Order Number 9502530

The sequence stratigraphy of the Richmond strata (Late Ordovician) in the Tristate area of Ohio, Kentucky, and Indiana derived from outcrops, cores, and geophysical logs

Petersen, Daniel W., Ph.D.

University of Cincinnati, 1994

U·M·I
300 N. Zeeb Rd.
Ann Arbor, MI 48106

THE SEQUENCE STRATIGRAPHY OF THE RICHMOND STRATA (LATE ORDOVICIAN) IN THE TRISTATE AREA OF OHIO, KENTUCKY AND INDIANA DERIVED FROM OUTCROPS, CORES, AND GEOPHYSICAL LOGS

A Dissertation Submitted to the

Division of Research and Advanced Studies
of the University of Cincinnati

in partial fulfillment of the
requirements for the degree of

DOCTOR OF PHILOSOPHY

in the Department of Geology
of the College of Arts and Sciences

1994

by

Daniel W. Petersen

B.S., University of Illinois, 1984

M.S., University of Cincinnati, 1987

Committee Chair: Wayne A. Pryor

UNIVERSITY OF CINCINNATI

May 16, 19 94

I hereby recommend that the thesis prepared under my supervision by Daniel W. Petersen

entitled The Sequence Stratigraphy of the Richmond Strata in the Tristate Area of Ohio, Kentucky and Indiana Derived from Outcrops, Cores, and Geophysical Logs

be accepted as fulfilling this part of the requirements for the degree of Doctor of Philosophy

Approved by:

ABSTRACT

The Richmond Group (Late Ordovician) in the tristate region of southwestern Ohio, north-central Kentucky, and southeastern Indiana consists of a succession of clastic and carbonate sediments deposited on a prograding intracratonic ramp and distal clastic fan. Six regional depositional facies have been delineated during a detailed examination of cores, outcrops, and geophysical logs across a 325 by 350 km study area. The facies, informally designated Facies A through F, are assigned to depositional environments consisting of: a shale-dominated shale distal intracratonic ramp; mixed carbonate and shale proximal intracratonic ramp; shallow subtidal to supratidal intracratonic ramp, and shallow-water, distal clastic wedge; based on their sedimentologic and paleontologic characteristics. Regional cross sections of these facies indicate that the distal clastic wedge prograded from the east and that the intracratonic ramp prograded from the south. In addition, isopach maps indicate that the depocenter of the basin was located southeastern Indiana and southwestern Ohio.

Two third-order sequences are recognized in the strata. They are named the Madison and Wayne Sequences in ascending stratigraphic order. The base of the Madison Sequence is correlative over the study area and characterized by an oxidized fossil hash overlain by an intensely burrowed shale. The Madison Sequence is composed of a distal, shale-dominated facies; a proximal, mixed carbonate and clastic facies; and an intertidal to supratidal dolomitic mudstone facies. The base of the Wayne Sequence is marked by the: (1) progradation of the shallow-subtidal to supratidal mudstone facies into the center of the basin, and a correlative migration of the distal clastic wedge facies across the eastern-half of the tristate region. A subsequent flooding surface is evidenced by a retrogressive proximal ramp composed of mixed carbonate and shale over the shallow water facies. A sea level curve generated from this study approximates global sea level curves verifying the significance of the named sequences.

This study is the first to definitively correlate the concurrent westward progradation of the distal clastic wedge into Ohio and the northward progradation of shallow subtidal to intertidal dolomudstones.

ACKNOWLEDGEMENTS

I wish to express my sincere gratitude to my committee chair Professor Wayne A. Pryor who suggested the topic and provided invaluable insight throughout the project. I would like to thank Professors J. Barry Maynard and Arnold I. Miller for critically reviewing the manuscript. Ben Dattilo provided valuable suggestions and discussions. Others assisting with the study included: Professors David Meyer, Paul Potter, Wayne Martin and Warren Huff; Bruce Braswell, Douglas Shrake, Mac Swinford, Stephen Petersen, and Randy Kertes. A special note of thanks goes to Peggy Rajski who completed the monumental task of copy editing the manuscript.

This project was partially funded by the Sedimentology Fund. The Indiana and Kentucky Geological Surveys donated geophysical logs which are now stored at the Department of Geology. ERM-North Central, Inc. provided materials, equipment, and expertise essential to the completion of the project.

Foremost, I would like to thank my wife Karen Petersen for her support, encouragement, and understanding throughout the duration of this study and her assistance with the preparation of the manuscript.

TABLE OF CONTENTS

Page

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF TABLES

LIST OF APPENDICES

1.0 INTRODUCTION

The Upper Ordovician strata in the tristate region of southwestern Ohio, northern Kentucky and southeastern Indiana are characterized by a series of mixed-clastic/carbonate sequences deposited immediately prior to and during the initial uplift of the ancestral Appalachian Mountains. Several sedimentologic models and stratigraphic interpretations of these strata have been proposed within the last 20 years, and sequence stratigraphic concepts have been recently applied to this interval. However, because none of these studies have included a detailed examination of all of the available subsurface data integrated with outcrop data, a fully comprehensive regional depositional model has not been developed for the tristate region.

In this paper, the sedimentologic character and stratigraphic relationships of the uppermost Ordovician strata (*i.e.*, the Richmond Group) in the tristate region of Ohio, Kentucky, and Indiana are evaluated to determine depositional environments, paleogeography, and sea level changes. The resulting data have been used to construct a regional sedimentation model that can now be employed to enhance paleoecologic studies;

improve regional correlations of the Upper Ordovician strata; and clarify the interrelationship of tectonic events, regional sedimentation, and sea level changes.

Most, if not all, of the outcrops in the study area have been previously examined in terms of their sedimentologic, paleontologic, paleoecologic, and/or ichnologic character. However, some of these outcrops are no longer accessible or are deteriorated including those along Tanner's Creek and the section at Ceaser's Creek Spillway. As a result, this study was conducted by combining current core and outcrop data with information compiled during previous studies to enable the reconstruction of the depositional environments.

At this time, only a few comprehensive studies have been completed that: (1) define the depositional environments and facies relationships of the Richmond Group, and (2) permit the development of detailed regional paleogeographic models and geologic cross-sections. For the most part, other studies have produced generalized models that include the geographic placement of facies or stratigraphic cross sections based on lithostratigraphic principles. Furthermore, they differ in their interpretation of the relationship of the facies relations and depositional strike. A few studies, including Hay (1981) and Weir *et al.* (1984) provide isopach maps of the facies however, these maps are based upon lithostratigraphic subdivisions. This dissertation presents a unique integration of outcrop, core, and subsurface data to provide a sequence stratigraphic framework from which Richmondian depositional events can be inferred.

Because sedimentary sections in the eastern midcontinent are often incomplete and poorly exposed, paleogeographic reconstructions and cross sections have not been used in models proposed by others. For example, the Upper Ordovician of Ohio, Kentucky, and Indiana is 1,000 feet (305 meters) thick and is composed of monotonously interbedded limestones and shales. A literature review of tristate Cincinnatian studies shows that few sections are over 150 feet (46 meters) thick, and most of these are composite sections. In landmark work by Tobin (1982) and Hay (1981), the Upper Ordovician is subdivided based on sedimentology and paleontology (Tobin) and clastic content (Hay). The combined efforts of these researchers are considered to be the most comprehensive studies on the Upper Ordovician of the tristate region available today.

The existing depositional models for the evolution of carbonate sequences in the study area have primarily focused on the lateral relationships of facies from continuous vertical carbonate successions by applying Walther's Rule of the Succession of Facies. This approach has been used frequently by sedimentologists both worldwide (Wilson, 1975) and in the study area (Tobin, 1982; Betz, 1984; and Walters 1988).

Sea level fluctuations and depositional strikes have been determined by evaluating limited outcrop data. More recently, Holland (1993), Dattilo (1994), Hohman and Keith (*in press*), and Jennette and Pryor (1993) have begun to examine the sequence stratigraphy of the Upper Ordovician. A detailed discussion of their work is included in Section 2.4.3.

Core and geophysical logs that were prepared during the drilling of stratigraphic borings and oil and gas storage wells in the tristate area provide a closely spaced data set of complete sections of the Ordovician strata. All of these data were evaluated to construct detailed cross sections. Gray (1972) and Hay (1981) have incorporated parts of these data sets into their interpretations of the Upper Ordovician stratigraphy. None of the existing studies have applied this data set to the Richmondian strata in the tristate region. The available gamma ray logs clearly show the general lithologic composition of the rock and more than 150 geophysical logs contain a complete signature of the Upper Ordovician section. All data were evaluated by using sequence stratigraphic techniques and concepts to identify lithofacies, depositional environments, sea level fluctuations, and the basin's history.

Although the cores provide a visual record of the sedimentologic and paleontologic character of the strata, cores of the Ordovician are relatively rare. The overall character of the strata was discerned in geophysical logs, which did not provide information on its paleontologic character and sedimentologic character such as sedimentary and ichnologic structures. Geophysical logs are more commonly available in the study area because of the requirements promulgated in state regulations. Thus, cores and outcrops were used to make sedimentologic and paleontologic inferences, and the geophysical logs were utilized to determine the lateral relations of facies.

1.1 The Sequence Stratigraphy Approach

The sequence stratigraphy concept was developed during seismic interpretations of sedimentary basins to permit the subdivision, correlation, and mapping of sedimentary rocks (Vail, 1987). This technique involves dividing sedimentary units into discrete packages called depositional sequences and systems tracts which are defined as follows:

- A depositional sequence is a relatively conformable succession of genetically related strata bounded by unconformities or their correlative conformities (Mitchum, 1977).
- A systems tract is a linkage of contemporaneous depositional systems, each characterized by a set of distinct depositional processes and/or lithofacies (Brown and Fisher, 1977).

Depositional sequences correlate basin-wide and sometimes globally, and are controlled by short-term eustatic sea level changes. Both depositional sequences and systems tracts have predictable lithologic patterns that permit a chronostratigraphic correlation of sedimentary packages (Vail, 1977). Although useful seismic data were not available, lithofacies geometries and distributions delineated in the geophysical logs were used to determine depositional environments and facies relations in a similar manner.

Holland (1993) and Hohman and Keith (*in press*) have proposed models that subdivide the Cincinnatian strata in five and two depositional sequences, respectively. Other studies (Jennette and Pryor, 1993 and Dattilo, 1994) have proposed sequences on the same scale as Holland's, but with differing sequence boundaries. In addition, Dattilo (1994) demonstrated that *lowstand systems tracts* and *transgressive systems tracts* thought to be thin to absent by Holland (1994) were present in the Miamitown Shale. The delineation of sequence boundaries and their recognition throughout the region is essential to permit the use of inferred chronostratigraphic packages for the construction and interpretation of global sea-level curves. This study will evaluate the proposed sequence stratigraphic models by examining the facies relationships of the upper part of the Cincinnatian section.

The Richmond Group is an optimal interval to interpret because the strata:

- Contain a diverse assemblage of depositional environments including intertidal to deep shelf sediments and a distal clastic wedge;
- Have been extensively examined in outcrop which provide detailed sedimentologic and paleontologic information; and
- Are easily recognizable in geophysical logs.

1.2 Purpose of This Study

The purpose of this study is to evaluate Late Ordovician deposition and to evaluate previously proposed sequence stratigraphic models by constructing a regional sequence stratigraphic model of the Richmond strata by:

- Correlating information derived from the evaluation of cores, outcrops, and geophysical logs;

- Constructing a regional depositional model of the Richmond Strata;
- Comparing and contrasting the recently proposed sequence stratigraphic models for the entire Cincinnatian interval to the model derived from this study.

This conceptual framework can then be used to re-evaluate the generalized sequence stratigraphic models for the Cincinnatian strata using geochemical and paleontological analysis.

2.0 BACKGROUND

This sections presents a description of the study area, basic concepts and definitions of sequence stratigraphy and a review of previously published literature.

2.1 Study Area

The study area consists of an approximately 44,100 square mile (112,896 square kilometer) tristate region that includes southwestern Ohio, northern Kentucky and southeastern Indiana (Figure 1). The area is rectangular shaped and includes Columbus, Ohio; Indianapolis, Indiana; and Lexington Kentucky.

