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STATE OF ILLINOIS
DEPARTMENT OF
REGISTRATION AND
EDUCATION
JOAN G. ANDERSON
DIRECTOR, SPRINGFIELD

ILLINOIS STATE GEOLOGICAL SURVEY

NATURAL RESOURCES BUILDING, URBANA, ILLINOIS 61801 TELEPHONE 217 344-1481

Jack A. Simon, CHIEF

October 13, 1978

Mr. A. H. Frost, Jr., Chief
Research Contracts, Procedures and
Reports Branch, Contract Division
U.S. Department of Energy
Oak Ridge Operations
P. O. Box E
Oak Ridge, Tennessee 37830

Dear Mr. Frost:

We are enclosing one copy of our quarterly report, ORO-EY-76-C-05-5203-12, for July 1-September 30, 1978, for Geological and Geochemical Studies of the New Albany Group in Illinois. Financial statements for August and September are included.

Sincerely yours,

Robert E. Bergstrom

Robert E. Bergstrom
Principal Geologist
Geological Group

cc: USDOE
Division of Fossil Energy
Oil, Gas, and Shale Technology
Washington, D.C.
(2 copies of report)

USDOE
Morgantown Energy Research Center
EGSP Project Office
Morgantown, West Virginia
(6 copies of report)

Science Applications, Inc.
Attention William G. McGlade
Morgantown, West Virginia
(1 copy of report)

DOE Contract Ey-76-C-05-5203
University of Illinois Code No. 1-46-26-80-360

Illinois State Geological Survey

GEOLOGIC AND GEOCHEMICAL STUDIES OF THE NEW ALBANY GROUP (DEVONIAN BLACK SHALE) IN ILLINOIS TO EVALUATE ITS CHARACTERISTICS AS A SOURCE OF HYDROCARBONS

Robert E. Bergstrom and Neil F. Shimp
Principal Investigators

Quarterly Progress Report - July 1-September 30, 1978
Report ORO-EY-76-C-05-5203-12

October 10, 1978

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1. ERDA REPORT NO.	2. TITLE
ORO-EY-76-C-05-5203-12	Geologic and Geochemical Studies of New Albany Group in Illinois.

3. TYPE OF DOCUMENT (Check one):

- ☐ a. Scientific and technical report
- ☐ b. Conference paper:
  - Title of conference ______
  - Date of conference ______
  - Exact location of conference ______
  - Sponsoring organization ______
- ☒ c. Other (Specify) Quarterly progress report (for July 1 - September 30, 1978)

4. RECOMMENDED ANNOUNCEMENT AND DISTRIBUTION (Check one):

- ☒ a. ERDA's normal announcement and distribution procedures may be followed.
- ☐ b. Make available only within ERDA and to ERDA contractors and other U.S. Government agencies and their contractors.

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Robert E. Bergstrom and Neil F. Shimp
Principal Investigators

Organization
Illinois State Geological Survey
Urbana, Illinois 61801

Signature Robert E. Bergstrom N. F. Shimp

Date October 11, 1978

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7. ERDA CONTRACT ADMINISTRATOR'S COMMENTS, IF ANY, ON ABOVE ANNOUNCEMENT AND DISTRIBUTION RECOMMENDATION:

8. PATENT CLEARANCE:

- ☐ a. ERDA patent clearance has been granted by responsible ERDA patent group.
- ☐ b. Report has been sent to responsible ERDA patent group for clearance
- ☐ c. Patent clearance not required.

INTRODUCTION

This report is for the fourth quarter, July 1 - September 30 of FY78, which concludes the second year of the Illinois State Geological Survey's geological and geochemical study of the New Albany Group for the U.S. Department of Energy (DOE). In this report we discuss the progress for the fourth quarter and summarize the progress for the year in terms of contract tasks and deliverables. Some delays are mentioned in connection with insufficient core material having been provided by DOE and as a result of late purchases of equipment caused by late funding.

To supplement this report the Geological Survey plans to publish a report in its Illinois Petroleum Series, presenting many of the stratigraphic and structure maps and cross sections and also expanded interpretive information from the study. We anticipate that this report will be completed near the end of the year.

GEOLOGICAL EVALUATION

Introduction

This project is a detailed analysis of the lithology, stratigraphy, and structure of the New Albany Group in Illinois to determine those characteristics of lithology, thickness, regional distribution, vertical and lateral variability, and deformation that are most relevant to the occurrence of hydrocarbons.

This study will result in the preparation of cross sections, facies maps, and geologic structure maps based on subsurface data available in the Illinois Survey files. Previous work in Illinois is being re-evaluated and updated. New data on the physical, chemical, and mineralogic characteristics of the New Albany will be derived from the studies of new cores in Illinois and will be incorporated into the stratigraphic and structural investigations of existing data.

Advise DOE on Drill Sites and Coring

Progress

Negotiations have been completed for a DOE "grass roots" core of the New Albany at a location near Hick's Dome in Hardin County, Illinois. Permission to drill has been given by the corporation owning the proposed site. This is one of the few locations in Illinois that a meaningful core of the New Albany can be taken without first penetrating several hundred or thousand feet of younger formations. Coring is expected to begin near the top of the New Albany Group, and about 400 to 450 feet of shale is expected to be cored. Plans are made to process the core material recovered in this drilling.

Another proposed core in Hamilton County, Illinois, failed when the original hole was junked because it was not drilled straight enough for coring. The possibility of future drilling in the same area exists, but plans by the operator have not been completed.

Problems

The lack of good core material from the central part of the basin continues to pose a problem for our work and will be only partially rectified by the Hardin County core. It is likely that accurate reading on potential gas content of the shale will not be obtained on the Hardin County core due to shallowness and disturbance, but it is hoped that mineralogic, petrographic, and chemical studies will be meaningful. The area is heavily faulted, mineralized, and contains igneous intrusions, however. The Hamilton County area proposed for another DOE core would be nearly perfect for our needs. If cores are eventually obtained from Hardin County and Hamilton County or nearby areas, our core needs for characterizing the New Albany in the Illinois Basin would be nearly complete.

Pool Maps for Illinois

Progress

A complete set of oil and gas pool maps for Illinois is available. These maps are on a scale of approximately 1:380,000. They show the location and approximate pool outline for each of the 21 individual producing zones in Illinois.

Computer Card File of Devonian Shale Tests

Progress

The card file of basic data from holes drilled through the Devonian shale now contains data from all Illinois counties underlain by the shale. The data contained on the cards are listed on Page 32 in the annual report of September, 1977.

Print-out of Devonian Shale Tests

Progress

A print-out of selected data on each of the holes in the card file was produced. This is contained in two large volumes on file at the Illinois State Geological Survey.

Computer Plotted Maps of Devonian Shale Tests

Maps have been plotted at a scale of 1:1,000,000 showing the location of all the holes in the card file. Fig. 1 is an index map showing the area now covered by the card file. The maps from the southern portion of Illinois were shown in the annual report of September 1977. The maps for the area added for 1978 are shown on Fig. 2 though 5. Any portion of the area can be plotted to any designated scale.

Structure Map On Base of New Albany

Revision of the previously published geologic structure map on the base of the Devonian black shale (top of Hunton Limestone Megagroup) is in progress. The map is being revised on the basis of the updated Devonian well file previously completed for this DOE project. The updating will greatly increase the accuracy of the previous map in certain places where questionable data were previously used.

Stratigraphic Cross Sections

Progress

To date, twenty-seven stratigraphic cross sections have been prepared for the New Albany Shale Group and adjacent strata in Illinois (Fig. 6). These cross sections, which provide the principal basis for regional stratigraphic correlation, are also linked to cross sections in Indiana and Kentucky.

The cross sections which have been prepared consist primarily of geophysical log tracings at a vertical scale of 20 feet to one inch. The logs are supplemented with core studies and sample studies where these are available, especially where geophysical logs themselves are lacking. The longest north-south cross sections consist of more than 40 wells. These sections have been drawn on long rolls of tracing paper which are as much as 3 feet wide and 25 feet long.

Our contract specifies ten east-west and three interlocking north-south cross sections as deliverable items to DOE. However, in view of the size of these cross sections, their reproduction is not feasible. The originals are on file at the Survey and are available for examination. Three simplified geophysical log cross sections were presented in the 1977 annual report to DOE. Additional simplified cross sections are planned for a forthcoming Illinois State Geological Survey publication in the Illinois Petroleum series.

Included with this report is a long interpretive cross section which extends from the Henderson County (Illinois) core southeastward to Crittenden County, Kentucky, in the deep basin area (Figs. 7 and 8, Table 1). The traverse of this cross section has been carefully selected to include all formations within the New Albany Group, thereby facilitating the study of stratigraphic relationship between all these formations. The best available geophysical logs have been used, and sample studies have been done for all wells having samples available.

Discussion

The long cross section (Figs. 7, 8; Table 1) illustrates the general stratigraphic relationships between the deep basin strata and the basin marginal strata. Three major stratigraphic assemblages can be recognized along the traverse of this cross section. The southeastern portion of the cross section (approximately from well 20 to well 33) shows a typical deep basin section of the New Albany. Brownish black shale is the dominant lithology, but there is a substantial gray to greenish gray shale and calcareous black shale. Although relationships of the New Albany to underlying strata are not entirely clear, this study has shown in agreement with North (1969) that the Blocher Shale grades laterally into limestone of the upper portion of the Lingle Formation. A vertical cut off (shown very generally in this cross section) is used to separate the two formations. North (1969) shows an unconformity separating the Blocher from the lower portion of the Lingle throughout the deep basin. However, geophysical and sample study evidence from the present study suggest that the relationship is not unconformable throughout the deep basin.

In most of the basin area, the New Albany is conformably overlain by the Chouteau Limestone. In some places there is apparently an abrupt contact between black shale (the Henryville Bed or equivalent) and limestone, although a thin intervening greenish gray shale, tentatively correlated with the Jacob's Chapel Bed of Indiana (Lineback, 1970) has been documented in some localities. In general, even where present, this shale bed is too thin to be resolved by geophysical logs or sample studies.

In tracing of bedding surfaces marked by geophysical discontinuites, which presumably approximate time planes, shows that basal New Albany strata are transgressive to the Northwest (see wells 17-22) and overlap an unconformity, which is marked by the Sylamore Sandstone. Clearly, the basal New Albany is older in the deep basin than in marginal areas.

The central portion of the cross section (approximately between 6 and 20) corresponds, in large part, to the Vandalia Arch of Workman and Gillette (1956). They postulated a positive structure to account for the relative thinness of the New Albany strata in this area. Stratigraphic relationships in the area are complex and are not completely understood. The sequence consists primarily of intertonguing and laterally intergrading brownish black shale, gray to greenish gray shale, siltstone, and limestone. Although the precise age relationships are difficult to ascertain, it is apparent that siltstones and limestones of the "Glen Park" Formation and Louisiana Limestone grade laterally into greenish gray and gray shales of the Hannibal and Saverton, which in turn grade into the olive black to brownish black shale of the upper part of the Grassy Creek Shale in the deep basin.

The northwestern end of the cross section (wells 1-6) roughly corresponds to the Petersburg Basin of Workman and Gillette (1956). On the basis of the thick stratigraphic sequence, they postulated a western basin, separated from the Illinois Basin by the Vandalia Arch. The New Albany sequence in this area consists largely of gray to greenish gray shale, with relatively minor olive black to brownish black shale, mostly in the lower portions. This is the most poorly documented area in the state; data are sparse and many are of questionable reliability. The exact nature of lateral and vertical gradational relationships is not well understood because geophysical log characteristics and sample lithology changes are very subtle; thus, tracing key horizons is difficult.

Throughout most of this area, the Hannibal and Saverton Shales are not separated because they cannot be consistently distinguished in the absense of the intervening "Glen Park" Formation or Louisiana Limestone. In much of this area the undifferentiated Hannibal-Saverton Shale may be largely Saverton equivalent because much of the Hannibal equivalent may have been eroded prior to deposition of the overlying Valmeyeran strata (Burlington Limestone and Fern Glen Formation). The contact between the Grassy Creek and Saverton Shales is gradational through a transition interval, requiring the use of vertical cutoffs. Also, in the northwestern area the Grassy Creek Shale becomes more like the Sweetland Creek in character; in much of the area, the two formations cannot be practically distinguished from each other.

Isopach Maps

Progress

Thickness data for the New Albany Shale Group and all formational subdivisions have been tabulated for the entire area of occurrence in Illinois. Revisions have been necessary in some areas, particularly as more data, such as sample studies, become available. A generalized thickness map of the New Albany Group (Fig. 9) has been completed. Thickness maps of all formational units are near completion and will be published this fall in a forthcoming Illinois State Geological Survey publication in the Illinois Petroleum series. Thickness maps of the Blocher, Sweetland Creek, Grassy Creek and Saverton Shales are specified as deliverable items in the DOE contract. In addition to these maps, we have also prepared thickness maps of the Louisiana Limestone, "Glen Park" Formation, and Hannibal Shale. Although these three formations do not contain much black shale, (there is some in the Hannibal), they are contained within the New Albany Group and are largely equivalent in age to black shale formations. Understanding all these formations is necessary to understanding the facies relationships and depositional environments of the New Albany Group as a whole.

The contract also specifies as deliverables thickness maps of organic rich subunits of the Blocher and Grassy Creek Shales. A high organic unit in the upper portion of the Grassy Creek is recognizable on gamma ray logs and on high quality electrical resistivity logs. Data are available to map this unit and perhaps one or two other less highly organic units in the Grassy Creek. A data base for subdividing the Blocher is much less extensive. Although gamma ray logs show a high organic lower unit and more calcareous upper unit, this distinction is not clear on the much more abundant electrical logs.

Problems

Several stratigraphic correlation problems still plague the work with New Albany stratigraphy. Some have delayed completion of finalized isopach maps. Many of these problems result from difficulties in recognizing details of facies transitions. In some areas, insufficient data are much of the problem, but even where data are relatively abundant, gradual subtle changes may be difficult to trace. Following is a discussion of some of the major problems which have been encountered.

The Blocher Shale in southeastern Illinois poses some problems. The calcareous shale of the Blocher grades laterally into limestone of the Lingle Formation, but the exact nature of the transition is difficult to ascertain. Perhaps the transition could be best represented by a stepwise series of vertical cutoffs, but since data are insufficient to work out such details, the transition has been represented in this study by a single generalized vertical cutoff.

In central Illinois the succession from the Grassy Creek Shale to the overlying Saverton Shale is transitional through an interval of interbedded black and gray shale. The approach in this study has been to assign the interval, or its lower portion, to the Grassy Creek where black shale predominates (as determined from geophysical logs and sample studies), but to the Saverton where gray shale predominates. Difficulties arise from various sources. Not all the various geophysical logs show principal discontinuities at the same depths. Gamma ray logs appear best for discriminating black from gray shale, but electric logs are much more plentiful. The major change from black to gray shale at the Grassy Creek-Saverton contact is commonly represented by a very subtle change in electrical resistivity. It is often difficult to pick a good contact based on sample studies within the transition zone.

The lateral relationships of the "Glen Park" Formation and the Louisiana Limestone to the Hannibal Saverton Shales are complicated. The Louisiana Limestone is not always easy to distinguish from the limestone in the upper portion of the overlying "Glen Park" Formation. In sections where only one of these limestones is present, it is not always easy to identify which one is present. Where the Louisiana is absent, the upper Saverton contact is commonly placed at the base of the limestone in the "Glen Park," thereby including equivalents of the lower portion of the "Glen Park" within the Saverton. In other areas the "Glen Park" become indistinguishable from the Hannibal and is combined with the Hannibal. Considerable age overlap is suggested for the strata assigned to the various formations within the Hannibal-Saverton interval.

Erosional thinning of the New Albany presents some special problems in mapping the group and certain formational subunits. In western Illinois where the New Albany is unconformably overlain by Valmeyeran (middle Mississippian) strata, the distribution of thicknesses is erratic, making contouring difficult. This necessitates a more general approach to contouring, including use of a larger contour interval. In the areas where the New Albany crops out or is overlain by Pleistocene or Pennsylvanian deposits (Fig. 9), the known thickness values are so erratically distributed that it is not even practical to contour these areas from existing data.

Sample Studies

Progress

Sample studies of well cuttings were begun in February 1978. Although these studies were not stipulated in the original contract, they have been found to be helpful as supplementary studies, especially since there has been a shortage of material from cores.

To date samples from more than 200 wells have been studied, but the sample sets from some wells have been too poor to merit detailed descriptions. 164 sample sets have been described in detail and sampled for further analyses. Samples have been taken from 100-foot intervals for clay mineralogy, chemical analyses, vitrinite reflectance, and petrographic thin sections. Samples must be picked carefully to avoid contamination by lithologies which do not truly represent the sample interval.

Sample studies provide a basis for lithologies interpretation of geophysical logs. For ease of comparison, lithologic logs from the sample studies have been drawn up on the corresponding geophysical logs. Sample depths and formation boundaries have been adjusted to geophysical log depths as appropriate.

Wells throughout the Illinois Basin have been studied, but the study has concentrated primarily in southern and central Illinois, where black shale predominates in the New Albany Group, and where all data, especially geophysical logs, are most abundant.

Problems

Sampling from some wells is difficult or impossible because of contamination of samples with chips caved from overlying strata. Missing intervals are encountered in some sample sets, making sample studies incomplete, or sometime impossible.

Biostratigraphy

Progress

Black shale samples from near the top of the New Albany Shale at Hicks Dome in Hardin County have been processed for conodont specimens by Rodney D. Norby of the Illinois Geological Survey. Unfortunately, these samples were barren of conodonts. However, in previous studies, conodont specimens have been found in the Devonian-Mississippian shales in other localities. Samples from other localities and stratigraphic positions will probably also be examined for conodonts. Biostratigraphic control afforded by conodonts could prove very useful for interpreting age and facies relationships within the shale sequence.

Problems

Although the highly organic black shales can be broken down fairly easily with a solution of sodium hypochlorite and sodium hydroxide, the process becomes increasingly less successful for shales of lower organic content.

Data Formats and Computer Maps

Progress

Final corrections have been made to data formats. Production of computer generated formation thickness and structure contour maps is awaiting finalization of data values. Since the mapping system has been tested, no more computer maps will be produced until all data values are finalized.

Linear Features of Illinois

Linear features visible on LANDSAT images of Illinois have been mapped on a 1:1,000,000 base using a Bausch & Lomb Zoom Transfer Scope(Fig.10). Bands 5 and 7 of LANDSAT images throughout Illinois were examined. Only linears large enough to appear significant on the 1:1,000,000 LANDSAT images were mapped. Man-made features such as interstate highways, railroads, pipelines, and canals were eliminated by comparison of the linears map to larger scale maps with cultural features indicated. Some short channelized stream segments may not have been eliminated and may be included as linear alluvial valleys on the lineaments map. In most cases, channelization occurred over a long enough distance that channelized streams were recognized by their lack of meanders and uniform stream width over long reaches.

The mapped lineaments include approximately 400 linear alluvial valleys, 9 fault traces, and 2 other lineaments. The 9 faults traces occur in southern Illinois and correspond to known zones of faulting. The two linear drainage divides occur in the "Driftless" area of northwest Illinois. Linear alluvial valleys occur throughout Illinois and appear to have a variety of origins.

From LANDSAT images and high-altitude photography alone, it is impossible to discriminate between linears that are bedrock-controlled and linears formed by blacial processes. Determining the origin of linears in a specific area of Illinois can be accomplished only when the linears in that specific area have been field investigated and the regional geology of the area is well understood. Therefore, the origin of most linears in Illinois can only be tentatively defined on the basis of available evidence.

A number of linears in western Illinois have been field investigated. These linears are related to the last glaciation of the region. High altitude aerial photography shows that drumlines and glacial fluting control to some extent the drainage patterns and hence, the orientation of linear alluvial valleys. Throughout much of western Illinois, linear alluvial valleys parallel glacial flow directions.

Some linear alluvial valley segments in western Illinois are bedrock controlled. Small linear valleys are present near the bluffs of the Illinois and Mississippi Rivers where streams with high gradients have cut down into the bedrock surface. A small number of long linear alluvial valley segments in western Illinois are developed in bedrock and appear to follow some linear features within the bedrock. In southeastern Illinois, a large number of linear features appear to be controlled by bedrock jointing or fracturing.

A study of linear features can be useful when the types of linears being studied are recognized. The presence of linears and the direction of their orientation are important only when the particular causes of their development are understood.

<u>Publication</u>

Reinbold, Mark L., in press, Stratigraphic relationships of the New Albany Shale Group (Devonian-Mississippian) in Illinois: U. S. Department of Energy, Morgantown Energy Technology Center, Second Eastern Gas Shales Symposium Preprints.

Abstract

The New Albany Shale Group and closely related, adjacent strata in the Illinois Basin can be classed into five main lithologies: black or brownish black shale; gray to greenish gray shale; calcareous or dolomitic shale; and limestone. Detailed stratigraphic correlations based on cores, geophysical logs, and sample studies indicate that these lithologies grade vertically and laterally into one another, with complex intertonguing relationships. In this report these relationships are illustrated by a long northwest-southeast cross section.

Facies distribution of the New Albany suggests that these strata were deposited in a stratified anoxic basin. Black shales, which reflect anoxic conditions, predominate near the center of the basin; these shales probably represent the deepest water environments. Olive, gray, and greenish-gray shales

predominate in basin flank areas; these lithologies indicate low to moderate oxygenation and probably shallower water environments. Limestones, which are thickest in marginal areas of the basin, probably were deposited in shallow, well-oxygenated water.

References

Lineback, J.A., 1970, Stratigraphy of the New Albany Shale in Indiana: Ind. Geol. Survey, Bull. 44, p. 73.

North, W.G., 1969, The Middle Devonian strata of southern Illinois: Ill. Geol. Survey Circ. 441, P. 45.

Reinbold, M.L., in press, Stratigrphic relationships of the New Albany Shale Group (Devonian-Mississippian) in Illinois: U. S. Dept. of Energy, Morgantown Energy Technology Center, Second Eastern Gas Shales Symposium. Preprints.

Workman, L.E., and Gillette, Tracy, 1956, Subsurface stratigraphy of the Kinderhookian Series in Illinois: Ill. Geol. Survey Dept. of Investigations 189, p. 46.

Table 1. Locations of wells in cross section (Fig. 7)

Well no.	Well Owner	Sec.	Twp.	Range	County
1.	Northern Illinois Gas No. 1 RAR (Core 041L)	32	8N	4W	Henderson
2.	Central Illinois Public Service No. SM 8 City of Macomb	17	6N	3W	McDonough
3.	Bur-Kan Pet. Co. No. 1 Miller Brothers	23	4N	2W	McDonough
4.	J. L. Pinkston No. 1 G. Blessman	3	19N	10W	Mason
5.	E. L. Wirth No. 1-A Leahy	21	16N	8W	Morgan
6.	Panhandle Eastern No. 7-15 Whitlock	15	13N	8W	Morgan
7.	Down State Drilling Co. No. 1 Malsbury	22	13N	7W	Sangamon
8.	L. A. Wright No. 1 Thoron	19	12N	6W	Macoupin
9.	Phillips Petroleum No. 5 Farmersville	33	12N	5W	Montgomery
10.	J. F. Dunnill No. 1 G. Gerlach	26	11N	5W	Montgomery
11.	E. L. Wirth No. 2 Poggenpohl et al.	10	10N	4W	Montgomery
12.	Atkins and Hale No. 1 Brown-Gregg	32	10N	3W	Montgomery
13.	Mobil No. 1 J. J. DeWerff	11	9N	3W	Montgomery
14.	P. Rossi No. 1 W. Singler	33	9N	2W	Montgomery
15.	Calvert Drilling Co. No. 1 J. Blackburn	8	7N	2W	Montgomery
16.	National Assoc. Pet. Co. No. 1 E. W. Hines	20	7N	1W	Fayette
17.	Energy Resources of Indiana No. 1 Stinebring-Ledbetter	31	7N	2E	Fayette
18.	C. E. Brehm No. 1 E. Ireland	21	6N	2E	Fayette
19.	Kewanee Oil Co. No. 7 J. Gehle	13	5N	2E	Fayette
20.	Shell No. 1 C. C. Ford	31	5N	3E	Fayette
21.	Total Leonard No. 1-25 Lane	25	4N	3E	Marion
22.	Southern Illinois Oil Producers No. 1 E.Fatheree	16	3N	5E	Clay
23.	Southern Illinois Oil Producers No. 1 L.Mearns	16	3N	6E	Clay
24.	J. W. Steele No. 1 R. Leak	15	2N	7E	Clay
25.	National Oil Co. No. 1 VanFossan-Brown	14	1N	8E	Wayne
26.	H. Luttrell No. 1 J.W. Fetherling	21	1S	9E	Wayne
27.	Collins Brothers Oil Co. No. 1 Hill	29	2S	9E	Wayne
28.	National Oil Co. No. 1 Granger	21	3S	9E	White
29.	C. E. Brehm No. 1 Winter-Renshaw	30	4S	10E	White
30.	J. Haley Production Co. No. 1 Tuley	21	6S	10E	White
31.	Humble No. 33 Busiek-Crawford C-87	11	8S	10E	Gallatin
32.	Texaco No. 1 J. M. Walters	29	9S	9E	Gallatin
33.	Shell No. 1 M. Davis	17	L	16	Crittenden, Ky.

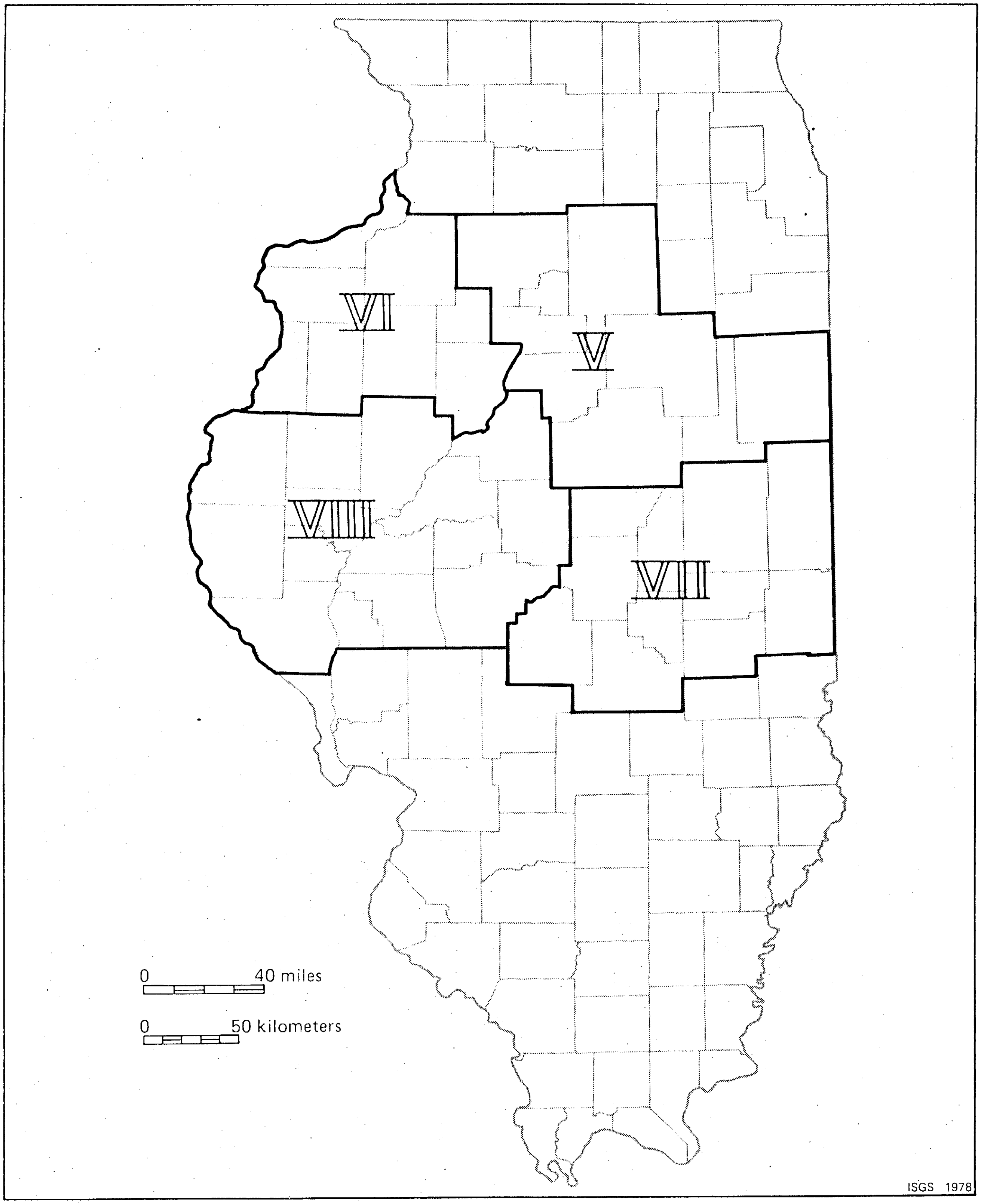


Figure 1. Areas of wells in the Upper Devonian shales added to the basic data file. The four sections and individual hole locations are shown on accompanying maps (figs. 2-5).

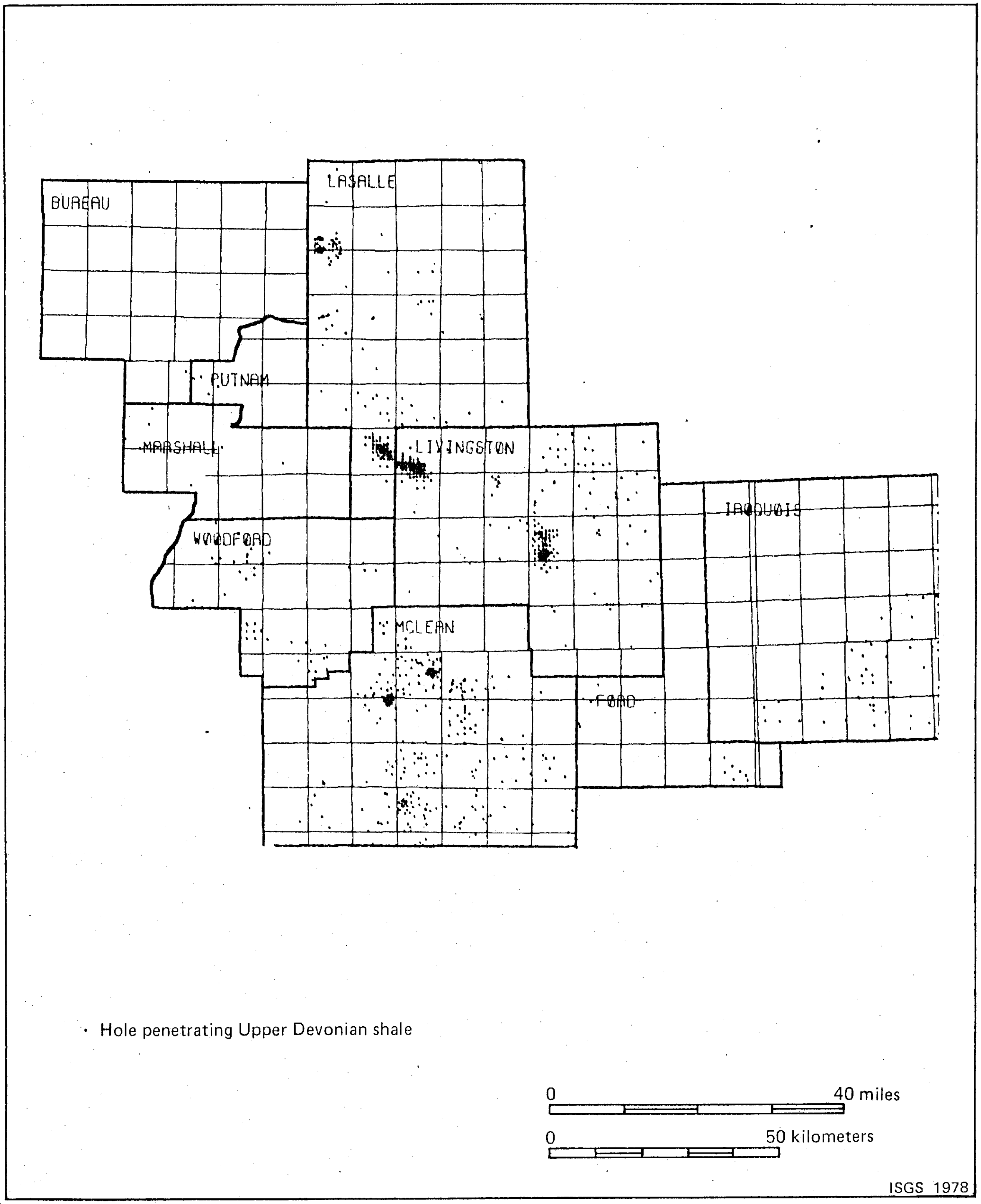


Figure 2. Devonian well locations, area V.

