AFTER JILSON, 1928**

subsurface is indicated in work done by Jillson (1921). Jillson called attention to a decrease in thickness over the crest of the structure in the interval between the Pennsylvanian Fire Clay Coal and the top of the Mississippian Newman Limestone, interpreting the area as a topographic high during that time. Thomas (unpublished manuscript, 1941; referenced in McFarlan, 1943), indicated that gas from the Silurian-Devonian Corniferous in Magoffin and Johnson Counties is associated with isopach thins of the Corniferous Limestone. He interpreted the evidence to indicate progressive development of the structure during Middle Silurian to Middle Devonian time.

If the interpretations by McFarlan, Jillson and Thomas are correct, the area of the Paint Creek Uplift was a topographic high from at least the Middle Silurian through the Pennsylvanian. The areal extent and continued growth of this major structural feature during the Paleozoic suggests that it is rooted in the basement.

C. Martin County

I. Warfield Fault

The Warfield fault is the most prominent structure in Martin County, Kentucky (Plates 2 and 3). The greatest offset at the top of the Devonian is approximately 200 feet near the West Virginia border, gradually decreasing to no offset over a distance of 10 miles to the west. The state geologic map of West Virginia shows the surface trace of the fault to extend some 20 miles to the east and north (Cardwell, et al, 1968).

A structural contour map drawn on the bottom of the Newman Limestone (Figure 9) shows a similar 200-foot offset in the Newman, which would indicate the fault was active after deposition of the Newman. Irregularities in structural contours in the Devonian shale along the trend of the Warfield fault suggests that the fault continues westward out of the mapped area but with greatly decreased throw.

Figure 10, a seismic section across the Warfield fault and anticline in Mingo County, West Virginia (Plate 1), shows movement down to the south along the fault from the Mississippian Newman Limestone to the Pre-Cambrian basement. The seismic section does not show the surface Pennsylvanian deformation. The seismic section does show that the Warfield fault is not part of the southern boundary of the Rome Trough. An un-named basement fault north of the Warfield anticline with thousands of feet of throw, primarily active during the Cambrian period, is the southern rim of the trough (Beardsley, 1980). The Warfield anticline is seen to be a passive basement structure formed between the development of the Rome Trough and Warfield fault.

II. Strike-Slip Fault

Plates 2 and 3 show a north-south striking, strike-slip fault through the center of Martin County. The Warfield fault on the west side of the strike-slip fault has less throw than on the east side. Richard Beardsley (1980) of Columbia Gas

FIGURE 9

STRUCTURE CONTOUR MAP ON BASE OF NEWMAN LIMESTONE, MARTIN COUNTY, KY.

FIGURE 10
SEISMIC SECTION ACROSS THE WARFIELD STRUCTURE
IN MINGO COUNTY, WEST VIRGINIA

Transmission Corporation has mapped basement involved strike-slip faults with the same trend that cross the Warfield fault in Mingo County, West Virginia.

The thickness map of the combined Berea Sandstone and Bedford Shale (Figure 11) shows the thickest Berea-Bedford interval generally along the trace of the strike-slip fault, suggesting that a topographic low, possibly caused by the same strike-slip fault, was present during deposition.

In addition, the thickness map of the Ohio Shale (Plate 4) shows thicks and thins in Martin County that seemingly relate to structural trends. For instance, there is a thinning of isopach lines on the Warfield anticline. This seeming adjustment to structures suggests basement movement during deposition. Of course, other possible causes for the irregular isopach contours are: flowage of the shales during structural disruption and faulting of the shale section. Similar flowage in structurally disrupted zones has been noted by Harris and Milici (1977), Lee (1979), Zafar and Wilson (1978) and Wilson (1980).

Structure contour maps drawn at the shallow Pennsylvanian Fire Clay Coal (McFarlan, 1943) and a geologic map drawn at the surface in Martin County (Huddle and Englund, 1962) show 25 to 125 feet (8 to 38 meters) of fault offset down to the north across the Warfield fault. An explanation must be found to resolve the problem of the different sense of movement between the surface and the subsurface.

FIGURE 11: ISOPACH MAP OF THE BERA SANDSTONE AND BEDFORD SHALE IN MARTIN COUNTY, KENTUCKY
KEVIN LEE, 1980

Evidence that bears on the problem are fractures and slickensides from an oriented core through the Ohio Shale just south of the Warfield fault that show a probable decollement zone which moved perpendicular to the Warfield fault (Evans, 1980).