2.1.1 Regional Geology

The dominant structural geologic feature of the region is the Cincinnati Arch, which is a broad regional anticline consisting of Paleozoic sedimentary rocks. The axis of the arch generally trends north-south and nearly bisects the southern half of the study area. In the northern third of

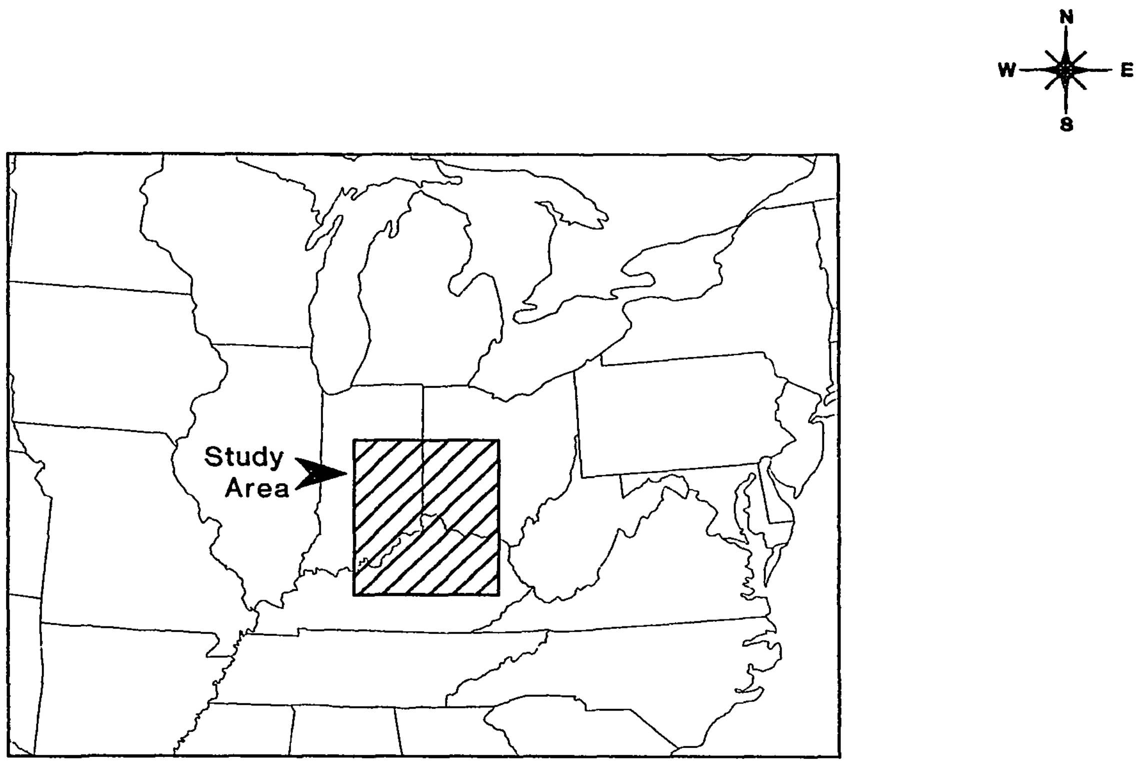


Figure 1

Map of the Study Area
Tristate Region of Ohio, Kentucy and Indiana

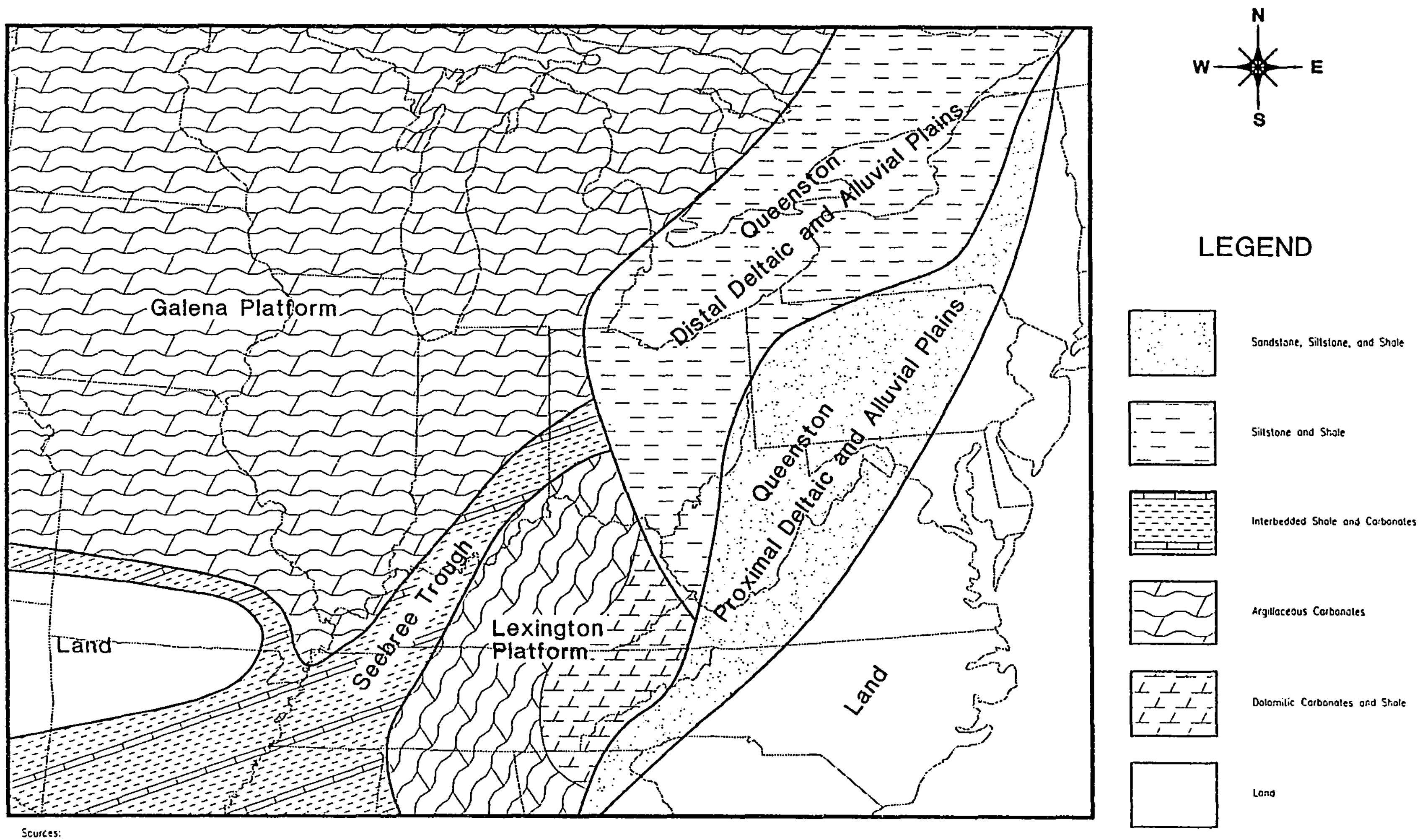
the study area, the arch divides into the Kankakee Arch which trends towards the northwest and the Findlay Arch which trends towards the northeast. The strata in the region are nearly horizontal but dip slightly away from arch on each flank. Locally, the dip may exceed 1/3°. Erosion at the crest of the Cincinnati Arch has removed the Richmond strata from the middle and south-central portion of the tristate region.

The tristate region was located approximately 15° south of the equator during the Late Ordovician (Scotese *et al.*, 1979) approximately 45° clockwise from its present position. Tectonic events in the Appalachian Mountains related to the closing of the Iapetus Ocean strongly influenced the sedimentation in the Midcontinent throughout the Paleozoic Age.

During the Middle to Late Ordovician, the Laurentian Craton collided with what appears to have been an island arc (Rast, 1989). This collision, known as the Taconic Orogeny, resulted in uplifts in the Blue Ridge and Piedmont Provinces and a thick westward progradation of clastic sediments onto the Midcontinent. The thickest sediment accumulations were in the eastern part of the Appalachian Basin where thousands of meters of flysch sediments prograded to the west.

During the Middle and Late Ordovician, the Lexington Platform and the Galena Platform were in central Kentucky and northern Indiana, respectively. Sedimentation on these platforms was dominated by mixed-carbonate and clastic sequences. These two platforms were separated by a southwest to northeast trending basin named the Seebree Trough, which was filled with fine grained clastics (Mitchell and Bergstrom, 1991). The location of the shallow platforms, the Seebree Trough and the clastic wedge prograding from the east are shown on a generalized paleogeographic reconstruction of the Cincinnatian Series (Figure 2). This map was derived from several regional studies including Weir et al. (1984), Keith (1988) and Dennison, 1976).

Dennison (1976) mapped the progradation of the thick redbed clastic wedge (*i.e.*, the Queenston Deltaic Complex) from central Pennsylvania into Ohio. The thickness of the redbeds



Sources:
Weir et al., 1984
Hohman and Keith, in press
Dennison, 1976

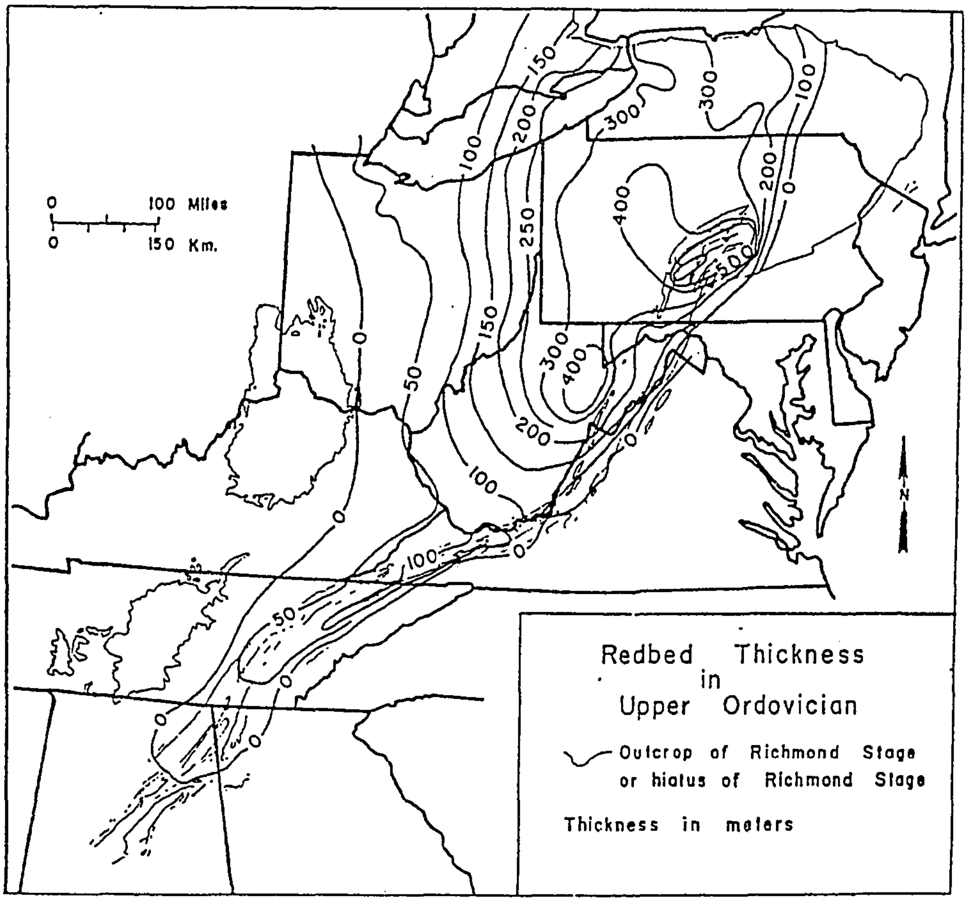
Figure 2

Generalized Paleogeographic Reconstruction Of the Cinicinnatian Series

deposited from the progradation of this clastic wedge from central Pennsylvania, westward into Ohio is shown on Figure 3. The exact age of the Queenston Deltaic Complex is difficult to determine because of the lack of fossiliferous material in the strata.