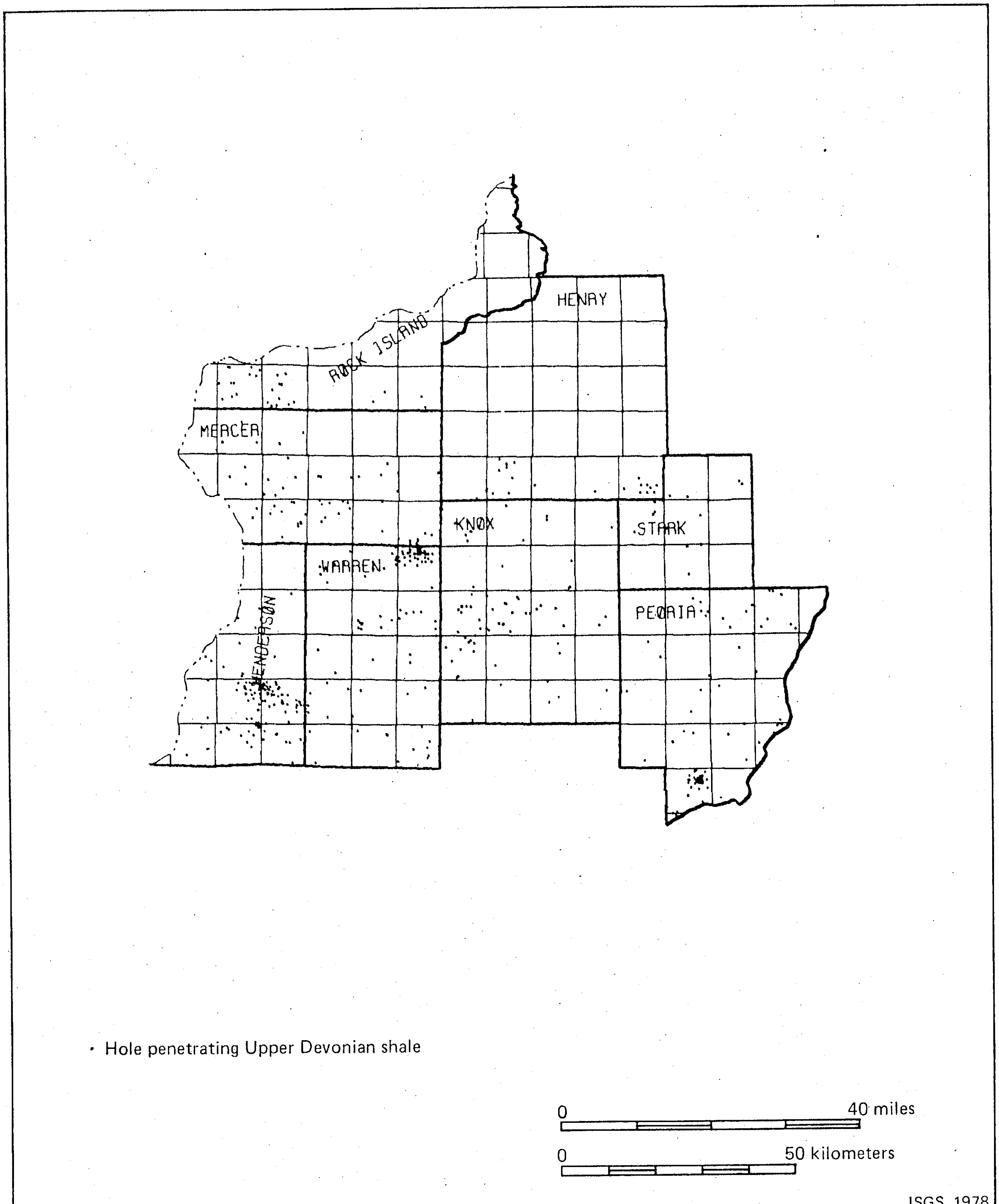


Figure 3. Devonian well locations, area VI.

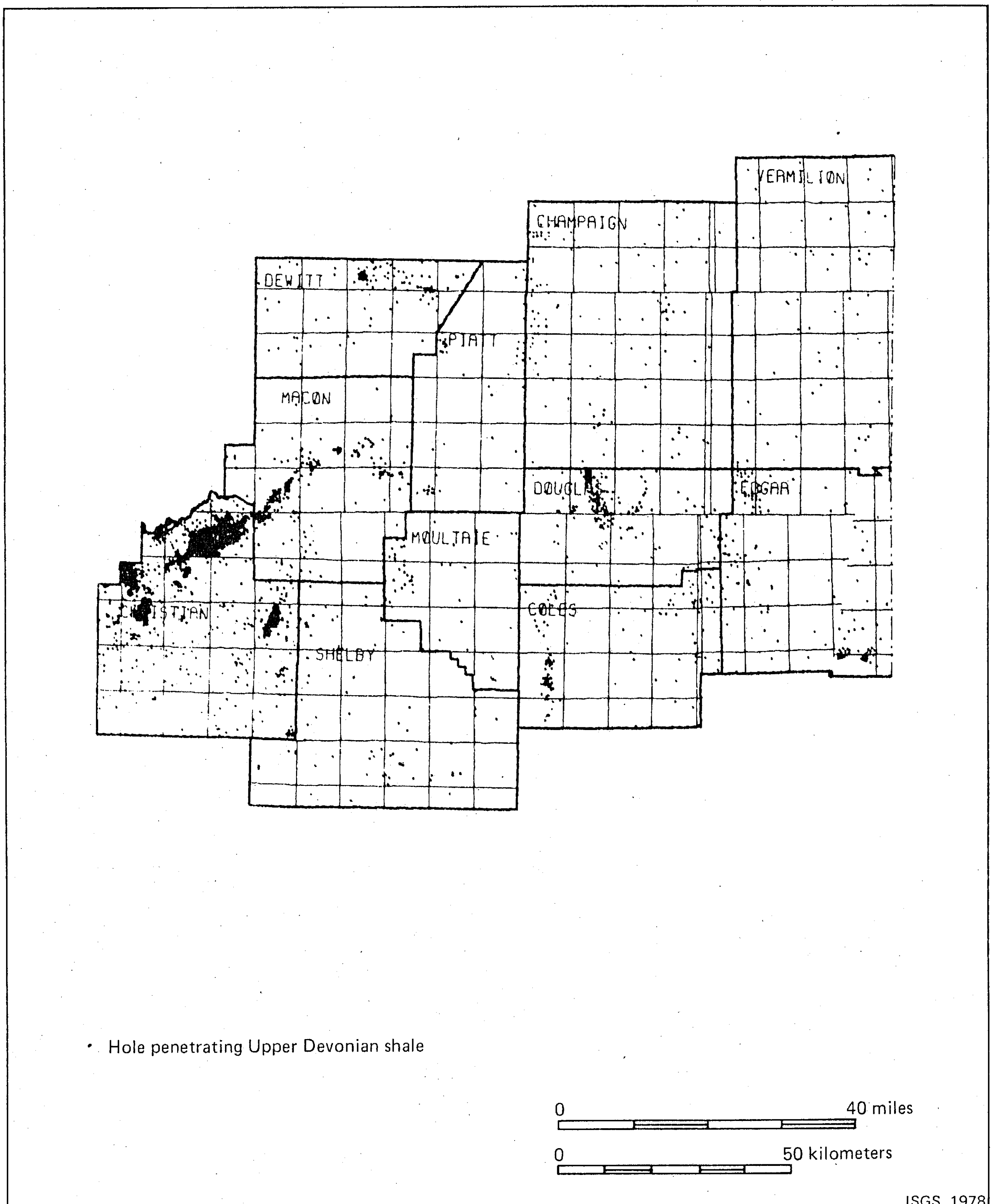


Figure 4. Devonian well locations, area VII.

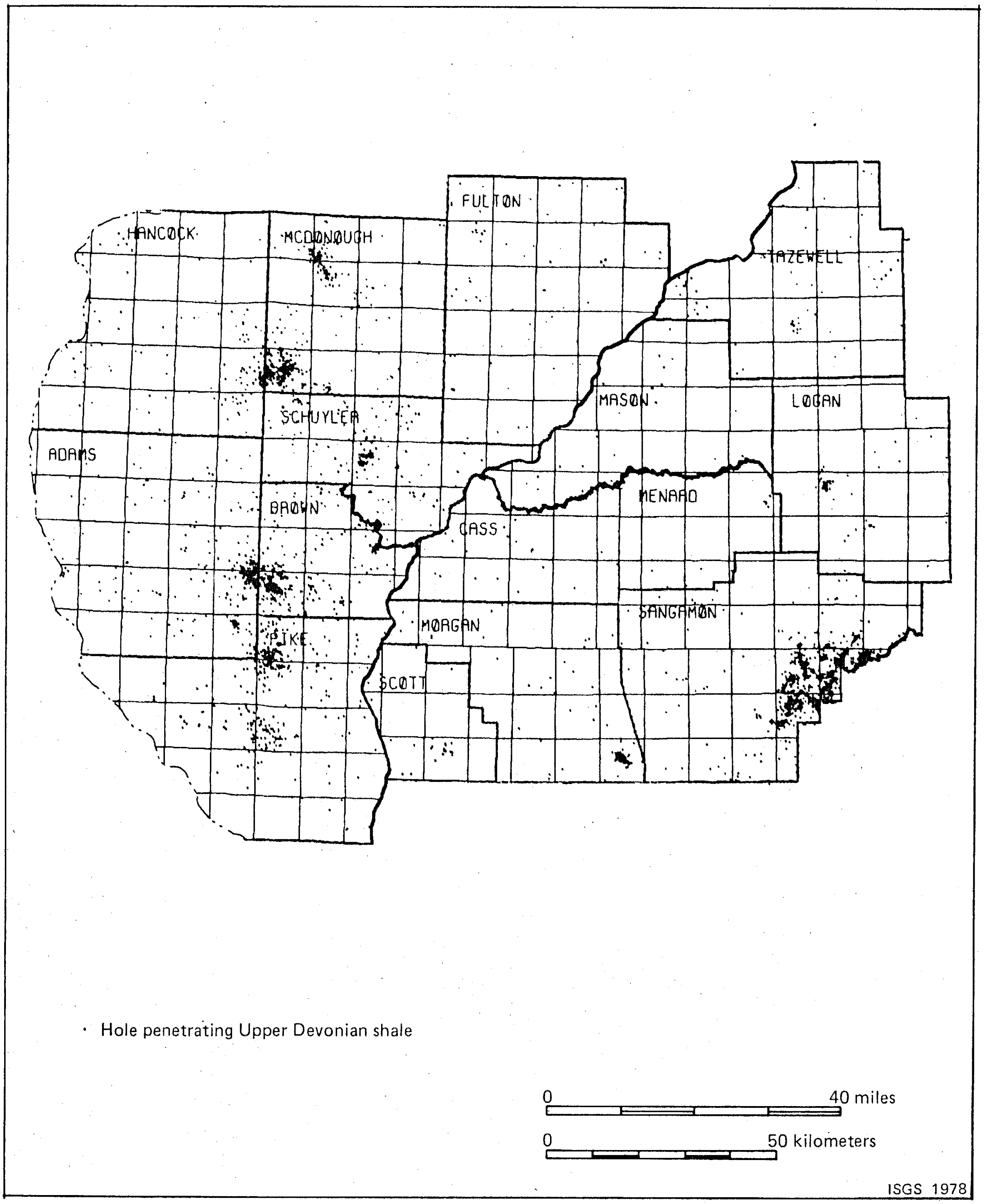


Figure 5. Devonian well locations, area VIII.

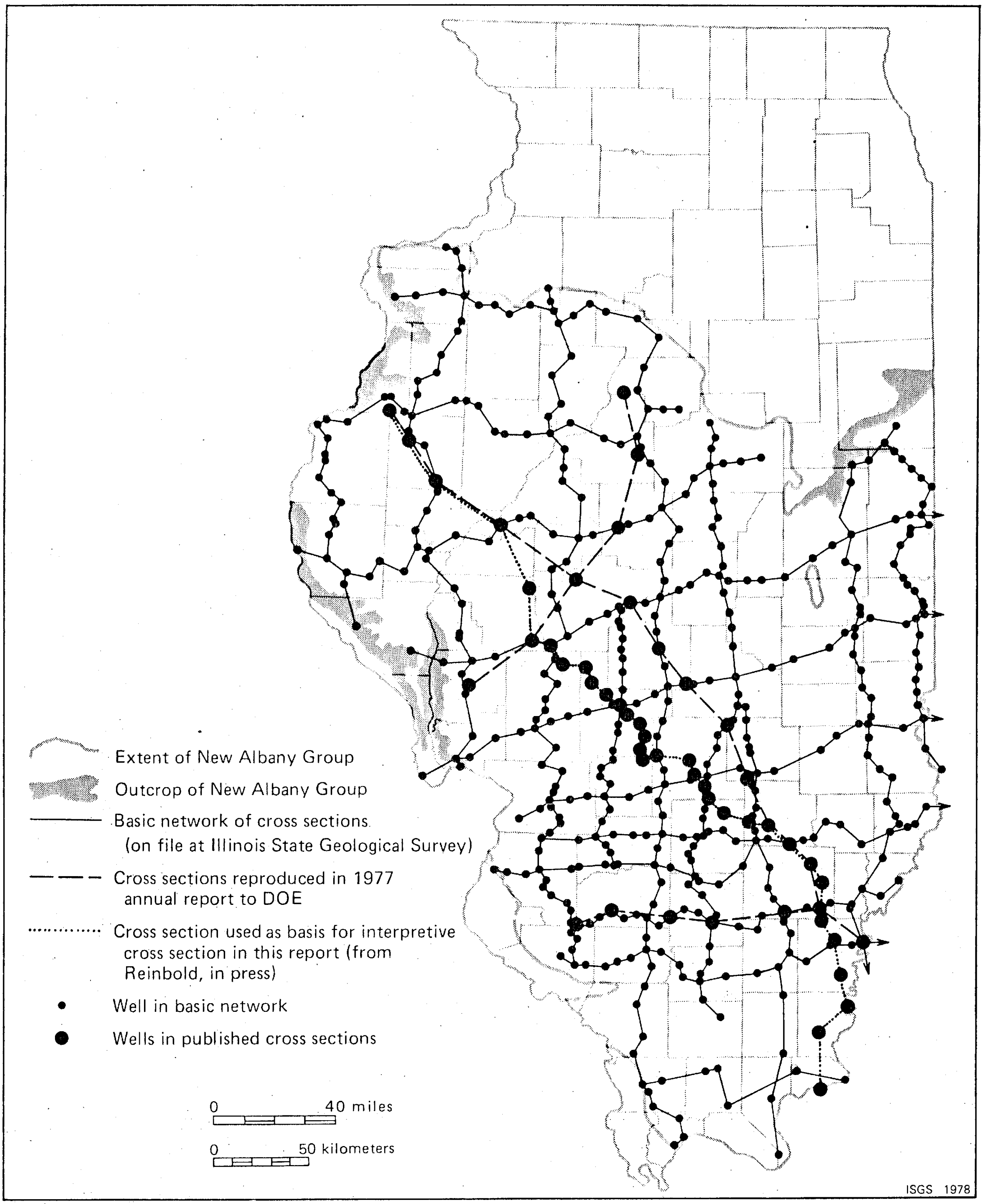


Figure 6. Locations of cross sections of the New Albany Shale Group and adjacent strata in Illinois.

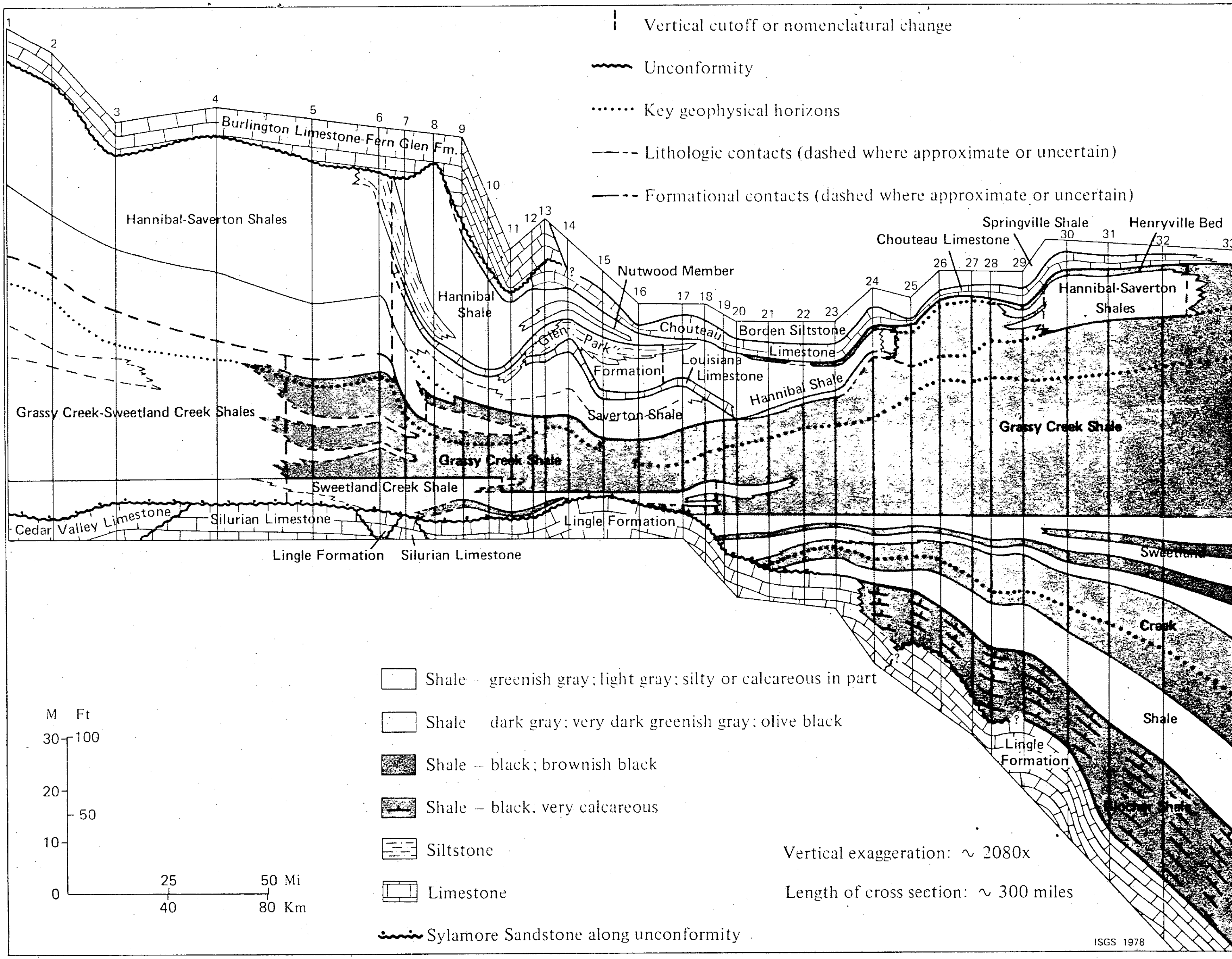


Figure 7. Generalized northwest-southeast cross section of New Albany Shale Group and adjacent strata in Illinois. (For well locations, see fig. 2 and table 1.) (From Reinbold, in press.)

Figure 8. Locations of wells used in cross section (fig. 7). See table 1 for descriptions of well locations. (From Reinbold, in press.)

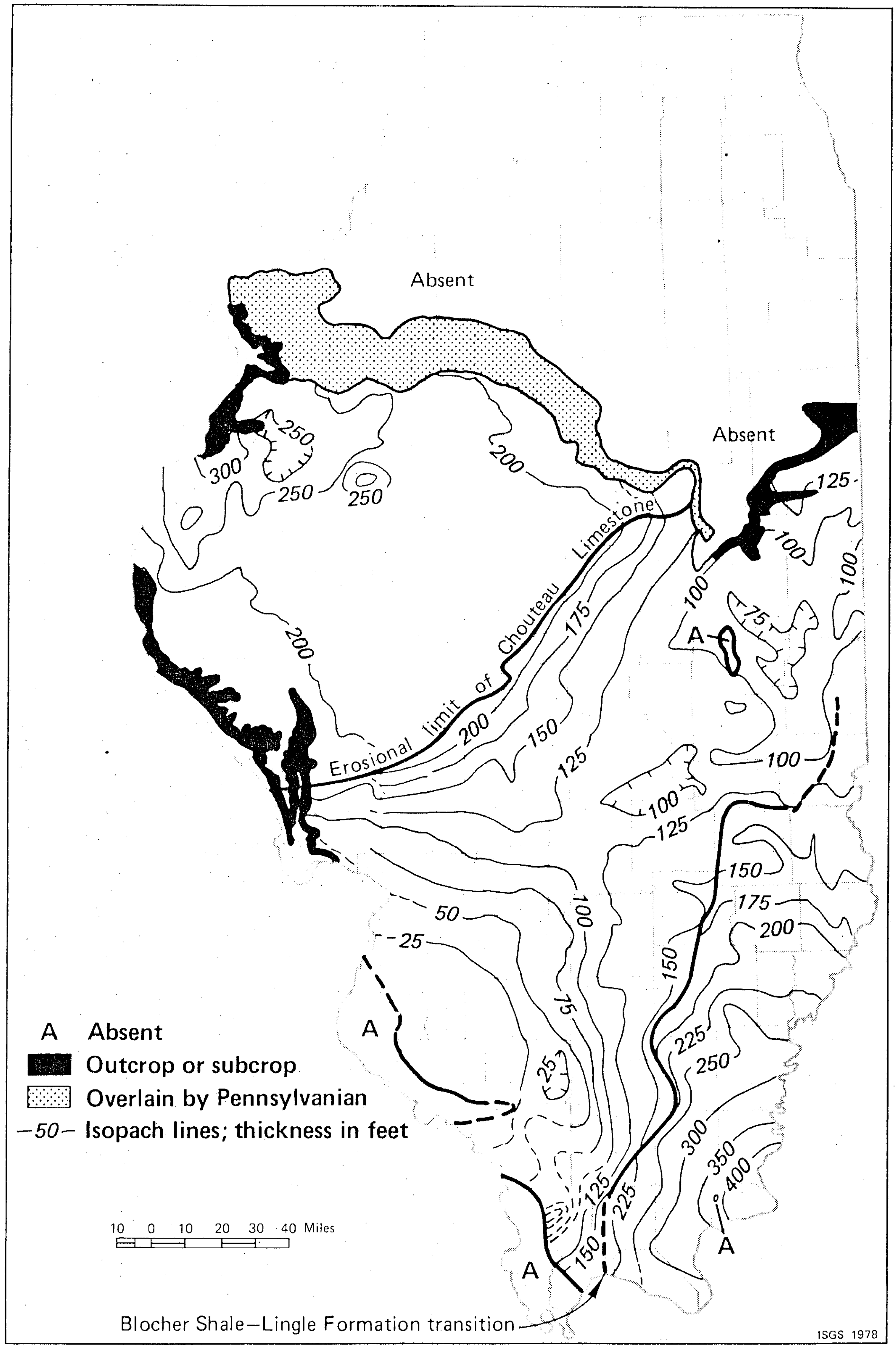


Figure 9. Thickness of the New Albany Shale Group. (From Reinbold, in press.)

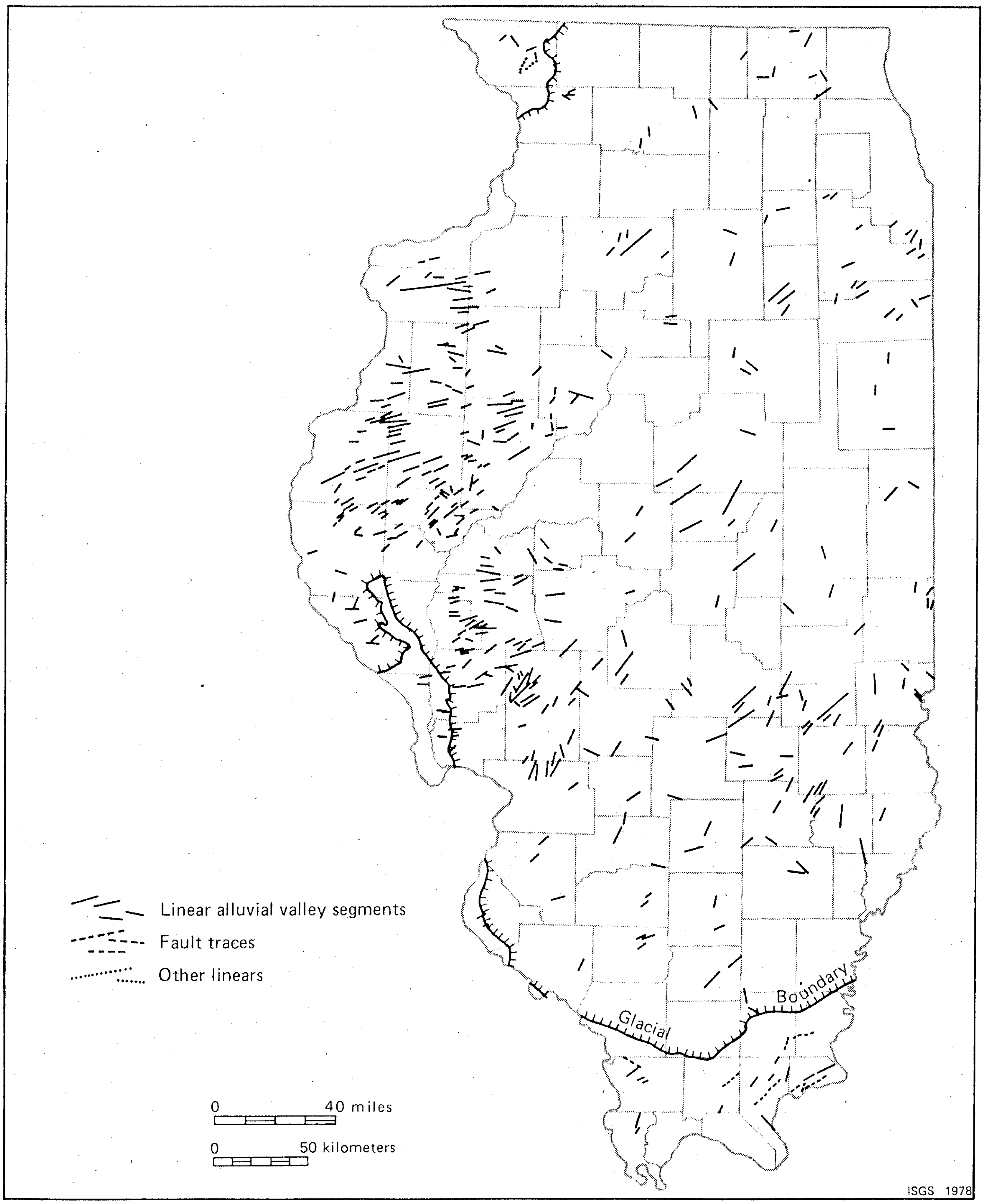


Figure 10. Landsat-image surface linears in Illinois.

MINERALOGIC AND PETROGRAPHIC CHARACTERIZATION

Introduction

This project is directed at characterizing in detail the mineralogic and petrographic properties of the New Albany Shale in Illinois. This includes the quantitative and qualitative characterization, by optical and X-ray techniques, of the inorganic mineral constituents, the dispersed organic matter, and the fabric of the shale. The data generated will provide a fundamental basis for regional and local correlations of geologic data, for interpretation of the sedimentology, depositional environment, diagenetic history, and for evaluation of hydrocarbon potentials based on the degree of thermal maturation of organic matter in the New Albany Shale.

Mineralogic and petrographic characterization of the selected samples from the 01IL (Sangamon County, Illinois) and the 01KY (Christian County, Kentucky) cores was completed in FY77 and the results were reported and discussed in our 1977 Annual Report. The present report summarizes our progress during FY78. Five cores were obtained for study through the DOE drilling program: 02IL (Effingham County, Illinois), 04IL (Henderson County, Illinois), 05IL (Edgar County, Illinois), 06IL (Tazewell County, Illinois), and 07IL (Fayette County, Illinois). Samples were selected from each of these cores through the entire New Albany at intervals of 10 feet or less for mineralogic and petrographic characterization. Complete results of the various characterizations (subtasks) are herein reported and discussed. Two other wells, previously drilled through the New Albany from which cuttings or chips were stored at the Survey, were added to the work for this year: 03IL (White County, Illinois) and 09IL (St. Clair County, Illinois). Samples from these wells were characterized for all subtasks possible, in view of the nature of the samples. Radiographic and certain orientation and microscopic data could not be obtained from these samples. In addition, over 250 supplementary samples from drill cuttings were carefully hand-picked and selected for inclusion in certain subtasks made possible by the nature of the samples. Results of the studies required for FY78 on these samples (identified by NAS numbers) are also reported below. Samples from well 08IL (Peoria County, Illinois) drilled some years ago from which cuttings are still available, will be part of the work to be accomplished during FY79.

Lithologic and Radiographic Characterization

Progress

During FY78, all selected samples from the 02IL (Effingham County, Illinois), 04IL (Henderson County, Illinois), 05IL (Edgar County, Illinois), 06IL (Tazewell County, Illinois), and 07IL (Fayette County, Illinois) cores were embedded in epoxy, slabbed, and radiographed. Lithologic and radiographic characterizations of these samples are presented in Tables 1 through 5, and they complete the work on this subtask for the cores obtained to date.

The style used to report sample descriptions is slightly different from that used in previous reports (including Harvey et. al., 1977, and our 1977 annual report to ERDA) because many of the samples in these cores were taken from intervals in which greenish-gray and black shales are thinly interbedded. These samples are described as two distinct lithologies, with the proportion of each and the bed thicknesses indicated in columns 5 and 6.

Bedding and laminations are used with two distinctly different meanings in these descriptions. Bedding is used to refer to layers of distinct color, structure, and composition, whereas laminations refer to thin, planar sedimentary structures that are usually segregations of organic matter or silty material. We interpret the interbedding of greenish-gray and black shale to be the result of changes in the oxygen content of the bottom waters in the New Albany (Cluff and Reinbold, 1978), whereas laminations are the result of minor fluctuations in currents or sediment supply, without any significant change in the bottom environment.

The lithofacies classification of Harvey et al., 1977, based on study of 01IL and 01KY cores, was found adequate to characterize all of the shale lithologies found in these cores. The lithofacies definitions used here have been modified slightly to permit a wider range of color and organic content within each lithofacies.

Samples of the Chouteau Limestone and Lingle Formation, at the top and bottom of the New Albany Shale Group, respectively, are not easily characterized by the same criteria used to describe shale samples. A different descriptive format is required and now being used for the carbonates within and adjacent to the New Albany Shale. The carbonate rock classifications of Folk (1962) and Dunham (1962) are used to classify these rocks.

Over 250 supplementary drill cutting samples have been selected and analyzed to date. The locations of these are listed in Table 6. Collection of more supplementary samples is now in progress. These samples are useful for clay mineralogy, vitrinite reflectance, thin section petrography, and trace element geochemistry. We hope to better define geographic variations in the New Albany Shale through the study of these samples.

Microscopic Characterization

Progress

Thin-sections were prepared and described for samples from the 02IL (Effingham County, Illinois), 03IL (White County, Illinois), 04IL (Henderson County, Illinois), 05IL (Edgar County, Illinois), 06IL (Tazewell County, Illinois), 07IL (Fayette County, Illinois), and 09IL (St. Clair County, Illinois) cores during FY78. The results of this subtask are included with the lithologic characterizations given in Tables 1 through 5. Additional descriptive information generated by the microscopic work will be summarized in our forthcoming publication on the New Albany Shale.

In addition, 156 supplementary thin sections of outcrop and well cutting samples were characterized during FY78. These samples are almost exclusively from sandstone and carbonate units below, within, and above the New Albany Group. Generally the thin sandstones within the New Albany Group are calcite cemented and do not appear to have significant porosity. This also appears to be the case for the abundant thin silt laminae found within the laminated black shale facies of the New Albany. The silt laminae and sandstones, therefore, probably do not serve as pathways for migration of gas through these shales, unless the gas is able to move along the interface between the coarse grained bed and adjacent clay.

The carbonate lithologies in the New Albany Group are quite variable and are principally of interest in deciphering the depositional environments of the shale and lateral facies transitions from shale to carbonate. This will also be summarized in one or more forthcoming papers.

Twenty-six samples are now being examined under the scanning electron microscope for evaluation of general fabric and mineralogy. Progress on this phase of the work has been severely limited by extensive repairs on the University's Cambridge SEM.

X-Ray Diffraction Mineralogy and Clay Orientation

Progress

Analysis of the clay mineralogy, clay orientation, and silt mineralogy was completed for the 03IL, 04IL, 05IL, 06IL, 07IL, and 09IL cores during FY78. Updated computer printouts of all the data on these cores are given in Tables 7 through 18. These complete the work on this subtask for all the cores obtained to date subject to this work.

Clay mineral analysis of the 02IL (Effingham County, Illinois) core was completed during October, and the results are presented in Table 7. The clay compositions in this core are similar to those observed in the 01IL (Sangamon County, Illinois) core. The clay orientation index varies from 1.2 to 2.5 and does not show any systematic variation with depth or lithology (Table 7). An orientation index of 1.0 represents a totally random alignment of clay flakes; increasing indices represent more perfect parallel alignment of the clays.

Clay mineral analysis of the 03IL (White County, Illinois) core was completed during December, and the results are presented in Table 9. The samples from this core have low chlorite contents and are intermediate in composition compared to the 01KY and 01IL core samples.

The organic content of the White County samples was determined from the weight loss during low-temperature ashing and is recorded in the last column of Table 9. These are only approximate values because the efficiency of the ashing process is dependent upon the size of the crushed particles placed in the asher (<20 mesh, in this case).

Clay mineral analysis of the 04IL (Henderson County, Illinois), 05IL (Edgar County, Illinois), 06IL (Tazewell County, Illinois), and 07IL (Fayette County, Illinois) cores was completed by June, and the results are presented in Tables 11, 13, 15, and 17. The clay mineralogy of these cores is very similar from one to another and is also similar to the 01IL and 02IL cores. At this time it appears that the New Albany contains more chlorite in the northern portion of the Illinois Basin than in the southern portion. Clay mineral analyses now in progress of well cutting samples should allow us to map any regional variations more precisely.

The 05IL (Edgar County, Illinois) core is unique in that a small, but significant amount of kaolinite was detected in all samples. Kaolinite was also detected in a few samples from the 04IL and 06IL cores and has been found in a few drill cutting samples from various locations in Illinois. Generally, however, kaolinite is absent from the New Albany Shale.

Two orientation slides were made for each of three samples from the 06IL (Tazewell County, Illinois) core to show the effect of lithologic variations within a single sample on clay orientation. The maximum observed range was 1.4 to 2.0 (06IL13L1).

Whole-rock silt mineralogy has been completed for 102 drill cutting samples from various locations throughout Illinois. A computer printout of these data is presented in Table 19. Analysis of this data is still in progress.

Clay mineral analyses of a standard sample (SDO-1) provided by the U. S. Geological Survey are presented in Table 20. The sample was divided into three splits, and four slides were made of each split: two by the smear technique (which we routinely use) and two by sedimentation.