The horizontal slickensides perpendicular to the Warfield fault suggest a possible explanation for the conflicting sense of movement along the Warfield fault based on surface and subsurface maps. It seems possible that the surface Warfield fault, which is up to the south, is the expression of a splay from the detachment zone in the Ohio Shale. The surface fault was initiated in the Ohio Shale from the pre-existing Warfield basement fault. This interpretation presumes that a basement fault was active prior to the detachment thrust as suggested by the evidence stated above (See Figure 12).

D. Eastern Pike County

I. D'Invilliers Folds

Mississippian and Devonian formations in eastern Pike County generally dip to the southeast. A notable feature is an anticlinal-synclinal structure which originates in West Virginia and continues south-southwestward toward the northern terminus of Pine Mountain (Plates 2 and 3). This structure, the D'Invilliers anticline of McFarlan (1943), narrows and structural relief slowly decreases to the south. It can be seen on the structure contour map on the Fire Clay Coal compiled by McFarlan from published county reports (Figure 2), but at this high stratigraphic level, it plunges to the northeast.

DIAGRAMMATICAL SKETCH OF THE SURFACE AND
SUBSURFACE WARFIELD FAULT

K. LEE 1980

Figure 13 shows the location of the New York-Alabama Lineament of King and Zeitz (1978). It is a lineament that is marked by a series of steep magnetic gradients which apparently is the boundary between basement rocks of distinctly different magnetic susceptibilities. King and Zeitz (1978) propose that the lineament is the southeastern edge of a stable crustal block that acted as a buttress for the strong deformation of the Appalachian foldbelt. Because of the large scale of the map (Figure 13), it is difficult to locate precisely the D'Invilliers structures, but they are in the same general area and have similar trends with the lineament, so it is likely that they are related in the same way that the Warfield fold in West Virginia follows the lineament (Shumaker, 1980). Figure 14 (Shumaker, 1977) is an interpretation of basement structure based on well data and the trends of steep magnetic gradient trends. The D'Invilliers structures are located over the southern extension of a proposed basement fault in West Virginia and along the New York-Alabama lineament. Because of the locations of these basement structures and the mapped features of the D'Invilliers folds, they are interpreted to be basement related structures.

The D'Invilliers anticlinal-synclinal structures have more structural relief on the base of the Ohio Shale (Plate 3) than on top of the shale (Plate 2). This may be a reflection of regional tilt, or detachment, but probably not syndepositional growth because the isopach map of the Ohio Shale in the

FIGURE 13

**LOCATION OF THE NEW YORK -
ALABAMA LINEAMENT OF KING
AND ZEITZ, 1978**

FIGURE 14
UNPUBLISHED BASEMENT MAP
BY R.C. SHUMAKER, 1977; MODIFIED
BY KEVIN LEE, 1980

area of the D'Invilliers folds (Plate 4) shows no definite evidence in the form of variations in thickness of the shale supporting syndepositional growth.

II. Pikeville Fault

In central Pike County the D'Invilliers structures are cut by a strike-slip fault that is perpendicular to them. This strike-slip fault, here called the Pikeville fault, is visible on the bottom of the Ohio Shale (Plate 3) as a terminus of structural trends. On Plate 2, the top of the Ohio Shale, the Pikeville fault shows as a disruptive pattern in the contours. The Pikeville fault is more obvious on a structure contour map of the base of the Newman Limestone in a portion of eastern Pike County (Figure 15).

All three structure contour maps of this area (Plates 2 and 3 and Figure 15) show that beds north of the Pikeville fault and west of the D'Invilliers folds dip gradually to the southeast. On the south side of the Pikeville fault, contours west of and parallel to the folds are closer together, indicating steeper dip. Whether that steeper dip of beds is caused by fault compression or by underlying basement movement is impossible to tell from evidence available in this study.

Figure 16 is a diagrammatical sketch representative of the Pikeville fault and D'Invilliers structures in eastern Pike County. The Pikeville fault cuts the D'Invilliers anticline, indicating the fault is post folding. The D'Invilliers folds are presumed to be Alleghenian.

FIGURE 15
CONTOUR INTERVAL=50ft.

STRUCTURE CONTOUR MAP ON BASE OF NEWMAN LIMESTONE, PIKE COUNTY, KENTUCKY

KEVIN LEE, 1980

0 2 4
MILES

All three maps (Plates 2 and 3 and Figure 15) show closely spaced straight contours west of the D'Invilliers structure and south of the Pikeville Fault. These consistent contours, the location of the structure on the east side of the Pike County uplift of Ammerman and Keller (Figure 4) and the proximity to the New York-Alabama Lineament (Figure 13), all suggest basement deformation was involved in formation of the structure.