2.1.2 Cincinnatian Geology

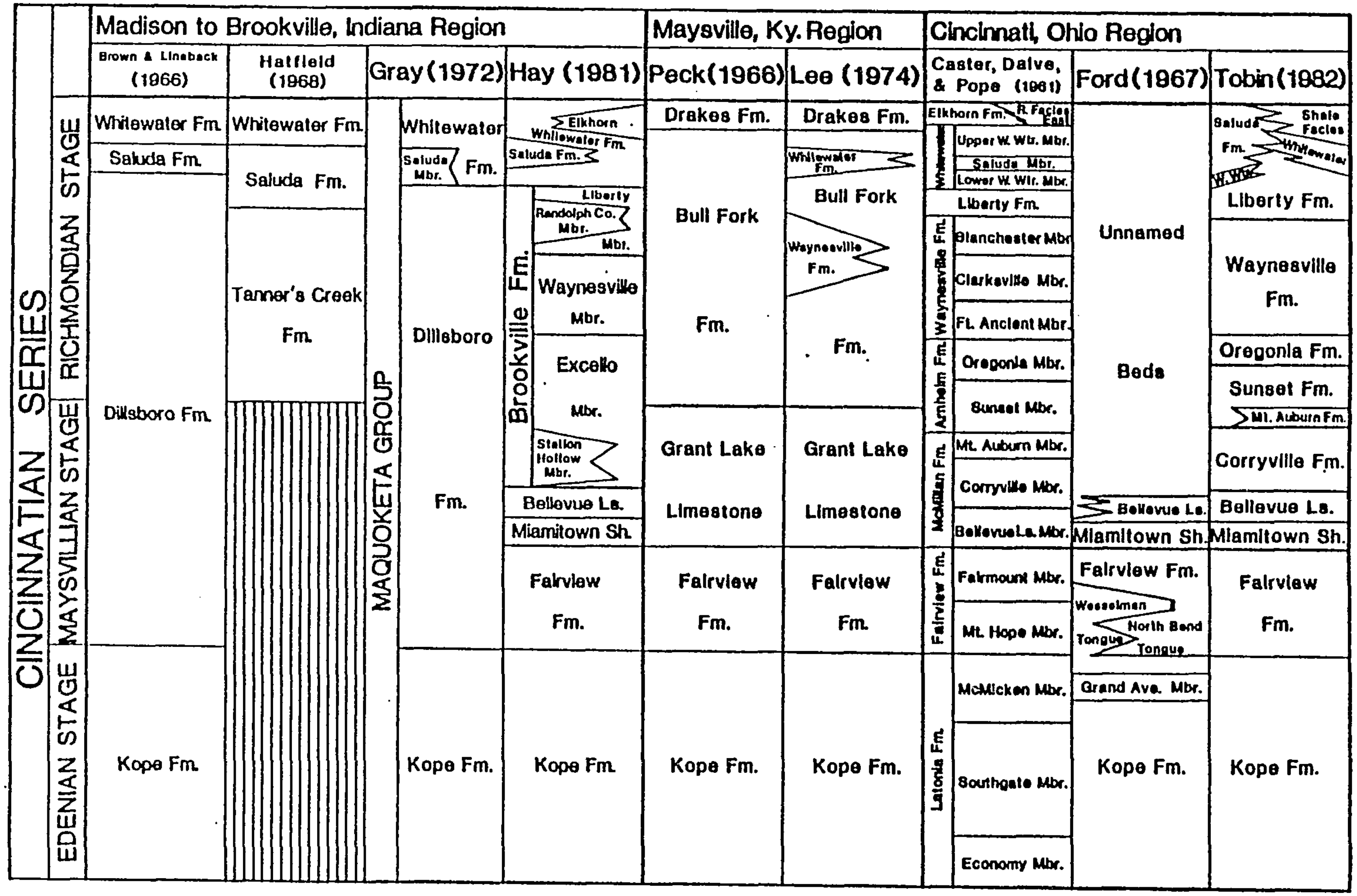
The bedrock in the study area consists chiefly of Lower Paleozoic limestones and shales. In the northern half of the study area, these strata are overlain by unconsolidated Illinoian and Wisconsin tills and outwash. The Upper Ordovician Cincinnatian Series consists of 800 or more feet (244 meters) of fossiliferous-interbedded shales and limestones as well as occasional thick limestone units. As illustrated on the stratigraphic correlation chart included as Figure 4, the Cincinnatian Series is divided into the Edenian, Maysvillian, and Richmondian Stages. The strata examined in this study belong to the Richmondian Stage, which is in the upper portion of the Cincinnatian Series. The rocks of the Richmondian strata include shales, interbedded limestones and



SOURCE: Dennison 1976.

Figure 3

Ispach Map Of Redbed Thickness



SOURCE: Schumacher, 1984.

Figure 4

Cincinnatian Stratigraphic Nomenclature

shales, mixed limestones and shales, and massive dolomites. The Richmondian strata are erosionally overlain by the Silurian Brassfield Formation, which is generally comprised of thick-bedded, glauconitic dolomites.

2.2 Sequence Stratigraphy

Sequence stratigraphic studies employ varying sequence stratigraphic terminology and associated set of concepts. The following sections examine the evolution of the approach, terminology, and conceptual use of the sequence stratigraphic methodology.

2.2.1 Overview of Sequence Stratigraphy

A detailed history of the development of sequence stratigraphy and its applications is provided in Sloss (1988). This section contains an outline of the pertinent historical use of this methodology in cratonic settings and definitions of terms used in this study.

Sequence stratigraphic practices were used in the Late

Eighteenth Century by geologists who were attempting to correlate packages of strata into groups and correlative time periods (Sloss, 1988). The first modern attempt at defining sequences was performed by Sloss *et al.* (1949) who believed that cratonic sequences could be correlated across the continent. During this phase of sequence stratigraphic evolution, North American interregional cratonic sequences were delineated by using North American Indian names such as Sauk, Tippecanoe and Kaskaskia) to emphasize the origins of the subdivisions.

Later work by Vail and Wilbur (1966) demonstrated the hemispheric distribution of these cratonic sequences by utilizing seismic profiling to identify sequences in the subsurface and found that:

- The characteristic shapes of the stratal packages provided information as to their origin,
- Relative sea level changes resulted in changes in the shapes of the stratal packages, and
- Onlapping sequences were the result of sea level rises.

The stratal packages referred to by Vail and Wilbur (1966) were also called sequences. Based on their early research efforts, sequence stratigraphy evolved from a North American cratonic sequence series to a world-wide coastal shelf and craton sequence stratigraphic concept.

2.2.2 Sequence Stratigraphic Concepts

Sequence stratigraphic terms and concepts are based on uses by Mitchum *et al.* (1977), Van Wagoner *et al.* (1990), Weimer (1992), and Posamentier and James (in press). As shown on Table 1, the fundamental unit of sequence stratigraphy is a sequence which is defined as a single stratigraphic unit of genetically related strata bounded at its base and top by unconformities or their correlative conformities (Mitchum *et al.* 1977). The fundamental building block of each sequence is a parasequence, or a relatively conformable, genetically related succession of beds or bedsets bounded by marine flooding surfaces or their correlative surfaces (Van Wagoner *et al.* 1990). The marine flooding surfaces separate older strata from younger strata, and are characterized by an abrupt increase in water depth. Each parasequence corresponds to the tract of a series of related facies. A succession of related

Table 1
Stratal Units in Hierarchy: Definitions and Characteristics

Stratal Units	Definitions	Range of Thickness (Feet)	Range of Lateral extents (Sq. Miles)	Range of times for formation (years)	Tool Resolution
Sequence	A relatively conformable succession of genetically related strata bounded by unconformities and their correlative conformities (Mitchum and others. 1977)	50 -5000	750 - 50,000	100,000 - 7,000,000	Paleo, Exploration Seismic, Well log, Core and Outcrop
Para - Sequence set	A succession of genetically related parasequences forming a distinctive stacking pattern and commonly bounded by major marine-flooding surfaces and their correlative surfaces.	25 - 650	20 - 3,000	8,000 -400,000	Exploration Seismic, Well log, Core and Outcrop
Para-Sequence	A relatively conformable succession of genetically related beds or bedsets bounded by marine-flooding surfaces and their correlative surfaces	10 -300	30 - 3,000	200 - 50,000	Well log, Core and Outcrop
Bedset	A relatively conformable succession of genetically related beds bounded by surfaces (called bedset surfaces) of erosion, non-deposition, or their correlative conformities	10 inches - 8 ft.	less than 1 - 800	1 - 3,000	Well log, Core and Outcrop
Bed	A relatively conformable succession of genetically related laminae or lamina-sets bounded by surfaces (called bedding surfaces) of erosion, non-deposition or their correlative conformities	less than 1 - 300	less than 1 - 900	less than 1 to 700	Well log, Core and Outcrop
Laminaset	A relatively conformable succession of genetically related laminae bounded by surfaces (called laminaset surface) of erosion, non-deposition or their correlative conformities	less than 1 - 6	less than 1 - 10	less than 1 year	Core and Outcrop
Lamina	The smallest megascopic layer	less than an inch	less than 1 year	less than 1 year	Core and Outcrop

Source: Van Wagoner *et al,* (1990).

parasequences form a parasequence set and the stratal stacking of these parasequence sets forms a sequence. The parasequence can be further broken down into bed and laminae sets as shown on Table 1.

Groups of parasequences can be related to relative sea level stands based on their relative stratigraphic position. Parasequences deposited during high sea level stands are termed *highstand systems tracts* (*HSTs*), while those deposited at low sea level stands are termed *lowstand system tracts* (*LSTs*). Parasequence sets developed during transgressions are termed *transgressive systems tracts* (*TSTs*) and those that developed at shelf margins during intermediate stands are termed *shelf-margin system tracts* (*SMSTs*). Depositional systems within each of these tracts are controlled by tectonics, sediment influx, and physiography. Therefore, as noted by Posamentier and James (*in press*) systems will rarely conform to simplified models. Paleogeographic reconstructions and relative sea level changes are deduced from the stacking patterns of these facies.

Two types of sequence bounding unconformities and sequences are delineated in the sequence stratigraphic approach. Posamentier *et al.* (1988) and Van Wagoner *et al.* (1990) differentiate these boundaries by the stratal arrangement of system tracts resulting from the eustatic and relative changes in sea level. *Type 1* sequences are composed of *LSTs*, *TSTs*, and *HSTs* bounded at their base by a *Type 1* unconformity. The presence of the *LST* at the base of the *Type 1* sequence differentiates it from the *Type 2* sequence. The presence of the *LST* infers movement of the shoreface into the basin. A *Type 1* sequence forms when the eustatic sea level falls at a rate that exceeds the rate of subsidence at the shelf margin. As a result, existing system tracts migrate basinward (prograde). A *Type 2* sequence is composed *SMSTs*, *TST*s and *HST*s and are bounded at their base by a *Type 2* unconformity. The *SMST* present in the *Type 2* sequence but not in the *Type 1* sequence is the result of the migration of the shallow water facies to the shelf margin. A *Type 2* sequence forms when the sea level falls at a rate that is slightly less than or equal to the rate of subsidence at the shelf margin. Thus, because there is no relative fall in sea level at the shelf margin, existing system tracts tend not to migrate during sea level falls (aggrade). A determination of which type of sequence is present provides information on the relationship between the relative basin subsidence and the rate of sea level change.

In an idealized model, *Type 1* and *Type 2* sequences evolve different stratal patterns (Van Wagoner *et al.*, 1990). These stratal patterns are recognized by their progradational, aggradational, and retrogradational parasequence stacking patterns. Progradational parasequence sets contain parasequences stacked towards the basin and the parasequences are successively younger basinward. Retrogradational parasequence sets consist of parasequences stacked towards the shoreline and the parasequences are successively younger landward. In aggradational parasequence sets, parasequences are stacked over each other and have no significant lateral shifts (Van Wagoner, *et al.*, 1990).

The delineation of these correlative sequence stratigraphic units enables the construction of a regional depositional model by:

- Mapping genetically related facies within a chronostratigraphic framework, and

- Relating sedimentation patterns to sea level falls.

2.3 Previous Studies

Because of the abundance of outcrops with well-preserved fossils and the accessibility of the outcrops, many studies have been published on various aspects of the Cincinnatian geology. These studies have concentrated on:

- Particular fossils or fossil groups (*i.e.*, Foerste 1904, 1910; Pojeta, 1971);
- The sedimentology or stratigraphy of a certain area or stratigraphic section (*i.e.*, Fox, 1962; Ford, 1967; Betz, 1984, Walters, 1988);
- The stratigraphy of the region (*i.e.*, Hay, 1981; Tobin, 1982); and
- Regional time correlations interpreted from microfossils (*i.e.*, Sweet *et al.*, 1959, 1964, Sweet, 1979).

Pertinent research related to the Richmond strata are divided into stratigraphic, sedimentologic, and sequence stratigraphic studies.