As can be seen by comparing these data, the results within each group of samples are in good agreement, but there are signficant differences between the first set of slides and the duplicates that were run a few weeks later. Due to energy conservation measures, the heat is turned off in our X-ray laboratory overnight. The room temperature drops to about 24° C, and this seems to be the temperature at which ethylene glycol can no longer enter between clay layers. Complete glycolation appears to occur at 26 to 27°C. The difference between the two sets of samples, therefore, is attributed to deglycolation during the night, which results in an apparent reduction of expandable clays when the slides are x-rayed early in the morning (before they re-equilibrate with the glycol atmosphere at higher, daytime room temperatures). This was a previously unsuspected source of error that has subsequently been eliminated. A temperature controlled environment for glycolation was installed and it has been in routine use for several months.

Vitrinite Reflectance

Progress

Tables 22 and 23 list the mean-random vitrinite reflectance data for the seven Illinois cores and forty-six supplementary drill cutting samples collected this year. The data in these tables completes the work on this subtask. The average reflectances of Illinois samples range from 0.37 percent (sample 01IL17L1) to 1.02 percent (sample NAS-121), with the majority of values falling between 0.40 and 0.65 percent.

A preliminary map of the distribution of the vitrinite reflectance data gathered to date is shown in Figure 1. The data indicate a trend of increasing reflectance values to the south and east. For example, samples from Christian County are lower in reflectance than samples from Fayette County to the south. Reflectance values in Washington County are lower than those in Jefferson and Wayne Counties to the east.

Saline and Pope Counties in southern Illinois have yielded average reflectance values between 0.90 and 1.01 percent. These are the highest values obtained to date, indicating the highest thermal maturity.

The reflectance data for each core is plotted against depth in Figures 2 and 3. Through the 240 feet or less of shale within a single core, no increase of reflectance with depth was detected. Because there is no reflectance gradient over this narrow range of depth, an average of all data collected for a single core is considered a valid estimation of the vitrinite reflectance of the core.

Data supporting the validity of our measurements have come from two sources. The reflectance of vitrinite in the vitrain bands found in some cores was nearly identical to those in associated macerated samples. As vitrains are generally a very reliable indicator of rank, the agreement between the vitrains and macerated samples indicates that the maceration process does not significantly alter the reflectance. Also, three samples from the Christian County, Kentucky core (01KY) were measured by John Castaño of Shell Development Company, Houston, Texas. His reflectance data correspond closely to our data for these samples.

The trends and patterns sighted in this report are made on a limited data base. Twenty-six additional well cutting samples from Illinois have been polished and are ready for reflectance analysis and thirty-five Illinois samples are now undergoing acid maceration. With data collected from these samples, from additional Illinois samples now being collected, and from samples provided by the Indiana Survey, a better understanding of the patterns of thermal maturity of the New Albany in the Illinois basin should result.

Sharpness ratios of the 10Å illite diffraction peak have been measured for a large number of Illinois samples and the results are listed in Tables 24 and 25. Such ratios have been used to determine relative degrees of diagenesis (Weaver, 1960). In figure 4, vitrinite reflectance is plotted against our sharpness ratio data. As no clear cut relationship between reflectance and sharpness ratio is demonstrated, illite may not be sensitive to the small changes in thermal maturity in the New Albany group of Illinois.

The data reported above completes the tasks specified for the project for FY78 with exception of the scanning electron microscope study. Progress on this phase will be given in the next monthly report and its completion is scheduled before the next quarterly report.

Publications

Four papers summarizing the results of various aspects of our study were prepared for presentation at professional meetings. The abstracts of these papers have been published and the references are listed below.

Cluff, R. M., and Reinbold, M. L., 1978, Anoxic conditions during New Albany Shale Group (Devonian-Mississippian) Deposition in the Illinois Basin: Geological Society of America abstracts with programs, v. 10, no. 6, p. 249.

Cluff, R. M., and Baxter, J. W., 1978, Problematical microfossils from the New Albany Shale Group (Devonian-Mississippian) in western Kentucky: Geological Society of America Abstracts with programs, v. 10, no. 7, p. 381.

Cluff, R. M., 1978, Organism-sediment relationships in the New Albany Shale Group (Devonian-Mississippian) of Illinois: Geological Society of America abstracts with programs, v. 10, no. 7, p. 381.

Hansman, M., Cluff, R. M., Harvey, R. D., and Burke, D. A., 1978, Organic maturity of the New Albany Shale Group (Devonian-Mississippian) in Illinois: Geological Society of America abstracts with programs, v. 10, no. 7, p. 416.

A paper summarizing our work during FY77 was presented at the First EGSP Symposium in Morgantown, West Virginia, by R. D. Harvey. This paper was published in the proceedings of that symposium and was reprinted by the Illinois Survey for distribution to the public. This reference is given below.

Harvey, R. D., White, W. A., Cluff, R. M., Frost, J. K., and DuMontelle, P. B., 1977, Petrology of New Albany Shale Group (Upper Devonian and Kinderhookian) in the Illinois Basin, a preliminary report: Preprints, First Eastern Gas Shales Symposium, October 17-19, 1977, Morgantown, West Virginia; p. 239-265. Reprinted in Illinois State Geological Survey Reprint Series, 1978-F.

We are now writing a detailed report summarizing the results of our work during FY77 and FY78. This report is tentatively scheduled for inclusion in the Illinois Petroleum Series.

REFERENCES

Cluff, R. M., and Reinbold, M. L., 1978, Anoxic conditions during New Albany Shale Group (Devonian-Mississippian) deposition in the Illinois Basin: Geological Society of America Abstracts with Programs, v. 10, no. 6, p. 249.

Dunham, R. J., 1962, Classification of carbonate rocks according to depositional texture: American Association of Petroleum Geologists, Memoir 1, p. 108-121.

Folk, R. L., 1962, Special subdivision of limestone types: American Association of Petroleum Geologists, Memoir 1, p. 62-84.

Harvey, R. D., W. A. White, R. M. Cluff, J. K. Frost, and P. B. DuMontelle, 1977, Petrology in New Albany Shale Group (Upper Devonian and Kinderhookian) in the Illinois Basin, a preliminary report: Preprints, First Eastern Gas Shales Symposium, October 17-19, 1977, Morgantown, West Virginia; p. 239-265. Reprinted in Illinois State Geological Survey Reprint Series, 1978-F.

Weaver, C. E., 1960, Possible uses of clay minerals in search for oil: American Association of Petroleum Geologists Bulletin, v. 44, p. 1505-1518.

TABLE 1 - LITHOLOGIC CHARACTERIZATION, EFFINGHAM COUNTY, ILLINOIS, CORE SAMPLES

SAMPLE NUMBER	DEPTH* (FT)	FORMATION	LITHO-FACIES	%	BED TK.	GRAIN SIZE	MUNSELL COLOR	LAMINATIONS TYPE	LAMINATIONS TK.	LAMINATIONS SPACE	BIO-TURB.	SYNAERESIS EARLY	SYNAERESIS LATE	PYRITE NODULES SIZE	PYRITE NODULES AB.	PYRITE NODULES DIST
02IL01L2	3009.8	CHOUTEAU LS.	LS	80	MB	6	5Y6/1	DWN	ML	VTKL	5			0- 0	0	
02IL01L2		HANN.-SAV. SH.	IA	20	VTNB	8	5GY4/1	MS			5			0- 0	0	
02IL01C1	3011.4	HANN.-SAV. SH.	IIB	100	TNB	8	N2-N4	MS			5	>25		5-15	15	BU
02IL02C1	3021.4	HANN.-SAV. SH.	IIA	100	TKB	8	5YR2/1	MS			5	10		2-10	5	BU
02IL03C1	3043.3	GRASSY CREEK SH	IVB	100	TKB	8	5YR2/1	E	VTNL	TNL	0			1- 5	>25	BD
02IL04C1	3053.0	GRASSY CREEK SH	IVB	100	TKB	8	5Y2/1	E	VTNL	TNL	0			5-15	10	RN
02IL04C2	3059.2	GRASSY CREEK SH	IVB	100	TKB	8	5Y2/1	E	VTNL	TNL	0			2- 8	>25	BD
02IL05C1	3065.3	GRASSY CREEK SH	IVB	100	TKB	8	5Y3/1	E	VTNL	TNL	0			2- 7	>25	BD
02IL05L2	3071.5	GRASSY CREEK SH	IIIA	50	MB	8	5Y2/1	DE	ML	ML	2	10		5-15	10	BD
02IL05L2		GRASSY CREEK SH	IIB	50	MB	8	5Y4/1	MS			6	>25		0- 0	0	
02IL06C1	3073.3	GRASSY CREEK SH	IVB	80	TNB	8	5YR2/1	E	TNL	ML	0			1- 3	20	BD
02IL06C1		GRASSY CREEK SH	IIA	20	VTNB	8	5Y4/1	MS			4	5		10-15	2	BD
02IL06L2	3081.1	SWEETLAND CR.SH	IIA	80	TNB	8	5Y4/1	MS			5	15		5-10	5	BU
02IL06L2		SWEETLAND CR.SH	IIA	20	VTNB	8	5Y2/1	MS			2			0- 0	0	
02IL07C1	3085.6	SWEETLAND CR.SH	IIA	50	TNB	8	5GY6/1	MS			5	5		2- 5	10	RN
02IL07C1		SWEETLAND CR.SH	IIIA	50	TNB	8	5Y2/1	DE	VTNL	ML	0			2-10	5	BD
02IL08C1	3096.7	SWEETLAND CR.SH	IVB	100	TKB	8	5YR2/1	E	TNL	ML	1			1-10	>25	BD
02IL09L1	3106.0	LINGLE LS.	LS	100	TNB	2	10YR5/2	MS			3			0- 0	0	

* Depth below logging reference @ 612.1 feet above mean sea level.

COLUMN HEADINGS AND ABBREVIATIONS:

Lithofacies: Classification of Harvey et al., 1977.
%: Percent of total sample represented by described lithology.
Bed Tk.: Bed thickness. TKB=thick beds, >30 cm; MB=medium beds, 10-30cm; TNB=thin beds, 1-10cm; VTNB=very thin beds, <1 cm.
Grain Size: Average grain size of rock, in Ø units.
Laminations, type: E=even, parallel; DE=discontinuous, even parallel; DWN=discontinuous, wavy, non-parallel; MS=massive, nonlaminated.
Laminations, tk: Thickness of laminae. VTKL=very thick, >30mm; TKL=thick, 10-30mm; ML=medium, 3-10mm; TNL=thin, 1-3mm; VTNL=very thin, <1mm.
Laminations, space: Spacing of laminae; same abbreviations as for thickness.
Bioturb: Bioturbation. 6=totally boiturbated; 5=very strongly bioturbated, but bedding is visible; 4=strongly bioturbated; 3=medium bioturbated; 2=weakly bioturbated; 1=sporadic burrows; 0=no bioturbation.
Pyrite nodules, size: Size range in mm.
Pyrite nodules, dist.: Distribution of nodules. BD=along bedding; BU=burrows; RN=random.
Pyrite nodules, ab.: Abundance of nodules, as represented by approximate number counted on radiograph.

TABLE 2 - LITHOLOGIC CHARACTERIZATION, HENDERSON COUNTY, ILLINOIS, CORE SAMPLES.

SAMPLE NUMBER	DEPTH* (FT)	FORMATION	LITHO-FACIES	%	BED TK.	GRAIN SIZE	MUNSELL COLOR	LAMINATIONS TYPE	LAMINATIONS TK.	LAMINATIONS SPACE	BIO-TURB.	SYNAERESIS EARLY	SYNAERESIS LATE	PYRITE NODULES SIZE	PYRITE NODULES AB.	PYRITE NODULES DIST
04IL01C1	323.3	HANN.-SAV. SH.	IA	100	TKB	8	5GY3/2	MS			6	>25		2-12	20	RN
04IL02C1	333.0	HANN.-SAV. SH.	IA	100	TKB	8	5GY4/2	MS			6	>25		2-10	15	RN
04IL03C1	343.4	HANN.-SAV. SH.	IIB	100	TKB	8	5GY3/2	MS			6	20		0- 0	0	
04IL04C1	353.0	HANN.-SAV. SH.	IA	100	TKB	8	5GY3/2	MS			6	5		0- 0	0	
04IL05C1	363.3	HANN.-SAV. SH.	IA	95	TKB	8	5GY4/2	MS			6			3-10	5	BU
04IL05C1		HANN.-SAV. SH.	SS	5	VTNB	4	N4	W	TNL	TNL	1			1-10	>25	BD
04IL06C1	373.2	HANN.-SAV. SH.	IA	100	TKB	8	5GY3/2	MS			5	>25		0- 0	0	
04IL07C1	383.4	HANN.-SAV. SH.	IIA	100	TKB	8	5GY5/2	DE	TNL	VTKL	5			0- 0	0	
04IL08C1	393.1	HANN.-SAV. SH.	IIA	100	TKB	8	5GY3/2	DE	ML	TKL	5			0- 0	0	
04IL09C1	403.5	HANN.-SAV. SH.	IIIA	80	TNB	8	5GY3/2	DE	VTNL	TNL	3			0- 0	0	
04IL09C1		HANN.-SAV. SH.	IIA	20	VTNB	8	10GY5/2	MS			3			0- 0	0	
04IL10C1	413.4	HANN.-SAV. SH.	IIIA	100	MB	8	5GY3/2	DE	ML	TKL	3			0- 0	0	
04IL11C1	424.4	HANN.-SAV. SH.	IIIA	90	TNB	8	5GY4/1	DE	VTNL	ML	2			1- 7	5	BD
04IL11C1		HANN.-SAV. SH.	IIA	10	VTNB	8	5G6/1	MS			2			0- 0	0	
04IL12C1	433.3	HANN.-SAV. SH.	IIA	60	VTNB	8	5G4/1	MS			2			0- 0	0	
04IL12C1		HANN.-SAV. SH.	IIIA	40	VTNB	8	5Y2/1	DE	TNL	TNL	2			0- 0	0	
04IL13C1	443.2	HANN.-SAV. SH.	IIIA	60	VTNB	8	5Y2/1	DE	TNL	TNL	2			1- 4	15	BD
04IL13C1		HANN.-SAV. SH.	IIA	40	VTNB	8	5G4/1	MS			2			2- 2	2	RN
04IL14C1	453.0	HANN.-SAV. SH.	IIIA	60	VTNB	8	5Y2/1	DE	VTNL	TNL	2			1- 2	10	RN
04IL14C1		HANN.-SAV. SH.	IIA	40	VTNB	8	5G4/1	MS			2			0- 0	0	
04IL15C1	463.2	GRASSY CREEK SH	IIIA	100	TKB	8	5Y2/1	DE	VTNL	TNL	1			1- 2	20	BD
04IL16C1	473.0	GRASSY CREEK SH	IIIA	100	TKB	8	5Y2/1	E	VTNL	TNL	1			1- 2	25	BD
04IL17L1	480.2	GRASSY CREEK SH	IIIA	100	TKB	8	5Y2/1	DE	VTNL	TNL	2			0- 0	0	
04IL17C1	482.4	GRASSY CREEK SH	IIIA	100	TKB	8	5Y2/1	DE	VTNL	TNL	1			1- 2	20	BD
04IL18C1	493.2	GRASSY CREEK SH	IA	100	TKB	8	5GY3/2	MS			5			3-10	>25	BU
04IL19C1	503.2	GRASSY CREEK SH	IIA	100	TKB	8	5GY4/2	MS			5			2- 2	5	RN
04IL19L1	505.7	GRASSY CREEK SH	IIIA	75	TNB	8	5YR2/1	E	TNL	TKL	3			5-10	5	BU
04IL19L1		GRASSY CREEK SH	IA	25	TNB	8	5G5/2	MS			5	15		5-30	15	BU
04IL20C1	513.4	GRASSY CREEK SH	IIIA	100	TKB	8	5Y2/1	DE	ML	VTKL	4			5-10	10	BD
04IL21C1	523.2	GRASSY CREEK SH	IIIA	100	TKB	8	5Y3/1	DE	TNL	TNL	2			1- 1	10	RN
04IL22C1	533.0	GRASSY CREEK SH	IVB	100	TKB	8	5Y2/1	DE	TNL	TNL	1			2- 4	>25	BD
04IL23C1	542.2	GRASSY CREEK SH	IVB	100	TKB	8	5Y3/1	E	VTNL	TNL	1			1- 1	>25	
04IL24C1	553.4	GRASSY CREEK SH	IVA	100	TKB	8	5Y3/1	E	VTNL	VTNL	1			3- 8	12	RN
04IL25C1	563.2	GRASSY CREEK SH	IVA	100	TKB	8	5Y3/1	E	VTNL	VTNL	1			3-12	5	RN
04IL26C1	573.0	GRASSY CREEK SH	IVA	100	TKB	8	5Y3/1	E	VTNL	TNL	0			1- 1	>25	RN
04IL27L1	582.6	GRASSY CREEK SH	IIIA	20	TNB	8	5YR2/1	DE	ML	TKL	3			1-10	5	BU
04IL27L1		SWEETLAND CR,SH	IA	80	MB	8	5GY5/2	MS			5			3-10	>25	BU
04IL27C1	583.4	SWEETLAND CR,SH	IA	100	TKB	8	5GY4/1	MS			6	>25		1- 3	5	BU
04IL28C1	593.2	SWEETLAND CR,SH	IA	100	TKB	8	5GY5/1	MS			6	>25		2-12	15	RN
04IL29L1	603.2	SWEETLAND CR,SH	IB	50	MB	6	10Y4/2	MS			6			2- 4	>25	BU
04IL29L1		SYLAMORE SS.	SS	50	MB	5	5Y6/2	MS			6			0- 0	0	
04IL29C1	604.5	CEDAR VALLEY LS	LS	100	TKB	3	5Y6/2	MS			6			0- 0	0	
04IL30C1	613.3	CEDAR VALLEY LS	LS	100	TKB	1	5Y6/2	MS			5			0- 0	0	

* Depth (to top of sample) below logging reference @ 772 ft. above mean sea level.

See table 1 for column headings and abbreviations. (Lamination type W=Wavy, parallel.)

TABLE 3 - LITHOLOGIC CHARACTERIZATION, EDGAR COUNTY, ILLINOIS, CORE SAMPLES.

SAMPLE NUMBER	DEPTH* (FT)	FORMATION	LITHO-FACIES	%	BED TK.	GRAIN SIZE	MUNSELL COLOR	LAMINATIONS TYPE	LAMINATIONS TK.	LAMINATIONS SPACE	BIØ-TURB.	SYNAERESIS EARLY	SYNAERESIS LATE	PYRITE NODULES SIZE	PYRITE NODULES AB.	PYRITE NODULES DIST
Ø5ILØ1L1	655.9	SWEETLAND CR.SH	IVB	1ØØ	TKB	8	5YR2/1	E	VTNL	VTNL	Ø			Ø- Ø	Ø	
Ø5ILØ1L2	660.2	SWEETLAND CR.SH	IIA	9Ø	TNB	8	N2	MS			4			1- 5	2Ø	BU
Ø5ILØ1L2		SWEETLAND CR.SH	IIIA	1Ø	VTNB	8	5Y4/1	DE	ML	ML	2			3- 5	15	BD
Ø5ILØ1L3	662.2	SWEETLAND CR.SH	IIA	5Ø	TNB	8	5YR2/1	MS			2			3- 7	2Ø	BU
Ø5ILØ1L3		SWEETLAND CR.SH	IIA	5Ø	TNB	8	5Y4/1	MS			5			3- 7	2Ø	BU

*Depth (to top of sample) below drilling reference at 654 ft. above mean sea level.
See Table 1 for column headings and abbreviations.

TABLE 4--LITHOLOGIC CHARACTERIZATION, TAZEWELL COUNTY, ILLINOIS, CORE SAMPLES

SAMPLE NUMBER	DEPTH* (FT)	FORMATION	LITHO-FACIES	%	BED TK.	GRAIN SIZE	MUNSELL COLOR	LAMINATIONS TYPE	LAMINATIONS TK.	LAMINATIONS SPACE	BIO-TURB.	SYNAERESIS EARLY	SYNAERESIS LATE	PYRITE NODULES SIZE	PYRITE NODULES AB.	PYRITE NODULES DIST
Ø6ILØ4C1	933.4	HANN.-SAV. SH.	IIB	1ØØ	TKB	8	5GY3/2	MS			5	>25		Ø- Ø	Ø	
Ø6ILØ6C1	954.0	HANN.-SAV. SH.	IIA	1ØØ	TKB	8	5GY3/2	MS			5	1Ø		1-2Ø	>25	BU
Ø6ILØ7C1	962.2	HANN.-SAV. SH.	IIB	1ØØ	TKB	8	5GY3/2	MS			5	>25		2Ø-2Ø	1	BU
Ø6ILØ8C1	973.4	HANN.-SAV. SH.	IIA	1ØØ	MB	8	5G2/1	MS			4			2-15	>25	BU
Ø6ILØ9C1	984.2	HANN.-SAV. SH.	IIB	1ØØ	TKB	8	5GY3/2	MS			5	>25		Ø- Ø	Ø	
Ø6IL1ØC1	993.1	HANN.-SAV. SH.	IIIA	75	TNB	8	5Y3/2	DE	TNL	ML	2			Ø- Ø	Ø	
Ø6IL1ØC1		HANN.-SAV. SH.	IIA	25	VTNB	8	5G4/1	MS			4			Ø- Ø	Ø	
Ø6IL11C1	1003.2	HANN.-SAV. SH.	IIIA	9Ø	TNB	8	5GY3/2	DE	VTNL	TNL	1			Ø- Ø	Ø	
Ø6IL11C1		HANN.-SAV. SH.	IIA	1Ø	VTNB	8	5GY5/2	MS			3			Ø- Ø	Ø	
Ø6IL11L1	1005.3	HANN.-SAV. SH.	IIIA	6Ø	TNB	8	5Y3/1	DE	VTNL	TNL	1			Ø- Ø	Ø	
Ø6IL11L1		HANN.-SAV. SH.	IIA	4Ø	VTNB	8	5G5/1	MS			3			Ø- Ø	Ø	
Ø6IL12C1	1014.1	HANN.-SAV. SH.	IIA	1ØØ	TKB	8	5GY3/1	DE	TNL	ML	3			Ø- Ø	Ø	
Ø6IL13C1	1024.1	HANN.-SAV. SH.	IIA	5Ø	TNB	8	5G4/1	E	VTNL	TKL	2			Ø- Ø	Ø	
Ø6IL13C1		HANN.-SAV. SH.	IIIA	5Ø	TNB	8	5Y2/1	E	VTNL	TNL	1			3- 4	4	BD
Ø6IL13L1	1025.5	HANN.-SAV. SH.	IIA	5Ø	TNB	8	5G5/1	E	VTNL	TKL	2			Ø- Ø	Ø	
Ø6IL13L1		HANN.-SAV. SH.	IIIA	5Ø	TNB	8	5Y3/1	E	VTNL	ML	1			1- 7	5	BD
Ø6IL13L2	1029.1	HANN.-SAV. SH.	IIIA	75	TNB	8	5Y2/1	E	TNL	ML	1			2Ø-2Ø	1	BD
Ø6IL13L2		HANN.-SAV. SH.	IIA	25	TNB	8	5G4/1	MS			1			Ø- Ø	Ø	
Ø6IL14L1	1032.8	HANN.-SAV. SH.	IIA	75	TNB	8	5G4/1	MS			2			Ø- Ø	Ø	
Ø6IL14L1		HANN.-SAV. SH.	IIIA	25	VTNB	8	5Y2/1	E	VTNL	TKL	1			Ø- Ø	Ø	
Ø6IL14C1	1034.2	HANN.-SAV. SH.	IIA	6Ø	TNB	8	5G4/1	MS			2			1- 3	>25	RN
Ø6IL14C1		HANN.-SAV. SH.	IIIA	4Ø	VTNB	8	5Y2/1	E	VTNL	TNL	1			Ø- Ø	Ø	
Ø6IL15C1	1044.1	HANN.-SAV. SH.	IIA	6Ø	VTNB	8	5G4/1	MS			2			Ø- Ø	Ø	
Ø6IL15C1		HANN.-SAV. SH.	IIIA	4Ø	VTNB	8	5Y2/1	E	VTNL	TNL	1			Ø- Ø	Ø	
Ø6IL16C1	1053.2	HANN.-SAV. SH.	IIA	5Ø	VTNB	8	5G4/1	MS			2			1- 1	>25	RN
Ø6IL16C1		HANN.-SAV. SH.	IIIA	5Ø	VTNB	8	5Y2/1	E	VTNL	TNL	1			Ø- Ø	Ø	
Ø6IL17C1	1063.2	HANN.-SAV. SH.	IVB	7Ø	TNB	8	5Y2/1	E	VTNL	TNL	Ø			1- 5	>25	BD
Ø6IL17C1		HANN.-SAV. SH.	IIA	3Ø	VTNB	8	5G4/1	MS			1			1- 2	>25	RN
Ø6IL18C1	1073.3	HANN.-SAV. SH.	IIIA	1ØØ	MB	8	5YR2/1	E	VTNL	ML	Ø			1- 1	>25	BD
Ø6IL19C1	1083.2	GRASSY CREEK SH	IVA	1ØØ	TKB	8	5YR2/1	E	VTNL	VTNL	1			Ø- Ø	Ø	
Ø6IL19L1	1085.2	GRASSY CREEK SH	IIIA	5Ø	MB	8	N2	E	VTNL	TNL	Ø			Ø- Ø	Ø	
Ø6IL19L1		GRASSY CREEK SH	IVA	5Ø	MB	8	N2	E	VTNL	VTNL	Ø			1-1Ø	>25	BD
Ø6IL2ØC1	1093.4	GRASSY CREEK SH	IVA	1ØØ	TKB	8	5YR2/1	E	TNL	TNL	Ø			4-2Ø	6	RN
Ø6IL21L1	1101.8	GRASSY CREEK SH	IIIA	1ØØ	TKB	8	5YR2/1	E	ML	ML	Ø			3-13	2Ø	BD
Ø6IL21C1	1103.1	GRASSY CREEK SH	IVA	1ØØ	TKB	8	5Y2/1	E	VTNL	VTNL	1			3- 4	3	RN
Ø6IL22L1	1111.4	GRASSY CREEK SH	IIIA	7Ø	TKB	8	5Y2/1	E	TNL	ML	1			1- 8	2Ø	BD
Ø6IL22L1		SWEETLAND CR.SH	IIB	3Ø	TNB	8	1ØGY5/2	MS			5	>25		1- 3	>25	BU
Ø6IL22C1	1113.4	SWEETLAND CR.SH	IIIA	1ØØ	TKB	8	5Y3/1	DE	ML	ML	2			3- 8	9	RN
Ø6IL23C1	1123.5	SWEETLAND CR.SH	IIIA	1ØØ	TKB	8	5Y3/1	DE	TNL	TNL	Ø			2- 3	2Ø	RN
Ø6IL24C1	1133.4	SWEETLAND CR.SH	IIA	1ØØ	TKB	7	5Y4/1	MS			5			1-1Ø	>25	BU
Ø6IL25L1	1141.1	SWEETLAND CR.SH	IA	1ØØ	TKB	8	5Y4/1	MS			6	>25		2-1Ø	>25	BU
Ø6IL25C1	1143.5	SWEETLAND CR.SH	IVB	1ØØ	TKB	8	5Y2/1	E	VTNL	VTNL	Ø			1-25	>25	BD
Ø6IL25L2	1145.7	SWEETLAND CR.SH	IVB	25	TKB	8	5Y2/1	E	VTNL	TNL	Ø			1- 2	>25	BD
Ø6IL25L2		SYLAMORE SS.	SS	25	TNB	Ø	5Y4/1	E	ML	ML	Ø			1- 3	>25	BD
Ø6IL25L2		CEDAR VALLEY LS	LS	5Ø	TKB	-1	1ØYR6/2	MS			6			1-3Ø	>25	BU

*Depth (to top of sample) below drilling reference at 641 ft. above mean sea level.
See Table 1 for column headings and abbreviations.

TABLE 5--LITHOLOGIC CHARACTERIZATION, FAYETTE COUNTY, ILLINOIS, CORE SAMPLES

SAMPLE NUMBER	DEPTH* (FT)	FORMATION	LITHO-FACIES	%	BED TK.	GRAIN SIZE	MUNSELL COLOR	LAMINATIONS TYPE	LAMINATIONS TK.	LAMINATIONS SPACE	BIO-TURB.	SYNAERESIS EARLY	SYNAERESIS LATE	PYRITE NODULES SIZE	PYRITE NODULES AB.	PYRITE NODULES DIST
07IL01L1	2719	CHOUTEAU LS.	LS	100	TKB	6	5Y4/2	MS			5			0- 0	0	
07IL01L2	2731	HANNIBAL SH.	IIIA	100	TKB	8	N2	DE	TNL	ML	0			0- 0	0	
07IL01L3	2737	HANNIBAL SH.	IIA	100	TKB	8	5Y3/2	MS			4			1- 3	2	RN
07IL02L2	2771.8	LOUISIANA LS.	LS	60	MB	8	5Y4/1	MS			5			0- 0	0	
07IL02L2		SAVERTON SH.	IIA	40	MB	8	5G5/1	MS			5			0- 0	0	
07IL03L1	2780.4	SAVERTON SH.	IIA	100	VTKB	8	N2	MS			2	10		0- 0	0	
07IL04L1	2811.0	GRASSY CREEK SH	IVB	100	TKB	8	5YR2/1	E	TNL	TNL	0			2-10	20	BD
07IL04L2	2813.1	SWEETLAND CR.SH	IIIA	100	TKB	8	5YR2/1	E	TNL	ML	0			1- 3	>25	BD
07IL05L1	2821.5	SYLAMORE SS	SS	100	MB	1	N6	MS			6			7- 7	1	BU

*Depth (to top of sample) below drilling reference at 525 ft. above mean sea level.
See Table 1 for column headings and abbreviations.

TABLE 6 - DRILL CUTTING SAMPLE LOCATIONS

Sample Numbers (NAS-)	County	Sec-T-R	Well Name
001-027	(various locations)		outcrop samples
028-029	Clay	16-3N-6E	So. Ill. Oil #1 Mearns
030-032	Effingham	32-6N-5E	Juniper Petrl. 12x-32 Gerth
033-034	Jefferson	18-3S-1E	Dunnill #1 Kujawa
035-039	Madison	35-5N-7W	B. Hall #1 Wehling
040-043	Mason	3-19N-10W	Pinkston #1 Blessman
044-045	Washington	30-2S-3W	Amoco Prod. #1 Kolweier
046-047	Washington	27-3S-1W	Juniper Petrl. #24x-27 Kubiak
048-051	Washington	1-3S-4W	Anschutz #1 Elgenrauch
052-055	Wayne	27-1N-7E	Pure Oil #3 Billington
056-059	Wayne	14-1N-8E	Nation Oil #1 Van Fossan-Brown
060-063	Wayne	28-1S-6E	Texaco NCT-1 Fuhrer
064-068	Wayne	29-2S-9E	Collins Bros. #1 Hill
069-074	Wayne	4-3S-7E	Savage/Zephyr #1 Sprague
075-082	Wise, VA		
083-088	Christian	28-13N-1W	Union Oil #1 Cleveland
089-092	Gallatin	11-8S-10E	Humble Oil #33 Busiek-Crawford
093-097	Gallatin	29-9S-9E	Texaco Walters
098-102	Greene	32-11N-11W	Kewanee Oil #1 Eula
103-105	Lawrence	29-4N-12W	Atlantic Richfield #77 Lewis
106-107	Logan	7-19N-3W	Allspach #1 Park
108-112	Macon	33-18N-2E	Hill #1 Haynes
113-117	Pope	10-13S-6E	Williams #1 Austin
118-121	Saline	34-10S-6E	Texas Pacific #1 Wells
122-126	Saline	32-10S-7E	Texota Oil #1 King
127-133	Wabash	9-1S-12W	So. Triangle Oil #D2 Zimmerman
134-135	Woodford	28-27N-3W	Centrl. Ill. Light #C18 Cilco
136-138	Champaign	12-22N-11E	Peoples Gas #1 Condit
139-141	Christian	25-11N-1E	Franks Petrl. #1 Wagner
142-146	Clay	11-2N-5E	Keystone Oil #1 Woomer-Campbell
147-149	Clark	4-10N-11W	Corley #1 Miller
150-151	Coles	27-12N-7E	Energy Prod. #G-1 Arterburn
152-155	Coles	20-14N-7E	Brehm #1 Lambert
156-157	Crawford	2-5N-11W	Bell #1 Miller
158-161	Crawford	12-5N-14W	Doheny #1 Arnold
162	Crawford	36-6N-11W	Slape Drilling #1 Kincaid
163	Crawford	6-7N-11W	K Oil #1 Mehler
164-165	Crawford	12-7N-11W	W Drilling #1 Brown
166-167	Crawford	31-7N-13W	Ill. Oil Invest #1 Mallory et al.
168-170	Cumberland	4-10N-9E	Texaco #1 McCandlish
171-174	De Witt	1-20N-4E	Peoples Gas #1 Lamb
175-176	Edgar	4-14N-14W	Jones-Simpson Drill. #1 Steele-Moss
177-178	Edgar	1-14N-14W	Wansan Petrl. #1 Sims
179-181	Effingham	3-7N-7E	Energy Res. #1 Niemerg
182-186	Hamilton	1-4S-5E	Kewanee Oil #1 Wellen
187-190	Hamilton	13-6S-5E	Shell Oil #4 Mohave
191-193	Hamilton	6-6S-7E	Texaco #1 Cuppy

TABLE 6 - CONTINUED

Sample Numbers	County	Sec-T-R	Well Name
194-196	Iroquois	21-24N-13W	Peoples Gas #1 Mumm
197-199	Iroquois	13-25N-11W	Peoples Gas #1 Keen
200-203	Jasper	1-8N- 8E	Total Leonard #1 Thoele
204-206	Jefferson	32-4S-3E	Juniper Petrl. #33x-32 Hayse
207-208	Lawrence	9-3N-11W	Shellensker Drill. #1 Seward
209	Madison	23-4N-5W	Stocker & Sitler #1 Suess
210-212	Marion	35-3N-2E	Brehm Drill. #1 Behnke
213-215	Lawrence	25-3N-13W	Highland Oil #1 Hobbs
216-217	McDonough	23-4N-2W	Bur-kan Petrl. #1 Chipman
218-220	McLean	33-23N-2E	Zimmerman #1 McLean Co.
221-225	McLean	31-23N-3E	Union Hill Gas #1 Bozarth
226-227	McLean	26-23N-6E	Garland & Hoover #1 Green
228-230	Piatt	13-21N-6E	Union Hill Gas #1 Buchan
231-233	Sangamon	11-15N-3W	Corley #1 Anderson
234-235	Sangamon	1-16N-6W	Caney Oil #1 Eugene
236-238	Vermillion	12-19N-11W	Allied Chem. #1 Allied Chem.
239-240	Vermillion	10-23N-11W	Peoples Gas Layden
241-243	Vermillion	15-23N-14W	Peoples Gas #1 Swanson
244-250	White	23-6N-9E	Haley Prod. #1 Trainor
251-253	Williamson	25-8S-3E	Brehm Drill. #1 Harris Unit
254-257	Macoupin	23-12N-6W	Crown II Mine (Penn. samples)
258-260	Williamson	17-9S-4E	Amax-Delta Mine (Penn. samples)
261-264	Gallatin	14-10S-8E	Eagle Strip Mine (Penn. samples)

TABLE 7—CLAY MINERALOGY AND ORIENTATION, EFFINGHAM COUNTY, ILLINOIS, CORE SAMPLES.