E. Knott County Area

Because of problems in differentiating the Ohio Shale from the Sunbury Shale, where the intervening Berea Sandstone is missing in the western portion of the field, it was decided that the top of the first brown shale recognized by the drillers would be used as a mapping datum. The first brown shale is probably equivalent to the Sunbury (???), but further stratigraphic work is needed to establish precise correlation.

In southern Knott County and surrounding areas of eastern Perry and southern Floyd Counties, structural dip in the Devonian is to the south, as opposed to other areas of the field where structural dip is to the southeast. The arch between the two strike domains (a probable extension of the basement involved Paint Creek Uplift) plunges southeastward across Floyd and Pike Counties (see Plates 2 and 3).

The east-west trending contours in this area of Knott County are at the south end of the Paint Creek Uplift, a pre-

existing structural basement high. From the Nicholas-Combs well #7239 in the Devonian in Perry County, Evans (1979) found a decollement zone indicated by horizontal slickensides, within the shale, assumed to be to the north. This supports the view of Shumaker (1977) that detachment has occurred in the shales in front of the Pine Mountain thrust. The southern end of the Paint Creek Uplift could have acted as a buttress against the advancing thrust sheets (deWys, 1979), causing the shales to trend in an east-west direction.

The north-south trending noses on the south side of the arch (the Paint Creek Uplift) are either folds or tears similar to those as mapped on the adjacent Pine Mountain block (Englund, 1968, 1971; Harris and Milici, 1977), but have far less relief or lateral offset. The interpretation that these are structural in origin rests in their linearity, parallelism, and the coupled nature of anticlines with adjacent synclines. It seems unlikely that these are erosional features because at this low regional gradient, estimated to be less than a 2° slope, the drainage should be dendritic. Furthermore, these features do not radiate from the central high area.

The north-south noses are better defined on top of the Ohio Shale than on the base of the shale, indicating that the tears are probably limited to the sedimentary cover.

F. Southern Floyd County

The area in central-southern Floyd County shows

intense disruption of contour patterns, especially on top of the Ohio Shale. This area is on the axis of the plunging Paint Creek Uplift between the two domains of regional dips.

Drill holes are sufficiently dense to establish this map pattern, but the pattern is so irregular as to be indeterminate. The noses and troughs of this area could be erosional or structural in origin. It is also possible that the stratigraphy of the area is so complex that to establish an accurate map is impossible. Further work may resolve this problem.

CONCLUSIONS

Detailed mapping of the subsurface structure of the Eastern Kentucky field, on top and bottom of the Devonian Ohio Shale, suggests that no one structural style predominates, but that both basement and detached structures are present. The mapping also shows that even where a particular structural style is present, interrelated structural effects are often present. The Warfield fault may be an example of this: a pre-existing basement fault may have served as a barrier to detachment and caused surface splays off of a detachment sheet.

The mapping also shows several strike-slip faults in the field that were previously unknown, and it suggests the possibility of additional strike-slip faults across the field.

Certain more specific conclusions arrived at during the investigation include:

- 1) Previous investigations into the structural geology of the Eastern Kentucky gas field correctly established the regional structural dip in the Devonian and Mississippian rocks, but failed to define and discover small folds and faults. The structure of the field, therefore, is not that of a simple monocline dipping to the south and east as defined in previous studies. Structure, as mapped at the surface in the field area, does not correspond to structure as mapped at the Devonian and Mississippian levels and, that structure, in turn, appears to be different from the structure on top of the basement.

2) The structure discernable in the Devonian Ohio Shale did not form in response to a simple individual stress field, nor during a single episode of deformation. Diverse trends of detached and basement structures grew during several episodes of deformation from the Cambrian through Permian. The Paint Creek Uplift in Morgan, Magoffin, and Breathitt Counties was determined to be a basement structure that was active throughout the Paleozoic.

The D'Invilliers folds and Warfield fault were determined to be basement induced structures, but both may also contain some detached deformation. The Warfield fault may have been periodically active through the Paleozoic, but the most active period of deformation for both structures is presumed to be during the Alleghenian orogeny.

Several linear zones at high angles to the Pine Mountain thrust are interpreted to be structural tears that may be limited to the sedimentary cover.

3) Details on various small structures discovered by this study include: The Warfield fault in Martin County is not part of the southern boundary of the Rome Trough, but is a part of the uplifted block along the southern margin of the trough. Offset on the fault in the subsurface is down to the south from at least the Mississippian to the basement. The surface Warfield fault may be a splay off of detachment horizons. The Warfield fault in Martin County is offset by at least one strike-slip fault. The D'Invilliers anticlinal and synclinal

structures in eastern Pike County are located over a southern extension of a proposed basement fault in West Virginia, and they are along the trend of the New York-Alabama lineament as mapped by King and Zeitz (1978). The D'Invilliers structures are cut by a strike-slip fault that postdated, or was contemporaneous with fold development.