2.3.1 Stratigraphic Studies

Nickles (1902) and Foerste (1910) initially subdivided the Cincinnatian Series by using index fossils and fossil assemblages. More recently, studies such as Hay (1981), Tobin (1982), and Weir *et al.* (1984), attempted to subdivide the strata according to their lithologic composition in compliance with the American Code of Stratigraphic Nomenclature. Two naming trends resulted from the lithostratigraphic subdivisions. The first tend was to lump thick sequences of strata into single formations such as the Bull Fork Formation and the Dillsboro Formation and the second trend was to redefine older nomenclature, on a lithostratigraphic basis (Tobin, 1982). None of the previously employed lithostratigraphic names were used during this study to simply the discussion of subsurface and outcrop data over a wide area. Instead, similar strata are grouped into the following six informal subdivisions:

- Facies A
- Facies B
- Facies C
- Facies D

- Facies E
- Facies F

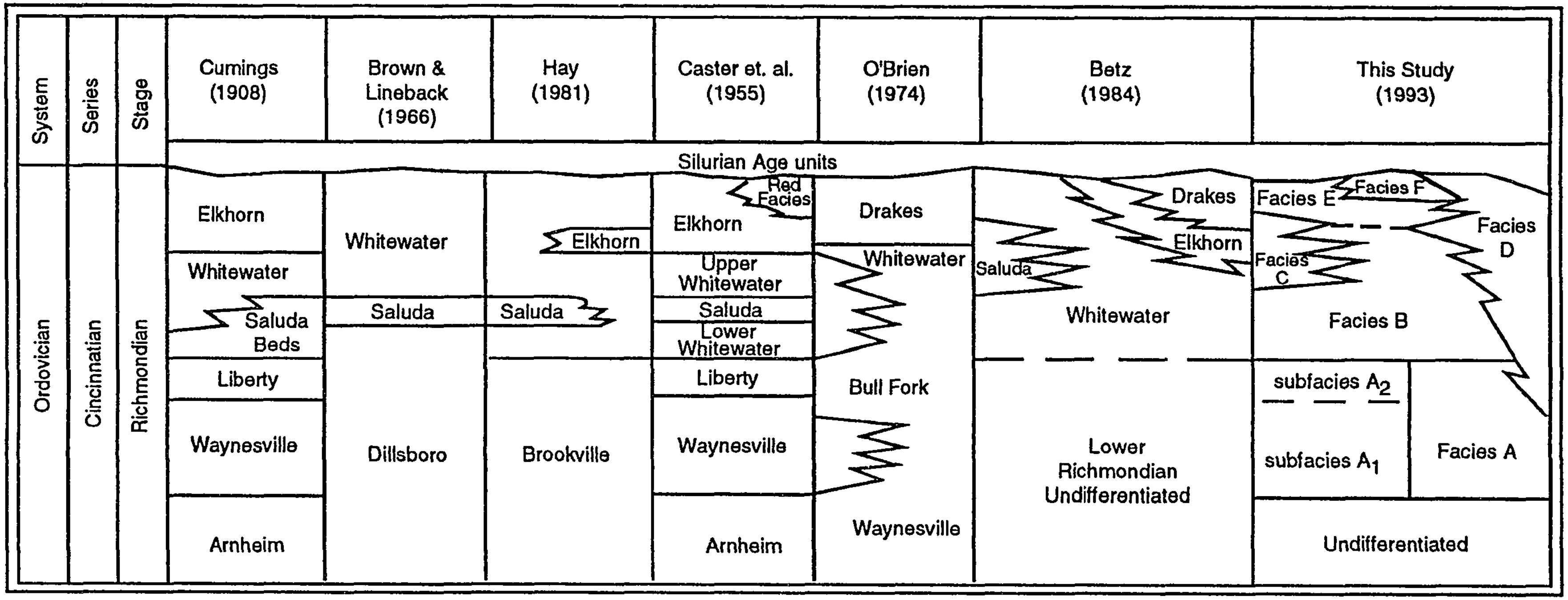
The stratigraphic relationships of the previously defined stratigraphic formations and the facies addressed in this study are presented in Figure 5. These correlations are discussed further in subsequent sections.

2.3.2 Sedimentologic Studies

Most of the Upper Ordovician rocks in the tristate region are characterized by repetitive successions of alternating carbonate and shale beds. Two general successions are recognized by previous authors, they are:

- Carbonate-clastic intervals composed of repetitive layering of carbonate and clastic beds, and
- Larger scale shoaling-upward successions that are a repetition of similar lithologic sequences throughout the section.

Shrake *et al.* (1988) provides an excellent overview of the strata and hypotheses concerning their origin and distribution.



(Facies and equivalent information discussed in text)

Figure 5

Correlation chart of standard nomenclature for the Richmond Group in southeastern Indiana, southwestern Ohio, and Northern Kentucky and the nomenclature used in this study.

The evolution of modern sedimentologic models for Cincinnatian deposition began with Anstey and Fowler (1969), who originally described shoaling-upward cycles in the Cincinnatian of southeastern Indiana as the result of major sea level fluctuations. Hay (1981) and Tobin (1982) conducted detailed studies of the Cincinnatian Series. Hay (1981) focused on the lithostratigraphy of the section by defining three cycles interpreted to be related to tectonic activity or glacio-eustatic sea-level fluctuations. Two of these cycles contained Richmond strata including:

- One that extended from the Corryville Member of the Grant Lake Limestone to the top of the Waynesville Formation, and
- Another that ranged from the top of the Waynesville Formation to the Ordovician-Silurian contact.

Tobin (1982) examined the sedimentology, ichnology, and autecology of the Cincinnatian strata. He divided the strata into three shoaling-upward cycles, one of which included the Richmondian strata. This Richmondian cycle started at the base of the Waynesville Formation and ended at the top of the Saluda Formation. Tobin (1982) noted the additional studies on the Richmondian strata were necessary to better understand the deposition at the end of the Ordovician. Because Tobin's (1982) study was completed prior to widespread use of the sequence stratigraphic approach, none of the associated terminology was directly incorporated into his study.

This study examines the strata from the base of the Waynesville Formation through the Ordovician-Silurian Unconformity. Regional facies distributions and thicknesses are used to reconstruct sedimentation variations, lateral migrations of facies, and infer relative sea level changes during deposition of the Richmondian strata. This model can be used to construct a definitive assessment of the recently proposed Late Ordovician sequence stratigraphic events by Holland, (1993), Jennette and Pryor (1993), Dattilo (1994), and Hohman and Keith *(in press)*.

Tobin (1982) constructed a depositional model that has been used as a basis for formation of strata during the Late Ordovician. His model incorporated shoaling-upwards cycles driven by sedimentation rates that exceeded basin subsidence/compaction or transgressive-regressive sea level fluctuations. In addition, Tobin (1982) proposed that episodic storms were responsible for the deposition of individual carbonate layers. Tobin's (1982) principle of a storm-dominated cratonic shelf with shoaling-upwards cycles driven by sea level changes or sedimentation/basin subsidence is generally accepted by recent studies.

Few published studies have examined the Cincinnatian Series strata in detail in the subsurface. The most prominent studies include Gray (1972), Bloemker (1981), Shrake *et al.* (1988), and Dattilo (1994). Gray (1972) examined the Cincinnatian Series by using cores, cuttings, geophysical logs, and outcrops. Gray (1972) extended the rock-unit term Maquoketa Group from the Illinois Basin to the Cincinnatian Series shales and limestones. In his report, Gray (1972) divided the Maquoketa into four informal units, designated as A, B, C, and D based on the shale content. Although the usefulness of Gray's (1972) work is limited by its broad scope and lack of paleontologic and sedimentologic data, it does provide an initial survey of well logs in the study area; and an accurate stratigraphic pick of the top of the section for part of the study area. Bloemker (1981) included an evaluation of the distribution of the Saluda Formation throughout southeastern Indiana based almost entirely on core data. However, because Bloemker (1981) did not use geophysical logs, his data are only useful to this study for comparing the thickness of facies and interpreting their depositional environments.

The ODNR (*i.e.*, Shrake *et al.* 1988) is in the process of relating cores to geophysical logs to outcrops. This research includes a correlation from core to geophysical logs in Clinton and Highland Counties in southwestern Ohio (Shrake *et al.*, 1988). However, these data cover less than one-quarter of the study area.

Fox (1962), Hay (1981), and Tobin (1982) examined the entire Richmond section and have identified shallow water (*i.e.*, the Saluda Formation) and deeper water (*i.e.*, the Liberty and Waynesville Formations) deposits. In addition, Betz (1984) and Walters (1988) have evaluated smaller sections of the Richmond Strata in southwestern Ohio and southeastern Indiana. Because of the detailed nature of their studies, many of their conclusions and some of their outcrop descriptions are discussed in this report.

Dattilo (1994) incorporated cores, geophysics and geophysical logs into a sequence stratigraphic study of the Miamitown Shale. However, his geophysical log database was initially constructed from the logs obtained for this study.

2.3.3 Review of Cincinnatian Sequence Stratigraphic Studies

Holland (1993), Jennette and Pryor (1993), Hohman and Keith, (*in press*), and Dattilo (1994) have recently examined the sequence stratigraphy of parts of the Cincinnatian Series. Holland (1993) examined the Cincinnatian strata in outcrops and delineated "sequences" of regressive packages by identifying the fauna and strata found in the outcrops and paleontologic evidence for sequence subdivisions. However, Holland (1993) did not review the cores or geophysical logs available in the area. The five parasequences recognized by Holland (1993) in the Cincinnatian Series were C_1 C_2, C_3, C_4, and C_5. Each of these sequences was defined by interpreted sea level rises preserved in the rock record. Holland concluded that *TST*s were thin or absent, and therefore the base of his sequences were placed at or near the maximum flooding surface. However, Holland (1993) was not able to completely correlate the distributions and thicknesses of the sequences because of the distance between each outcrop and the limited number of outcrops examined. As a result, Holland is currently in the process of reassessing his sequence subdivisions.

Jennette and Pryor (1993) examined the alternation of proximal and distal storm facies of the Kope and Fairview Formations and outlined 4^{th} and 5^{th} order cycles that were inferred to be the result of high frequency, glacio-eustatic sea level changes controlled by ice volume. A lack of regional data from well logs and cores limited the examination of sediment influx and an estimate of the order of magnitude of the sea level changes. In addition, Jennette and Pryor (1993) defined the basal sequence as the upper part of the Point Pleasant Formation.

Hohman and Keith (*in press*) examined the Upper Ordovician sequence stratigraphy from subsurface data in the southern Illinois Basin extending from eastern Indiana through southern Illinois. Based upon their examination of the geophysical logs, one sequence and two facies tracts were identified in the Cincinnatian strata. Smaller scale stratal patterns, such as those observed in the Richmond, were assigned to parasequences. The dispute between parasequence and sequences is important because determining the order of magnitude of identified stratal patterns is essential to intracratonic and global correlation of sedimentary packages and sea level changes.

Dattilo (1994) examined the Edenian and Maysvillian Formations in the tristate area and concentrated on the Miamitown Shale by using cores, outcrops and geophysical logs. In contrast to Holland (1993), Dattilo (1994) delineated significant *LSTs* and *TSTs*. In addition, unlike Hohman and Keith (*in press*), Dattilo (1994) classified the smaller stratal packages within the Upper Cincinnatian as parasequences and not systems tracts.

In contrast to Hohman and Keith (*in press*), this study provides a more detailed analysis of a smaller stratigraphic interval (*i.e.*, only Richmondian strata) over a slightly different area and incorporates the vast wealth of subsurface, core and outcrop data available. The location of this study is important because the Richmond strata are thickest near the Ohio-Indiana border, at the margin of Hohman and Keith's (*in press*) study area. On the other hand, Jennette and Pryor (1993), examined a lower stratigraphic interval over a smaller area, in much greater detail and correlated smaller cycles across their study area.

All of the geophysical logs in this study include data from the rest of the Upper Ordovician section and trends in these strata were considered in some of the conclusions reached. However, detailed correlations of smaller units was prohibited by the greater distances between geophysical logs compared to the outcrops described by Jennette and Pryor (1993) and the decreased resolution of these geophysical logs.

This study will compare and contrast conclusions derived by Holland (1993), Jennette and Pryor (1993), Hohman and Keith (*in press*) and Dattilo (1994) and will provide a paleogeographic reconstruction of the Richmond.

3.0 PROCEDURES

The methodology used to describe, identify and correlate strata in the tristate area and the procedures employed to integrate data from outcrops, cores, and geophysical logs into a sequence stratigraphic model are presented in the following sections.

3.1 Outcrops

A vast amount of sedimentologic, paleontologic and general geologic data on the Richmondian strata in the tristate region has been collected by various authors from outcrops occurring along the flanks of the Cincinnati Arch. To incorporate this data into this study, the strata in the outcrops had to be accurately correlated with the core and geophysical log data.