SAMPLE NUMBER	DEPTH*	ILL	CHL	EXP	COI
02IL01C1	3011.4	5.5	2.5	2.5	2.5
02IL02C1	3021.4	6.0	2.5	1.5	1.2
02IL03C1	3043.3	5.5	2.5	2.0	2.4
02IL04C1	3053.0	7.0	2.0	1.0	2.1
02IL04C2	3059.5	7.0	2.0	.5	1.5
02IL05C1	3065.3	6.0	2.5	1.5	1.7
02IL05L2	3071.5	7.0	2.0	1.0	1.3
02IL06C1	3073.3	5.5	2.0	2.5	2.3
02IL06L2	3081.1	7.5	2.5	0.0	2.1
02IL07C1	3085.6	5.0	2.0	3.0	1.8
02IL08C1	3096.7	5.5	2.5	2.5	2.5

*Depth (to top of sample) below drilling reference at 612.1 feet above mean sea level.

COLUMN HEADINGS: ILL = illite; CHL = chlorite; KAO = kaolinite; EXP = expandable mixed-structure clays; COI = clay orientation index; LTA = organic content determined by weight loss during low-temperature ashing.

TABLE 8—WHOLE ROCK MINERALOGY, EFFINGHAM COUNTY, ILLINOIS, CORE SAMPLES.

OBSERVED PEAK HEIGHTS (COUNTS/SEC)

SAMPLE	DEPTH*	MCA	QTZ	FLD	KSP	PLG	KSP/PLG	CAL	DOL	CAL+DOL	SID+APA	PYR	MAR	PYR+MAR	MINERAL
NUMBER		19.8	20.8	23.5	27.6	27.9		29.4	30.8		32.1	33.2	52.0		TWO THETA
02IL01C1		55	175	30	0	80	0/100	0	0	0	10	0	0	0	
02IL01L2		15	30	0	0	10	0/100	500	50	550	0	0	0	0	
02IL02C1		60	185	35	5	70	6/ 93	0	0	0	10	5	5	10	
02IL03C1		50	150	25	0	45	0/100	0	0	0	10	25	10	35	
02IL04C1		55	170	20	0	45	0/100	15	0	15	10	55	15	70	
02IL04C2		60	140	30	40	50	44/ 55	0	75	75	15	40	12	52	
02IL05C1		60	140	30	45	60	42/ 57	10	55	65	20	40	10	50	
02IL05L2		60	130	30	0	60	0/100	0	80	80	20	15	5	20	
02IL06C1		60	135	30	0	70	0/100	15	25	40	15	30	10	40	
02IL06L2		70	140	30	5	55	8/ 91	55	35	90	21	18	5	23	
02IL07C1		70	130	25	40	60	39/ 59	0	30	30	20	25	5	30	
02IL08C1		70	105	25	50	60	45/ 54	15	45	60	20	32	7	39	
02IL09L1		0	205	0	0	0	0/ 0	500	195	695	10	10	0	10	

*Depth (to top of sample) below drilling reference at 612.1 feet above mean sea level.

COLUMN HEADINGS: MCA = mica; QTZ = quartz; FLD = all feldspars; KSP = potassium feldspar; PLG = plagioclase; CAL = calcite; DOL = dolomite; SID & APA = siderite and/or apatite; PYR = pyrite; MAR = marcasite.

TABLE 9 - CLAY MINERALOGY AND ORGANIC CONTENT, WHITE COUNTY, ILLINOIS, CORE SAMPLES.

SAMPLE NUMBER	DEPTH*	clays (parts/10) ILL	CHL	EXP	LTA %
Ø3ILØ4L1	4510	7.Ø	1.Ø	2.Ø	9.6
Ø3ILØ9L1	4560	8.Ø	1.Ø	1.Ø	4.5
Ø3IL19L1	4661	6.5	1.5	2.Ø	9.1
Ø3IL2ØL2	4675	8.5	Ø.Ø	1.5	3.1
Ø3IL22L1	4695	8.5	1.Ø	1.Ø	3.3
Ø3IL24L1	4715	7.5	Ø.Ø	2.5	2.4
Ø3IL26L2	4744	7.Ø	Ø.Ø	3.Ø	2.5

*Depth (to top of sample) below drilling reference at 385 feet above mean sea level.

See table 7 for column headings.

TABLE 10- WHOLE ROCK MINERALOGY, WHITE COUNTY, ILLINOIS, CORE SAMPLES.

OBSERVED PEAK HEIGHTS (COUNTS/SEC)

SAMPLE NUMBER	DEPTH*	MCA	QTZ	FLD	KSP	PLG	KSP/PLG	CAL	DOL	CAL+DOL	SID+APA	PYR	MAR	PYR+MAR	MINERAL TWO THETA
		19.8	20.8	23.5	27.6	27.9		29.4	30.8		32.1	33.2	52.Ø		
Ø3ILØ1L1	4480	35	66	15	Ø	3Ø	Ø/1ØØ	3Ø5	4Ø	345	15	Ø	Ø	Ø	
Ø3ILØ7L1	4540	45	144	2Ø	Ø	5Ø	Ø/1ØØ	12	4Ø	52	15	45	17	62	
Ø3IL12L1	4590	55	132	25	35	5Ø	41/ 58	Ø	35	35	17	3Ø	13	43	
Ø3IL2ØL1	4673	72	12Ø	33	5Ø	65	43/ 56	2Ø	97	117	15	1Ø	Ø	1Ø	
Ø3IL2ØL3	4676	47	1Ø7	35	45	55	44/ 54	Ø	213	213	15	1Ø	Ø	1Ø	
Ø3IL23L1	4705	48	122	25	Ø	53	Ø/1ØØ	15	93	1Ø8	1Ø	37	5	42	
Ø3IL26L1	4735	52	137	3Ø	5Ø	45	52/ 47	3Ø	135	165	1Ø	16	Ø	16	

*Depth (to top of sample) below drilling reference at 385 feet above mean sea level.

See table 8 for column headings.

TABLE 11 - CLAY MINERALOGY AND ORIENTATION, HENDERSON COUNTY, ILLINOIS, CORE SAMPLES.

SAMPLE NUMBER		DEPTH*	clays (parts/10) ILL	CHL	KAO	EXP	COI
04IL01C1		323.3	7.5	2.5	0.0	0.0	1.4
04IL02C1		333.0	6.0	2.0	0.0	1.5	1.5
04IL03C1		343.4	5.5	2.5	0.0	2.0	1.0
04IL04C1		353.0	6.0	2.5	0.0	1.5	1.9
04IL05C1		363.3	5.5	2.0	0.0	2.5	1.3
04IL06C1		373.2	5.5	2.5	0.0	2.0	1.5
04IL07C1		383.4	5.0	2.0	0.0	3.0	1.2
04IL08C1		393.1	5.0	2.5	0.0	2.5	1.5
04IL09C1		403.5	5.0	2.0	0.0	3.0	1.3
04IL10C1		413.4	6.0	3.0	0.0	1.5	1.4
04IL11C1		424.4	5.5	3.0	0.0	1.5	1.2
04IL12C1		433.3	6.0	2.5	0.0	1.5	1.5
04IL13C1		443.2	6.0	2.5	0.0	1.5	1.5
04IL14C1		453.0	6.5	2.5	0.0	1.0	2.5
04IL15C1		463.2	5.5	2.5	0.0	1.5	1.7
04IL16C1		473.0	5.0	2.0	0.0	3.0	1.3
04IL17L1		480.2	6.5	2.5	0.0	1.0	1.2
04IL17C1		482.4	5.0	2.5	0.0	3.0	1.3
04IL18C1		493.2	5.0	2.5	0.0	2.5	1.1
04IL19C1		503.2	6.5	2.0	0.0	1.0	1.1
04IL19L1	1	505.7	5.5	2.5	0.0	2.0	1.6
04IL19L1	2	505.7	0.0	0.0	0.0	0.0	3.3
04IL20C1		513.4	6.5	2.0	0.0	1.5	1.4
04IL21C1		523.2	6.5	2.0	0.0	2.0	2.0
04IL22C1		533.0	5.5	2.5	0.0	1.5	1.7
04IL23C1		542.2	5.0	2.5	0.0	2.5	1.9
04IL24C1		553.4	6.5	2.5	0.0	1.5	1.3
04IL25C1		563.2	6.5	2.5	0.0	1.5	1.4
04IL26C1		573.0	6.0	2.5	0.0	1.5	1.2
04IL27L1	1	582.6	6.5	3.0	0.0	.5	1.3
04IL27L1	2	582.6	0.0	0.0	0.0	0.0	1.0
04IL27C1		583.4	6.0	2.5	0.0	1.5	1.3
04IL28C1		593.2	5.5	2.5	0.0	2.0	1.1
04IL29L1		603.2	5.5	2.0	.5	1.5	1.3
04IL29L1	2	603.2	5.0	1.5	0.0	3.0	****
04IL29L1	3	603.2	7.5	2.0	0.0	.5	****
04IL29C1		604.5	6.5	1.5	0.0	2.0	****
04IL30C1		613.3	6.0	2.0	0.0	2.0	****

*Depth (to top of sample) below drilling reference at 772 feet above mean sea level.

See Table 7 for column headings.

TABLE 12- WHOLE ROCK MINERALOGY, HENDERSON COUNTY, ILLINOIS CORE SAMPLES.

OBSERVED PEAK HEIGHTS (COUNTS/SEC)

SAMPLE NUMBER	DEPTH*	MCA	QTZ	FLD	KSP	PLG	KSP/PLG	CAL	DOL	CAL+DOL	SID+APA	PYR	MAR	PYR+MAR	MINERAL TWO THETA
		19.8	20.8	23.5	27.6	27.9		29.4	30.8		32.1	33.2	52.0		
04IL01C1	323.3	65	125	50	70	0	100/ 0	0	245	245	15	12	0	12	
04IL02C1	333.0	60	145	35	65	0	100/ 0	0	280	280	20	25	0	25	
04IL03C1	343.4	60	110	40	55	0	100/ 0	0	360	360	15	15	0	15	
04IL04C1	353.0	65	105	45	70	0	100/ 0	0	230	230	12	10	0	10	
04IL05C1	363.3	55	120	45	65	0	100/ 0	0	360	360	12	20	0	20	
04IL06C1	373.2	60	120	55	75	0	100/ 0	0	265	265	10	17	0	17	
04IL07C1	383.4	70	100	65	75	0	100/ 0	0	225	225	20	20	0	20	
04IL08C1	393.1	60	90	55	85	0	100/ 0	0	200	200	15	20	0	20	
04IL09C1	403.5	60	100	50	65	0	100/ 0	0	160	160	17	15	0	15	
04IL10C1	413.4	70	110	50	65	0	100/ 0	0	135	135	12	10	0	10	
04IL11C1	424.4	60	105	45	60	0	100/ 0	0	165	165	15	20	0	20	
04IL12C1	433.3	60	115	45	70	0	100/ 0	0	165	165	12	25	0	25	
04IL13C1	443.2	60	110	50	70	0	100/ 0	0	150	150	10	0	0	0	
04IL14C1	453.0	65	105	50	70	0	100/ 0	0	125	125	15	25	0	25	
04IL15C1	463.2	85	165	26	45	45	50/ 50	20	45	65	25	17	0	17	
04IL16C1	473.0	75	175	35	50	0	100/ 0	20	70	90	25	15	0	15	
04IL17L1	480.2	55	140	20	50	0	100/ 0	0	60	60	15	15	0	15	
04IL17C1	482.4	80	195	25	50	40	55/ 44	25	75	100	0	15	0	15	
04IL18C1	493.2	80	190	25	50	45	52/ 47	25	40	65	20	15	0	15	
04IL19C1	503.2	80	190	35	50	45	52/ 47	20	45	65	0	0	0	0	
04IL19L1	505.7	55	120	20	40	38	51/ 48	0	36	36	18	12	0	12	
04IL20C1	513.4	75	160	20	70	0	100/ 0	20	50	70	12	25	5	30	
04IL21C1	523.2	80	135	25	50	50	50/ 50	0	90	90	30	17	0	17	
04IL22C1	533.0	75	140	25	50	50	50/ 50	30	95	125	30	40	0	40	
04IL23C1	542.2	75	125	30	50	50	50/ 50	0	90	90	30	30	5	35	
04IL24C1	553.4	75	145	25	60	55	52/ 47	25	160	185	35	25	5	30	
04IL25C1	563.2	75	120	30	50	50	50/ 50	0	200	200	0	15	0	15	
04IL26C1	573.0	70	135	20	40	40	50/ 50	20	65	85	25	35	10	45	
04IL27L1	582.6	55	82	25	35	23	60/ 39	29	350	379	10	15	0	15	
04IL27C1	583.4	60	75	20	25	20	55/ 44	0	500	500	15	25	0	25	
04IL28C1	593.2	70	95	20	25	15	62/ 37	15	500	515	0	15	0	15	
04IL29L1	603.2	16	125	10	18	0	100/ 0	20	500	520	0	0	0	0	
04IL29C1	604.5	20	175	5	25	0	100/ 0	60	500	560	5	55	0	55	
04IL30C1	613.3	20	40	0	0	0	0/ 0	500	500	1000	0	10	0	10	

*Depth (to top of sample) below drilling reference at 772 feet above mean sea level.

See table 8 for column headings.

TABLE 13 - CLAY MINERALOGY AND ORIENTATION, EDGAR COUNTY, ILLINOIS, CORE SAMPLES.

SAMPLE NUMBER	DEPTH*	clays (parts/10) ILL	CHL	KAO	EXP	COI
Ø5ILØ1L1	655.9	4.5	2.5	.5	2.5	1.7
Ø5ILØ1L2	660.2	5.Ø	2.5	.5	2.Ø	1.7
Ø5ILØ1L3	662.2	4.Ø	2.Ø	.5	3.5	1.5

*Depth (to top of sample) below drilling reference at 654 feet above mean sea level.

See Table 7 for column headings.

TABLE 14- WHOLE ROCK MINERALOGY, EDGAR COUNTY, ILLINOIS, CORE SAMPLES.

OBSERVED PEAK HEIGHTS (COUNTS/SEC)

SAMPLE	DEPTH*	MCA	QTZ	FLD	KSP	PLG	KSP/PLG	CAL	DOL	CAL+DOL	SID+APA	PYR	MAR	PYR+MAR	MINERAL
NUMBER		19.8	20.8	23.5	27.6	27.9		29.4	30.8		32.1	33.2	52.0		TWO THETA
05IL01L1	655.9	60	115	25	40	0	100/ 0	0	55	55	20	47	7	54	
05IL01L2	660.2	65	140	28	48	0	100/ 0	0	62	62	15	25	0	25	
05IL01L3	662.2	48	105	28	45	0	100/ 0	0	65	65	13	34	6	40	

*Depth (to top of sample) below drilling reference at 654 feet above mean sea level.

See Table 8 for column headings.

TABLE 15- CLAY MINERALOGY AND ORIENTATION, TAZEWELL COUNTY, ILLINOIS, CORE SAMPLES.

SAMPLE NUMBER		DEPTH*	clays (parts/10) ILL	CHL	KAO	EXP	COI
06IL04C1		933.4	4.5	2.0	0.0	3.5	.9
06IL05C1		943.5	7.5	2.0	0.0	.5	****
06IL06C1		954.0	5.5	2.0	0.0	2.5	1.2
06IL07C1		962.2	5.0	2.0	0.0	2.5	1.2
06IL08C1		973.4	5.5	2.5	0.0	2.5	1.2
06IL09C1		984.2	5.5	2.5	0.0	2.0	1.3
06IL10C1		993.1	5.0	2.5	0.0	2.5	1.3
06IL11C1		1003.2	6.0	3.0	0.0	1.0	1.3
06IL11L1		1005.3	6.0	2.5	0.0	1.5	2.5
06IL12C1		1014.1	6.5	3.0	0.0	1.0	1.5
06IL13C1		1024.1	6.0	2.5	0.0	1.0	2.0
06IL13L1		1025.5	4.5	2.0	0.0	3.5	1.4
06IL13L1	2	1025.5	0.0	0.0	0.0	0.0	2.0
06IL13L2		1029.1	5.0	2.5	0.0	2.5	2.9
06IL14L1	1	1032.8	4.5	2.5	.5	2.5	2.2
06IL14L1	2	1032.8	0.0	0.0	0.0	0.0	1.9
06IL14C1		1034.2	6.0	2.5	0.0	1.5	1.6
06IL15C1		1044.1	6.0	2.5	0.0	1.5	1.1
06IL16C1		1053.2	6.5	2.0	0.0	1.0	1.4
06IL17C1		1063.2	6.5	2.0	0.0	1.5	1.9
06IL18C1		1073.3	6.5	2.0	0.0	1.0	1.9
06IL19C1		1083.2	7.0	2.5	0.0	.5	1.6
06IL19L1		1085.2	6.5	2.5	.5	.1	1.7
06IL19L1	2	1085.2	0.0	0.0	0.0	0.0	1.8
06IL20C1		1093.4	6.0	3.0	0.0	1.0	1.8
06IL21L1	1	1101.8	5.0	2.5	.1	2.0	1.5
06IL21L1	2	1101.8	0.0	0.0	0.0	0.0	2.0
06IL21C1		1103.1	6.5	2.5	0.0	1.0	1.7
06IL22L1		1111.4	6.0	2.5	.1	2.0	1.3
06IL22L1	2	1111.4	0.0	0.0	0.0	0.0	1.7
06IL22C1		1113.4	6.5	2.5	0.0	1.0	1.4
06IL23C1		1123.5	6.5	2.5	0.0	1.0	1.9
06IL24C1		1133.4	6.0	2.5	0.0	1.5	1.2
06IL25L1	1	1141.1	7.5	2.5	0.0	.1	1.3
06IL25L1	2	1141.1	0.0	0.0	0.0	0.0	1.8
06IL25C1		1143.5	6.0	1.5	0.0	2.5	2.4
06IL25L2	1	1145.7	0.0	0.0	0.0	0.0	2.0
06IL25L2	2	1145.7	0.0	0.0	0.0	0.0	1.9

*Depth (to top of sample) below drilling reference at 641 feet above mean sea level.

See Table 7 for column headings.

TABLE 16– WHOLE ROCK MINERALOGY, TAZEWELL COUNTY, ILLINOIS, CORE SAMPLES.

OBSERVED PEAK HEIGHTS (COUNTS/SEC)

SAMPLE NUMBER	DEPTH*	MCA	QTZ	FLD	KSP	PLG	KSP/PLG	CAL	DOL	CAL+DOL	SID+APA	PYR	MAR	PYR+MAR
MINERAL TWO THETA		19.8	20.8	23.5	27.6	27.9		29.4	30.8		32.1	33.2	52.0	
06IL04C1	933.4	65	125	35	55	0	100/ 0	0	315	315	10	0	0	0
06IL05C1	943.5	60	130	30	50	0	100/ 0	0	90	90	17	0	0	0
06IL06C1	954.0	55	170	20	65	0	100/ 0	0	235	235	8	13	0	13
06IL07C1	962.2	56	113	24	40	0	100/ 0	10	110	120	14	13	0	13
06IL08C1	973.4	70	100	30	50	0	100/ 0	0	117	117	15	15	0	15
06IL09C1	984.2	62	125	30	60	0	100/ 0	15	120	135	15	5	0	5
06IL10C1	993.1	65	115	30	55	0	100/ 0	13	148	161	15	5	0	5
06IL11C1	1003.2	65	126	30	50	0	100/ 0	0	81	81	10	10	0	10
06IL11L1	1005.3	50	102	20	33	0	100/ 0	0	187	187	5	10	0	10
06IL12C1	1014.1	65	115	35	57	40	58/ 41	20	83	103	20	15	0	15
06IL13C1	1024.1	67	105	30	60	0	100/ 0	0	126	126	10	10	0	10
06IL13L1	1025.5	60	95	25	50	0	100/ 0	0	82	82	10	5	0	5
06IL13L2	1029.1	70	103	30	50	0	100/ 0	0	25	25	5	5	0	5
06IL14L1	1032.8	57	80	30	50	0	100/ 0	0	180	180	10	13	0	13
06IL14C1	1034.2	65	103	45	70	0	100/ 0	0	91	91	10	15	0	15
06IL15C1	1044.1	80	140	50	85	0	100/ 0	0	125	125	20	22	0	22
06IL16C1	1053.2	70	105	42	68	0	100/ 0	0	137	137	13	15	0	15
06IL17C1	1063.2	48	106	40	63	0	100/ 0	0	190	190	15	20	0	20
06IL18C1	1073.3	58	110	46	80	0	100/ 0	0	63	63	15	15	5	20
06IL19C1	1083.2	45	100	45	70	0	100/ 0	0	45	45	13	20	7	27
06IL19L1	1085.2	60	119	35	62	0	100/ 0	0	20	20	15	38	15	53
06IL20C1	1093.4	51	120	30	50	30	62/ 37	15	20	35	15	60	10	70
06IL21L1	1101.8	49	140	26	40	0	100/ 0	72	15	87	15	45	20	65
06IL21C1	1103.1	56	125	25	48	40	54/ 45	0	25	25	20	25	5	30
06IL22L1	1111.4	70	140	25	35	35	50/ 50	0	26	26	10	15	5	20
06IL22C1	1113.4	60	125	25	35	35	50/ 50	0	20	20	20	15	0	15
06IL23C1	1123.5	57	86	23	40	0	100/ 0	0	50	50	15	25	5	30
06IL24C1	1133.4	60	150	25	50	0	100/ 0	25	165	190	10	10	1	11
06IL25L1	1141.1	65	155	26	45	0	100/ 0	0	97	97	15	15	0	15
06IL25C1	1143.5	55	127	30	45	0	100/ 0	15	63	78	15	30	0	30
06IL25L2	1145.7	25	75	8	15	8	65/ 34	175	500	675	10	40	5	45

*Depth (to top of sample) below drilling reference at 641 feet above mean sea level.

See table 8 for column headings.

TABLE 17 – CLAY MINERALOGY AND ORIENTATION, FAYETTE COUNTY, ILLINOIS (07IL), AND ST. CLAIR COUNTY, ILLINOIS (09IL), CORE SAMPLES.

SAMPLE NUMBER	DEPTH*	clays (parts/10) ILL	CHL	EXP	COI
07IL01L1	2719	6.5	2.0	1.5	1.0
07IL01L2	2731	5.0	2.5	3.0	1.0
07IL01L3	2737	7.5	2.0	1.0	1.0
07IL02L1	2771.8	6.0	2.5	1.5	****
07IL02L2	2773.0	6.0	2.0	2.0	1.0
07IL03L1	2780.4	5.5	2.0	2.5	1.2
07IL04L1	2811.0	7.0	2.5	.5	1.7
07IL04L2	2813.1	7.0	2.5	.5	1.4
07IL05L1	2821.5	6.0	2.0	2.0	****
09IL01L3	1774	6.5	2.5	1.0	****

*Depth (to top of sample) below drilling reference at 525 feet above mean sea level for 07IL core; 474 feet above mean sea level for 09IL core.

See Table 7 for column headings.

TABLE 18 – WHOLE ROCK MINERALOGY, FAYETTE COUNTY, ILLINOIS (07IL), AND ST. CLAIR COUNTY, ILLINOIS (09IL) CORE SAMPLES.

OBSERVED PEAK HEIGHTS (COUNTS/SEC)

SAMPLE NUMBER	DEPTH*	MCA	QTZ	FLD	KSP	PLG	KSP/PLG	CAL	DOL	CAL+DOL	SID+APA	PYR	MAR	PYR+MAR	MINERAL
		19.8	20.8	23.5	27.6	27.9		29.4	30.8		32.1	33.2	52.0		TWO THETA
07IL01L1	2719	8	12	0	0	0	0/ 0	500	20	520	0	0	0	0	
07IL01L2	2731	71	108	32	50	53	48/ 51	0	20	20	15	0	0	0	
07IL01L3	2737	55	87	25	45	50	47/ 52	152	95	247	15	0	0	0	
07IL02L1	2771.8	60	172	35	52	70	42/ 57	15	15	30	12	5	0	5	
07IL02L2	2773.0	20	75	0	18	17	51/ 48	400	25	425	5	20	0	20	
07IL03L1	2780.4	65	218	37	50	70	41/ 58	0	23	23	12	3	0	3	
07IL04L1	2811.0	60	137	32	45	55	44/ 54	0	20	20	11	22	8	30	
07IL04L2	2813.1	47	117	25	47	45	51/ 48	0	35	35	15	19	5	24	
07IL05L1	2821.5	8	330	0	0	0	0/ 0	120	315	435	0	15	0	15	
09IL01L3	1774	59	137	25	35	45	43/ 56	0	20	20	15	18	7	25	

*Depth (to top of sample) below drilling reference at 525 feet above mean sea level for 07IL core; 474 feet above mean sea level for 09IL core.

See Table 8 for column headings.

TABLE 19 - WHOLE ROCK MINERALOGY OF DRILL CUTTING SAMPLES

OBSERVED PEAK HEIGHTS (COUNTS/SEC)

SAMPLE NUMBER	DEPTH*	MCA	QTZ	FLD	KSP	PLG	KSP/PLG	CAL	DOL	CAL+DOL	SID+APA	PYR	MAR	PYR+MAR	MINERAL
		19.8	20.8	23.5	27.6	27.9		29.4	30.8		32.1	33.2	52.0		TWO THETA
NAS-028	4420	42	125	25	40	45	47/ 52	30	42	72	15	27	5	32	
NAS-031	3920	51	162	15	0	50	0/100	53	35	88	15	25	0	25	
NAS-032	3990	82	160	30	0	72	0/100	83	52	135	20	27	5	32	
NAS-034	3650	50	115	25	35	45	43/ 56	55	25	80	10	30	7	37	
NAS-036	1590	37	138	17	47	45	51/ 48	188	156	344	13	13	0	13	
NAS-037	1640	50	117	21	50	50	50/ 50	100	117	217	15	16	5	21	
NAS-041	435	72	155	35	60	0	100/ 0	30	145	175	18	15	0	15	
NAS-043	550	47	100	20	42	35	54/ 45	0	45	45	10	15	5	20	
NAS-045	2690	62	154	25	40	65	38/ 61	0	70	70	18	18	0	18	
NAS-046	2900	57	130	23	0	55	0/100	0	50	50	16	27	5	32	
NAS-049	2660	69	140	31	45	58	43/ 56	0	20	20	20	25	5	30	
NAS-055	4730	58	182	33	50	63	44/ 55	0	45	45	18	56	10	66	
NAS-057	4640	61	165	42	51	51	50/ 50	0	42	42	17	20	0	20	
NAS-059	4745	62	142	27	0	65	0/100	0	40	40	25	36	14	50	
NAS-061	4775	60	131	31	45	45	50/ 50	0	33	33	13	21	6	27	
NAS-062	4885	60	149	21	40	57	41/ 58	15	102	117	17	20	6	26	
NAS-065	4940	52	125	30	40	45	47/ 52	40	40	80	19	19	0	19	
NAS-067	5040	47	122	25	30	42	41/ 58	16	25	41	17	25	0	25	
NAS-068	5135	29	64	15	20	23	46/ 53	295	118	413	5	8	0	8	
NAS-071	4990	55	125	30	38	40	48/ 51	35	30	65	30	25	0	25	
NAS-073	5155	43	92	20	30	40	42/ 57	88	97	185	15	15	0	15	
NAS-085	2185	57	163	35	48	50	48/ 51	38	25	63	10	10	0	10	
NAS-088	2285	50	114	32	50	55	47/ 52	0	25	25	12	25	15	40	
NAS-090	4355	42	124	22	35	25	58/ 41	20	28	48	10	31	7	38	
NAS-091	4455	55	120	27	30	45	39/ 59	20	40	60	19	25	10	35	
NAS-092	4555	50	110	25	0	50	0/100	50	105	155	23	20	0	20	
NAS-093	3980	43	150	22	0	50	0/100	18	27	45	20	23	0	23	
NAS-094	4090	44	99	27	35	50	41/ 58	0	30	30	21	28	8	36	
NAS-095	4190	37	105	22	37	45	45/ 54	0	46	46	22	22	0	22	
NAS-096	4300	32	76	20	30	30	50/ 50	117	112	229	5	10	5	15	
NAS-101	495	45	92	23	40	29	57/ 42	0	13	13	13	13	5	18	
NAS-103	2780	26	80	17	30	41	42/ 57	10	41	51	10	32	9	41	
NAS-104	2890	42	90	14	25	30	45/ 54	14	112	126	22	15	0	15	
NAS-106	1033	51	110	22	38	33	53/ 46	15	19	34	10	5	0	5	
NAS-107	1154	40	86	21	32	0	100/ 0	20	23	43	8	35	8	43	
NAS-110	1880	46	93	22	27	30	47/ 52	0	0	0	12	14	0	14	
NAS-111	1925	56	93	20	0	32	0/100	60	15	75	15	12	0	12	
NAS-114	3030	50	145	20	36	36	50/ 50	0	46	46	18	31	0	31	
NAS-115	3140	58	105	25	30	56	34/ 65	0	30	30	27	28	7	35	
NAS-116	3250	51	105	18	26	47	35/ 64	13	77	90	19	17	5	22	
NAS-117	3330	46	122	26	34	35	49/ 50	212	145	357	10	23	5	28	
NAS-119	3940	52	157	31	50	45	52/ 47	48	44	92	17	38	6	44	
NAS-120	4030	46	144	24	39	48	44/ 55	25	42	67	25	25	5	30	
NAS-121	4140	50	135	22	0	50	0/100	25	64	89	15	25	0	25	
NAS-123	2440	45	108	28	0	45	0/100	24	85	109	16	30	0	30	
NAS-124	2550	50	97	21	30	45	39/ 59	0	44	44	40	65	9	74	
NAS-125	2650	68	125	25	50	58	46/ 53	0	135	135	38	15	0	15	
NAS-126	2750	41	125	20	33	40	45/ 54	98	169	267	13	53	5	58	
NAS-129	3705	57	154	22	41	38	51/ 48	22	28	50	15	25	10	35	
NAS-130	3795	54	113	22	33	43	43/ 56	13	23	36	13	28	10	38	
NAS-131	3895	32	68	20	29	25	53/ 46	207	150	357	9	19	0	19	
NAS-134	770	41	96	27	45	0	100/ 0	30	245	275	10	10	0	10	
NAS-135	875	40	130	16	0	27	0/100	176	58	234	16	15	0	15	
NAS-138	620	101	185	35	65	60	51/ 47	0	95	95	25	30	5	35	
NAS-141	2780	80	171	35	65	58	52/ 47	47	55	102	20	20	0	20	

TABLE 19 - CONTINUED

NAS-144	4420	65	195	35	53	48	52/ 47	28	55	83	12	30	10	40
NAS-145	4520	69	160	33	45	65	40/ 59	70	105	175	15	46	0	46
NAS-148	2300	50	115	25	27	39	40/ 59	25	35	60	15	46	9	55
NAS-151	3005	45	95	21	40	39	50/ 49	0	20	20	12	20	0	20
NAS-154	2990	55	90	33	47	39	54/ 45	0	25	25	15	25	7	32
NAS-157	2865	40	110	20	35	40	46/ 53	32	32	64	10	39	12	51
NAS-160	4000	55	129	30	45	45	50/ 50	30	25	55	16	17	0	17
NAS-161	4120	51	116	27	40	50	44/ 55	25	45	70	17	25	0	25
NAS-162	2870	63	122	26	40	44	47/ 52	25	140	165	19	15	5	20
NAS-164	2620	65	115	27	35	35	50/ 50	38	27	65	19	15	0	15
NAS-169	3730	58	150	26	47	37	55/ 44	0	54	54	15	30	8	38
NAS-172	1040	55	92	36	52	0	100/ 0	143	26	169	16	17	5	22
NAS-176	1780	50	110	26	35	0	100/ 0	43	43	86	15	35	0	35
NAS-178	650	68	121	25	40	45	47/ 52	0	34	34	20	22	5	27
NAS-181	4130	47	117	25	41	50	45/ 54	18	38	56	14	25	8	33
NAS-183	5090	76	221	45	65	70	48/ 51	0	61	61	23	65	12	77
NAS-186	5200	57	120	33	50	55	47/ 52	33	78	111	15	22	7	29
NAS-188	4945	55	129	40	50	45	52/ 47	33	47	80	24	35	6	41
NAS-192	4880 ?	40	100	25	40	45	47/ 52	37	29	66	20	23	5	28
NAS-193	4990 ?	29	94	17	30	25	54/ 45	180	110	290	7	7	0	7
NAS-195	400	45	80	28	45	0	100/ 0	17	61	78	10	18	5	23
NAS-196	490	48	81	32	45	0	100/ 0	15	35	50	10	18	7	25
NAS-199	320	40	96	18	36	0	100/ 0	0	35	35	15	22	8	30
NAS-202	4150	43	87	21	42	40	51/ 48	28	24	52	15	21	7	28
NAS-206	4630	43	117	22	30	46	39/ 60	30	27	57	12	22	8	30
NAS-207	3080	50	133	23	40	40	50/ 50	22	51	73	22	25	5	30
NAS-208	3190	57	148	30	45	55	44/ 54	13	45	58	43	26	0	26
NAS-212	3720	51	111	20	0	58	0/100	32	32	64	15	25	7	32
NAS-213	3525	54	170	30	55	0	100/ 0	0	34	34	18	18	0	18
NAS-214	3630	55	115	32	45	63	41/ 58	0	34	34	20	23	10	33
NAS-215	3700	40	111	21	36	30	54/ 45	191	165	356	10	28	5	33
NAS-216	535	45	94	28	47	35	57/ 42	0	36	36	12	13	0	13
NAS-220	1335	46	102	25	32	25	56/ 43	20	30	50	15	21	0	21
NAS-223	575	39	125	17	42	30	58/ 41	75	42	117	16	12	0	12
NAS-224	730	41	115	20	35	0	100/ 0	48	70	118	15	11	0	11
NAS-227	890	40	89	22	35	33	51/ 48	61	62	123	14	32	0	32
NAS-230	475	47	90	23	40	0	100/ 0	20	22	42	14	14	4	18
NAS-233	1700	42	90	22	43	35	55/ 44	21	27	48	10	25	0	25
NAS-234	1355	41	100	30	50	0	100/ 0	27	47	74	10	13	5	18
NAS-237	1090	50	88	22	38	28	57/ 42	18	67	85	15	10	0	10
NAS-240	540	35	86	30	46	0	100/ 0	20	40	60	10	32	6	38
NAS-242	620	38	135	23	37	0	100/ 0	0	50	50	10	17	0	17
NAS-246	4650	45	145	21	35	40	46/ 53	38	36	74	9	31	8	39
NAS-248	4760	44	124	18	33	44	42/ 57	0	59	59	15	33	7	40
NAS-249	4890	30	85	20	26	31	45/ 54	205	146	351	8	15	0	15
NAS-252	4410	41	105	27	31	50	38/ 61	15	32	47	13	26	5	31
NAS-253	4510	45	127	25	28	36	43/ 56	11	60	71	15	20	0	20

*Depth (to top of sample)

MCA = mica; QTZ = quartz; FLD = all feldspars; KSP = potassium feldspar; PLG = plagioclase; CAL = calcite; DOL = dolomite; SID & APA = siderite and/or apatite; PYR = pyrite; MAR = marcasite.