Complex and irregular fold patterns in the Devonian Shale in southern Floyd County apparently reflect either intersecting structural trends or erosional features or both.

Structure contours in the Devonian in southern Knott and Perry Counties trend east-west, while the Pine Mountain Thrust strikes northeast-southwest. Thrust sheets between right lateral strike-slip faults apparently have differentially pushed the rocks in this section of Knott and Perry Counties to the north, where they were shoved against the southern end of the Paint Creek Uplift.

Figure 17 is a summary of structures in the study area.

FIGURE 17. Summary of structures in the study area

SUGGESTIONS FOR FUTURE WORK

The following are suggestions for future work that could greatly add to the understanding of the structure and production of the Eastern Kentucky field:

1) Put the data set from this project on a computer tape for quick data selection and retrieval. Trend Surface Analysis can be run in areas of poor data reliability, and where smaller contour intervals than presented in this study are desired.

2) The structure in Knott, Floyd, and Perry Counties is complex and needs further study. All shale horizons as recorded on the drillers' logs need interpretation so the Big Lime is a reliable horizon to model from in that area.

3) Construct a detailed isopach map of the Sunbury Shale, and compare it to isopach maps of the other dark shale facies within the Ohio shale. Its comparison could lead to a better understanding of the depositional environment of the Ohio shale.

4) Construct a detailed isopach map of the Berea Sandstone. This map can be compared to structure maps to help define areas of active structural growth during the Mississippian.

5) The structure of Eastern Kentucky should be integrated with the type and trend of structure in southwestern West Virginia.

6) Construct a structure contour map on the base of

the Newman Limestone. The Newman is often a prolific producer in the Eastern Kentucky field, and it's structure should be determined.

7) Now that detailed structure of the field has been outlined, the relationship of individual structures to production from the shale should be examined.

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PLATE 1
REGIONAL STRUCTURE
OF EASTERN KENTUCKY

PLATE 4
ISOPACH MAP OF THE OHIO
SHALE IN SECTIONS OF MARTIN
AND PIKE COUNTIES, KENTUCKY

CONTOUR INTERVAL = 20 ft.

APPENDIX D

HYDROLOGY DATA

1979 - 1980

Robert R. Beebe

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LINEAMENTS AND GROUND-WATER CHEMISTRY AS EXPLORATION TOOLS FOR
DEVONIAN SHALE GAS IN THE MIDWAY-EXTRA FIELD OF WEST VIRGINIA *

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- * Based on research performed under DOE Contract number DE-AC21-76MC05194; presented at Joint DOE/EGSP-ES/AAPG Symposium, October, 1979, Morgantown, West Virginia.

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ABSTRACT

A hydrogeologic study was done in the Midway-Extra gas field where gas wells tap Devonian shales in northern Putnam County, West Virginia. Lineaments were mapped and shallow ground water was surveyed for physical and chemical parameters, to determine if lineaments or ground water may be useful for shale gas exploration. Landsat lineaments, defined from satellite imagery, have no effect on water well yield and are associated with low gas well yields. Short photolineaments, defined from low-altitude stereo photography, are excellent sites for high-yielding water wells and good sites for high-yielding gas wells. These lineaments appear to represent permeable zones about 400 feet wide at shallow depth, and perhaps 0.5 miles wide in the Devonian shales. Photolineaments oriented N60°W-N30°E are especially well associated with high-yielding gas wells. Photolineaments bearing 60°-90° from the general structural trends are strongly related to high-producing gas wells in both the Midway-Extra and Cottageville¹ study areas. Final open flow is in general greater for gas wells near high-producing water wells, but the trend is not statistically significant. Final open flow is especially great for gas wells near water wells or springs having high bicarbonate or nitrate concentrations. High bicarbonate content is in part likely to be caused by oxidation of methane gas in shallow ground water. Photolineaments and ground-water chemistry may well prove to be valuable exploration tools for Devonian shale gas in other areas.

INTRODUCTION

A hydrogeologic investigation was undertaken in the Midway-Extra gas field of Putnam County, West Virginia, to determine if lineaments and shallow ground-water chemistry are associated with gas well productivity in Devonian shale. This study follows a similar earlier study in the Cottageville gas field of Jackson County, West Virginia.¹ The primary purpose of this study was to determine if the same statistical trends for gas well yield exist for both the Midway-Extra and Cottageville gas fields; any such trends could then aid in developing new inexpensive exploration techniques for Devonian shale gas.