Outcrop descriptions are used in this study to:

- Interpret depositional environments of lithostratigraphic subdivisions,
- Enhance previous interpretations of intervals already described,

- Clarify transitions between facies, and
- Evaluate previous correlations in the outcrop and subsurface.

Outcrops were measured with a hand level on a bed-by-bed scale to identify changes small-scale and large scale changes in the rocks. The outcrops examined during this study are shown on Table 2 along with their locations, and the facies observed at each location. The descriptions of these outcrops are included as Appendix A. The geographic location of each outcrop is illustrated on Figure 6.

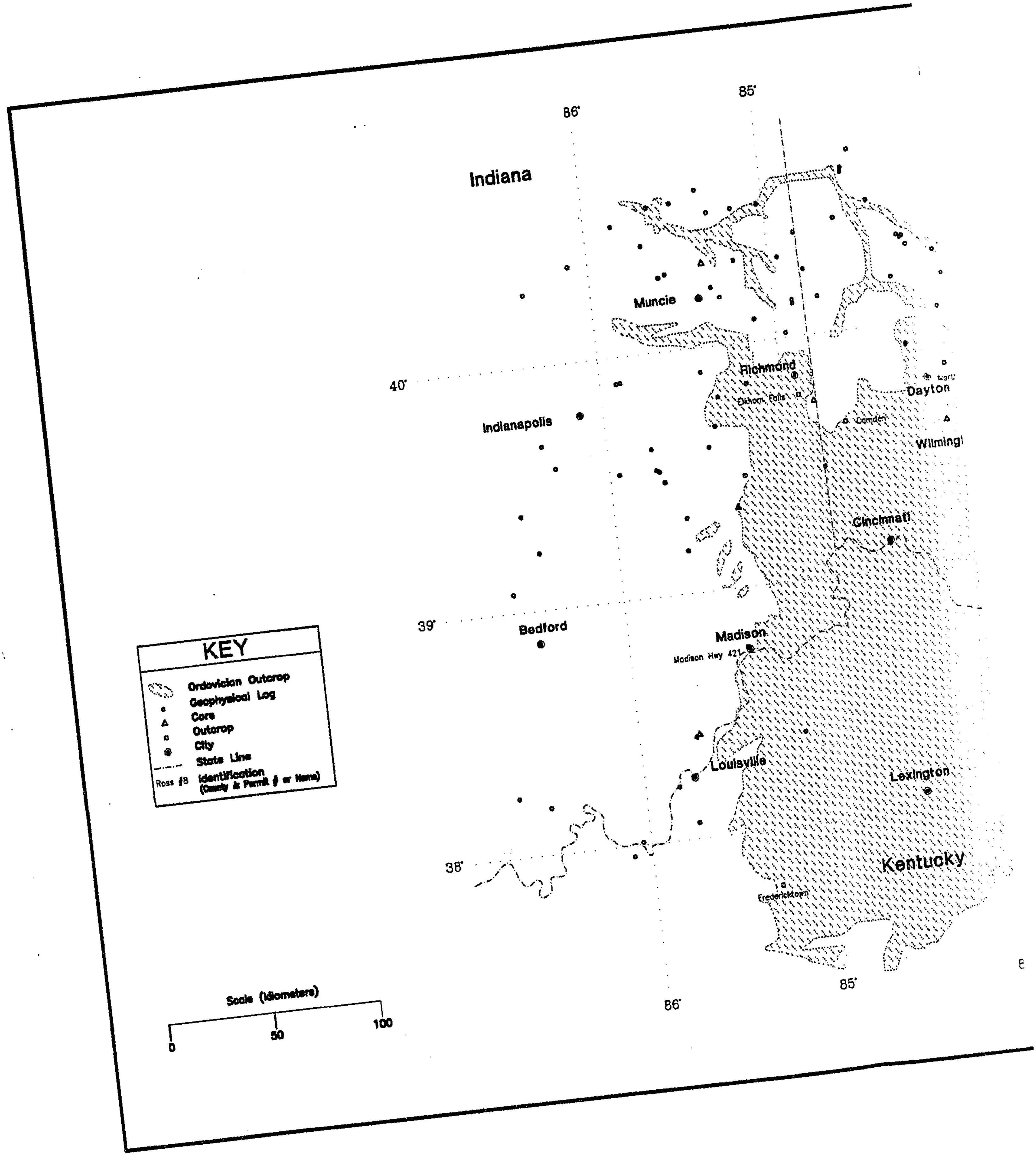
Because of the enormous area covered by the study and the thickness of strata in the sections, some of the outcrop descriptions derived by earlier workers are incorporated into this study including:

- The Tanners Creek sections (Fox, 1962);
- The Brookville sections (Tobin, 1982); and
- The Madison section (Walters, 1988).

All outcrops discussed in this study have been examined by the author.

Table 2
Outcrop Location and Facies

Outcrop Name	Location	Longitude	Latitude	Facies Present
Burnt Cabin Road	Highway 32 at intersection of Burnt Cabin Road, west of Seaman, Ohio.	89.606°	38.998°	A and D
Camden	Route 725, approximately 1/2 mile west of Camden, Ohio.	84.670°	39.617°	A_2 and B
Elkhorn Falls	Outcrops along Elkhorn Creek, approximately 3 miles south of Richmond, Indiana.	84.918°	39.753°	B, D and E
Fredericktown	Highway 150, approximately 4.5 east of Blue Grass Parkway, Fredricktown, Kentucky.	85.376°	37.769°	B and C
Madison Highway 421	Highway 421 approximately 10 miles north of Bedford, Indiana.	85.376°	38.749°	A, B and C
North Dayton	Wright Brothers Memorial on Rt. 444, Dayton Ohio.	84.087°	39.796°	B and D


Indiana
Muncie
Richmond
Dayton
Elkhorn Falls
Camden
Wilmingt
Indianapolis
Cincinnati
Bedford
Madison
Madison Hwy 421
Louisville
Lexington
Kentucky
Fredericktown
KEY
Ordovician Outcrop
Geophysical Log
Core
Outcrop
City
State Line
Ross #8
Identification (County & Permit # or Name)
Scale (kilometers)
0
50
100
86°
85°
40°
39°
38°

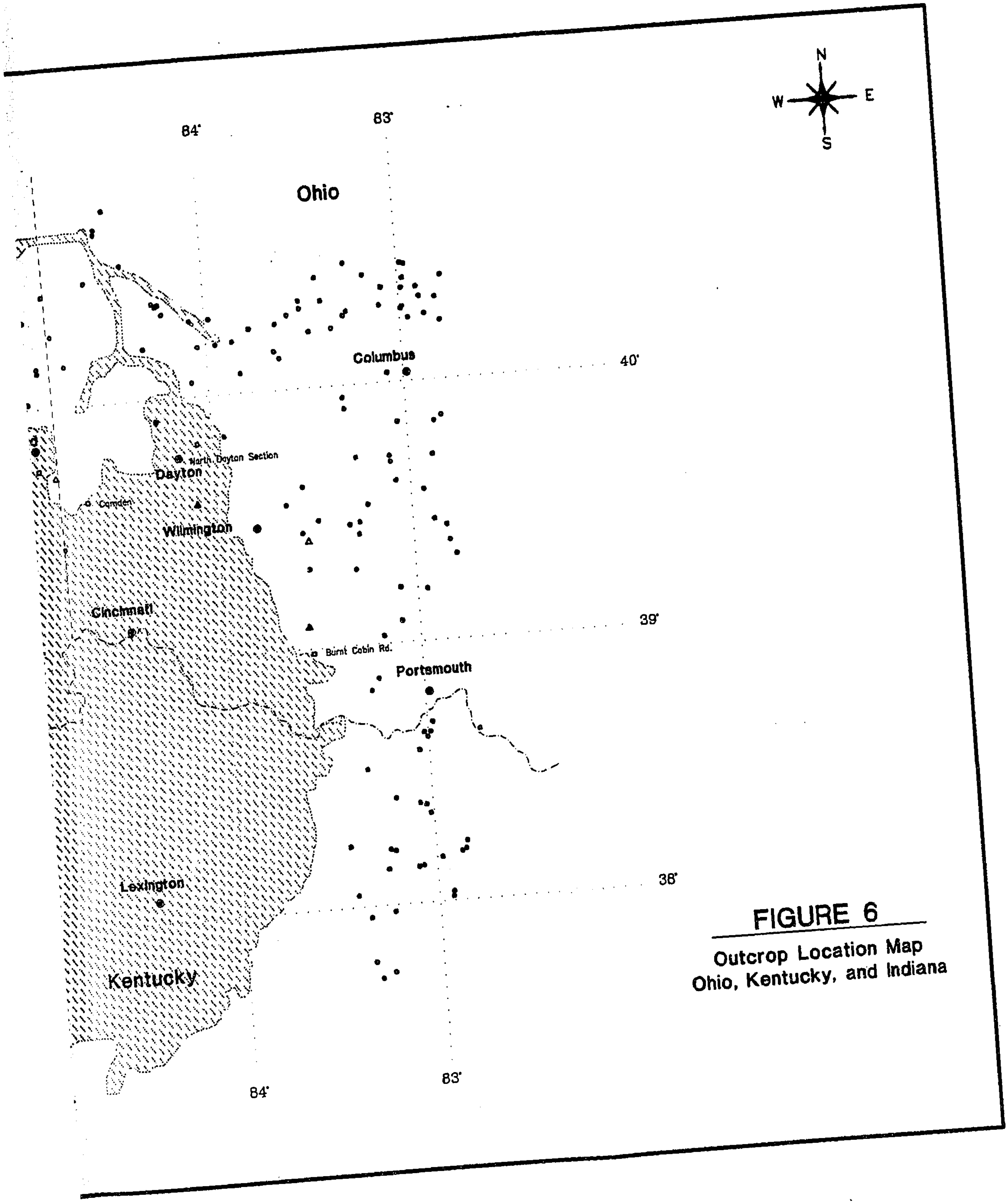


FIGURE 6

Outcrop Location Map
Ohio, Kentucky, and Indiana

3.2 Cores

Cores were used to compare the lithologic character of the strata to the geophysical log response to permit correlation of the strata using geophysical logs. The vertical continuity of the cores is high, and therefore, provides an important source of stratigraphic relationships. Because this study did not include a micropaleontologic analysis, a limited amount paleontological of data was obtained from the description of the core samples. However, significant lithologic and sedimentologic data were collected from the cores because sedimentary properties could be identified from the limited sample size.

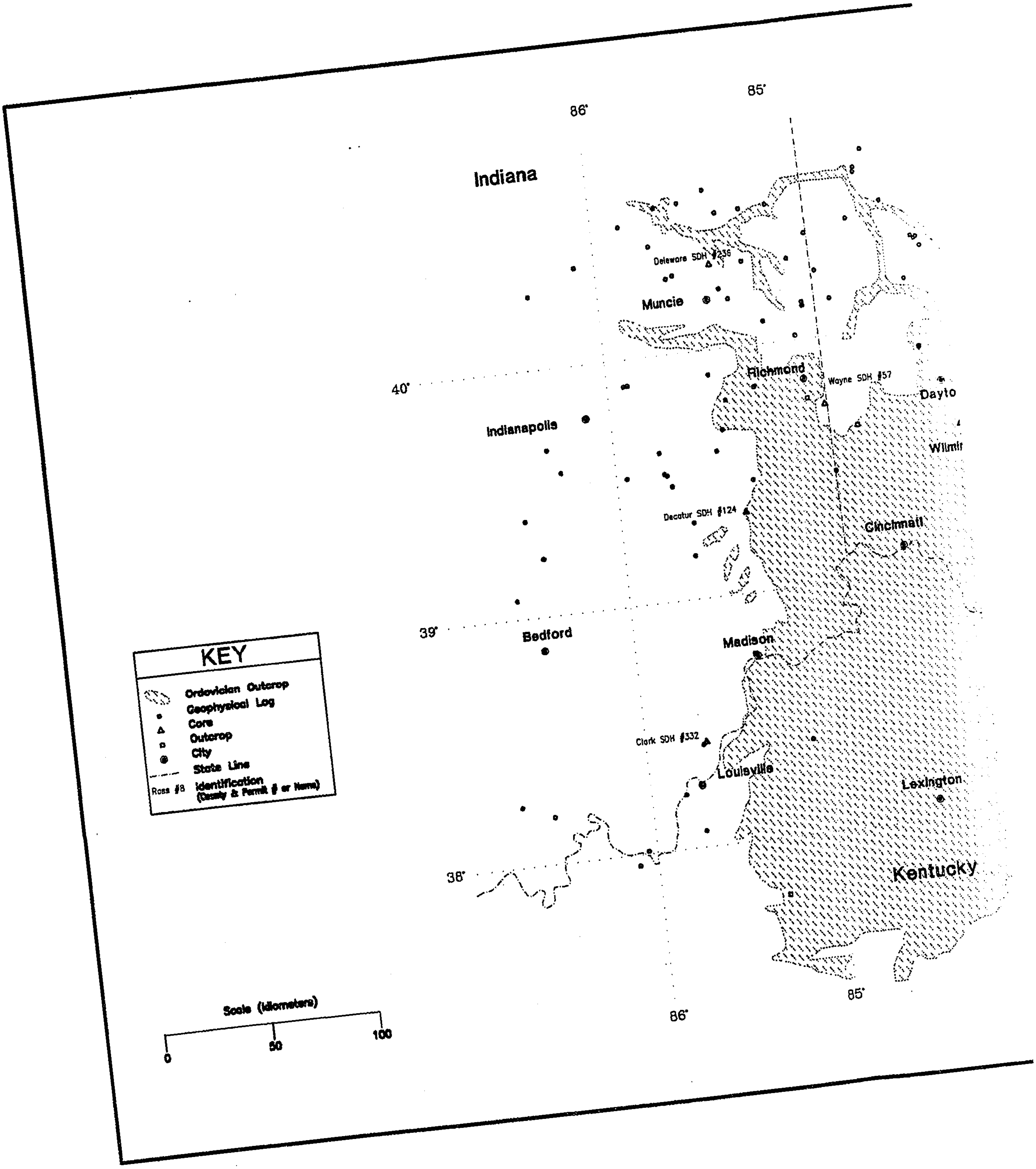
Seven important cores located within the study area include:

- Indiana Geological Survey Cores SDH #57, SDH #124, SDH#236 and SDH #332; and
- The Ohio Department of Natural Resources Cores: DGS #2626, and DGS #2627 and DGS #2682.