TABLE 20: CLAY MINERALOGY, STANDARD SAMPLE SDO-1.

SAMPLE NUMBER	DEPTH	ILL	CHL	KAO	EXP	
SDO-1 D		6.5	2.5	.5	.1	smear slides
SDO-1 E		7.0	2.5	1.0	0.0	
SDO-1 F		6.0	2.0	.5	1.5	
SDO-1 G		7.0	2.0	.5	.5	sedimented slides
SDO-1 H		6.0	2.0	.5	1.0	
SDO-1 I		7.0	1.5	.5	1.0	
SDO-1 J		5.0	2.0	.5	2.0	smear, duplicates
SDO-1 K		5.0	2.5	.5	2.0	
SDO-1 L		5.5	1.5	.5	2.0	
SDO-1 M		6.0	1.5	.5	2.0	sedimented, duplicates
SDO-1 N		5.5	2.0	.5	2.0	
SDO-1 O		5.0	1.5	.5	3.0	

See Table 7 for column headings.

TABLE 21: WHOLE ROCK MINERALOGY, STANDARD SAMPLE SDO-1.

OBSERVED PEAK HEIGHTS (COUNTS/SEC)

SAMPLE	DEPTH	MCA	QTZ	FLD	KSP	PLG	KSP/PLG	CAL	DOL	CAL+DOL	SID+APA	PYR	MAR	PYR+MAR	MINERAL
NUMBER		19.8	20.8	23.5	27.6	27.9		29.4	30.8		32.1	33.2	52.0		TWO THETA
SDO-1 A		50	115	15	0	35	0/100	0	25	25	0	65	15	80	
SDO-1 B		35	100	10	0	30	0/100	0	25	25	12	65	12	77	
SDO-1 C		60	140	20	0	40	0/100	0	0	0	0	90	20	110	

See Table 8 for column headings.

TABLE 22 - MEAN-RANDOM VITRINITE REFLECTANCE, ILLINOIS AND KENTUCKY CORE SAMPLES

API NUMBER	SAMPLE NUMBER	N	R 0	STD DEV	PERCENT VITRINITE IN EACH REFLECTANCE CLASS																	VITRAIN BAND
					<.25	.30	.35	.40	.45	.50	.55	.60	.65	.70	.75	.80	.85	.90	.95	1.0	>1	
1604731175	01KY01L1	35	.46	.05	0	0	3	9	17	49	23	0	0	0	0	0	0	0	0	0	0	
1604731175	01KY01C1	59	.39	.08	0	12	20	27	17	10	10	2	0	2	0	0	0	0	0	0	0	
1604731175	01KY01C1	33	.52	.07	0	0	0	0	9	39	21	21	0	6	3	0	0	0	0	0	0	
1604731175	01KY02L1	50	.48	.09	0	0	0	18	24	16	20	12	6	4	2	0	0	0	0	0	0	
1604731175	01KY02C1	27	.36	.10	4	26	26	15	7	11	4	4	4	0	0	0	0	0	0	0	0	
1604731175	01KY02C1	31	.56	.09	0	0	0	0	13	13	23	13	19	10	10	0	0	0	0	0	0	
1604731175	01KY03L1	36	.46	.09	0	0	11	14	17	14	22	19	0	3	0	0	0	0	0	0	0	
1604731175	01KY03C1	32	.33	.11	31	16	22	9	6	9	0	0	6	0	0	0	0	0	0	0	0	
1604731175	01KY03C1	46	.53	.08	0	0	0	2	30	35	13	2	9	4	0	0	0	0	0	0	0	
1604731175	01KY04C1	49	.82	.30	0	0	0	4	2	10	12	6	4	4	2	2	2	2	12	4	32	
1604731175	01KY04L1	50	.53	.11	0	0	0	8	20	18	14	6	16	14	0	2	2	0	0	0	0	
1604731175	01KY05C1	33	.41	.08	0	0	22	22	22	22	9	3	0	0	0	0	0	0	0	0	0	
1604731175	01KY05L1	48	.58	.11	0	0	2	6	2	10	15	19	19	15	6	4	2	0	0	0	0	
1604731175	01KY07C1	62	.39	.06	0	0	16	31	31	14	3	0	2	0	0	0	0	0	0	0	0	
1604731175	01KY07L1	12	.37	.05	0	0	33	25	42	0	0	0	0	0	0	0	0	0	0	0	0	
1604731175	01KY08C1	44	.52	.07	0	0	0	2	14	20	27	27	4	2	2	0	0	0	0	0	0	
1604731175	01KY08L1	23	.44	.04	0	0	4	13	30	48	4	0	0	0	0	0	0	0	0	0	0	
1604731175	01KY09C1	43	.55	.10	0	0	2	2	16	5	16	26	21	5	2	5	0	0	0	0	0	
1604731175	01KY10L1	16	.48	.07	0	0	0	12	25	19	25	12	6	0	0	0	0	0	0	0	0	
1604731175	01KY10C1	32	.52	.11	0	0	9	3	12	19	9	16	12	19	0	0	0	0	0	0	0	
1604731175	01KY11L1	24	.51	.08	0	0	4	0	12	29	12	29	8	4	0	0	0	0	0	0	0	
1604731175	01KY11C1	16	.44	.10	0	0	12	31	25	6	6	12	6	0	0	0	0	0	0	0	0	
1604731175	01KY12C1	23	.79	.36	0	0	9	9	9	0	9	0	9	0	4	4	4	0	4	4	36	
1604731175	01KY12L1	27	.60	.14	0	0	0	0	15	7	11	15	18	15	7	0	4	4	4	0	0	
1604731175	01KY13L1	21	.53	.12	0	0	0	14	19	19	9	5	9	9	9	5	0	0	0	0	0	
1604731175	01KY13C1	17	.51	.28	12	12	12	18	0	6	12	6	0	0	0	0	6	0	12	0	6	
1216700115	01IL01L2	15	.43	.06	0	0	7	20	33	33	7	0	0	0	0	0	0	0	0	0	0	
1216700115	01IL04L1	14	.46	.13	0	0	28	7	21	7	14	7	0	7	7	0	0	0	0	0	0	
1216700115	01IL10L1	6	.49	.11	0	0	0	17	33	17	0	0	33	0	0	0	0	0	0	0	0	
1216700115	01IL11L1	40	.39	.10	10	18	12	12	18	20	8	0	2	0	0	0	0	0	0	0	0	
1216700115	01IL14L1	43	.40	.11	23	5	9	9	12	26	12	5	0	0	0	0	0	0	0	0	0	
1216700115	01IL16L1	48	.41	.09	4	4	23	8	21	23	10	4	0	0	0	0	0	0	0	0	0	
1216700115	01IL17L1	50	.37	.13	24	16	12	8	18	6	4	8	4	0	0	0	0	0	0	0	0	
1216700115	01IL19L1	50	.40	.11	16	8	4	10	34	18	2	4	2	0	2	0	0	0	0	0	0	
1216700115	01IL21L1	23	.38	.05	0	13	26	26	30	4	0	0	0	0	0	0	0	0	0	0	0	
1204922705	02IL01C1	45	.66	.14	0	0	0	0	2	9	11	16	11	13	9	13	4	2	7	2	0	
1204922705	02IL02C1	50	.52	.07	0	0	2	4	4	24	28	28	8	2	0	0	0	0	0	0	0	
1204922705	02IL03C1	50	.44	.07	0	0	6	22	32	22	10	4	4	0	0	0	0	0	0	0	0	
1204922705	02IL03C1	51	.49	.03	0	0	0	0	12	39	45	4	0	0	0	0	0	0	0	0	0	VIT
1204922705	02IL04C1	26	.49	.06	0	0	0	4	19	23	46	0	4	4	0	0	0	0	0	0	0	
1204922705	02IL04C2	29	.47	.07	0	0	0	10	28	34	14	10	0	3	0	0	0	0	0	0	0	
1204922705	02IL05C1	31	.48	.06	0	0	3	6	16	23	32	19	0	0	0	0	0	0	0	0	0	
1204922705	02IL05L2	26	.47	.08	0	0	4	12	31	15	23	12	4	0	0	0	0	0	0	0	0	
1204922705	02IL06C1	50	.47	.07	0	0	4	6	18	34	32	2	0	4	0	0	0	0	0	0	0	
1204922705	02IL06L2	27	.52	.09	0	0	4	0	11	30	15	18	7	15	0	0	0	0	0	0	0	
1204922705	02IL07C1	36	.51	.10	0	0	6	14	11	14	11	14	25	6	0	0	0	0	0	0	0	
1204922705	02IL08C1	50	.56	.03	0	0	0	0	0	2	32	52	14	0	0	0	0	0	0	0	0	VIT
1219304694	03IL03L1	35	.53	.10	0	0	3	6	11	9	31	17	3	17	3	0	0	0	0	0	0	
1219304694	CP1666-I	27	.55	.08	0	0	0	0	15	7	26	18	26	0	7	0	0	0	0	0	0	
1219304694	03IL18L1	50	.60	.09	0	0	0	2	4	6	12	20	24	16	8	6	2	0	0	0	0	
1219304694	03IL19L2	50	.54	.09	0	0	0	8	6	20	16	20	20	2	6	2	0	0	0	0	0	
1219304694	03IL21L1	62	.61	.08	0	0	0	0	0	6	18	24	24	11	8	6	2	0	0	0	0	
1219304694	03IL25L1	33	.70	.10	0	0	0	0	0	3	0	9	9	27	27	6	9	3	3	3	0	
1207120411	04IL09C1	32	.45	.08	0	0	6	25	19	22	12	9	6	0	0	0	0	0	0	0	0	
1207120411	04IL13C1	50	.47	.08	0	0	4	12	30	20	14	8	10	2	0	0	0	0	0	0	0	
1207120411	04IL17C1	50	.47	.03	0	0	0	0	28	52	18	2	0	0	0	0	0	0	0	0	0	VIT
1207120411	04IL17C1	50	.41	.11	10	26	20	6	18	4	8	6	2	0	0	0	0	0	0	0	0	
1207120411	04IL21C1	46	.48	.08	0	2	13	17	35	11	13	6	2	0	0	0	0	0	0	0	0	
1207120411	04IL25C1	50	.51	.09	0	0	6	4	16	16	22	18	14	4	0	0	0	0	0	0	0	
1204501209	05IL01L1	45	.46	.07	0	0	7	7	24	31	20	7	4	0	0	0	0	0	0	0	0	
1204501209	05IL01L2	50	.44	.06	0	0	2	20	38	26	8	4	2	0	0	0	0	0	0	0	0	
1204501209	05IL01L4	50	.47	.02	0	0	0	0	10	82	8	0	0	0	0	0	0	0	0	0	0	VIT
1217921198	06IL10C1	37	.50	.08	0	0	5	5	11	27	19	16	14	3	0	0	0	0	0	0	0	
1217921198	06IL13C1	43	.49	.08	0	0	5	7	12	26	30	9	12	0	0	0	0	0	0	0	0	
1217921198	06IL16C1	52	.45	.07	0	0	2	17	35	23	14	8	0	2	0	0	0	0	0	0	0	
1217921198	06IL19C1	50	.42	.06	0	0	18	22	24	28	2	6	0	0	0	0	0	0	0	0	0	
1217921198	06IL25C1	50	.41	.07	0	0	12	40	28	8	8	0	2	2	0	0	0	0	0	0	0	
1205101324	07IL01L2	50	.56	.12	0	0	4	10	6	10	12	10	20	16	10	2	0	0	0	0	0	
1205101324	07IL02L1	41	.55	.11	0	0	0	10	10	17	10	17	10	15	5	7	0	0	0	0	0	
1205101324	07IL03L1	47	.44	.13	4	15	6	13	17	13	8	6	11	4	2	0	0	0	0	0	0	
1205101324	07IL04L1	39	.46	.08	0	0	10	15	18	28	15	8	3	3	0	0	0	0	0	0	0	
1205101324	07IL04L2	52	.50	.07	0	0	2	4	21	25	23	15	8	2	0	0	0	0	0	0	0	
1216301757	09IL01L3	51	.50	.09	0	4	8	6	12	10	29	16	14	2	0	0	0	0	0	0	0	

TABLE 23 - MEAN-RANDOM VITRINITE REFLECTANCE, DRILL CUTTING SAMPLES

API NUMBER	SAMPLE NUMBER	N	R 0	STD DEV	PERCENT VITRINITE IN EACH REFLECTANCE CLASS <.25	.30	.35	.40	.45	.50	.55	.60	.65	.70	.75	.80	.85	.90	.95	1.0	>1	VITRAIN BAND
1202505036	NAS- 028	50	.49	.14	0	0	18	10	18	14	8	4	12	8	2	0	6	0	0	0	0	
1204922498	NAS- 031	50	.58	.14	0	0	6	6	4	12	16	14	10	12	10	2	4	4	0	0	0	
1204922498	NAS- 032	50	.62	.11	0	0	0	2	2	6	18	22	14	10	6	12	4	4	0	0	0	
1208101167	NAS- 033	50	.60	.10	0	0	2	2	2	6	20	16	16	18	12	2	4	0	0	0	0	
1211901187	NAS- 036	50	.51	.11	0	0	8	6	10	20	28	12	4	4	4	0	4	0	0	0	0	
1211901187	NAS- 037	50	.52	.09	0	0	2	6	10	28	14	22	12	2	2	0	0	2	0	0	0	
1212500062	NAS- 043	50	.49	.08	0	0	2	10	22	22	22	10	8	4	0	0	0	0	0	0	0	
1218902866	NAS- 045	50	.54	.09	0	0	4	0	8	20	26	18	16	2	2	0	4	0	0	0	0	
1218923041	NAS- 046	50	.59	.08	0	0	0	0	6	4	20	22	14	24	8	2	0	0	0	0	0	
1218922957	NAS- 050	51	.53	.08	0	0	0	0	10	23	23	28	10	2	0	2	0	2	0	0	0	
1219100827	NAS- 053	50	.70	.09	0	0	0	0	0	0	0	8	20	22	20	14	6	10	0	0	0	
1219106524	NAS- 058	50	.69	.12	0	0	0	0	0	4	6	16	14	16	20	8	4	2	4	6	0	
1219106524	NAS- 059	51	.64	.13	0	0	0	6	2	8	4	8	20	24	10	6	6	8	0	0	0	
1219100503	NAS- 061	50	.68	.10	0	0	0	0	0	4	6	14	8	20	26	6	8	8	0	0	0	
1219100503	NAS- 062	51	.57	.11	0	0	0	2	10	10	26	14	14	18	0	4	0	4	0	0	0	
1219104404	NAS- 066	41	.59	.14	0	0	0	2	12	15	7	29	10	2	2	7	5	7	0	0	0	
1219104404	NAS- 067	50	.59	.11	0	0	0	4	4	12	20	14	16	14	10	2	2	2	0	0	0	
1219104404	NAS- 068	42	.68	.11	0	0	0	0	0	2	10	14	10	17	17	14	5	12	0	0	0	
1219104240	NAS- 071	51	.70	.16	0	0	0	0	4	4	10	16	14	10	2	12	2	8	10	10	0	
1219104240	NAS- 072	53	.72	.13	0	0	0	0	2	4	4	9	8	17	11	13	11	13	4	4	0	
1202102375	NAS 085	50	.54	.09	0	0	4	2	8	20	18	22	18	4	2	2	0	0	0	0	0	
1202102375	NAS 087	38	.44	.08	0	0	8	29	21	18	11	5	8	0	0	0	0	0	0	0	0	
1205902832	NAS 090	50	.49	.10	0	0	4	10	24	16	18	10	6	6	4	2	0	0	0	0	0	
1205902832	NAS 091	58	.55	.09	0	0	0	0	5	19	41	14	2	10	5	3	0	0	0	0	0	
1205902832	NAS 092	51	.50	.08	0	0	0	10	14	27	24	8	10	6	2	0	0	0	0	0	0	
1205903316	NAS 093	50	.70	.18	0	0	0	6	6	6	12	6	2	8	6	2	14	14	14	4	0	
1205903316	NAS 094	53	.69	.11	0	0	0	0	0	0	11	11	8	23	15	17	9	0	6	0	0	
1205903316	NAS 095	51	.85	.08	0	0	0	0	0	0	0	0	2	2	6	18	12	35	18	4	4	
1205903316	NAS 096	50	.74	.10	0	0	0	0	0	0	0	2	18	20	20	16	6	4	10	4	0	
1206100189	NAS 102	22	.47	.08	0	0	5	23	18	18	9	18	9	0	0	0	0	0	0	0	0	
1210107425	NAS 103	51	.52	.07	0	0	0	0	22	14	25	27	4	4	4	0	0	0	0	0	0	
1210107425	NAS 104	52	.60	.06	0	0	0	0	2	2	12	29	37	12	8	0	0	0	0	0	0	
1210700113	NAS 107	51	.44	.06	0	0	6	8	45	37	0	0	2	2	0	0	0	0	0	0	0	
1215100244	NAS 116	31	.72	.16	0	0	0	0	3	10	6	10	10	3	10	3	19	10	13	3	0	
1215100244	NAS 117	40	1.09	.12	0	0	0	0	0	0	0	0	0	0	0	5	0	5	0	5	85	
1216523981	NAS 120	55	1.00	.12	0	0	0	0	0	0	0	0	0	0	0	5	7	7	9	22	48	
1216523981	NAS 121	52	1.02	.13	0	0	0	0	0	0	0	0	2	6	0	10	12	17	19	8	26	
1218526176	NAS 128	69	.62	.12	0	0	0	0	3	9	16	25	16	9	4	7	6	4	0	1	0	
1218526176	NAS 130	41	.48	.08	0	0	2	5	24	34	12	10	10	2	0	0	0	0	0	0	0	
1220300235	NAS 135	25	.58	.10	0	0	0	0	4	8	24	32	12	0	8	8	4	0	0	0	0	
1202323824	NAS 148	44	.54	.06	0	0	0	2	2	16	34	25	18	2	0	0	0	0	0	0	0	
1203300710	NAS 161	40	.64	.08	0	0	0	0	3	5	3	18	23	25	15	10	0	0	0	0	0	
1203300294	NAS 164	50	.61	.14	0	0	0	6	10	10	6	16	12	12	10	8	4	2	4	0	0	
1203330012	NAS 167	61	.61	.10	0	0	0	2	2	8	20	15	23	11	11	3	3	2	0	0	0	
1203531385	NAS 169	63	.56	.11	0	0	2	6	5	13	27	16	13	10	3	3	0	3	0	0	0	
1204500517	NAS 176	87	.45	.08	0	0	7	9	46	18	11	3	1	0	1	2	0	0	0	0	0	

TABLE 24 - SHARPNESS RATIO DATA, ILLINOIS AND KENTUCKY CORE SAMPLES

API NUMBER	SAMPLE NUMBER	DEPTH (FT)	10.5A PEAK	10.0A PEAK	SHARPNESS RATIO
1604731175	01KY01L1	2181	16.	9.	1.78
1604731175	01KY01C1	2182	84.	30.	2.80
1604731175	01KY02L1	2189	14.	4.	3.50
1604731175	01KY02C1	2191	60.	18.	3.33
1604731175	01KY03L1	2217	30.	11.	2.73
1604731175	01KY04L1	2231	22.	10.	2.20
1604731175	01KY05L1	2244	26.	12.	2.17
1604731175	01KY06L1	2256	70.	31.	2.26
1604731175	01KY07L1	2264	32.	9.	3.56
1604731175	01KY08C1	2270	20.	12.	1.67
1604731175	01KY09C1	2280	18.	7.	2.57
1604731175	01KY10C1	2291	26.	14.	1.86
1604731175	01KY11C1	2300	24.	13.	1.85
1604731175	01KY12C1	2310	14.	7.	2.00
1604731175	01KY13C1	2319	17.	7.	2.43
1216700115	01IL01L2	1576	27.	16.	1.69
1216700115	01IL04L1	1602	19.	14.	1.36
1216700115	01IL04L1	1602	28.	10.	2.80
1216700115	01IL11L1	1668	23.	11.	2.09
1216700115	01IL14L1	1698	27.	14.	1.93
1216700115	01IL16L1	1723	27.	14.	1.93
1216700115	01IL17L1	1731	24.	13.	1.85
1216700115	01IL19L1	1754	18.	6.	3.00
1216700115	01IL21L1	1776	29.	15.	1.93
1204922705	02IL01L2	3010	11.	7.	1.57
1204922705	02IL01C1	3011	29.	11.	2.64
1204922705	02IL02C1	3021	33.	17.	1.94
1204922705	02IL03C1	3043	25.	12.	2.08
1204922705	02IL04C1	3053	27.	13.	2.08
1204922705	02IL04C2	3060	35.	18.	1.94
1204922705	02IL05C1	3065	50.	19.	2.63
1204922705	02IL05L2	3072	40.	15.	2.67
1204922705	02IL06C1	3073	39.	15.	2.60
1204922705	02IL06L2	3081	40.	15.	2.67
1204922705	02IL07C1	3086	37.	10.	3.70
1204922705	02IL08C1	3097	38.	18.	2.11
1204922705	02IL09L1	3106	7.	4.	1.75
1219304694	03IL01L1	4480	30.	12.	2.50
1219304694	03IL07L1	4540	32.	14.	2.29
1219304694	03IL12L1	4590	50.	14.	3.57
1219304694	03IL20L1	4673	52.	25.	2.08
1219304694	03IL20L3	4676	41.	21.	1.95
1219304694	03IL23L1	4705	34.	18.	1.89
1219304694	03IL26L1	4735	38.	19.	2.00
1207120411	04IL09C1	404	37.	17.	2.18
1207120411	04IL13C1	443	30.	17.	1.76
1207120411	04IL17C1	482	49.	19.	2.58
1207120411	04IL21C1	523	70.	25.	2.80
1207120411	04IL25C1	563	63.	27.	2.33
1217921198	06IL10C1	993	48.	20.	2.40
1217921198	06IL13C1	1024	41.	17.	2.41
1217921198	06IL16C1	1053	37.	20.	1.85
1217921198	06IL19C1	1083	46.	18.	2.56
1217921198	06IL25C1	1144	43.	21.	2.05

TABLE 25 - SHARPNESS RATIO DATA, DRILL CUTTING SAMPLES

API NUMBER	SAMPLE NUMBER	DEPTH (FT)	10.5A PEAK	10.0A PEAK	SHARPNESS RATIO
1202505036	NAS 028	4420	40.	14.	2.86
1204922498	NAS 031	3920	34.	19.	1.79
1204922498	NAS 032	3990	62.	24.	2.58
1208101167	NAS 034	3650	45.	17.	2.65
1211901187	NAS 036	1590	29.	12.	2.42
1211901187	NAS 037	1640	51.	17.	3.00
1212500062	NAS 041	435	46.	15.	3.07
1212500062	NAS 043	550	47.	16.	2.94
1218902866	NAS 045	2690	32.	16.	2.00
1218923041	NAS 046	2900	44.	14.	3.14
1218922957	NAS 049	2660	51.	21.	2.43
1219100827	NAS 055	4730	50.	18.	2.78
1219106524	NAS 057	4640	50.	20.	2.50
1219106524	NAS 059	4745	55.	18.	3.06
1219100503	NAS 061	4775	37.	16.	2.31
1219100503	NAS 062	4885	43.	19.	2.26
1219104404	NAS 065	4940	34.	15.	2.27
1219104404	NAS 067	5040	34.	15.	2.27
1219104404	NAS 068	5135	12.	8.	1.50
1219104240	NAS 071	4990	41.	19.	2.16
1219104240	NAS 073	5155	26.	12.	2.17
1202102375	NAS 085	2185	23.	12.	1.92
1202102375	NAS 088	2285	39.	12.	3.25
1205902832	NAS 090	4355	26.	12.	2.17
1205902832	NAS 091	4455	34.	14.	2.43
1205902832	NAS 092	4555	34.	17.	2.00
1205903316	NAS 093	3980	24.	11.	2.18
1205903316	NAS 094	4090	42.	16.	2.63
1205903316	NAS 095	4190	37.	17.	2.18
1205903316	NAS 096	4300	14.	9.	1.56
1206100189	NAS 101	495	29.	14.	2.07
1210107425	NAS 103	2780	28.	13.	2.15
1210107425	NAS 104	2890	38.	18.	2.11
1210700113	NAS 106	1033	26.	9.	2.89
1210700113	NAS 107	1154	29.	14.	2.07
1211500823	NAS 110	1880	27.	9.	3.00
1211500823	NAS 111	1925	25.	10.	2.50
1215100244	NAS 114	3030	28.	15.	1.87
1215100244	NAS 115	3140	38.	15.	2.53
1215100244	NAS 116	3250	37.	20.	1.85
1215100244	NAS 117	3330	19.	10.	1.90
1216523981	NAS 119	3940	37.	12.	3.08
1216523981	NAS 120	4030	37.	15.	2.47
1216523981	NAS 121	4140	41.	19.	2.16
1216503505	NAS 123	2440	34.	18.	1.89
1216503505	NAS 124	2550	41.	16.	2.56
1216503505	NAS 125	2650	41.	18.	2.28
1216503505	NAS 126	2750	29.	12.	2.42
1218526176	NAS 129	3705	30.	12.	2.50
1218526176	NAS 130	3795	32.	14.	2.29
1218526176	NAS 131	3895	22.	8.	2.75
1220300235	NAS 134	770	24.	13.	1.85
1220300235	NAS 135	875	33.	11.	3.00
1201901424	NAS 138	620	59.	22.	2.68
1201922776	NAS 141	2780	44.	25.	1.76
1202501447	NAS 144	4420	40.	16.	2.50
1202501447	NAS 145	4520	40.	17.	2.35
1202323824	NAS 148	2300	[illegible]	[illegible]	[illegible]

TABLE 25 - SHARPNESS RATIO DATA, DRILL CUTTING SAMPLES
(CONTINUED)

1202922459	NAS	151	3005	41.	18.	2.28
1202922450	NAS	154	2990	37.	17.	2.18
1203300524	NAS	157	2865	26.	14.	1.86
1203300710	NAS	160	4000	37.	16.	2.31
1203300710	NAS	161	4120	44.	19.	2.32
1203302498	NAS	162	2870	37.	17.	2.18
1203300294	NAS	164	2620	24.	13.	1.85
1203531385	NAS	169	3730	56.	19.	2.95
1203900391	NAS	172	1040	44.	22.	2.00
1204500517	NAS	176	1780	26.	13.	2.00
1204500966	NAS	178	650	38.	16.	2.38
1204922476	NAS	181	4130	45.	15.	3.00
1206501276	NAS	183	5090	53.	15.	3.53
1206501276	NAS	186	5200	36.	19.	1.89
1206500760	NAS	188	4945	33.	18.	1.83
1206503450	NAS	192	4880	33.	19.	1.74
1206503450	NAS	193	4990	13.	7.	1.86
1207500996	NAS	195	400	38.	19.	2.00
1207500996	NAS	196	490	29.	17.	1.71
1207501015	NAS	199	320	42.	18.	2.33
1207922576	NAS	202	4150	39.	13.	3.00
1208122946	NAS	206	4630	28.	11.	2.55
1210127798	NAS	207	3080	33.	15.	2.20
1210127798	NAS	208	3190	50.	26.	1.92
1212125806	NAS	212	3720	51.	20.	2.55
1210102628	NAS	213	3525	38.	17.	2.24
1210102628	NAS	214	3630	56.	23.	2.43
1210102628	NAS	215	3700	28.	15.	1.87
1210900180	NAS	216	535	44.	19.	2.32
1211300333	NAS	220	1335	40.	18.	2.22
1211300067	NAS	223	575	32.	15.	2.13
1211300067	NAS	224	730	36.	17.	2.12
1211300357	NAS	227	890	39.	16.	2.44
1214700040	NAS	230	475	38.	20.	1.90
1216722304	NAS	233	1700	34.	18.	1.89
1216701441	NAS	234	1355	29.	16.	1.81
1218301848	NAS	237	1090	36.	14.	2.57
1218301845	NAS	240	540	36.	15.	2.40
1218301825	NAS	242	620	28.	14.	2.00
1219307815	NAS	246	4650	29.	14.	2.07
1219307815	NAS	248	4760	39.	16.	2.44
1219307815	NAS	249	4890	22.	11.	2.00
1219902531	NAS	252	4410	38.	13.	2.92
1219902531	NAS	253	4510	30.	14.	2.14

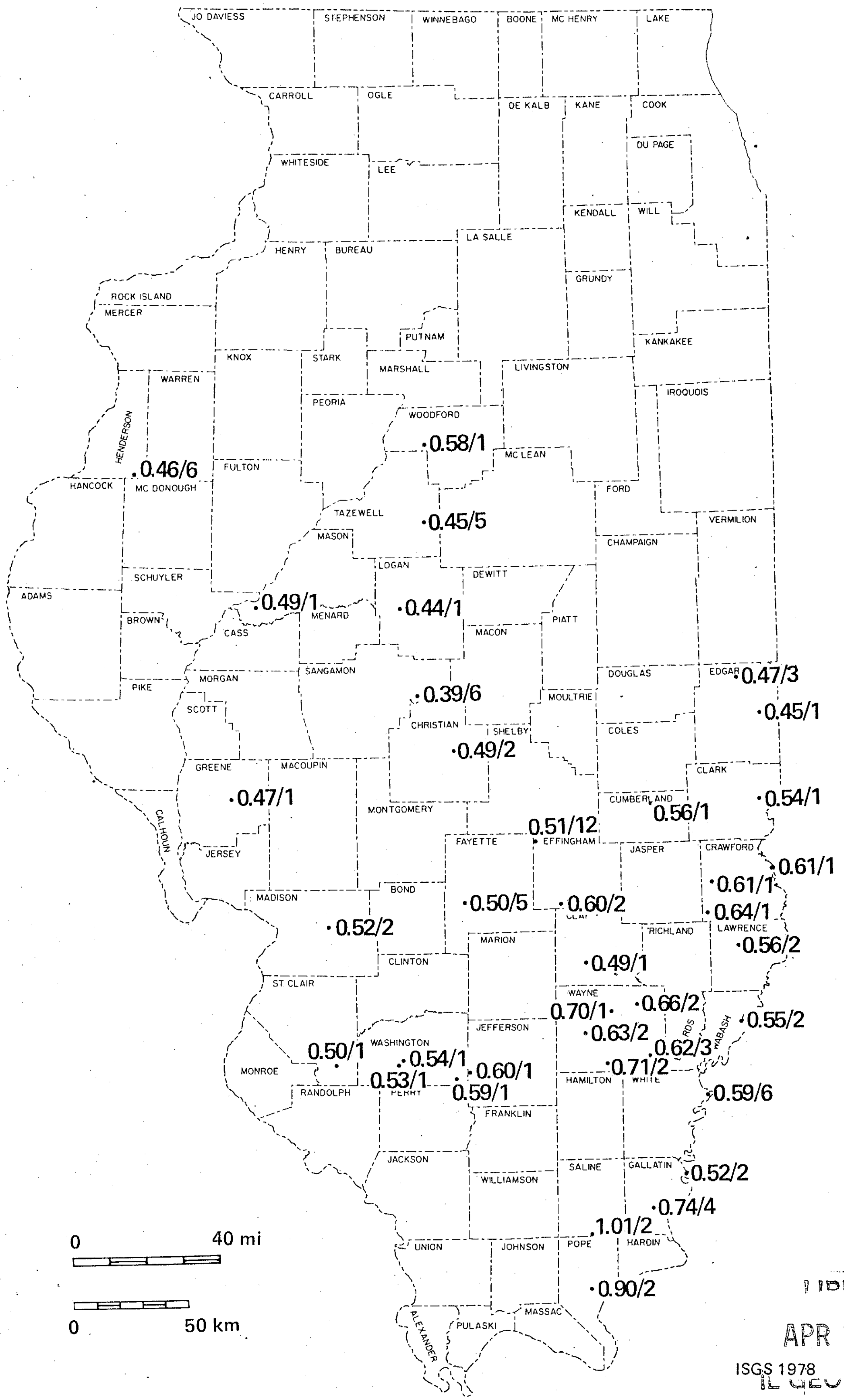


Fig. 1. Map of the distribution of mean-random vitrinite reflectance data.