Figure 1 depicts the study area in northern Putnam County. This region is about 100 square miles in area, with about one-third of it being occupied by the Midway-Extra gas field. A portion of this gas field located southwest of the Kanawha River was not included in this study. Also the circled gas wells of Figure 1, located near Eleanor, were excluded from the study since they are not within the Midway-Extra field. Open flow data are available for most of the 101 remaining gas wells in Figure 1; these wells produce mainly from Devonian shales.

Two types of lineaments were mapped for this study - Landsat lineaments and short photolineaments. On Figure 1, lines at least 1 1/2 miles long represent Landsat lineaments mapped from satellite imagery. Shorter lines are photolineaments, mapped from low-altitude black-and-white photographs in stereo coverage; these lineaments are defined by straight valleys or stream segments at least one-quarter mile long. Photolineaments were classified according to three degrees of certainty - certain (class 1), somewhat certain (class 2), and uncertain (class 3); class 1 photolineaments are indicated by the boldest lines on Figure 1. All lineaments were identified and plotted before gas well locations and yields were determined from Schaefer², in order to avoid subjective bias in testing for lineament-yield associations.

Seventy-four water wells and six springs were studied for characterizing shallow ground water (Figure 1). Physical well parameters such as well yield, well depth, and original depth to water were obtained from well owners and drillers. Water chemical tests were performed for 32 water wells and springs, and 20 of these are located within the Midway-Extra gas field. Temperature and specific conductance were measured in the field, and two water samples were taken from each well and spring. One set of samples was field tested with acid and later analyzed in the laboratory for iron, calcium, and magnesium concentrations. Water samples of the second set were kept cool until they could be analyzed for pH, bicarbonate, nitrate, sulfate, chloride, and sodium in the laboratory. All analyses were done within 48 hours of sampling.

LINEAMENT ASSOCIATIONS

First water well yield and then gas well yield were tested for possible associations with lineament proximity. Water well yield, estimated in gallons per minute, was tested for associations with Landsat lineament proximity. By the one-tailed Mann Whitney U test,³ yield is not significantly different for water wells located closer than versus those farther than a critical distance from the nearest Landsat lineament, for tests involving 500, 1000, and 2000 feet as critical distances. Landsat lineaments are therefore not associated with water well yield in either the Cottageville field of Jackson

County¹ or in the Midway-Extra field.

Water well yield was next tested against photolineament proximity. Wells within 200 feet of a photolineament center line have significantly greater yield (about four times greater) than more distant wells at the 0.01 alpha probability level by the Mann Whitney U (one tailed) test; the alpha probability indicated the probability that no significant difference exists between two groups of tested data. Water wells within 150 feet yield about four times greater than wells 150-200 feet of a photolineament center line, but this difference is not statistically significant at the 0.05 alpha probability level. These results are in general similar to those for the Cottageville area¹ and other clastic rock terrains studied elsewhere in West Virginia. Near Cottageville, water well yield is significantly greater for wells located within 100-200 foot wide photolineament zones centered along plotted photolineament center lines; in the Midway-Extra area, influential photolineament zones are 300-400 feet in width. Short photolineaments apparently represent underlying zones of increased fracture permeability, at least with respect to shallow ground water. A resistivity survey run across one photolineament in the study area indicated a resistivity anomaly resembling the effect of a fracture zone at least 60 feet in width.

Gas well yield was next tested for possible trends with lineaments. Both initial open flow (measured before well stimulation by fracturing) and final open flow (measured after well stimulation) were tested. These data were obtained from Schaefer.² Figure 2 shows contoured initial open flow for all shale gas wells in the study area. Initial open flow is probably the better indicator of natural gas reservoir permeability. Figure 3 depicts contoured final open flow for all shale gas wells. Final open flow is probably the better measure of relative well productivity and rock fracture influences on well yield.

Figures 2 and 3 show locations of plotted Landsat lineaments with respect to the major gas producing areas. Such lineaments, represented in general by valleys, appear to bound the high gas production zones to the north and south; Landsat lineaments are poor locations for shale gas wells. Landsat lineaments are similarly associated with low shale gas yields in the Cottageville area.^{1,4,5} Perhaps deeply-penetrating fractures have bled off the shale gas under the Landsat lineaments.