A list of these cores, their locations and elevations, and the facies observed in each of them is provided on Table 3, and associated geographic locations are shown on Figure 7. These

Table 3
Core Location and Facies

Boring Name	County, State	Longitude	Latitude	Facies Present
DGS#2626	Highland Co., Ohio	83.618°	39.050°	A_1, A_2, B_1, and D
DGS#2627	Warren Co., Ohio	85.116°	39.566°	A_1, A_2, B_1 and D
DGS #2682	Highland Co., Ohio	83.574°	39.378°	A_1, A_2, B_1 and D
SDH #57	Wayne Co., Indiana	84.829°	39.720°	A_1, A_2, B, D and E
SDH #124	Decatur Co., Indiana	85.332°	39.325°	A_1, A_2, B, C and E
SDH #236	Delaware Co., Indiana			E, F
SDH # 332	Clark Co., Indiana	85.696°	38.421°	A, B, and C



86°
85°
Indiana
Delaware SDH #236
Muncie
Richmond
Wayne SDH #57
Dayto
40°
Indianapolis
Wilmi
Decatur SDH #124
Cincinnati
39°
Bedford
Madison
KEY
Ordovician Outcrop
Geophysical Log
Core
Outcrop
City
State Line
Ross #8 Identification (County & Permit # or Name)
Clark SDH #332
Louisville
Lexington
38°
Kentucky
85°
86°
Scale (kilometers)
0
50
100

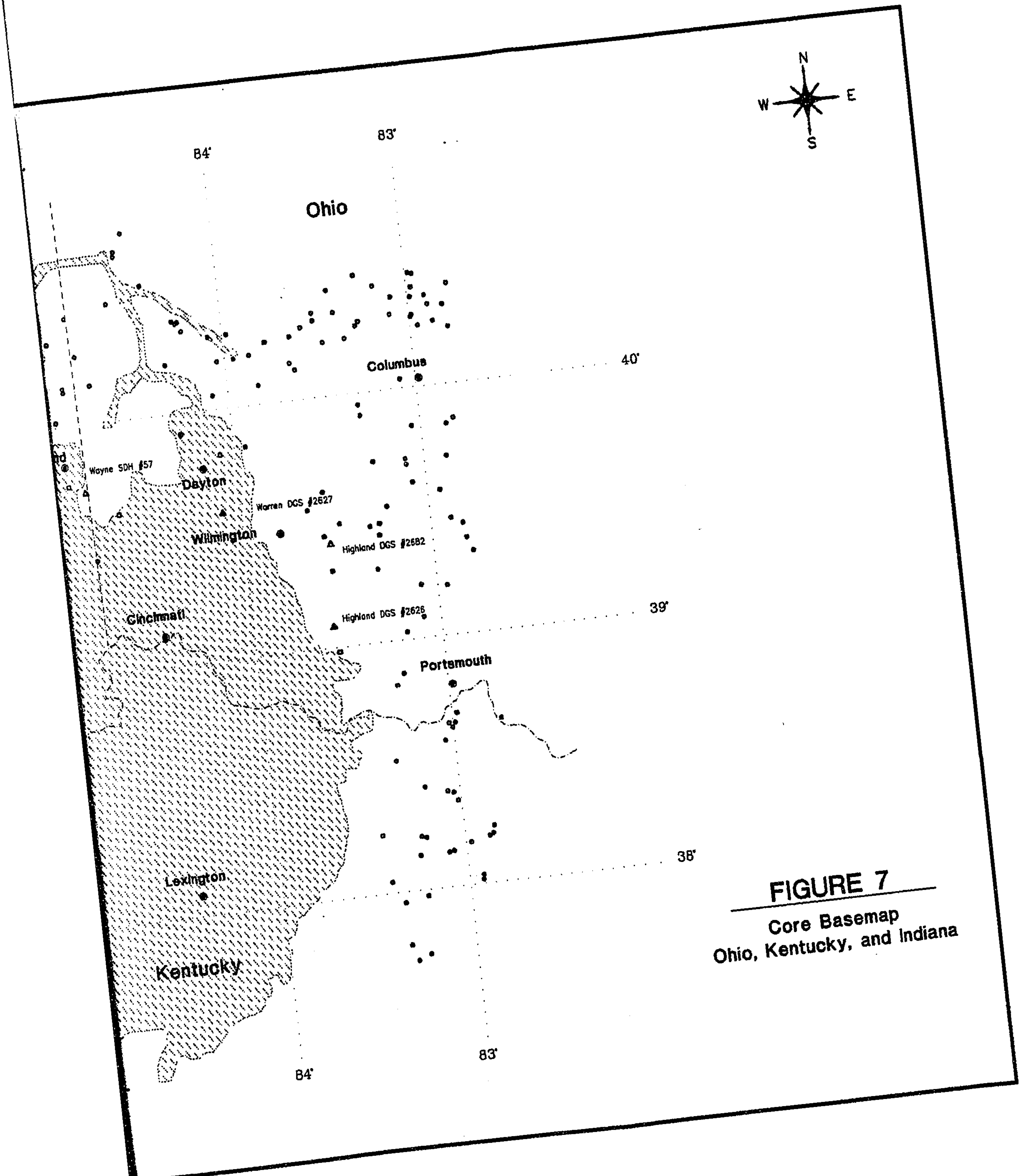


FIGURE 7

Core Basemap
Ohio, Kentucky, and Indiana

cores were selected for study based upon their location and stratigraphic intervals sampled.

The lithologic data from the cores were used to correlate outcrops to the subsurface geophysical logs, and the sedimentologic data was utilized in the construction of the depositional model. The cores in Indiana were also described on a bed-by-bed scale to identify smaller scale sedimentologic features of the facies. The cores in Ohio were described on a larger scale based on lithologic changes because the splitting and testing of these cores was not permitted by the Ohio Geological Survey. The descriptions of cores examined during this investigation are included in Appendix B.

3.3 Geophysical Logs

Geophysical logs were utilized to correlate facies across the study area, and to map thickness trends in each facies. Paleontologic and sedimentologic data from outcrops and cores were mapped from these correlations. During this study, a geophysical log database was constructed by:

- Obtaining and examining geophysical logs from older data sets that examined the strata in the study area (*i.e.*, Gray, 1972) or strata above or below the section of interest to secure background information about the location and quality of data that might be available;

- Manually searching through each state's geological survey well record files to augment the database;
- Determining the geographic location of each well identified in the geophysical logs and incorporating their locations into a single geographic coordinate system; and
- Graphically reproducing the geophysical logs at the same scale to permit an accurate correlation and construction of geological cross sections.

Interpretation of this geophysical log database permitted the construction of a regional Richmond depositional model.

3.3.1 The Selection of Geophysical Logs

Geophysical logs were obtained by searching through existing databases including Stith's (1986) Trenton Studies and Gray's (1972) study of the Maquoketa Group in Indiana. Over 40 geophysical logs were collected from these existing databases.

After examining numerous logs, it became evident that gamma ray log best differentiated the Cincinnatian shales and carbonates. Other logs, such as spontaneous potential and resistivity logs did not accurately identify small scale changes in the strata. Density-dependent logs such as the neutron log were also useful for differentiating the dolomite from carbonate lithologies.

The majority of the logs were collected by manually searching each state's geological survey well log files on a county-by-county basis and concentrating on well log sets that:

- Incorporated gamma ray tools and neutron tools, and
- Logged the entire Richmond section.

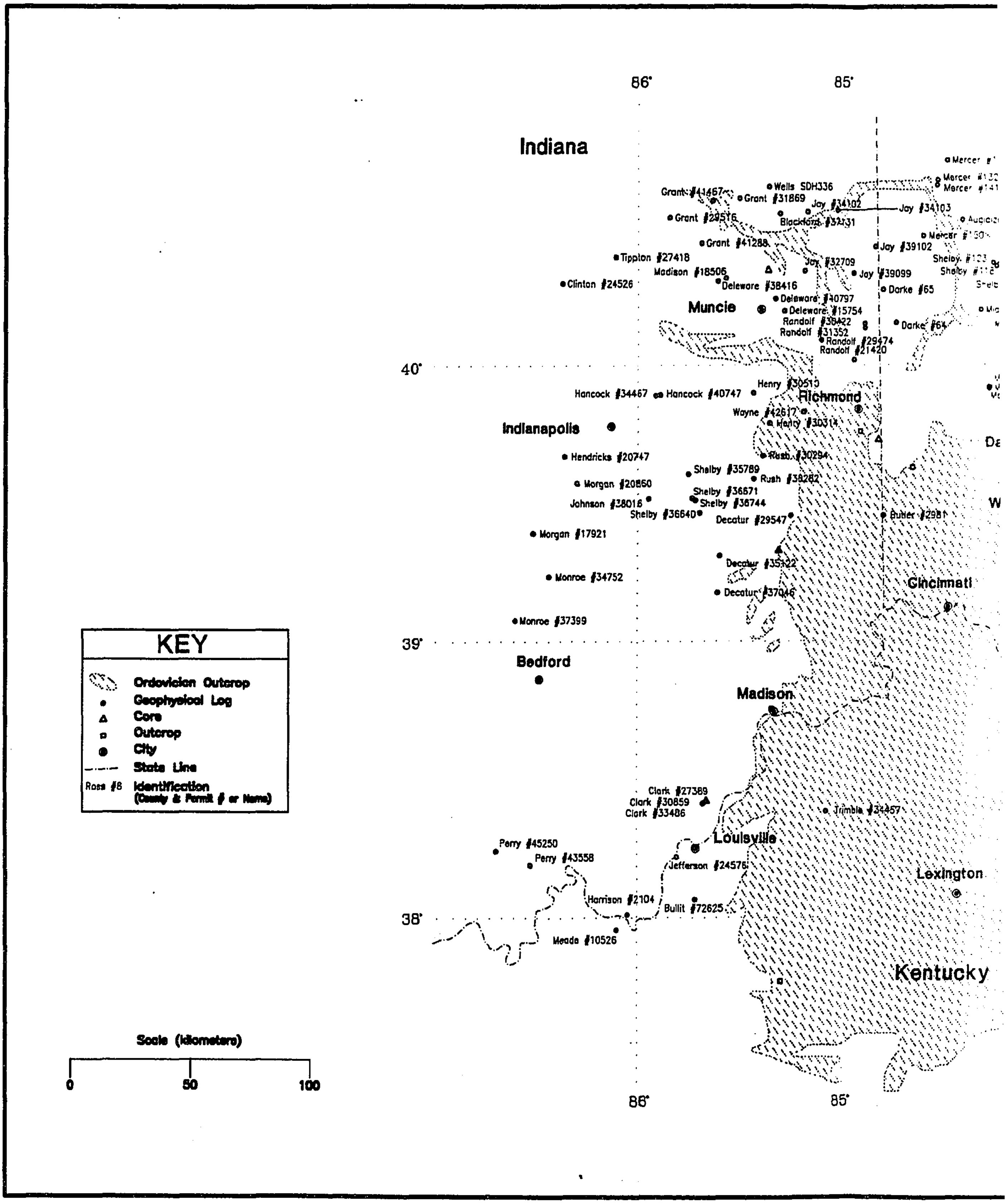
However, gamma ray logs that record the Richmond interval in the tristate region are not very common. When appropriate logs were located each log and its location were identified and recorded on a computer database (Appendix C).