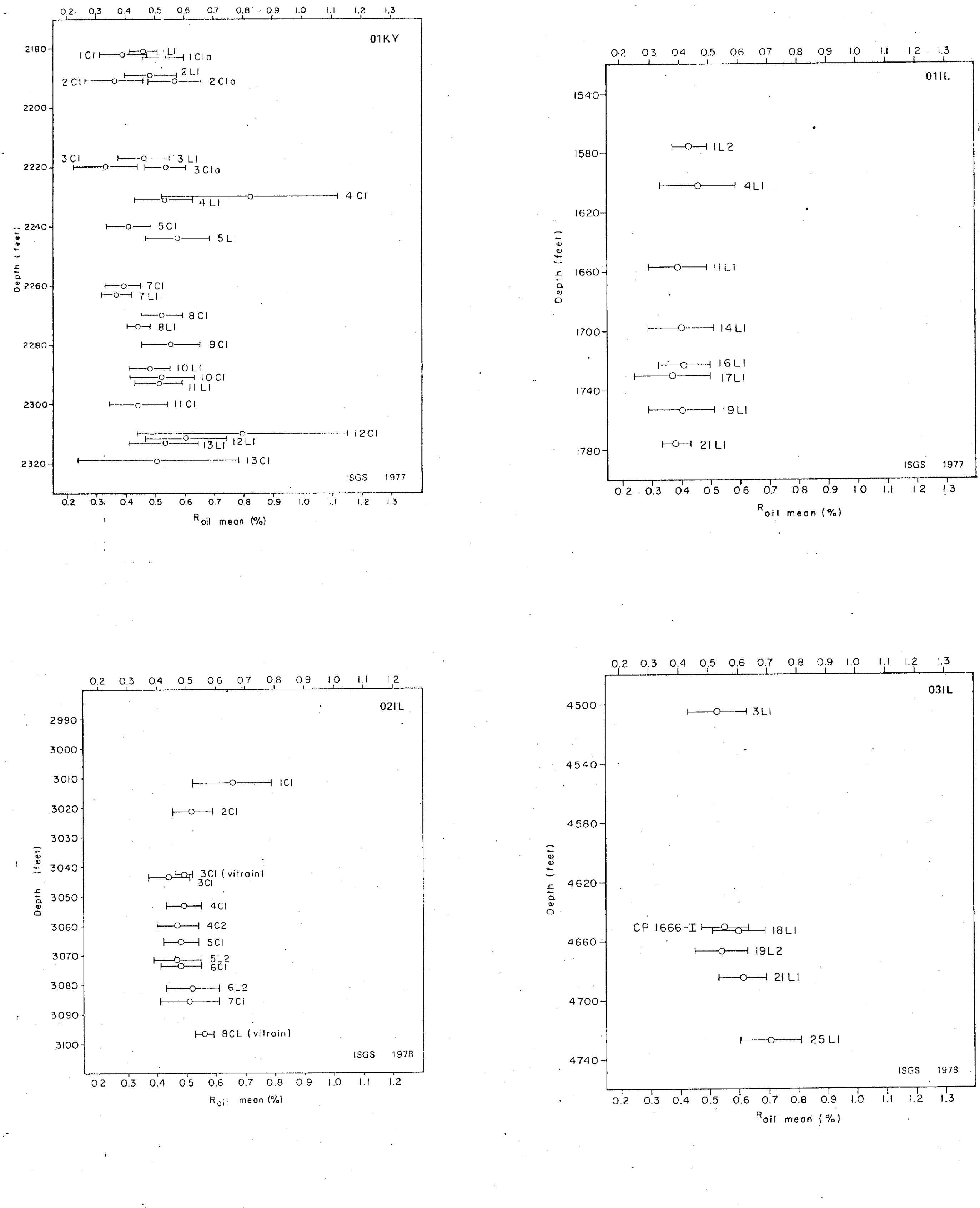


Fig. 2. Mean-random vitrinite reflectance data plotted against depth for the Christain County, Kentucky (01KY); Sangamon County, Illinois (01IL); Effingham County, Illinois (02IL); and White County, Illinois (03IL) cores.

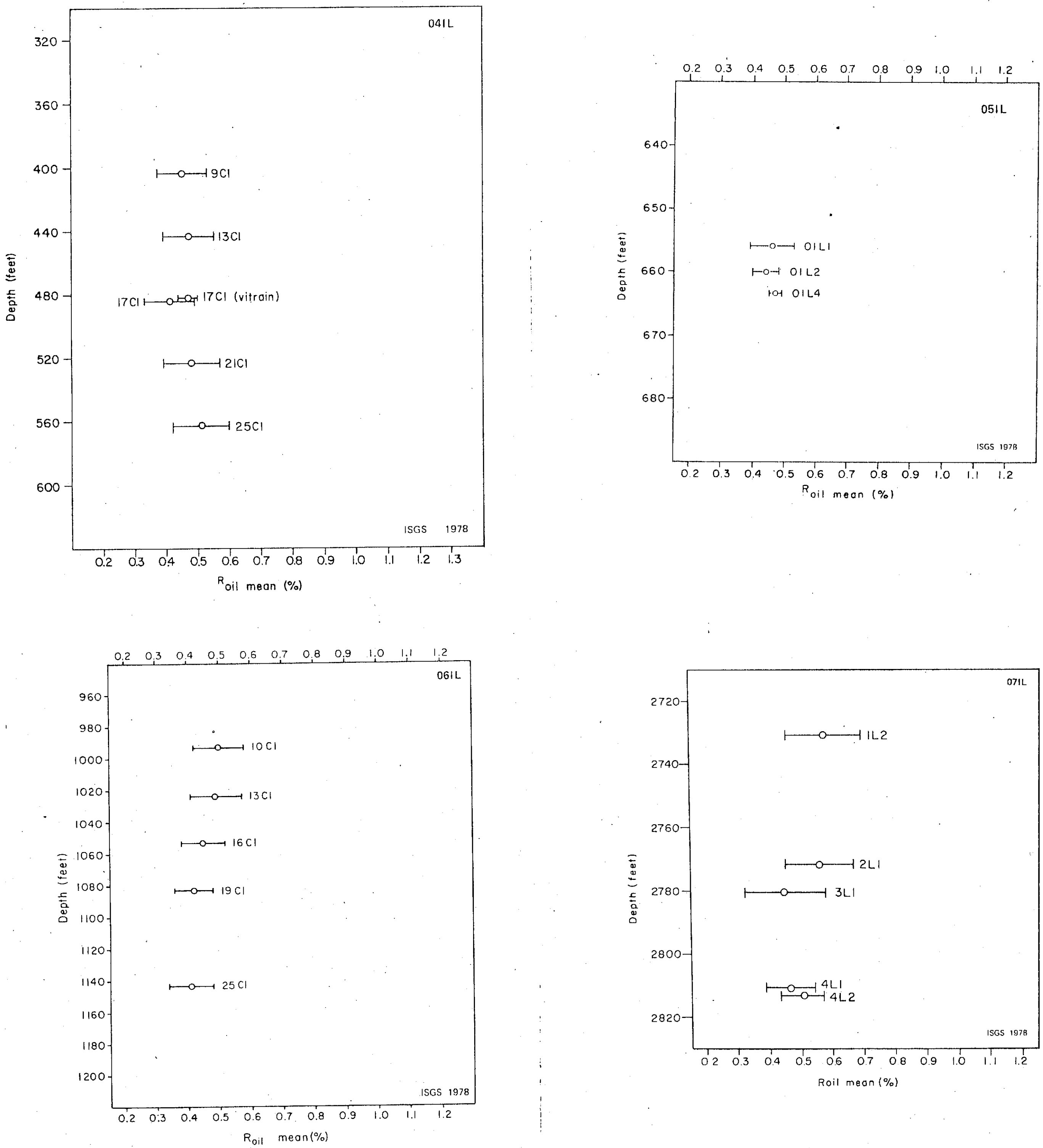


Fig. 3. Mean-random vitrinite reflectance data plotted againse depth for the Henderson County, Illinois (04IL); Edgar County, Illinois (05IL); Tazewell County, Illinois (06IL); and Fayette County, Illinois (07IL) cores.

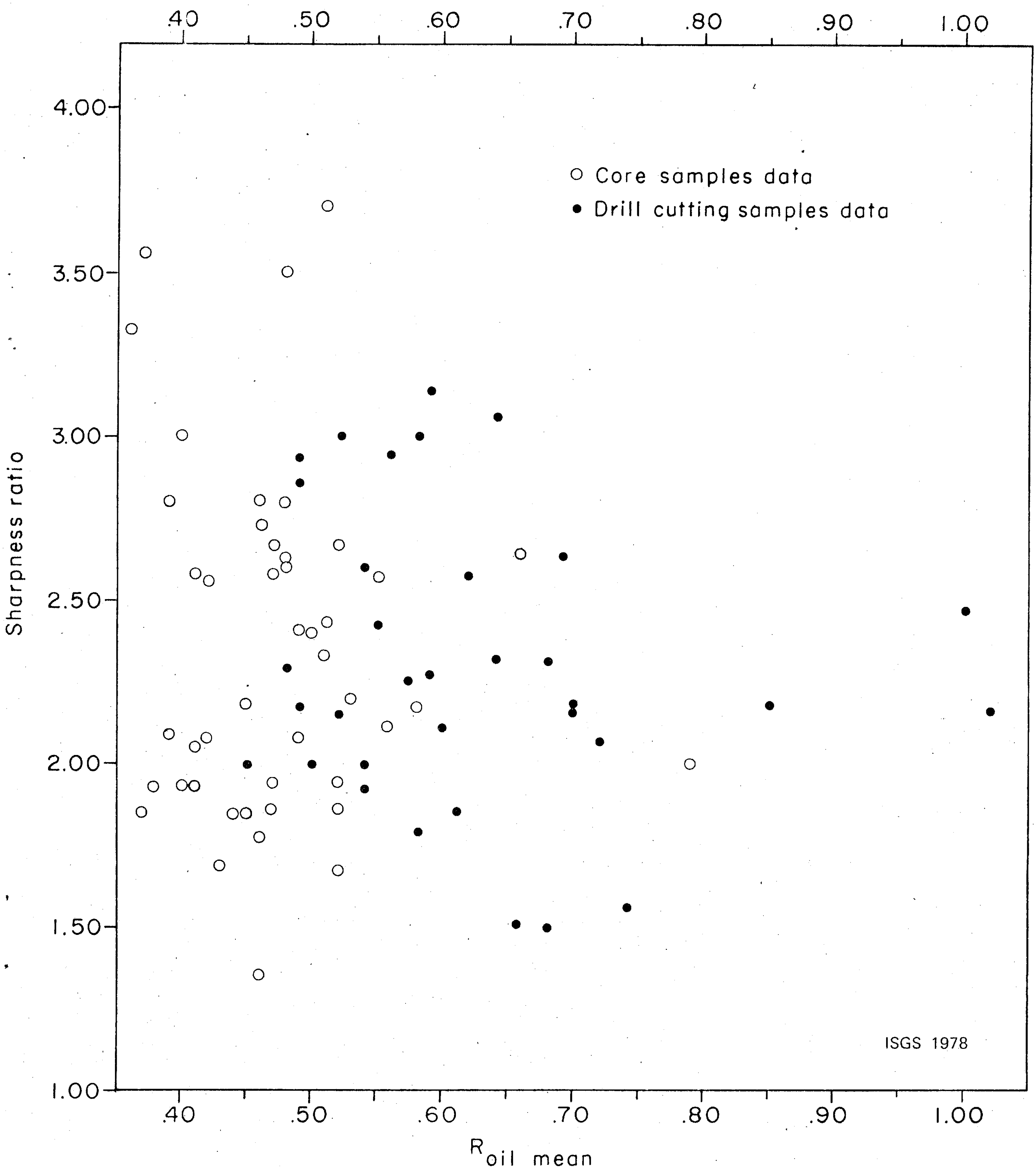


Fig. 4. Sharpness ratio plotted against mean-random vitrinite reflectance.

PHYSICAL CHARACTERIZATION

Introduction

This project is a study of the index properties, directional properties, and strength of oriented core of Devonian black shale from the Illinois Basin. Index properties include moisture content, specific gravity, bulk density, and Shore hardness. Directional seismic velocities will be determined with an acoustical bench. Strength tests include point load fracture strength and indirect tensile strength (Brazilian split). Fracture frequency, drilling rate, and core recovery are also compiled as an additional mechanical index.

Summary

The second year's testing program has nearly completed the specified tasks for all oriented cores received. The results or a summary of the results of most of the tasks have been reported in previous reports. The following table summarizes the reporting of the deliverable items as specified within the physical characterization tasks, for each of the four cores.

Deliverable Item	Core Number			
	01KY	02IL	04IL	06IL
Moisture Content	4-77*	4-77	4-77	4-77
Specific Gravity	4-77	4-77	4-77	4-77
Shore Hardness	4-77	4-77	4-77	Completed
Seismic Velocities	4-78	4-78	4-78	4-78
Point Load Index	3-78	3-78	3-78	In Progress
Indirect Tensile Strength	3-78	3-78	3-78	In Progress
Fracture Frequencies	4-77	4-77	Completed	Completed
Point Load Fracture Orientation	2-78	2-78	2-78	In Progress
Natural Fracture Orientation	2-78	Completed	Completed	Completed

*Dates refer to quarterly report and year.

Destructive Testing

Progress

Point load testing and indirect tensile testing are about 70 percent complete for core 06IL. The results are similar to previously tested cores from Illinois (second and third quarterly reports for 1978). The point load test results show a preferred orientation of fractures similar to core 04IL. The indirect tensile testing data are compatible. The detailed results will be presented upon completion of the testing.

A summary of the point load testing program is shown in Figure 1. While not complete, the fracture frequency rosette for core 06IL will look similar to that of core 04IL.

Non-Destructive Testing

Progress

All samples tested from cores 01KY, 02IL, 04IL, and 06IL have shown considerable velocity variation from sample to sample but very little variation within a sample. The total range of velocities of samples tested from all oriented cores was 3.18 to 5.15 KM/SEC. Since there are so few samples from each hole (Table 1), the results have been lumped by lithology and summarized in Figure 2. The average variation within any sample ranges from 0.05 KH/SEC to 0.10 KM/SEC (Fig. 2) or in other terms less than ten percent of the range of velocity measurements for that particular lithology. The velocity measurement within a sample shows less than three percent of the mean velocity for that lithology. There is no apparent preferred velocity direction indicated by any of the sonic testing to date.

General

The trend shown in Figure 2 (rock type vs. velocity) is similar to that shown by both point load and indirect tensile testing (Figures 3 and 4). While the point load testing indicates a preferred fracture orientation, the magnitude is masked by variation in apparent tensile strength due to lithologic variation. After completion of the laboratory testing of core 06IL, the results of the physical testing program for oriented cores will be summarized.

Table 1 - Sample Distribution for Acoustic Velocity Testing

Core Number	Lithology I	II	III	IV
01KY	1	1	5	12
02IL	-	-	-	-
04IL	4	17	9	-
06IL	-	16	14	5

Lithology: I-greenish-gray mudstone; II-olive-gray shale; III-poorly laminated brownish-black shale; IV-finely-laminated brownish-black shale.

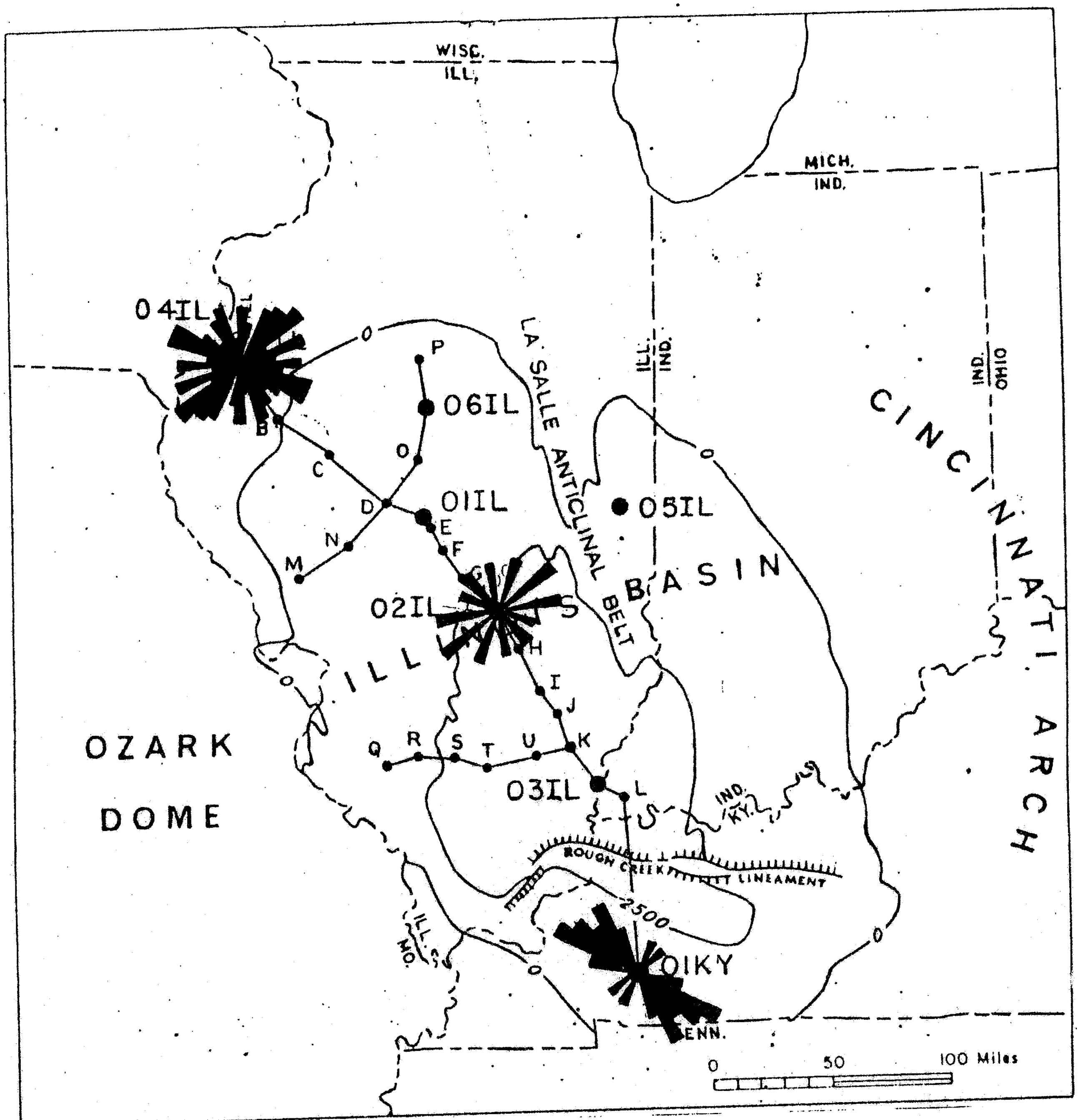
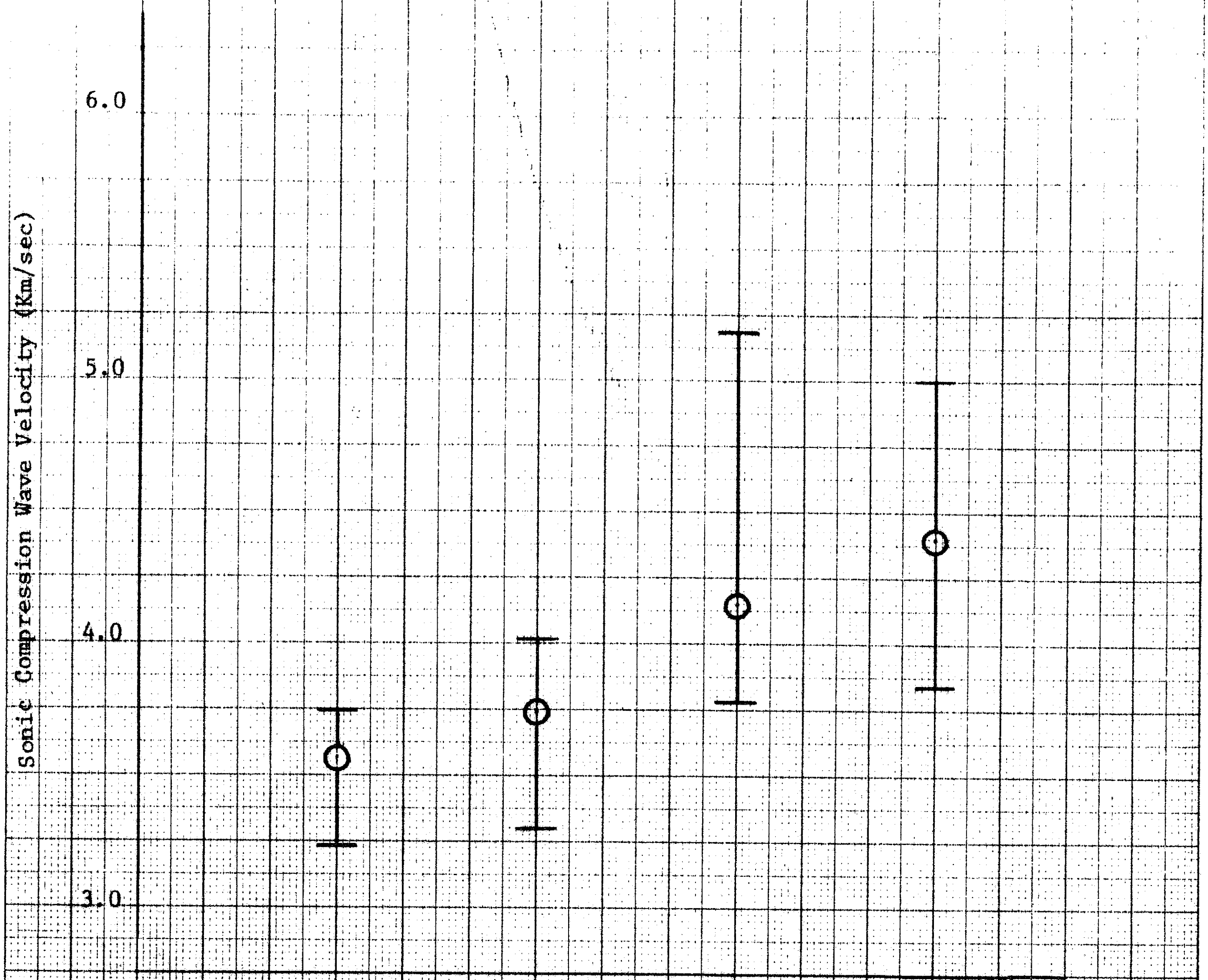


Fig. 1. Summary of point load testing results for cores 01KY, 02IL, 04IL. Frequency of point load fractures is plotted on map showing locations of test cores and wells used in this study. Contours show elevation (in feet) of the base of the New Albany Shale Group (after Swann and Bell, 1958, fig. 2).



Lithology	I	II	III	IV
Sample Number	5	24	28	17
Average Sample Variation (Km/s)	0.076	0.052	0.101	0.049

Fig. 2 Acoustic Velocities From Completed Core Testing.

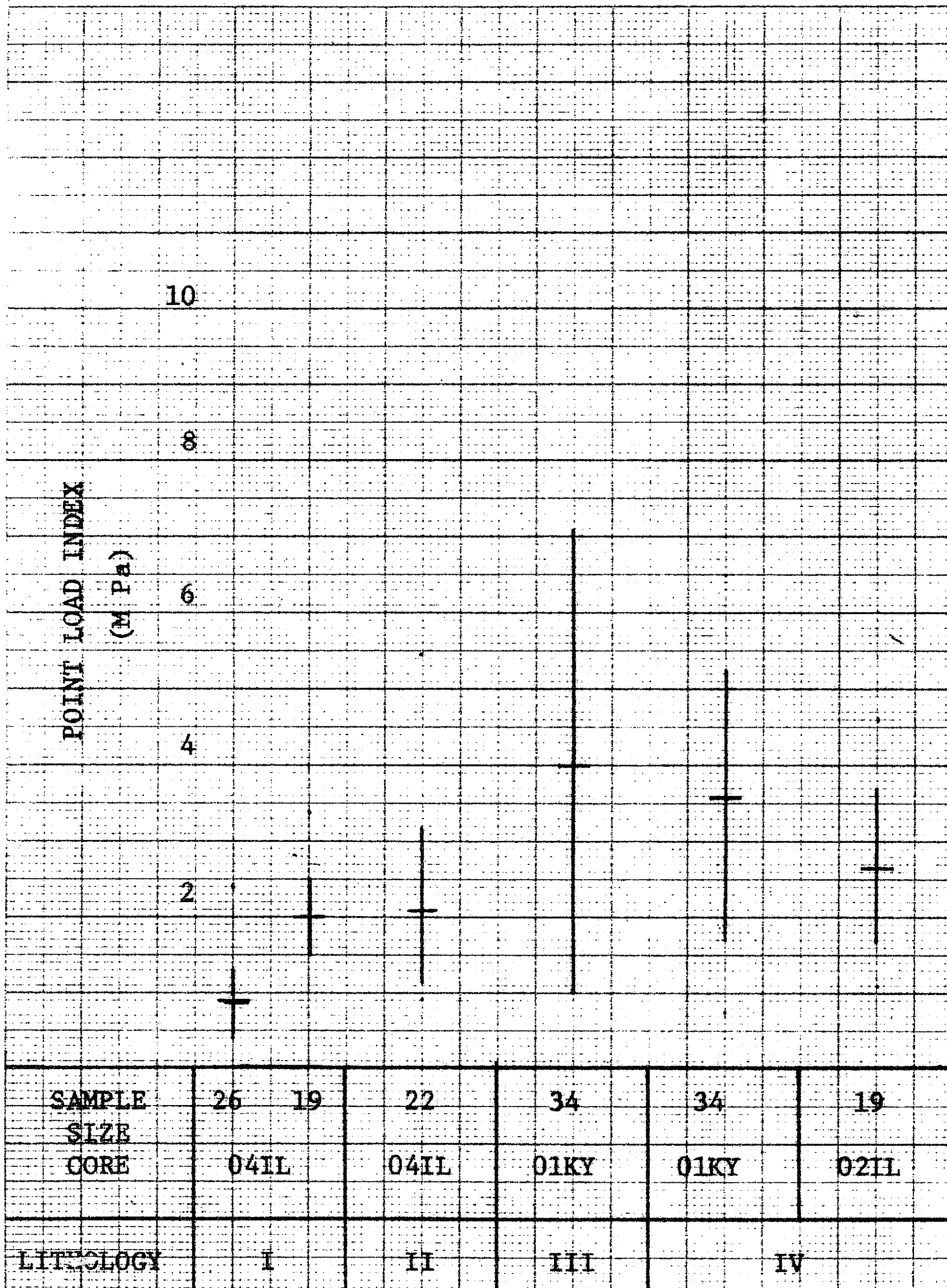


Fig. 3. POINT LOAD INDEX VALUES FROM COMPLETED CORE TESTING.

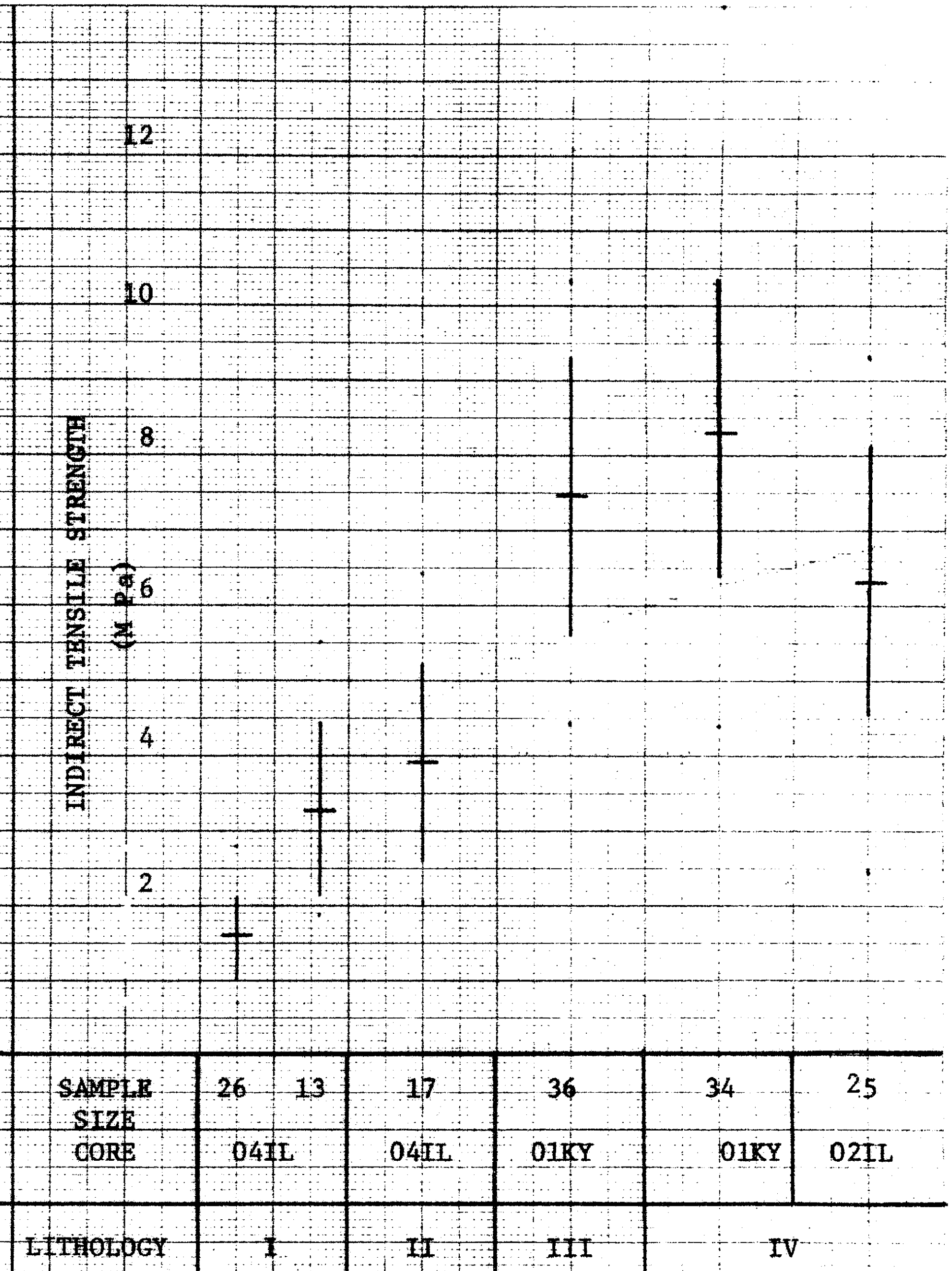


Fig. 4. INDIRECT TENSILE STRENGTH VALUES FROM COMPLETED CORE TESTING.

GEOCHEMICAL CHARACTERIZATION

QUANTITATIVE DETERMINATION OF MAJOR, MINOR, AND TRACE ELEMENTS IN SHALES

Introduction

Determine not less than 49 major, minor, and trace elements in 300-500 shale samples, which are representative cross sections of the cores taken. Include organic and mineral carbon; total hydrogen; total sulfur and when that exceeds 0.5 percent, pyritic and sulfate sulfur. Also, report other elements observed during normal routine analysis. The data generated will be used to evaluate 1) the potential economic importance of trace element concentrations in organic-rich shales, 2) new geochemical exploration techniques for natural gas, 3) trace element enrichment in shale organic matter, 4) the occurrence of heavy metal sulfides in shale, 5) potential catalytic effects of trace elements on shale pyrolysis yields, and 6) potential disposal problems.

Elemental Anaylsis

Progress

To September 30, ending two years under contract, 243 samples including two reference standards, were received for complete analysis for major, minor and trace elements. An additional 23 samples were received for major and minor elements analysis or for carbon analysis. Concerning the 243 samples for total analysis, the preliminary data on 59 samples, including the two reference standards were tabulated in quarterly reports. Similar preliminary data are on hand for the next 52 samples (S00073 through S00125).

It is not considered useful at this stage of the contract to report preliminary data. Only when final data are ready on a set of samples will these data be reported. This will also circumvent the problem of preliminary data being referenced.

The task of preparing tables of final data for the first 111 samples proceeds as time allows. Our results on the two shale reference standards indicated we were having problems with some determinations, i.e., inaccurate total carbon and total hydrogen analyses, inaccurate sulfur determinations by X-ray fluorescence spectroscopy, low bias to the uranium values determined by neutron activation analysis, etc. Many determinations had to be redone and all the revised data are not yet in.

For preparing tables of the final values of elemental concentrations for the shale samples, selection of the most probable concentration value for an element determined by two or three methods has proven to be time-consuming. There is no reliable value for the concentration of a few elements in the reference standards. Sometimes two or three methods give quite similar values for the concentration of an element in the reference standards but give results randomly varying from one method to another on a suite of samples. Usually it is necessary to study all the data on an element for a set of samples and use patterns in the variations among values to select the most probable concentration value. However, because a change in matrix may have one effect upon a given method and a different effect upon another method, the method chosen as giving the best result for an element in one set of samples may not do the same in the next set of samples. Thus the selection process has to be applied anew with each set of samples.

Meanwhile, with corrected procedures, analyses are continuing on the shale samples on hand, with results presently being recorded on the set of 46 samples numbered S00126-S00171 inclusive. Analyses are proceeding steadily by all methods except by direct-reading optical emission spectroscopy and neutron activation analysis. The direct-reader emission instrument is employed in the analysis of other samples for a period of about four months; the analyst doing the neutron activation work on the shale samples resigned as of August 20 and a replacement has not yet been hired.

Milestones

The progress noted herein does not comply with the milestones given for this task on page 20 of the second part of the fiscal 1978 contract (Modification No. A002). It was stated in that modification to the contract that complete analysis should be available on 350 core samples by September 1978. A revised accounting of the amount of work being done for this task and of the rate at which it is done and can be expected to be done is outlined in the contract proposed for fiscal 1979.