Photolineament proximity was next tested for possible associations with gas well yield. Although both initial and final open flow are generally greater for wells located within 0.4 kilometers of a photolineament, these trends are not statistically significant at the 0.05 alpha probability level by the Mann Whitney U test. Scattergram plots of gas well yield versus photolineament proximity suggest that about 0.8 kilometers or 0.5 miles is the optimum width for photolineament zones associated with high-yielding gas wells.

Photolineament orientation was then tested for possible associations with gas well yield. When yield was plotted versus the orientation of the nearest photolineament to a well, definite trends were apparent. As is evident from Figure 4, the percentage of high-yielding gas wells is greatest for wells near photolineaments oriented N60°W-N30°E, for both initial and final open flows. Well yield is significantly greater for gas wells near N60°W-N30°E photolineaments than for gas wells near photolineaments having other orientations; by the Mann Whitney U test, this trend is significant at the 0.05 and 0.10 alpha probability levels, for initial open flow (IOF) and final open flow (FOF) respectively. Also, FOF is significantly greater (at a 0.05 alpha probability) for wells near N60°W-N0°E photolineaments than for wells near photolineaments having other orientations. High gas well yield is significantly associated with photolineaments oriented 60°-90° from the general structural trend of shale gas fields in both the Cottageville and Midway-Extra areas; this suggests that such photolineaments represent fracture zones that are especially permeable to gas flow in these areas.

In order to test the usefulness of N60°W-N30°E bearing photolineaments in exploration for Devonian shale gas, a density map was prepared for these lineaments and compared to the gas yield trends of Figures 2 and 3. The density map of Figure 5 was prepared by use of an orthogonal grid of lines defining square sections one mile long on a side. This grid was oriented parallel to the north-south and east-west directions. The density of N60°W-N30°E photolineaments was determined for each square-mile section, by measuring the cumulative length of these lineaments and plotting this number at the center of each section. Figure 5 represents hand-contoured density in miles per square mile, based on 100 square-mile sections.

The photolineament density map of Figure 5 was superimposed on the gas yield maps of Figures 2 and 3, to determine if significant overlaps occur between high photolineament density and high gas yield areas. A second orthogonal grid defining square sections 2000 feet long on a side was superimposed on the overlays of Figure 5 on Figures 2 and 3; grid line intersections were then counted as points

occurring in one of four type areas - high photolineament density and high gas yield; high photolineament density and low gas yield; low photolineament density and high gas yield; and low photolineament density and low gas yield. The 221 grid points were categorized, totaled for each area type, and plotted in 2X2 contingency tables. Chi-square contingency tests with the Yates correction were then performed to determine if any significant associations exist between N60°W-N30°E photolineament density and gas yield, for both IOF and FOF and for various definitions of high versus low density and gas yield. The only data tested were for grid points located within an area containing the plotted gas wells of the Midway-Extra field in Figure 1.

Table 1 shows the results of comparisons between IOF and the density of N60°W-N30°E photolineaments. Chi-square test results indicate that photolineament density is significantly associated with IOF. High lineament density areas have a significantly large proportion of high-yielding wells (over 100 MCF/day IOF), compared with low lineament density areas. Locating gas wells in high-density areas for N60°W-N30°E photolineaments would yield a 45 percent success rate for densities exceeding 1.5 mi/mi², and a 71 percent success rate for densities exceeding 2.0 mi/mi², if success is defined by yields exceeding 100 MCF/day for IOF.

Table 2 gives the results of statistical comparisons between FOF and the density of N60°W-N30°E photolineaments. Again all tests show statistically significant associations between lineament density and FOF. Locating gas wells in areas with lineament densities exceeding 1.5 mi/mi² would respectively yield 89, 58, and 11 percent success rates with regard to 100, 500, and 1000 MCF/day for FOF. Similar results are evident in Table 2 for wells in areas with lineament densities exceeding 2.0 mi/mi², but such areas are smaller and would place greater restrictions on gas exploration.

The photolineaments of Figure 1 were next examined for possible differences among class 1, 2, and 3 photolineaments with respect to gas yield associations, to determine if additional gas exploration trends could be discovered based on photolineament class. Gas wells near class 1 (most certain) photolineaments have higher yields for both IOF and FOF than wells near class 2 or class 3 photolineaments, but these trends are not strong enough to be statistically significant at the 0.05 alpha probability level by the Mann Whitney U test. Class 1 photolineaments were next tested alone for possible well yield associations with lineament proximity. Gas wells within 0.4 kilometers of the nearest class 1 photolineament have higher IOF and FOF yields than more distant wells; for FOF data, this trend is statistically significant by the Mann Whitney U test at the 0.05 alpha probability level, with yields being three to four times greater for wells within 0.4 kilometers of a class 1 photolineament. However since about 86 percent of the mapped class 1 photolineaments are oriented N60°W-N30°E, it is possible that this trend for class 1 photolineament proximity is caused mainly by factors relating to photolineament orientation.