In most cases, all of available gamma ray logs for a particular county were included if they contained the entire Richmond section. However, a number of geophysical logs were selected by their quality and location because of the large number of geophysical logs available in particular areas such as the southeastern and northeastern corners of the study area. Logs that were difficult to read, prepared on a small scale or contained "gain" adjustments were sometimes eliminated in areas with a numerous logs. Appendix C contains a list of all of the geophysical logs used in this study, their permit numbers, descriptive locations, and an indication of the types of logs available. All of the geophysical logs used in this study are stored at the H. N. Fisk Laboratory of Sedimentology at the University of Cincinnati. In addition, most of them can also be obtained from the state geological survey offices.

3.3.2 The Geographic Location of Geophysical Logs

The location of each well described in each of the respective geophysical logs was determined using United States Geological Survey (USGS) 7.5-minute topographic maps. However, the locations of many of the older wells were recorded by using a number of older surveys including the Virginia Military Survey that are no longer placed on USGS topographic maps. Some of these borings were located by calling various local and state agencies and searching old telephone books. After locating each well on a USGS 7.5-topographic map, the elevation of each well was compared to the elevation indicated on the topographic map. If there were obvious differences, additional research was conducted to identify the proper well locations. After each well was located, its longitude and latitude were determined.

Although the longitude/latitude system is adequate for locating data on a regional scale, it cannot be easily used to plot data on computer contouring programs because one degree of latitude is approximately 1.3 times that of the longitude scale. On larger scale projects, the Universal Transverse Mercator (UTM) grid is often used to plot data. However, the field area traverses three different UTM grids. A conversion system on the Radian CPS/PC mapping program permitted the conversion of longitude/latitude positions to UTM coordinates of the 17th principal meridian. Figure 8 is a location map of geophysical logs used in this study. Appendix C contains the derived geographic coordinate locations for each core and geophysical log.



Indiana
Kentucky
86°
85°
40°
39°
38°
Muncie
Richmond
Indianapolis
Bedford
Madison
Cincinnati
Louisville
Lexington
Wells SDH336
Grant #31869
Grant #29516
Grant #41288
Tippton #27418
Madison #18506
Clinton #24526
Delaware #38416
Jay #34103
Jay #39102
Jay #39099
Darke #65
Hancock #34467
Hancock #40747
Wayne #42617
Hendricks #20747
Shelby #35789
Rush #38282
Morgan #20860
Shelby #36671
Johnson #38016
Shelby #36744
Decatur #29547
Morgan #17921
Monroe #34752
Monroe #37399
Clark #27389
Clark #30859
Clark #33486
Perry #45250
Perry #43558
Jefferson #24576
Harrison #2104
Bullit #72625
Meade #10526
KEY
Ordovician Outcrop
Geophysical Log
Core
Outcrop
City
State Line
Ross #8
Identification
(County & Permit # or Name)
Scale (kilometers)
0
50
100

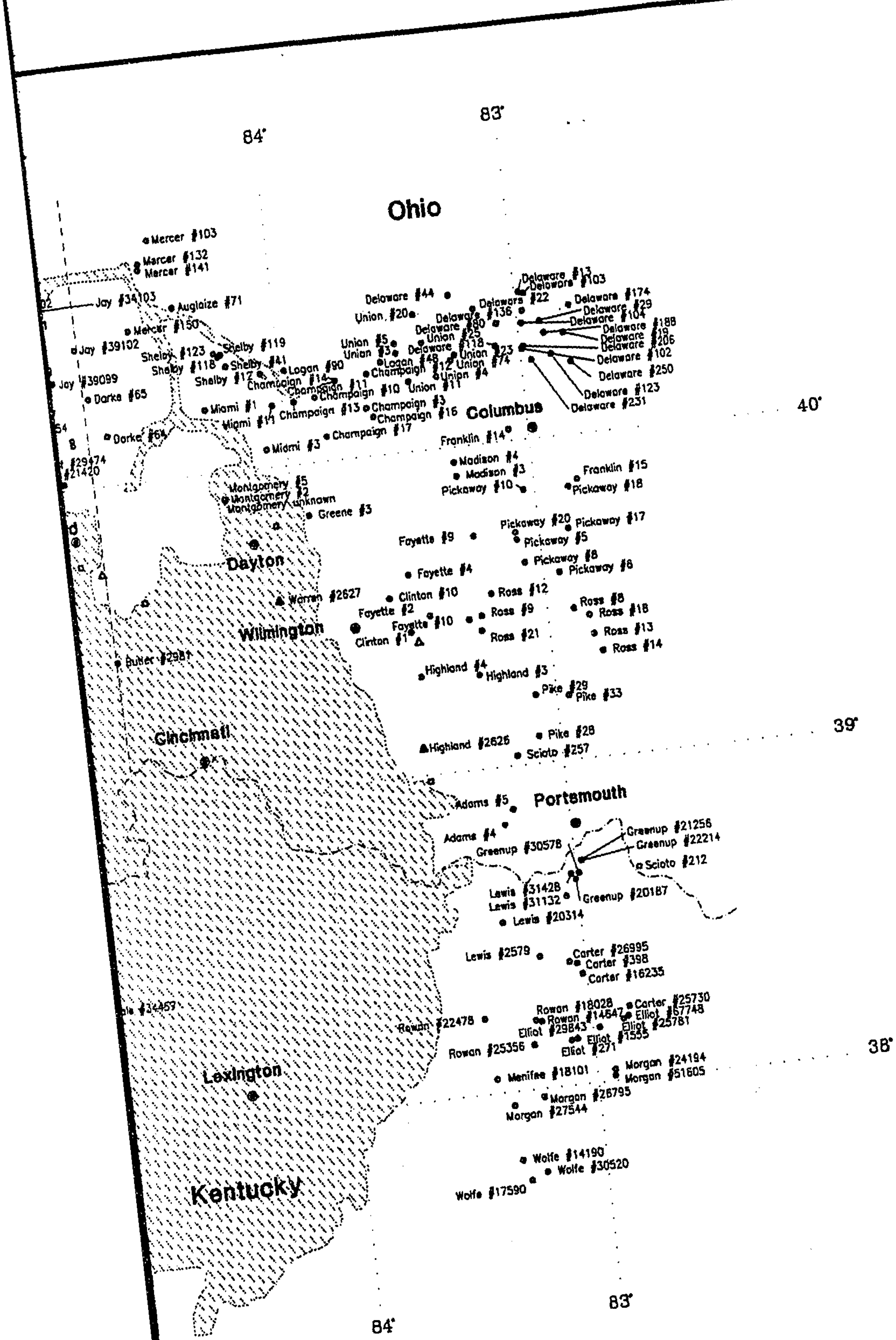


FIGURE 8

Geophysical Log Basemap Ohio, Kentucky, and Indiana

3.4 Interpretation of Geophysical Logs

Gamma ray and neutron logs were used in this study to correlate strata and interpret parasequence stacking patterns, from which the regional depositional model was constructed. In general, almost all correlations were based on responses of the gamma ray log to the strata while the neutron log was occasionally used to assist in the interpretation of rock type.

According to Schlumberger (1985), the gamma ray logs provide a measurement of the natural radioactivity in a particular strata. The gamma rays recorded on this log are high energy electromagnetic waves that are emitted from radioactive isotopes. In the Cincinnatian strata, the most common radioactive isotope is potassium (K^{40}). This potassium isotope is most concentrated in clays and least concentrated in pure carbonates and sandstones. The gamma response to a particular formation is proportional to the concentration of radioactive material within the formation (Schlumberger, 1985). Thus, clean sandstones and carbonates containing little radioactive materials will normally exhibit low gamma ray responses, and shales with their high clay content will exhibit higher gamma ray responses. The gamma ray log response generally reflects the radioactive shale content of the strata in sedimentary formations such as those present in tristate region.

A variety of neutron logs including the classic neutron log, the formation density log, and the compensated formation density logs were used in this study to enhance the gamma ray log correlations. Although the availability of each of these logs varied from boring to boring, most geophysical logs included a neutron log.

A neutron log measures the amount of hydrogen (generally in pore water) within a particular formation being observed. To measure the density, a radioactive source that emits high-energy neutrons is lowered into the borehole. When these neutrons collide with the nuclei of the formation material, the neutron loses some of its energy via Compton scattering (Schlumberger, 1985). Because collisions with heavy nuclei do not reduce the energy of the neutron significantly, the major energy loss is caused by collisions with hydrogen in the formation. When the energy of the neutron is significantly reduced, the neutron is captured by the nuclei of atoms, which becomes excited and emits a high energy gamma ray. The scattered gamma rays are then measured by a detector and utilized as an indication of formation density. The number of collisions is directly proportional to the formation's hydrogen content which occurs as water and hydrocarbons within the pores. Because water is also present in the crystalline structure of some minerals (*i.e.*, gypsum), additional corrections are necessary for some types of rock. In general, porous rocks such as shale will have a low neutron density, and nonporous rocks such as pure carbonates will have a high neutron density.

Both gamma ray and neutron logs were used to correlate strata across the tristate region. Because the dominant components of the Cincinnatian strata are shale and carbonates, it was relatively easy to interpret the gross lithologies observed in the gamma ray logs. As illustrated in Figure 9, gross lithologies could be interpreted from the geophysical logs. Shale-dominated strata with occasional carbonate beds have a high gamma ray deflection with occasional lower gamma ray response ("kicks"), and as the mass of carbonate layers