TRACE ELEMENT DISTRIBUTION IN ORGANIC AND INORGANIC FRACTIONS OF SHALE

Introduction

Develop chemical and/or physical methods for the separation of the organic and inorganic phases of shales, and determine the trace elements that are associated with each phase. Methods tested include float-sink gravity separations, mechanical separations (Humphrey Spiral), acid extractions, and zonal centrifugation. Compare results of analyses for ten shales, their gravity fractions, and their separated organic phases to determine the elements closely associated with organic matter. Separation procedures that are most promising will be used to study further the organically combined trace elements in additional shale samples. This research is designed to yield new information concerning chemical variations in shale organic matter, which is the shale component about which little is known and which may be the most characteristic feature of gas bearing shales.

Progress

Three methods under investigation for the separation of the organic and inorganic phases of shales have now been tested. Both the float-sink procedure and the Humphrey Spiral have failed to yield concentrations of the organic material felt to be suitable for our purposes. The Humphrey Spiral gave a product which contained 20 percent to 40 percent inorganic matter and float-sink procedures yielded products ranging in mineral content from 8 percent to 15 percent. These rather high mineral contents are due in part to the difficulty in handling and processing of the shales when ground to a sufficiently small particle size to release the finely dispersed mineral particles from the organic matter. The resulting relatively high concentrations of mineral matter in the products from these procedures prohibit extrapolation of the elemental values to the pure organic concentration as the minerals may contribute a disproportionate amount to the concentration of the element being determined.

The chemical procedure has been found to be the best method for demineralizing the shales so far. A product having an ash value as low as 1.5 percent has been prepared. Concentrations of most elements have been determined in this "organic" product at levels well above the mathematical contribution possible from the mineral residue left in the material. Only the alkali elements, with the possible exception of sodium, show no association with the organic fraction at the detection limits of the methods used for analysis. All other elements determined at this point (Ag, As, Ba, Br, Cs, Eu, Fe, Ga, Hf, La, Lu, Mn, Mo, Ni, Sb, Sc, Se, Sm, Sr, Ta, Tb, Th, U, Yb, and Zn) show some correlation with the organic fraction of the shales.

The acid extraction procedure may be stripping some of the elements from the organic molecule (e.g. chelated elements) and other elements, those dissolved from the minerals, may be exchanging with those attached to the organic material. For these reasons confirmation of the values needs to be obtained from some type of process other than acid extraction.

A fourth method to be tested is a gradient density centrifugation technique. Equipment for this test is now in house and preliminary testing is under way. This technique should allow the separation of colloids and would therefore not restrict the use of extremely fine grinding to release the mineral particles. Once this technique has been developed application to gas-producing shales will be undertaken. Correlation of the organically associated trace elements with gas producing and nonproducing shales may yield an indicator for determining production feasibility.

To date all milestones, with the exception of testing of the gradient density equipment, have been met. This testing is under way, after a delay caused by contract funding and should be completed this quarter.

Preliminary data and some conclusions based on the values were presented in the September monthly report in compliance with deliverable commitments.

MODE OF OCCURRENCE AND RELATIVE DISTRIBUTION OF HYDROCARBON PHASES IN SHALE

Introduction

Determine the character of off-gases from approximately 10-foot intervals in cores collected in the Illinois Basin. In addition, determine the relative distribution of hydrocarbons in ten specially prepared core samples, which are the same as those in previous unit. Preserve the samples in airtight containers and subsequently analyze them for evolved gases; highly volatile, low-molecular weight liquids; medium-volatile hydrocarbons; and solvent-extracted, low-volatile hydrocarbons by GC analysis of shale pyrolytic products.

Determine the carbon isotopic composition of methane in off-gases from core samples whenever sufficient methane can be collected. Compare these data to other pertinent data such as gas composition and vitrinite reflectance for the purpose of making interpretations as to the origin and maturity of the gas. Perform laboratory experiments to study the relative effects and significance of chemical and isotopic fractionation that occur as gas is released from core samples.

Data accumulated can be evaluated to gain a better understanding of the origin, migration, and location of natural gas associated with the shales.

Progress

The milestones for this task include the analysis of released gases, and of high-, medium- and low-volatile organic components for quantity and composition. The released gas analysis is to be run on all core samples received from the Illinois Basin. The high-, medium- and low-volatile organic analysis is to be run on ten selected samples.

Progress on this task was delayed from eight to ten months because of lateness in funding and time required to obtain equipment. Also, only one sample has so far been taken from each core taken from the Basin at this time. This has been done in anticipation of receiving more cores which will yield a wider scope of the organic matter in the black shale of the Illinois Basin.

A preliminary progress report on the distribution of the hydrocarbon phases in shale follows.

Released Gas Analysis

Analyses of released gas from the last available cores - Henderson County, Illinois (04IL) and Tazewell County, Illinois (06IL) were completed and reported in the December 1977 monthly report. A brief summary of the hydrocarbon content of the released gases is given in Tables 1 and 2. The average values indicate the gas to be quite wet. The yield of released gas was less than 0.03 cubic feet of gas per cubic foot of shale.

Volatile Hydrocarbon Analysis

A rapid procedure for the pyrolysis of shale samples and the subsequent use of gas chromatography for the determination of the C_1 to C_5 pyrolysis products has been developed.

Small samples (150 to 350 mg) of pulverized shale are accurately weighed into a clean quartz reaction tube (200 mm x 12 mm ID). The tube is closed with a rubber serum cap and evacuated at room temperature for ten minutes.

The tube is then inserted into a tube furnace which has been previously heated to the appropriate pyrolysis temperature (450°C or 600°C) and held there for five minutes.

The noncondensable gases at 29±1°C are sampled from the headspace for gas chromatographic analysis. The gas chromatograph is fitted with a 1 ft. X 1/8 in. stainless steel precolumn (Tenax GC, 60-80 mesh) and a 6 ft. X 1/8 in. stainless steel separation column packed with Chromosorb 102. The helium carrier gas flow rate was 20 ml/min. The column was temperature-programmed from 40°C at 8°C/min. up to 170°C and held at that temperature for eight minutes. The yields are quantified by using a pure gas reference (cyclopropane). Peak areas were measured and relative percents calculated with a Perkin-Elmer Sigma 10 Data processor.

Figure 1 shows a typical chromatogram of the non-condensable headspace gas released fron a shale sample (S00095, also SDO-I) heated to 450°C in an evacuated tube. The headspace gases are composed of n-parafins and 1-olefins containing 1 to 5 carbon atoms. The weight percents of the gases released from two standard samples and two core samples are given in Tables 3 and 4. The reproducibility of the gas chromatography system exceeded 95 percent confidence level by statistical tests of the natural gas sample.

Using known amounts of a pure gas standard (cyclopropane), the yields of pyrolysis products are determined. The yield averages are listed in Table 3. The pyrolysis gas contains less methane than the average for natural gases. The percent wetness of the gas produced by pyrolysis is shown in Table 5. Because the total pyrolysis time was only five minutes, pyrolysis of samples may not be complete, especially at the lower temperatures; therefore the yields in Table 6 are not maximized. These results show that relatively large quantities of combustible gases can be readily obtained by pyrolysis of shale. They also show the variations in yield that may be obtained from different shales.

Medium Volatile Hydrocarbon Analysis

Pyrolysis

Four shale samples were analyzed for medium- and low-volatile hydrocarbons. The sample descriptions are as follows: S00095 from a road-cut on Interstate 64 near Morehead in Rowan County, Kentucky: S00060 from a limestone quarry near Indianapolis; 02IL04C1 from Effingham County, Illinois (3053 ft.), and 04ILC1 from Henderson County, Illinois (453 ft.).

A pyrolysis-gas chromatograph technique was used to analyze for medium- and low-volatile organics in the black shale. A "Pyroprobe 190" (Chemical Data Systems, Inc., Oxford, Pennsylvania) was used to pyrolyze the samples directly into the injection port of the gas chromatograph. A heating rate of 75°C/millisecond was used to attain the desired pyrolysis temperature. The total pyrolysis time was 40 sec. The evolved gases were trapped on a precolumn packed with glass beads and held at liquid nitrogen temperature. The liquid nitrogen was removed and the organic species were eluded onto the GC column (SP2100 or Dexsil 300-10 ft. X 1/8 in.) by temperature programming from ambient to 330°C at 8°C/min. The gas chromatograph was equipped with a flame ionization detector and an electronic data processor.

The results of the pyrolysis studies using the "Pyroprobe 190" unit are given in Table 7 and in Figures 2, 3, 4, and 5.

For comparison, the series of compounds was divided into six groups with the following boiling ranges: (A) up to 60°C; (B) 60°C to 142°C; (C) 142°C to 235°C; (D) 235°C to 302°C; (E) 302°C to 356°C; (F) above 356°C. The peak area of each component was measured by a Perkin-Elmer Sigma 10 Data processor. The results are listed in Table 7. At a pyrolysis temperature of 600°C or above, the four shales show a similar tendency in that the low boiling range fraction (A) predominates. The other fractions (See Figures 2,3,4, and 5) decrease gradually as the boiling range increases. At a pyrolysis temperature of 450°C, there are some differences. The two samples S00095 and S00060 show fraction B predominating while the two samples 02IL04C1 and 04IL14C1 show fraction C, which is higher boiling than fraction B, predominating.

This analysis allows one to assess the distribution by boiling range of organic compounds present in the shale oil derived by pyrolysis and the chromatogram from pyrolysis at 450°C may serve as a "finger print" for each sample.

Solvent Extraction

The above four shale samples were also extracted with benzene-methanol (70:30;V:V) in a soxhlet extraction apparatus. The extracted organic matter was then separated into aliphatic, aromatic and asphaltene fractions by activated alumina column chromatography. Elemental analyses, infrared spectra were run on the whole extract and the fractions. Gas chromatography and pyrolysis studies have been run on some of the fractions.

Results of the benzene-methanol solvent extractions of four shale samples and the elemental analyses of the derived fractions are given in Table 8. Only about 4 to 5 percent of the total organic matter is extracted from the shale with a (70:30, V:V) mixture of benzene-methanol. The hydrogen to carbon ratio in the original shale is probably high due to hydrogen derived from inorganic hydroxyl and bound water in the mineral part of the shale.

The H/C ratios of the chromatographic fractions are within the expected range. The infrared spectra of the aliphatic fractions are clean and typical of spectra of pure aliphatic compounds. The spectra of the aromatic fraction have both aliphatic and aromatic peaks. This is likely due to side chains on the aromatic rings. As expected the asphaltene spectra are quite complex.

Stepwise pyrolysis in 100° steps from 250°C to 850°C of the asphaltene indicates that the major production of volatile pyrolysis products takes place near 550°C. At the lower temperatures small amounts of C_{12} to C_{20} are volatilized. The 550°C chromatograph is quite complex with a major portion of the products being in the C_1-C_{12} range with lesser amounts up to C_{36}. At 850°C the products resemble natural gas for the most part.

Isotopic Analysis of Released Gases

No additional cores have been made available during FY78 which released sufficient quantities for methane for isotopic analyses. The results of all isotopic analyses on cores collected in FY77 were reported in the Annual Report for that year.

Laboratory Study of Chemical and Isotopic Fractionation

Laboratory studies are being carried out to help evaluate the changes in chemical and isotopic composition occurring as a result of the loss of gas during the collection of core samples. The first portion of this research has now been completed.

In this study, an attempt was made to duplicate the conditions that exist during collection of samples. A segment from core 01KY was sealed in a high pressure vessel and evacuated for 96 days to remove all of the gas originally present. The vessel was then filled to a pressure of 965 psi with natural gas of known chemical and isotopic composition. After 76 days, uptake of gas appeared to have stopped, and it was assumed that equilibrium had been achieved. The gas was then gradually released over a period of 2 hr, simulating the gradual decrease in pressure that occurs as a core sample is removed from a well (phase 1). The pressure was maintained at atmospheric pressure for another 2 hr, simulating the time during which a core is described and segmented for canning (phase 2). Splits of the gas released were collected at periodic intervals and analyzed. These results were presented and discussed in the September 30, 1977 Annual Report.

In phase 3 of this study, the sample was closed in and the pressure allowed to build up, simulating the canning of a core sample. The head space gas was periodically analyzed and the results of these analyses are shown on Figure 6. Figures 6a and 6b show the changes in chemical composition as a function of time, Figure 6c shows the change in isotopic composition and Figure 6d shows the pressure in the sample container. The periodic drops in pressure are primarily the result of removal of sample for analysis; however, one of the pressure drops shown on the figure was caused by a leak which developed in the system. Figure 6e shows an estimate of the amount of gas released by the shale core during phase 3 of the experiment. It should be emphasized that this curve is only an estimate because of possible errors in the pressure measurements and a lack of information on the amount of gas lost through leakage.

During the later part of phase 3, little change in composition was observed. This was partially a result of the relatively small amount of gas diffusing out of the shale compared to the amount present in the sample container (i.e. dilution effect). To determine more precisely the composition of the gas diffusing out of the shale, the sample container was periodically evacuated to approximately 5 psig during phase 4 of the study.

The changes in composition observed during the first 20 days of the experiment are not entirely understood, but are believed to be a result of inequilibrium during the initial pressurization of the sample. For example, during pressurization, methane being lighter and smaller than ethane would migrate into the shale pores more rapidly than ethane. A gradient would therefore be established from the outside of the core to the center. The outer sections of the core would be enriched in ethane (low C_1/C_2 ratio) and the central portion would be enriched in methane (high C_1/C_2 ratio). Upon initiation of the degasification the direction of gas migration would reverse. This would result in two opposing effects; methane would migrate out more rapidly, but the outer sections of the core would be enriched in ethane. These two conflicting effects are believed to be the cause of the confusing results during the first ten days of the experiment. If this is true, then the dashed lines shown on Figure 6 may be more representative of the changes that would have occurred had an initial equilibrium been achieved.

The relationship between these data and the possible changes in chemical and isotopic composition that occur prior to canning of a core sample are unclear. The preliminary data do suggest, however, that significant changes in the chemical and isotopic composition of natural gas can occur during degassing of shale cores. It is therefore very important that the core samples be sealed into containers as quickly as possible after they are cut.

The lack of equilibration encountered in this preliminary study prevents the use of these data for interpreting the adequacy of extrapolation as a method of correcting for fractionation. The continuation of this study is being carried out using 3/4 inch diameter cores. These smaller cores should allow equilibrium to be achieved in a much shorter time than was possible with the large core sample used in the initial study. Because funds for the purchase of necessary equipment were not made available until almost half-way through the contract year, the continuation of this study is just getting started. Small core samples have been cut and are now being degassed in preparation for pressurization. The data suggest that very significant changes occur during the initial degassing period. However, the actual effects of the assumed inequilibrium are not known. Some light may be shed on these questions by a further mathematical evaluation of the data.

One point of particular interest in these data is that during the degassing, the released gas becomes "enriched" in the heavier chemical species, but depleted in the heavier isotopic species ($C^{13}H_4$). This depletion in $C^{13}H_4$ is the opposite of what would be expected. Future experimental work will emphasize explaining this phenomenon.

Because of the problems encountered with this study, future fractionation studies will be carried out on 3/4 inch diameter cores. These smaller cores will make equilibrium more easily to achieve.

Adsorption/Desorption Studies of Gases Through Shales

Introduction

With nitrogen and carbon dioxide, determine internal surface area on shale core samples; on selected samples, use methane as the adsorbate (sorbate) at pressures within the range of 1 to 80 atmospheres. Comparison of these properties in gas-producing and non-gas-producing shales will be made to determine the relationship of shale physical properties to gas recovery.

Progress

A paper entitled "Use of Internal Surface Area and High-Pressure Methane Sorption Data to Estimate Capacity for Gas Production from the New Albany Shale Group" by Robert R. Frost and Josephus Thomas, Jr. will be presented at the Second Eastern Gas Shales Symposium in Morgantown, October 16-18,

1978. The paper summarizes the work to date in this program, particularly with regard to high-pressure methane adsorption. Following is the abstract of the paper.

Internal surface areas (ISA) measured via the BET method with N_2 and CO_2 as adsorbates at _196^o and -77^{o}C, respectively, were determined on shale samples from Christian County, Kentucky, and from Effingham and Tazewell Counties in Illinois. High-prssure (up to 100 atmospheres) methane sorption isotherms at 28^{o}C were determined for selected shale samples. After the determination of a sorption isotherm, the methane at approximately 100 atmospheres surrounding the shale sample was released to atmospheric pressure, and the release of the sorbed methane with time was then measured at constant pressure (1 atm).

Data are presented which show a general direct correlation between the CO_2 ISA, porosity, and the high-pressure methane sorption capacity of the shale samples. The release rate of the sorbed methane is relatively independent of the methane sorption capacity but shows a general inverse correlation with the CO_2/N_2 ISA ratio. Thus, the CO_2/N_2 ISA ratio is a useful indicator of the amount of fracturing (natural or induced) necessary in a shale formation to obtain reasonable rates of gas production.

At this point, we have determined the internal surface area values from both nitrogen and carbon dioxide adsorption on all the shale core samples that we have received. This represents a total of 122 core samples from the Illinois Basin. We have run an additional 27 samples from the Appalachian Basin.

From the ISA values we have selected 20 samples, a representative number, for further study using methane as the adsorbate (sorbate) gas near room temperature and at pressures up to 100 atmospheres. These have been run and reported.

Samples will continue to be run as they are received.

Table 1. Henderson County Well - (04IL)
Summary of Hydrocarbons Released

	%						
	Methane	Ethane	Propane	i-Butane	n-Butane	i-Pentane	n-Pentane
High	58.22	10.53	10.95	10.36	27.26	21.04	14.86
Average	32.26	7.21	8.54	8.34	21.59	12.92	8.79
Low	15.97	4.23	4.93	4.00	10.84	8.60	4.56

Table 2. Tazewell County Well - (06IL)
Summary of Hydrocarbons Released

	%						
	Methane	Ethane	Propane	i-Butane	n-Butane	i-Pentane	n-Pentane
High	86.44	18.54	25.97	8.24	23.92	13.70	14.91
Average	34.83	10.01	17.92	5.69	17.86	7.16	6.30
Low	14.07	1.59	4.13	1.88	5.96	3.45	1.93

Table 3. Relative wt % of the production of n-paraffins and 1-olefins with 1-5 carbons

600°C \ ave wt%	S00095	S00060	02IL04Cl	04IL14Cl
CH_4	31.99	33.50	35.08	32.75
C_2H_4	8.85	9.66	7.64	12.70
C_2H_6	19.95	19.51	23.75	16.92
C_3H_6	13.09	13.08	8.55	15.26
C_3H_8	9.13	7.87	12.52	6.64
C_4H_8	1.72	5.20	3.82	6.10
C_4H_{10}	4.44	4.51	3.99	6.45
C_5H_{10}	1.98	1.77	1.56	} 4.68
C_5H_{12}	2.51	2.26	1.88	

Table 4. Relative wt % of the production of n-paraffins and 1-olefins with 1-5 carbons

450°C \ ave wt%	S00095	S00060	02IL04Cl	04IL14Cl
CH_4	21.49	19.24	6.48	19.90
C_2H_4	6.42	6.55	4.10	6.63
C_2H_6	20.31	20.05	12.18	18.15
C_3H_6	12.11	12.74	15.33	14.66
C_3H_8	14.26	13.47	16.29	11.87
C_4H_8	7.27	8.59	12.76	10.86
C_4H_{10}	7.83	7.49	14.15	9.86
C_5H_{10}	3.16	3.71	9.8	} 8.08
C_5H_{12}	4.26	6.25	8.6	

Table 5. Absolute Gas Yield from Pyrolysis

Pyrolysis Temp. \ Gas Yield ft^3 gas/shale	Shale Sample			
	S00095	S00060	02IL04Cl	04IL14Cl
600°C	7.11	8.00	2.27	2.49
450°C	1.40	0.64	0.07	0.73

Table 6. Wetness of Pyrolysis Gas Product

Pyrolysis Temp. \ Gas Wet. %	Shale Sample			
	S00095	S00060	02IL04Cl	04IL14Cl
600°C	68.0	66.5	64.9	67.3
450°C	78.5	80.8	93.5	80.1

Table 7. The Distribution "By Boiling Range" of Organic Compounds Present in Oil Derived by Pyrolysis

Starting Material	S00095			S00060			02IL04Cl			04IL14Cl		
Temperature of Pyrolysis (°C)	450	600	750	450	600	750	450	600	750	450	600	750
% of Compounds boiling in range												
(A) <60°C	29.21	44.77	52.88	27.46	34.56	52.46	15.06	38.61	54.41	34.53	44.36	55.05
(B) 60°— 142°	40.75	20.80	24.67	27.95	16.68	18.20	30.64	18.11	22.25	21.10	20.36	20.58
(C) 142°— 235°	23.23	14.80	11.91	27.27	17.66	12.09	34.27	15.15	11.82	30.49	14.31	14.57
(D) 235°— 302°	5.50	9.97	7.53	12.50	12.71	10.72	14.66	11.99	5.84	19.78	12.18	6.49
(E) 302°— 356°	1.31	5.28	2.92	4.82	12.38	5.18	5.00	11.56	4.63	4.11	6.56	2.31
(F) 356°C <		2.42	0.09		5.55	1.35	0.36	4.49	1.05		2.23	1.00

Table 8. Soxhlet Extraction, Column Chromatography and Elemental Analysis of Eastern Black Shale

Sample Number	Element	Shale	Benz-MEOH Extract	Chromatography Fraction Aliphatic	Aromatic	Ashphaltene
Indiana		%	0.48%	8.19%	19.94%	45.68%
Standard	C	8.80	81.40	85.14	85.83	80.44
Sample	H	1.32	9.58	12.90	10.21	8.89
	N	NA	2.05	None	None	3.17
	S	1.56	2.41	NA	NA	2.87
	H/C	(1.79)	1.40	1.82	1.42	1.32
Ohio Standard			0.41%	10.97%	17.98%	37.66%
Sample	C	13.45	81.40	86.42	87.91	82.46
SD0-1	H	1.83	10.34	13.24	10.14	9.17
	N	0.31	1.75	None	None	3.26
	S	5.25	1.19	NA	NA	1.55
	H/C	(1.62)	1.45	1.83	1.39	1.32
02lL04Cl			0.60%	18.73	19.40	27.42
Effingham	C	8.51	86.15	86.33	88.58	84.05
County, Ill.	H	1.51	11.45	13.65	11.05	9.04
	N	NA	0.78	None	0.66	1.88
	S	NA	0.71	NA	NA	1.21
	H/C	(2.11)	1.58	1.88	1.49	1.28
04IL14Cl			0.27%	18.92	16.22	59.46
Henderson	C	3.07	82.81	86.57	87.88	NA
County, Ill.	H	0.72	9.35	12.66	9.81	NA
	N	NA	1.65	≤0.16	≤0.21	NA
	S	1.07	1.29	NA	NA	1.09
	H/C	(2.79)	1.34	1.74	1.32	NA

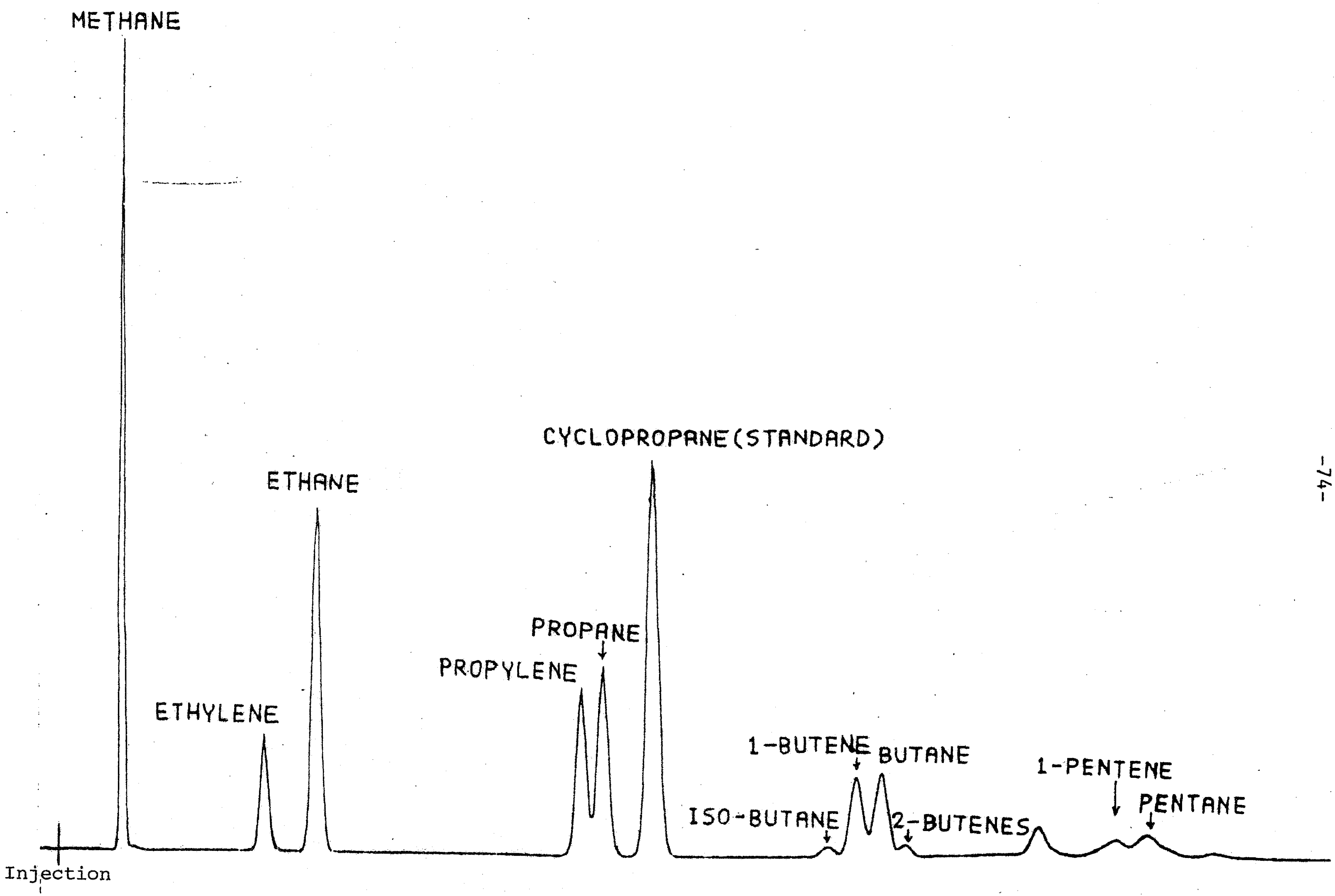


Figure 1: Gas-Chromatography of Simple Hydrocarbon Gases from Shale (S00095) heated at 450°C. Column: Stainless Steel 6 ft x 1/8 in. Chromasorb 102 with precolumn 1 ft X from 40°C to 170°C (Hold 8 min.).

Relative Distribution by Boiling Range of Organic Compounds Derived From Shale
Pyrolyzed at 450°C and at 600°C

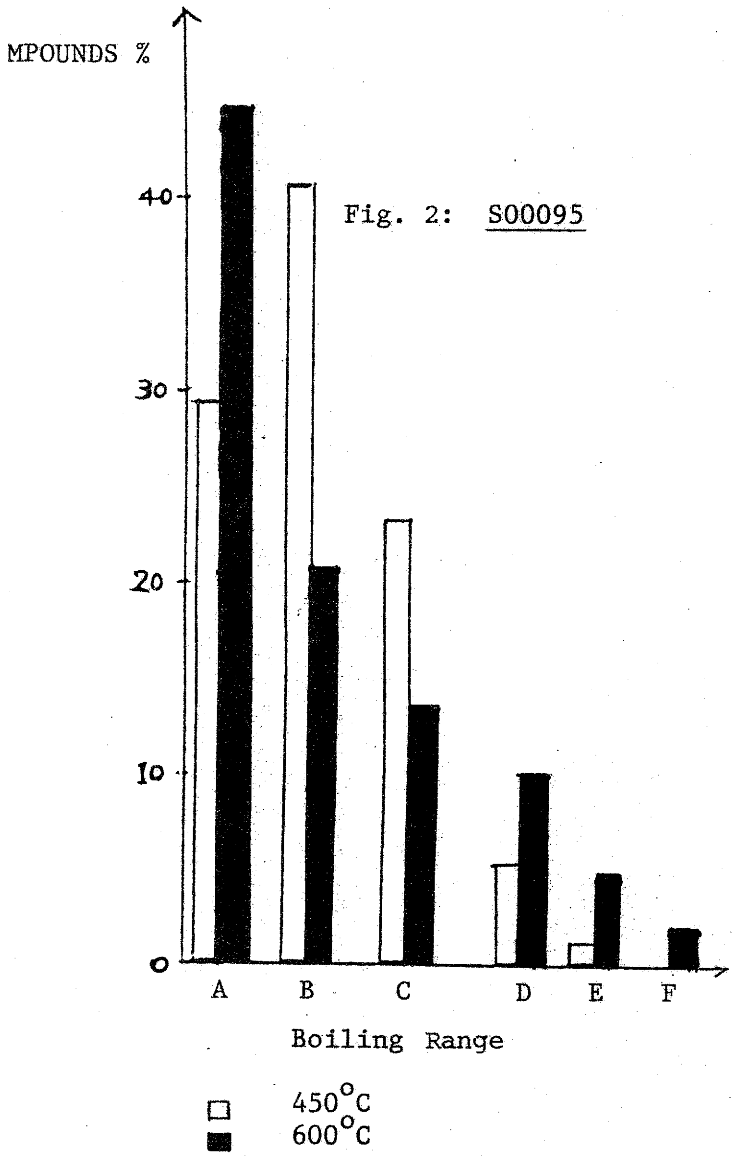


Fig. 2: S00095

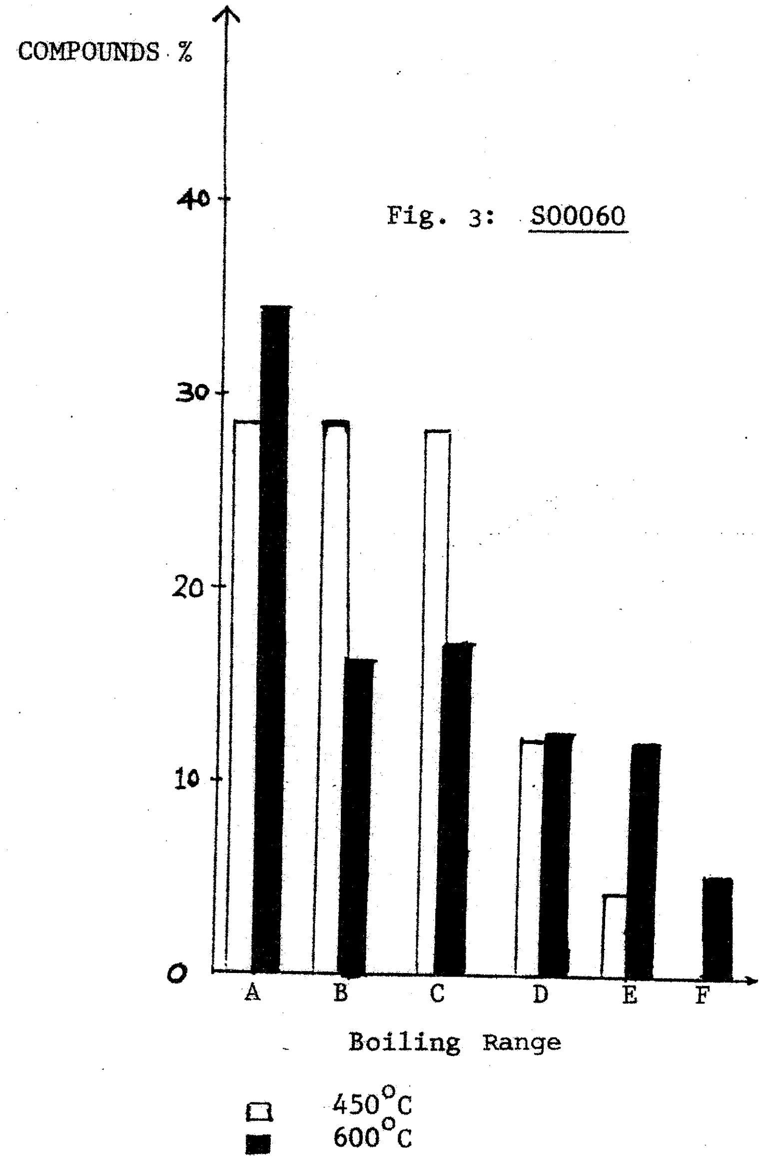


Fig. 3: S00060

Relative Distribution by Boiling Range of Organic Compounds Derived From Shale Pyrolyzed at 450°C and at 600°C