Class 1 photolineament density was calculated, hand contoured in a manner similar to Figure 5, and statistically tested against gas well yield using 2X2 contingency table tests similar to Tables 1 and 2. Only trends for FOF data proved to be significant at the 0.05 alpha probability level. FOF gas yield is significantly greater for wells located in areas having at least 1.0 mi/mi² densities of class 1 photolineaments; if gas wells were located at random using an orthogonal grid, 64 percent would have FOF yields exceeding 100 MCF/day, and 39 percent would have FOF yields exceeding 500 MCF/day. Although these success rates are remarkable, results for N60°W-N30°E photolineament density are better (from the first two tests of Table 2).

GROUND-WATER ASSOCIATIONS

Water wells and springs were next tested for possible associations with gas well yield. A comparison was made of water well yield with gas well yields for the closest gas well to each water well, within the study area portion of the Midway-Extra gas field. Both initial and final open flow are higher on average for gas wells near high-producing water wells, but this trend is not statistically significant at a 0.05 alpha probability by the Mann Whitney U test. Photolineament associations with both high water well and high gas well yields could possibly explain this trend.

Ground-water chemistry was next tested for possible associations with gas well yield. Trends of chemical parameters with gas well yield were explored for the 19 water wells and one spring within the Midway-Extra field. Of all the chemical parameters tested for well and spring waters, only bicarbonate and nitrate concentrations exhibit significant associations with FOF gas well yield. Wells or springs located within areas having gas wells exceeding 100 MCF/day FOF (from Figure 3) have significantly higher bicarbonate and nitrate concentrations compared to ground-water supplies elsewhere in the Midway-Extra field, at the 0.05 alpha probability level by the Mann Whitney U test. Figure 6 illustrates the trends for bicarbonate and nitrate versus FOF gas yield. Similar plots and tests

were not done with regard to greater-than versus less-than 500 MCF/day FOF, since only two water wells occur on or within the 500 MCF/day contour of Figure 3. Also, tests of IOF data did not indicate any statistically significant associations between gas well yield and bicarbonate or nitrate concentration.

The statistical associations of bicarbonate and nitrate contents with FOF gas yield in the Midway-Extra gas field are similar to bicarbonate and nitrate associations with IOF gas yield in the Cottageville gas field.¹ FOF data were not tested in the Cottageville study. These similarities between two Devonian shale gas fields strongly suggest that bicarbonate and nitrate are not coincidentally associated with gas well yield. Optimum ground-water concentrations of bicarbonate and nitrate are at least 470 mg/l and 1.75 mg/l respectively, for gas exploration in the Midway-Extra area. When results from the Midway-Extra study and Cottageville study¹ are combined, optimum gas exploration concentrations appear to be at least 475 mg/l and 3 mg/l for bicarbonate and nitrate respectively. In the cottageville area, five out of seven gas wells should exceed 100 MCF/day IOF where ground water exceeds 475 mg/l bicarbonate, and two out of three gas wells should exceed 100 MCF/day IOF where ground water exceeds 3 mg/l nitrate.

Shallow ground-water chemistry could well serve as the basis for a new gas exploration technique in Devonian shale and other rock terrains, if similar chemical associations are found in future studies elsewhere. Gas exploration would also be more reliable if plausible explanations with supporting evidence were available for the observed chemistry-gas yield trends. Since the Cottageville study was published,¹ new evidence strongly suggests a particular origin for the high bicarbonate concentrations in shallow ground water over high-producing gas zones. It is likely that a significant portion of ground-water bicarbonate over major gas-producing reservoirs is derived from the oxidation of methane gas. Such gas could have slowly migrated upward along rock fractures to shallow aquifers. Oxidation of methane could then have occurred with either sulfate or dissolved oxygen as the oxidizing agent. Evidence for this theory is derived from a study of six water wells known to be contaminated with natural gas in Monongalia County, West Virginia. These wells exhibit abnormally high bicarbonate and abnormally low sulfate and hardness concentrations compared to nearby wells lacking gas contamination. No explanations are proposed at present for the association of ground-water nitrate with gas well yield.

CONCLUSIONS

Several conclusions are apparent from this study of lineaments and shallow ground water in the Midway-Extra gas field, especially in relation to a similar earlier study in the Cottageville gas field. Landsat lineaments (defined from satellite imagery) have no effect on water well yield but are poor places to locate high-yielding shale gas wells in the Midway-Extra and Cottageville areas. Short photolineaments (defined from low-latitude photographs) mark excellent sites for high-yielding water wells in both areas, but photolineaments have a more pronounced effect on water well yield in the Midway-Extra area, where they denote zones of increased near-surface permeability about 400 feet wide.