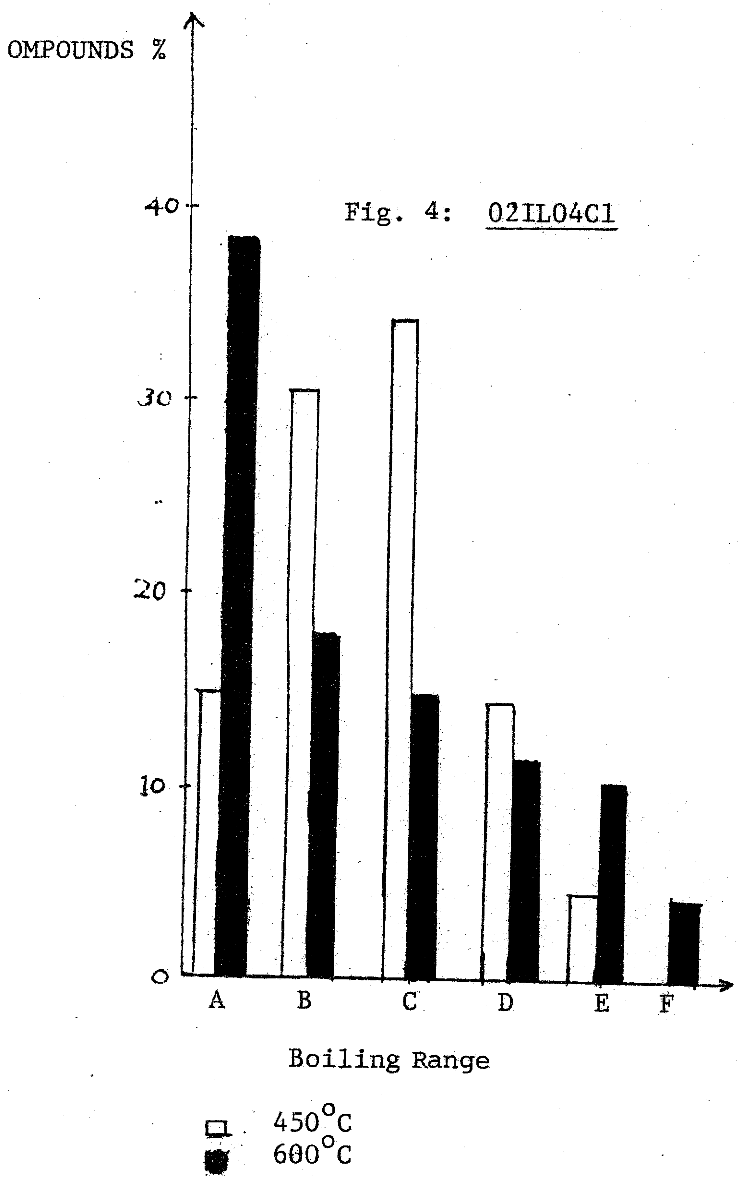


Fig. 4: 02IL04C1

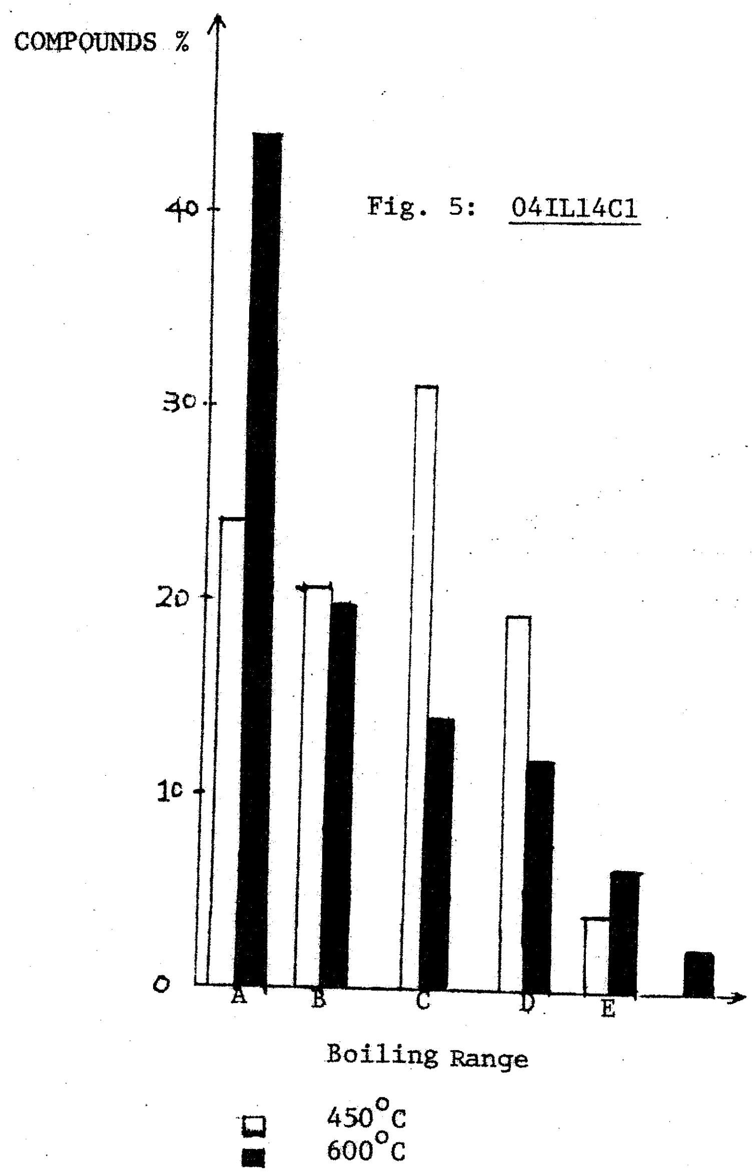


Fig. 5: 04IL14C1

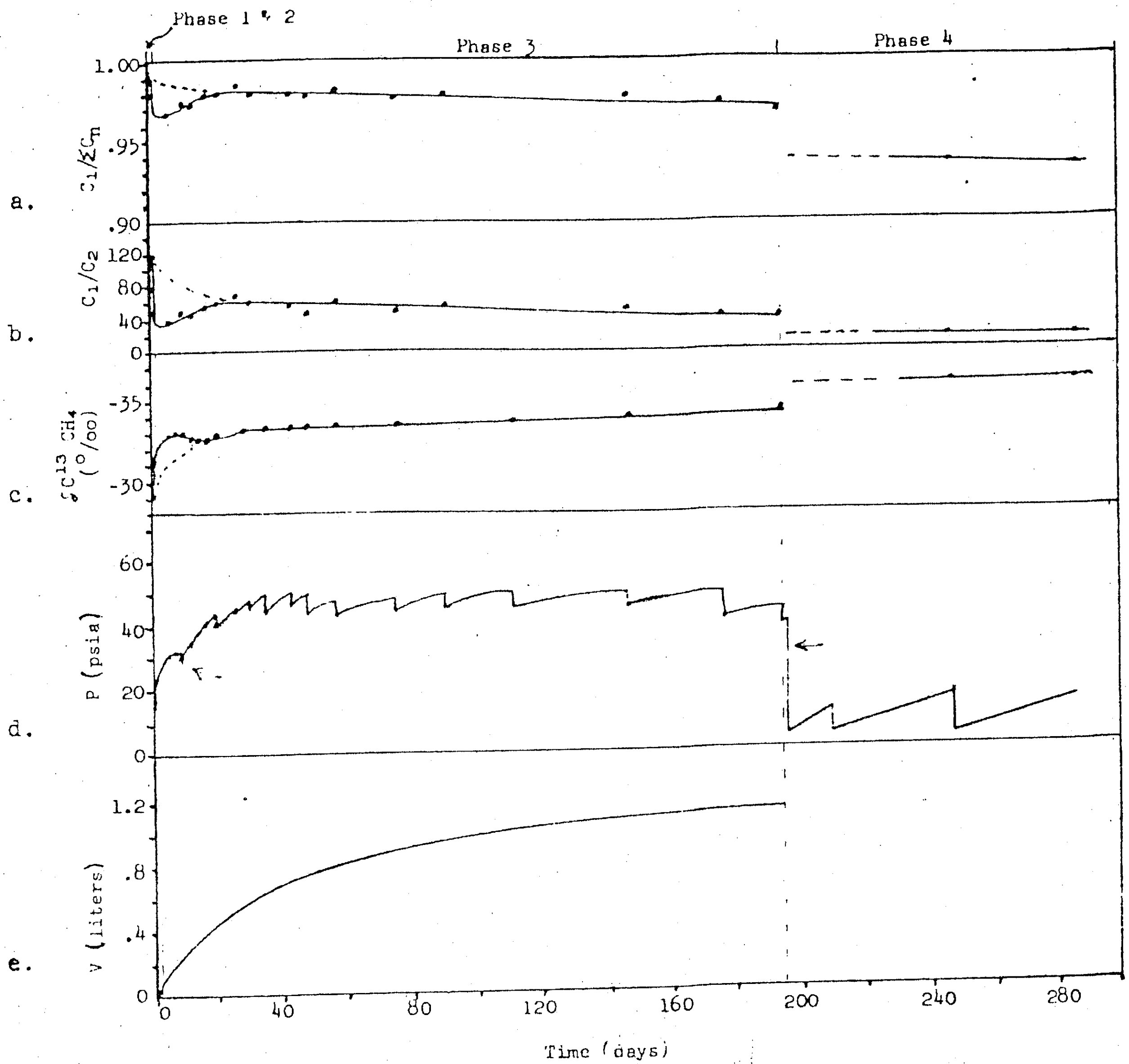


FIGURE 6 Changes in the composition of the head-space gas during the fractionation experiment. The volume shown on (e) is an estimate of the amount of gas released from the shale during Phase 3 of the experiment only.

MINERS—MINERAL RESOURCE EVALUTION SYSTEM

Introduction

The Illinois State Geological Survey has developed several data processing packages over the past seven years in support of various research efforts. In 1975 a study by computer of coal reserves in Illinois was made possible by the combining of several of these processing packages, plus the addition of a numerical surfaces package, into a rather loose system. After the study was completed, our efforts turned to the refinement, expansion, and linkage of these routines into a system that could process data to determine mineral reserves and mineral quality, provide information from extensive data files, process retrieved data, and display the results—all in one pass through the computer. Financial support from the Department of Energy (DOE) as part of their Eastern Gas Shales Project allowed the completion of this system. Although the DOE support has been of considerable help it represents only about 30 percent of the overall effort that has gone into the development of this system.

MINERS is a system that is designed to create a filing system for geological, geochemical and geophysical data; allow rapid retrieval of data for processing in whatever manner desired; provide the capability of using numerical surface routines; and display the results on base maps drawn by computer and plotter. It brings together several sub-systems, each of which was originally intended to perform certain tasks. For instance, ILLIMAP, a computer-plotter system that draws base maps of any portion of the State of Illinois from a section to the entire state, at any scale, is an integral part of MINERS. ILLIMAP was developed in the late 1960's as a support device for our research staff so that the many maps and overlays needed by them during the research phase of a project, and for final display, could be done by computer and plotter quickly, cheaply, and accurately. Several hundred maps showing Illinois geology have been turned out since the completion of this system. Over 40 copies of the system have been given to those needing a mapping capability in Illinois.

A User's Manual is being prepared to aid in implementing and using MINERS.

STRUCTURE

The MINERS system is divisible into four major operational areas—1) file generation and maintenance, 2) retrieval (QUAD), 3) GEOMAPS, a series of routines allowing construction of up to three numerical surfaces, and operations between these surfaces, plus areal extent and volumetric computations, and 4) ILLIMAP, a base map drawing and data plotting package for Illinois (see flow diagram).

MINERS is organized as a number of Data Files rather than a single file of geological and geochemical data from wells, borings, and other sources. This organization was adopted because not all items of information are obtained for each boring; Therefore a single data file that reserved a storage space for each information item would contain many blank spaces, resulting in a waste in storage and processing time.

The primary, or index, file of MINERS contains 35 basic items of information about each boring or source of Geological/Geochemical information. The data items contained therein are those that for various reasons are best located in a file that can be, and most frequently is, accessed every retrieval run. The file contains such items as the API number of the boring, operator, fee name, elevation, location, drilling tools, total depth, availability of geophysical and other data logs, etc. Most of these data items have entries in every boring. If the data being entered into the data base pertained to coal mines, for instance, instead of borings, the file would include all the mines having data and become an index of all the mines having data in the data base.

The files constructed by MINERS are a branching set of files where the index file is the top file and all the remaining files pertaining to a particular data base refer to subsets of the primary file. These files are composed of fixed-length, sequential records with pointers locating all the individual parts of the complete record. These pointers indicate the location of another part of the complete record in another file and can point upstream, downstream or both. In the EGSP study the secondary files include a sedimentary structure file, a lithologic file and a chemical analyses file. These three files can contain varying values at different intervals of the core. Lithology, for instance, in most cases will vary significantly over a few tens of feet of core, and is therefore described at varying depths in a core. The same holds true for the sedimentary structure file and the chemical analyses file. These files may also have subsets, and therefore pointers to another downstream file. There is for all practical purpose no limit, as far as MINERS is concerned, to the number of secondary files created or their position in the stream. The only limitations are a maximum of 100 data items per file, up to 16 disk drives available for on-line use, and a total of 4,000 files. It is believed that the above conditions are sufficient to handle most geologic data bases.

Data are entered into a data base by MINERS through a program that is given the information about file structure from input language recorded by the designer of the file. The information necessary is essentially a description of the file, which tells MINERS how many data items are to go into the file and the length of each item. Each data item has a unique name, which insures that the data items desired in a retrieval run will be the ones retrieved. The names are kept in a file, the Item Name Dictionary. To retrieve data, the proper data item name is used, instead of codes or formulas, as the system operates on English language words. The unique names are entered into the system at the time the file is created. As each data item is created for a file, the unique name and its field length are put into the Item Name Dictionary. A Master File Dictionary is also created that contains a complete list of all the files pertaining to the particular data base. This organization is obviously retrieval oriented and should speed retrieval considerably, because the unique name is used in the retrieval request. The needed data items can be located quickly by a hashing scheme. As soon as the data item is located, its file and location are known.

New files may be added or old ones deleted anytime after the construction of the primary file. Operations allowed in file generation and maintenance are 1) create a file, 2) delete a file, 3) add a record to any file on the data base, 4) delete a record, and 5) alter items in a record. The latter operation will address any individual data item in the data base and make whatever change is desired.

Retrieval

A retrieval system call QUAD has been in use at the Illinois Survey for some time. It has been altered on several occasions in order to process files that the original design could not handle. Its ability to handle a wide range of retrieval criteria, capability of handling many files on one pass and versatility of output caused us to decide to include QUAD as the retrieval operation in MINERS.

In the retrieval phase of MINERS the request is created using English words for the identification of the data items, the conditions attached to each item, and the operators between items. Only the files that include any of the data items desired will be processed in most cases. Operations such as "=" for equal, ">" for greater than, and "<" for less than can be used as conditions applicable to data items as well as for relationships between data items.

All the commands in the retrieval request are translated into machine processible actions by MINERS and then carried out. The files accessed in the retrieval run are primarily those that contain one or more data items needed to satisfy the retrieval request. QUAD does not search files for data items but determines which data items meet the retrieval conditions when the items are located by a separate program and brought to QUAD for examination. It is not necessary to search all the files having any data items mentioned in the retrieval request. Where the .AND. operator is used (data item .AND. data item) and each data item is in a different file, searching the shortest file will satisfy the expression. However, if the .OR. (data item .OR. data item) expressions is used and the data items are in different files, both files will have to be searched. It appears that it should be possible to devise a set of rules that could optimize file searching in order to speed up retrieval, and we intend to pursue this possibility sometime in the future.

Considerable leeway is allowed insofar as output from a retrieval run is concerned. The output can 1) be of any item or items mentioned in the retrieval request, 2) include any item or items in the complete well record of any record meeting the retrieval conditions, 3) save for future use a list of pointers that will locate any well record meeting the retrieval conditions 4) be in a format for input to our numerical surface routines (GEOMAPS), 5) be in a format for input to ILLIMAP, or 6) be the values of expressions involving one or more data items. The file used for saving pointers from a retrieval run for future use is called a DOMAIN file, and can save considerable machine time where later used. The most common use of a DOMAIN file will most likely be as input to a later retrieval run where this file of selected data (the DOMAIN file) has already been created, saving the expense of searching through however many files would be needed to satisfy the conditions of the original run. DOMAIN files can be accessed and processed only through QUAD, a feature that serves somewhat to protect these files from unauthorized use.

The capability of multiple output from retrieval runs should be very useful when working with geological data. Frequently there is need to process the same data in more than one way. Or, there is need for several different data outputs from the same retrieval run. QUAD has been designed to accomplish these needs by allowing output as described earlier. GEOMAPS and ILLIMAP require specific formats for the incoming data, but if the retrieved data are headed for output on a printer the order of data items and column headings must be supplied. GEOMAPS and ILLIMAP formats are stored internally and only need to be referenced. QUAD will then organize the output file so that no manual intervention is required nor will a halt in the processing take place.

Special Processing

In processing of geologic data, many programs and routines are required in order to process data in the special applications that are necessary to obtain the correct results. In many instances the programs developed for research personnel can be used only in certain cases, such as programs that are used in chemical analyses, or in repetitive periodic reports, etc. In many cases, however, programs can be designed that allow usage over a wide range of applications, contouring and trend surface analysis being good examples. GEOMAPS is such a package.

GEOMAPS is a series of routines that are required for reserve calculations of tabular bodies and other resource evaluation studies. The operations covered by these routines include a) numerical surface approximation (weighted least squares, finite difference techniques), b) trend surface analysis (maximum orthogonal polynomial degree is 8), c) isopaching, d) intersurface integration (calculation of volume and areas), e) intersurface operations (addition, subtraction, multiplication, or division between up to three surfaces), and f) intrasurface operations (manipulation of a portion of a surface). Many uses can be made of these routines, the most useful one at ISGS being the contouring routine.

The package of programs that make up GEOMAPS is adapted from STAMPEDE, an IBM-written series of programs that are no longer maintained by IBM. The programs as written by IBM satisfied our needs only in a basic manner. That is, we could use most of the routines, but in most cases they did not go far enough. Hence, extensive revision of the STAMPEDE routines resulted in GEOMAPS, a series of programs oriented toward volumetric calculations of tabular bodies.

One of the more important additions to the original IBM programs was the geographic positioning of the numeric surfaces in reference to a base map. Any surface constructed in Illinois can be accurately located within the state, thereby allowing data from any file that contains geographic data to be processed without going through some additional geographic positioning step.

Data can be captured from maps of any scale, converted to Lambert projection, and used in GEOMAPS in whatever mix of data is desired. Of course, in the calculation of reserves of most any commodity geographic positioning of the reserves is important.

A potential problem with GEOMAPS is that it is tied to IBM equipment. Some of the routines in STAMPEDE are written in IBM assembly language, and where these routines were incorporated into GEOMAPS the assembly language routines were kept intact, inasmuch as MINERS has been developed on IBM equipment. For users of MINERS that do not have IBM equipment, other packages can be substituted. We have used SURFACE II (written by Kansas Geological Survey) for the numerical surface routines on the CYBER 175, and other packages are available from software development groups. These other packages may or may not be easy to substitute for GEOMAPS, and we have no experience on which to fall back. We have not attempted to fit SURFACE II into MINERS as a substitute for GEOMAPS so have no information on the difficulty or ease of this particular procedure. Inasmuch as we intend to eventually make MINERS into an inter-active system, we will need to use some numerical surface routines other than STAMPEDE. We hope to be able to use SURFACE II.

Two capabilities that we have found desirable, and ones that we will add to MINERS before it is considered complete, are a method of digitizing, storing, and processing line data, and a method of separating data into classes, and processing it. This latter desire, which requires a classification grid, allows one to work with data such as found on soil map, where a line divides data types instead of being made up of points of equal value. Preliminary work has been done on both procedures but little programming has been accomplished.

Lines on a map can represent many things. Contour lines represent points of equal value. Mined-out areas are shown by lines. Outlines of areas, such as the outlines of oil and gas fields, are shown by lines. Facies changes are shown by lines. These lines are valuable to many geological interpretations and need to be digitized, stored, and processed. A method of storing, identifying, retrieving, and using the data these lines represent will be added to the GEOMAPS portion of MINERS.

ILLIMAP

ILLIMAP is a base map drawing and plotting system that has been used extensively by the Illinois Survey. ILLIMAP was designed for use in Illinois only, and at present will draw base maps only in Illinois. However, ILLIMAP is being extended to cover the Illinois Basin, which underlies a little more than one-third of Indiana and roughly the same faction of Kentucky. Through cooperation with the Indiana Geological Survey, the Kentucky Geological Survey, and other interested parties, we hope to eventually have a mapping capability for all of Indiana and Kentucky, in addition to Illinois, by 1980.

Geographic location of data is not essential in all research projects. Statistical processing or use of data calculated as an average for an area usually does not carry location as a data item. But geological understanding of an area almost always requires that the data being studied be related spatially before a complete picture of the geological history can be determined. The requirement of providing an x-y coordinate for data points frequently leads to considerable extra work. Usually the x-y coordinate is measured by a digitizer or some other means, converted to some map projection, and entered into a file. This extra processing step, in order to obtain location data, frequently results in x-y coordinates being obtained on a project by project basis, a situation that does not allow full data usage over a large geographic area, or forces the use of selected data only. ILLIMAP was designed to overcome this problem by calculating the location of each data point as it is entered in the file. Each section corner in Illinois has been digitized from USGS topographic maps. Not only does this approach give a high degree of accuracy when drawing base maps, but it also allows the conversion of section-township-range notation to a map projection (Lambert Conic in the case of ILLIMAP). Hence, any data item related to borings, outcrops, mines, or anything else having a geographic location can be given an x-y coordinate at the time of file generation by the computer.

Any possible combination of footage from section or interior lines or quarter-quarter designations can be handled, in most cases. The programs that determine the x-y coordinate in Lambert feet were designed according to the Federal Land Act of 1796, the Act that set up the 36-section rectangular grid survey system.

ILLIMAP maps can be drawn to whatever scale is requested. A single section is the smallest entity that can be drawn, and the State of Illinois the largest that ILLIMAP can draw as a base map. Practically any area in between can be drawn. This capability is possible because ILLIMAP is structured on a township basis. That is, it draws a map one township at a time until the requested area has been covered. Maps can be drawn by requesting: 1) up to 10 selected sections, 2) 500 selected townships, 3) one county or any number of counties as long as the total number of townships does not exceed 500, 4) a rectangular area bordered by lines of latitude-longitude, or 5) the entire state. The number of townships that can drawn on one map can be enlarged if the computer being used has enough CPU memory to handle the added requirement.

Time is another factor that is important when making maps. Drafting a map takes time, and the amount of time can be considereable. ILLIMAP eliminates the need for substantial drafting. CPU time seldom exceeds two minutes, most maps using less than one minute CPU time on the University of Illinois IBM 360/75. This, of course, refers only to the time required by the CPU to calculate the pen movements of the plotts. Plotting, contouring, etc. are additional steps and fluctuate widely in time and cost according to equipment used. However, we have found no instance where a map could be drafted quicker and/or cheaper than making it by computer and plotter.

MACHINE REQUIREMENTS

Owing to the fact that the principal computer available to the Illinois Geological Survey during most of the developmental period of MINERS has been an IBM 360/75, MINERS is written for use on IBM 360 computers. However, some users may not have IBM computers available.

All parts of MINERS except GEOMAPS and some routines in file generation should compile on non-IBM computers with the same ease or problems attendant to any large FORTRAN IV program. ILLIMAP has been compiled on many different computers and only the PDP11 series has caused problems. A large amount of memory is required, somewhere between 300 and 400 K bytes of IBM 360 memory, but this requirement is no longer as restrictive as it once was. Many medium-sized minicomputers have memories of sufficient size now to handle MINERS. Further, because MINERS is modular in structure, the possibility of overlaying portions of the system is very good. Hence, we expect that with optimization of the system, MINERS should fit into a memory size available in a wide range of minicomputers. Actually, we believe that MINERS will have considerable appeal and be used most in an interactive mode on minicomputers having time-sharing operating systems with several CRT terminals on the system. Adding large disk drives to the minicomputer system should provide on-line access to several different data bases through the MINERS system. The amount of additional programming required to accomplish an interactive system is not too great and should be well worth the effort.

The GEOMAPS portion of the system will not compile on non-IBM computers. As explained earlier, some of the routines are written in 360 assembly language which of course will not compile on non-IBM computers. We have purchased from the Kansas Geological Survey a package of routines (called SURFACE II) that accomplish the same operations as the IBM-written routines in GEOMAPS. SURFACE II must be purchased individually by each user of MINERS that desires to use this package and hence cannot be an integral part of MINERS. Other packages that construct numerical surfaces and perform operations on them and between them are available, and can be substituted in GEOMAPS for the present routines. Depending on the package used and the computer MINERS will run on, this may or not be a substantial problem. The routines in file generation that are written in IBM 360 Assembler will have to be rewritten if MINERS is to be used on non-IBM equipment.

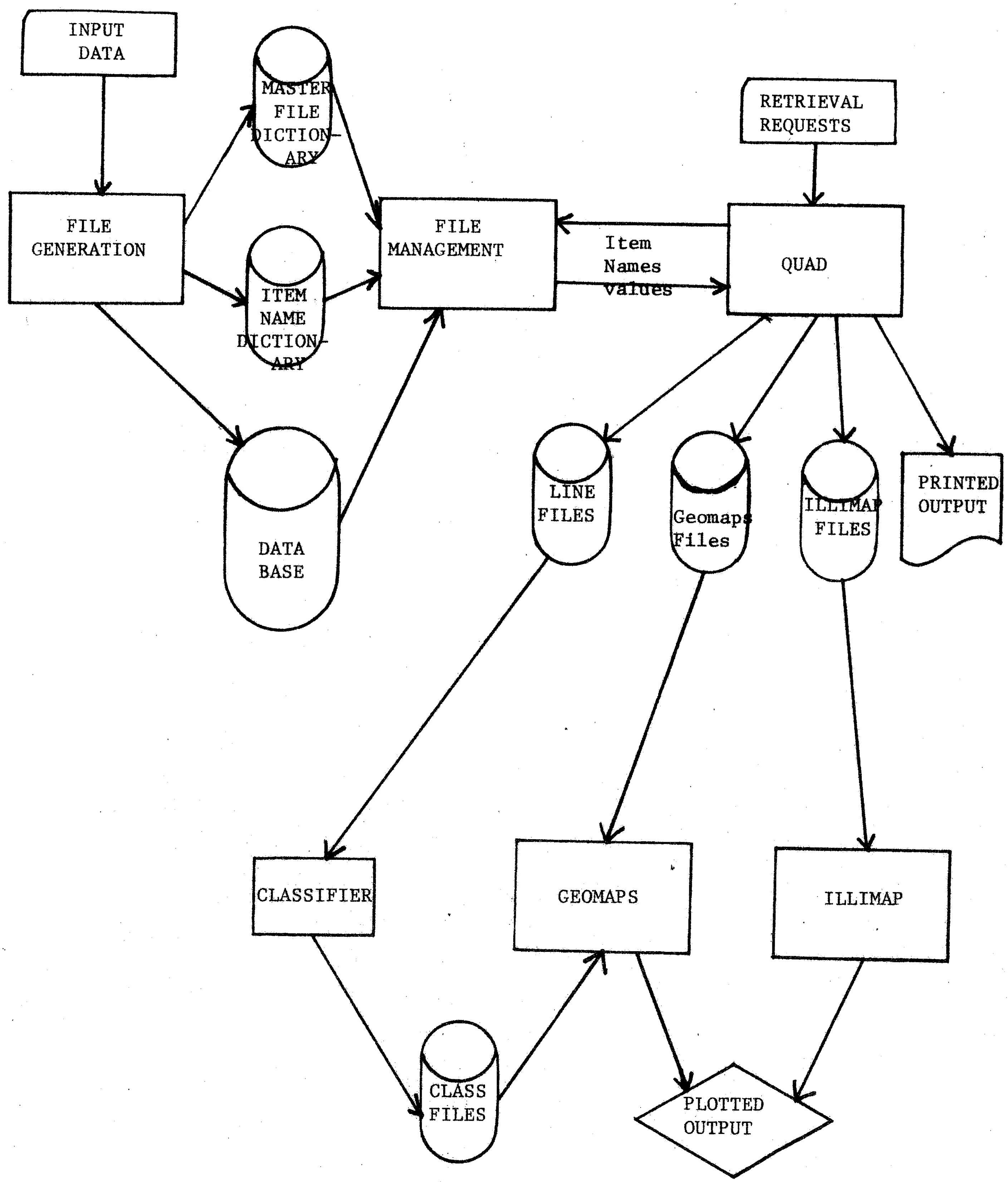
OPERATION OF SYSTEM

Organization of the files is very important to the efficient operation of the system. MINERS can handle files of any length and size, as long as there are no more than 100 data items. However, an important factor in the design of the system was a means of constructing files that would be conducive to efficient retrieval. Each person that wants to use MINERS may have a different idea as to how he wants to design the files. Some general comments concerning the reasons why we believe certain methods are better than others may be helpful.

The primary file is an index of all the borings, or mines in the data base. The data items carried in this file can be any in the data base, but to be most efficient, selectivity of data items that go into any MINERS file should be practiced. Insofar as the EGSP data are concerned, two types of data are best suited to the primary file: data that is useful in several files and data that have only one value for the boring. An example that fits both criteria is location. Location of a data item is required in many instances, but to put the location of a boring in more than one file is a waste of storage space. Inasmuch as the primary file is a dictionary of all borings in the EGSP data base, it is the most logical file for location data. If the ground location of any data items is required in the retrieval output, the primary file can be accessed for this data. Elevation is another example of the type of data item that belongs in the primary file.

Files downstream from the primary file can contain as many data items and as many records as one wishes. However, MINERS was designed for fast and efficient retrieval, and files containing a large number of data items do not usually lend themselves to fast retrieval. Files with as few data items as are practical is the best approach. For example, one area of investigation in the EGSP study is to measure a number of physical characteristics of the black shale. About 50 data items are involved. a number that is considered small for today's mass storage methods. Each time that retrieval of any data in this 50-item file would be desired, the entire file would have to be searched in order to locate all the data requested. However, if this file were to be broken up into 3 or 4 files, each file containing only closely related items, whenever data retrieval was requested only the file or files containing the data items desired would be searched. The savings in time realized by search through a few small files instead of a smaller number of large files can be considerable, particularly in an interactive system. MINERS has been designed with the idea in mind that the smallest amount of data possible should be searched in order to satisfy a retrieval request.

Most retrieval requests access only a few of the possible data items in a file. And, normally, the data items desired are closely related. If one knew prior to a retrieval request which data items were desired the retrieval run could be made most efficient by having already in a file only the data items described and also only those borings having data on those items. For example, let us assume that we have 10,000 borings in a file (500 of which have drill-stem test data). On each of these borings we are carrying 300 items of information, 25 of which have to do with drill-stem tests. If this file is kept as one file and a retrieval request is made in which the information desired is the presence of gas on drill-stem test, the entire 10,000 record file will have to be searched in order to satisfy the retrieval request. If however, the 25 items of drill-stem test data were separated into a file containing just these items, the retrieval request could be directed to a small file of only 500 borings. MINERS attempts to accomplish this ideal situation by having each data base divided into a number of files, with the data items going into each file being carefully selected.



MINERS STRUCTURE AND DATA FLOW DIAGRAM

CONTRACTOR FINANCIAL MANAGEMENT REPORT

REPORT FOR MONTH ENDING: August 31, 1978

TO: U.S. Department of Energy
Contract Division
Research Contracts, Procedures and Reports Branch
P.O. Box E, Oak Ridge, Tennessee 37830

FROM: Robert E. Bergstrom
Neil F. Shimp
Illinois State Geological Survey
Urbana, Illinois 61801

2. CONTRACT VALUE $

3. FUND LIMITATION $

4. INVOICE AMOUNTS BILLED $

5. TOTAL PAYMENTS RECEIVED $

1. DESCRIPTION OF CONTRACT
a. TYPE: Contract
b. NO.: EY-76-C-05-5203
c. SCOPE OF WORK: Geology, Geochemistry
Devonian Black Shale
d. AUTH. CONTRACT REPRESENTATIVE (Signature): Robert E. Bergstrom; Neil F. Shimp
PREPARATION DATE: Oct. 11, 1978

6. REPORTING CATEGORY	7. COSTS INCURRED		8. ESTIMATED COSTS/ $ TO COMPLETE			9. ESTIMATED FINAL COSTS
	DURING MONTH a.	CUMULATIVE TO DATE b.	SUBSEQUENT MONTH a.	BALANCE OF FISCAL YEAR b.	BALANCE OF CONTRACT c.	
Salaries, wages	$16,584.52	$182,584.90	$16,300.00	$-7,363.57		
Indirect cost	10,945.78	119,017.27	10,700.00	-4,665.77		
Fringe benefits	1,373.20	15,039.83	1,120.00	25,008.69		
Commodities, materials, supplies	44.03	6,974.97	800.00	7,531.31		
Travel	—	3,715.08	400.00	3,668.84		
Equipment	601.24	14,021.58	900.00	41,668.92		
Laboratory preparation	—	1,011.30	—	1,988.60		
Computer	1,673.20	11,678.52	500.00	5,536.70		
Contractual						
Nuclear reactor	510.00	1,685.00	—	2,630.00		
Mass spectrograph	—	—	—	8,500.00		
Telecommunications	56.92	415.14	25.00	384.86		
Totals	$31,788.89	$356,143.59	$30,745.00	$84,888.58		

EPA Form 1900-11 (10-71)

CONTRACTOR FINANCIAL MANAGEMENT REPORT

REPORT FOR MONTH ENDING: September 30, 1978

TO: U.S. Department of Energy
Contract Division
Research Contracts, Procedures and Reports Branch
P.O. Box E, Oak Ridge, Tennessee 37830

FROM: Robert E. Bergstrom
Neil F. Shimp
Illinois State Geological Survey
Urbana, Illinois 61801

2. CONTRACT VALUE $

3. FUND LIMITATION $

4. INVOICE AMOUNTS BILLED $

5. TOTAL PAYMENTS RECEIVED $

1. DESCRIPTION OF CONTRACT
a. TYPE: Contract
b. NO.: EY-76-C-05-5203
c. SCOPE OF WORK: Geology, Geochemistry Devonian Black Shale
d. AUTH. CONTRACT REPRESENTATIVE (Signature): Robert E. Bergstrom, Neil F. Shimp
PREPARATION DATE: 10/12/78

6. REPORTING CATEGORY	7. COSTS INCURRED		8. ESTIMATED COSTS/ $ TO COMPLETE			9. ESTIMATED FINAL COSTS
	DURING MONTH a.	CUMULATIVE TO DATE b.	SUBSEQUENT MONTH a.	BALANCE OF FISCAL YEAR b.	BALANCE OF CONTRACT c.	
Salaries, wages	15,617.88	198,202.78	16,300.00	-22,981.45		
Indirect cost	10,307.80	129,325.07	10,700.00	-14,973.57		
Fringe benefits	1,453,45	16,493.28	1,120.00	23,555.24		
Commodities, materials, supplies	294.70	7,269.67	800.00	7,236.61		
Travel	489.88	4,204.96	400.00	3,178.96		
Equipment	38,285.79	52,307.37	900.00	3,383.13		
Laboratory preparation	-----	1,011.30	------	1,988.60		
Computer	1,504.96	13,183.48	1,500.00	4,031.74		
Contractual						
Nuclear reactor	-----	1,685.00	------	2,630.00		
Mass spectrograph	1,000.00	1,000.00	------	7,500.00		
Telecommunications	64.34	479.48	25.00	320.52		
Totals	69,018.80	425,162.39	31,745.00	15,869.78		

EPA Form 1900-11 (10-71)