Gas wells located within 0.4 kilometers of a photolineament in the Midway-Extra area have higher yields. Final open flow (after well stimulation) is especially higher for wells near class 1 (most certain) photolineaments. When broken down by orientation, photolineaments bearing N60°W-N30°E are especially associated with high-producing gas wells in the Midway-Extra area. In both the Cottageville and Midway-Extra gas fields, photolineaments oriented 60°-90° from general structural trends are especially associated with high-yielding gas wells; this suggests that such photolineaments represent permeable fracture zones of similar orientation in Devonian shale reservoirs.

Final open gas flow is related to shallow ground water in the Midway-Extra area. Gas wells usually have high final open flows near high-yielding water wells, which might be explained by permeable rock fractures associated with photolineaments near the high-yielding wells. Final open flows are higher for gas wells near water wells or springs with high bicarbonate or high nitrate concentrations, in both the Midway-Extra and Cottageville study areas. Optimum ground-water concentrations for gas exploration in both areas appear to be at least 475 mg/l for bicarbonate and at least 3 mg/l for nitrate. One likely theory concerning bicarbonate is that methane gas is migrating upward along rock fractures to shallow aquifers, where it is being oxidized to bicarbonate.

NOMENCLATURE

MCF/day = thousands of cubic feet per day (gas flow)
 IOF = initial open flow, in MCF/day
 FOF = final open flow, in MCF/day

mi/mi² = total photolineament length in miles, per square mile of area
 mg/l = milligrams per liter concentration units
 N = north
 W = west
 E = east

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TABLE 1

INITIAL OPEN FLOW GAS WELL YIELD VERSUS
 DENSITY OF N60°W-N30°E BEARING PHOTOLINEAMENTS

		Photolineament Density		
		Low	High	
Gas Well Yield		1.50 mi/mi ²		
100 MCF/day	Low	191	11	Chi Square = 32.2 Probability of Error = 0.001 Success Rate = 45%
	High	10	9	
Gas Well Yield		2.00 mi/mi ²		
100 MCF/day	Low	199	2	Chi Square = 28.7 Probability of Error = 0.001 Success Rate = 71%
	High	10	5	

TABLE 2

FINAL OPEN FLOW GAS WELL YIELD VERSUS
DENSITY OF N60°W-N30°E BEARING PHOTOLINEAMENTS

		<u>Photolineament Density</u>			
		1.50 mi/mi ²			
<u>Gas Well Yield</u>		Low	High		
100 MCF/day	Low	96	2	Chi Square = 9.0	
	High	106	17	Probability of Error = 0.01	
		1.50 mi/mi ²		Success Rate = 89%	
<u>Gas Well Yield</u>		Low	High		
500 MCF/day	Low	186	8	Chi Square = 35.9	
	High	16	11	Probability of Error = 0.001	
		1.50 mi/mi ²		Success Rate = 58%	
<u>Gas Well Yield</u>		Low	High		
1,000 MCF/day	Low	200	17	Chi Square = 4.3	
	High	2	2	Probability of Error = 0.05	
		2.00 mi/mi ²		Success Rate = 11%	
<u>Gas Well Yield</u>		Low	High		
100 MCF/day	Low	98	0	Chi Square = 4.7	
	High	116	7	Probability of Error = 0.05	
		2.00 mi/mi ²		Success Rate = 100%	
<u>Gas Well Yield</u>		Low	High		
500 MCF/day	Low	186	3	Chi Square = 7.4	
	High	28	4	Probability of Error = 0.01	
		2.00 mi/mi ²		Success Rate = 57%

Figure 1. Map of the Midway-Extra Study Area, Showing Lineaments, Devonian Shale, Gas Wells, and Surveyed Water Wells and Springs. Circled shale gas wells near Eleanor are not within the Midway-Extra gas field.

Figure 2. Contour Map of Initial Open Flow (Before Stimulation)
for Shale Gas Wells of the Study Area.

Figure 3. Contour Map of Final Open Flow (After Stimulation)
for Shale Gas Wells of the Study Area

Figure 4. Gas Well Yield Versus Orientation of Nearest Photolineament to a Gas Well for the Study Area.

Figure 5. Density Map for Photolineaments Oriented N60°W-N30°E in the Study Area.
Density is reported in miles of lineament length per square mile of area.