Permit #2626
Highland Co., Ohio

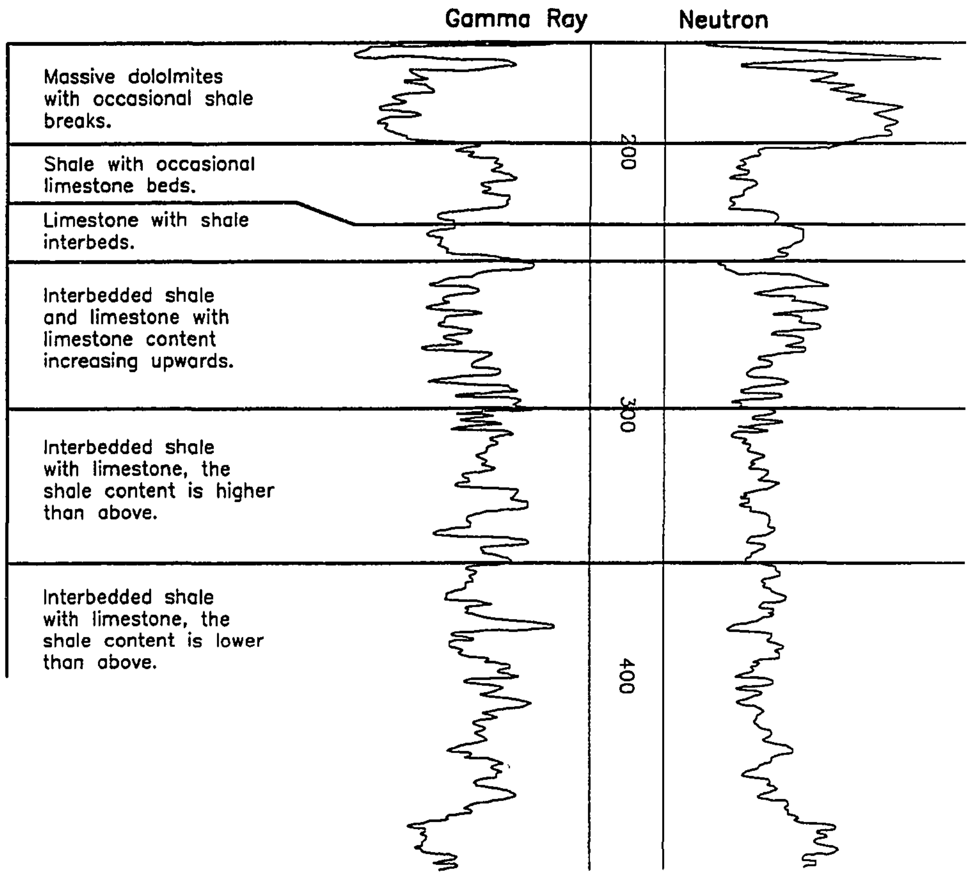


FIGURE 9

GEOPHYSICAL LOG INTEPRETATION
ODS CORE #2626
HIGHLAND COUNTY OHIO

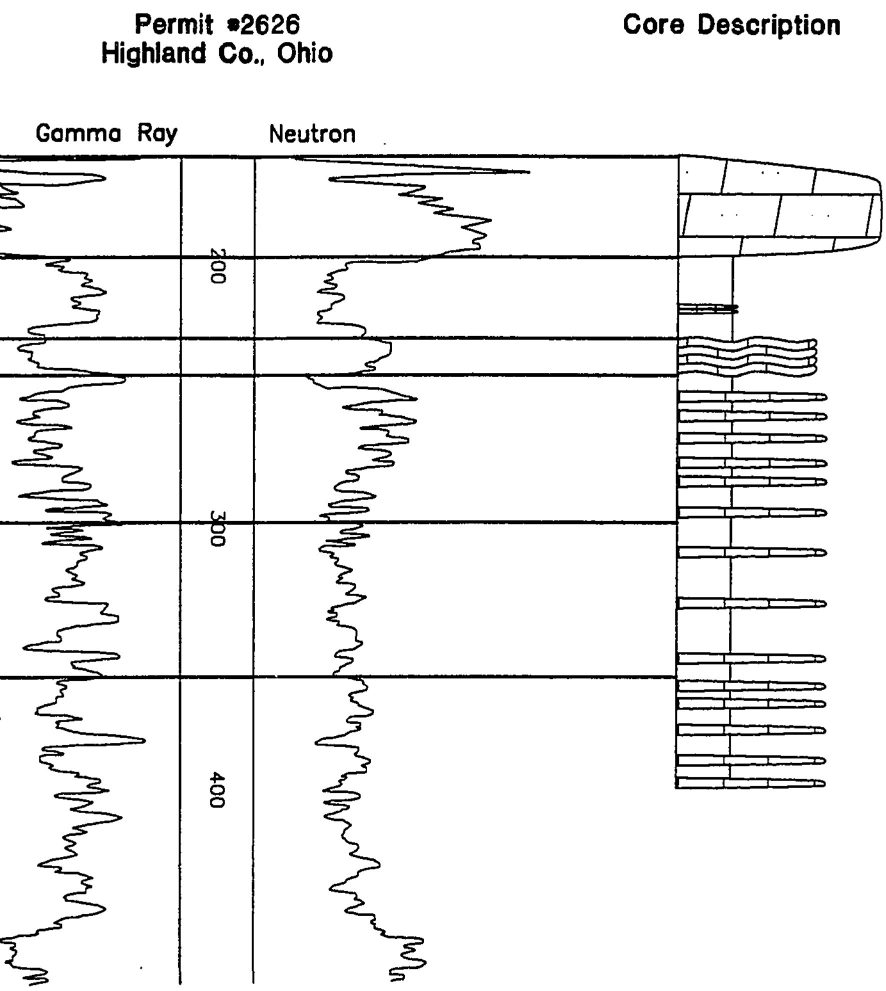


FIGURE 9

PHYSICAL LOG INTEPRETATION
ODS CORE #2626
HIGHLAND COUNTY OHIO

increases the number and size of the carbonate kicks increase. In strata where shale-dominated sequences grade vertically into carbonate-dominated sequences, the gamma ray response in the shale is high with few limestone kicks and decreases gradually with more frequent and thicker carbonate deflections. In the carbonate-rich sections, the gamma ray response is low with a few high gamma ray deflections. The neutron density response for these formations is generally the inverse of the gamma ray log.

3.5 Correlation of Logs, Cores, and Outcrops

The logs, cores, and outcrops were correlated using the methodologies described below. First, a cursory examination of the outcrops and cores was completed. Afterwards, the geophysical log signatures were compared to nearby outcrops and cores to determine what lithologic characteristics present in the outcrops and cores were also detected by the geophysical logs. The outcrops and cores were reexamined in detail based upon the geophysical log comparison and information regarding rock type, fossil content, and sedimentary characteristics was recorded. The cores were correlated to nearby outcrops using sedimentologic characteristics, but general faunal content, fossil abundance and taphonomy were considered where possible. After comparing the descriptions of strata contained in cores and outcrops to the geophysical log correlations, generalized facies were derived that were observable in outcrop, core, and geophysical logs.

The basic steps used to correlate the well database consisted of correlating:

- Major stratigraphic contacts and marker beds in the logs,
- The generalized facies described above,
- General progradational, aggradational, and retrogradation patterns.

By correlating the cores and logs to outcrops, the vast wealth published paleontologic and sedimentologic data was used to enhance interpretations of depositional environments and paleoecology.

It was important to correlate major marker beds and stratigraphic contacts in order to ascertain the position of the section that the log covered. These picks were usually made during initial review of the logs. The most prominent makers chosen were the K-Bentonites, of the Black River Group, the base of the Maquoketa, and the Ordovician-Silurian contact.

These markers were identified after communications various researchers at the Ohio, Indiana, and Kentucky geological surveys.

Individual logs were correlated with each other using several methods including:

- Selecting various discernable deflections in the logs;
- Correlating major shale-dominated sections with each other including the prominent shale intervals were at the top of the Richmondian section in eastern Indiana and Ohio, and at the base of the Richmondian section in Indiana, Ohio and Parts of Kentucky;
- Placing logs next to each other and moving them up and down (slipping) so that 20- to 50- foot (6 to 15 meters) sections of strata were compared based on the shape of the high magnitude deflections and on the position of smaller deflections; and

- Discerning stratal stacking patterns with lithologic trends including shaling and shoaling strata.

Close well logs were compared to each other and then regional correlations were completed by making transects across the tristate region. The correlations were verified by checking for closure on smaller regional cross sections.

During and after the correlation of the geophysical log data set, Richmondian strata were correlated with outcrops and cores using the shale percentage, and gamma ray logs available for each core. The shale percentage logs were obtained from the Ohio and Indiana Geological Surveys. The shale percentage logs were constructed by measuring the thickness of each bed in a core. The percentage of shale is derived by dividing the thickness of shale beds in a given interval by the total thickness of the interval. According to Shrake *et al.* (1988), the patterns of shale percentage logs closely resemble the deflections produced in gamma ray logs. Hence, units with high percentages of shales have a positive deflection in the gamma ray logs and shale percentage logs. One major drawback to this method, is that some of the beds in the Cincinnatian consist of bryozoan rich wackestones and determining the shale percentage in these beds in cores and outcrops is difficult. According to Shrake *et al.* (1988) the shale percentage logs do not match the gamma ray logs precisely. However, Gray (1972) and Dattilo (1994) successfully used this methodology to correlate cores with gamma ray logs and outcrops.

After the geophysical logs were correlated with the cores, the outcrop to core correlations were reevaluated to ensure proper integration of the outcrop data. After the outcrop to core to geophysical log correlations were completed, regional facies correlations were made using the geophysical log correlations. From this integrated database, information about the deposition and paleoecology of each facies was obtained through literature research, site investigations, and numerous discussions with leading researchers of these strata including Benjamin F. Dattilo, William T. Fox, Henry H. Gray, Wayne D. Martin, David L. Meyer, Arnold I. Miller, R. C. Frey, Wayne A. Pryor, and varied investigators from Ball State University, the University of Cincinnati, Miami University, The Ohio State University, the Indiana Geological Survey, The Kentucky Geological Survey, the Ohio Geological Survey, and the Illinois Geological Survey. Although the personnel from the

Ohio Survey have correlated some of the cores, only the published data were made available to the author.

4.0 FACIES ANALYSIS

Six facies designated as Facies A through Facies F were delineated in this study based upon dominant rock types, sedimentary structures, and stratigraphic relationships. However, these informal units are not intended to be used for formal stratigraphic purposes.

The facies, which are significant in a sedimentologic sense, mappable on a regional scale, and recognizable in outcrop, core and geophysical logs were delineated according to:

- The nature and occurrence of shale and carbonate units, including layering, bedding, thickness, and gross clastic content;
- The stratigraphic position in relation to inferred flooding surfaces;
- Diagnostic sedimentary features prominent in various commonly occurring mappable rock types;
- Lithologic contrasts between adjoining facies to enable the units to be identifiable in geophysical logs; and
- The stratigraphic position to permit the division of similar facies occurring in distinct

transgressive/regressive intervals.

In addition, because of the regional expanse of the study area, some gradational rock associations were grouped together to enable the mapping of sedimentary units over large areas rather than minimize the ecologic and sedimentologic significance within.

The six facies identified during this study were named after their most distinguishing sedimentologic and lithologic characteristics as follows:

- Facies A: Interbedded planar to lenticular shales and carbonates present at the base of the section.
- Facies B: Wavy- to nodular-bedded carbonates mixed with shales overlying the lower shales.
- Facies C: Massive dolomudstones occurring in southeastern Indiana and north-central Kentucky.
- Facies D: Dolomitic claystone and siltstone present in the eastern half of study area.
- Facies E: Wavy- to nodular-bedded carbonates mixed with shale which over shallow water facies.
- Facies F: Massive dolomudstones present in north-central

portion of the tristate region.

Although Facies B and C resemble Facies E and F respectively, stratigraphic, sedimentologic, paleontologic, and lithologic variations were identified during a detailed examination of these strata. Figures 10 through 13 are geophysical log interpretations that correlate the geophysical logs to cores to outcrops and delineate the facies defined in this study. Figure 10 illustrates the relationship between the Burnt Cabin Road Outcrop and the Highland County Core DGS #2626 and its associated geophysical log. The facies correlations in south-central Ohio, central Ohio, and northern Kentucky east of the Cincinnati Arch were made on the basis of this log/core record which included Facies A, B, and D. Correlations in this area were more difficult than in north-central Ohio and southeastern Indiana, because of the similar gross lithologic content of the strata.

The stratigraphic relationship of the North Dayton Section and the Camden Section to the Warren County Core DGS #2627 is shown in Figure 11. The thickness and rock types of Facies A, B, and D in the core are similar to those of the outcrops. However, as shown on Figures 10 and 11, an increase in

Permit •2626
Highland Co., Ohio

FACIES	DESCRIPTION
Silurian	Grainstones, light olve gray to medium gray, biclastic, glauconite, pyrite, thin bedded to massive.
D	Shale, greenish gray with grayish red layers from 206 to 214', 1 to 10 cm limestone beds which are mottled at top.
B	Interbedded grainstones (60%) packestones (30%) and wackestones (10%), mostly bryozoans bioclasts, nodular bedding 2 to 5 cm.
A_2	Interbedded shales and grainstones and packestones, olive gray shales with medium gray carbonates, horizontal burroughs abundant in places, increasing shale content with depth, generally planar bedded.
A_1	Interbedded shales and grainstones and packestones, olive gray shales with medium gray carbonates, horizontal burroughs abundant in places, shale content much greater than above, planar beded.

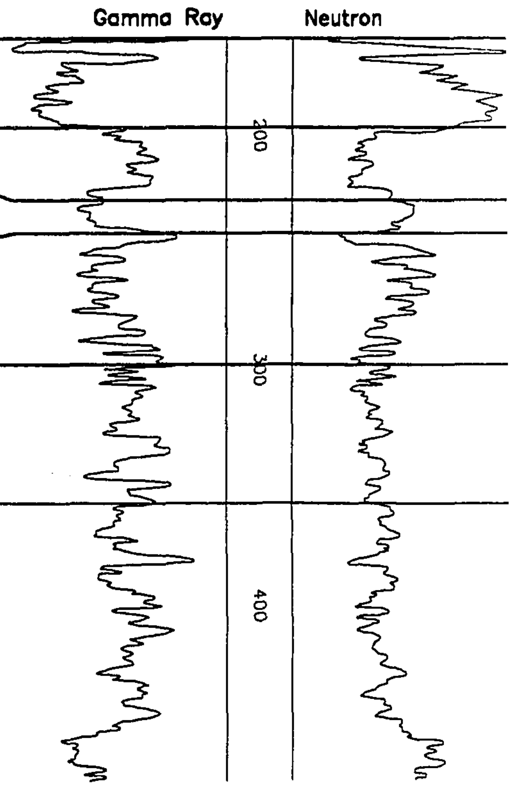


FIGURE 10

Facies Correlations
ODS Core •2626
Highland County, Ohio

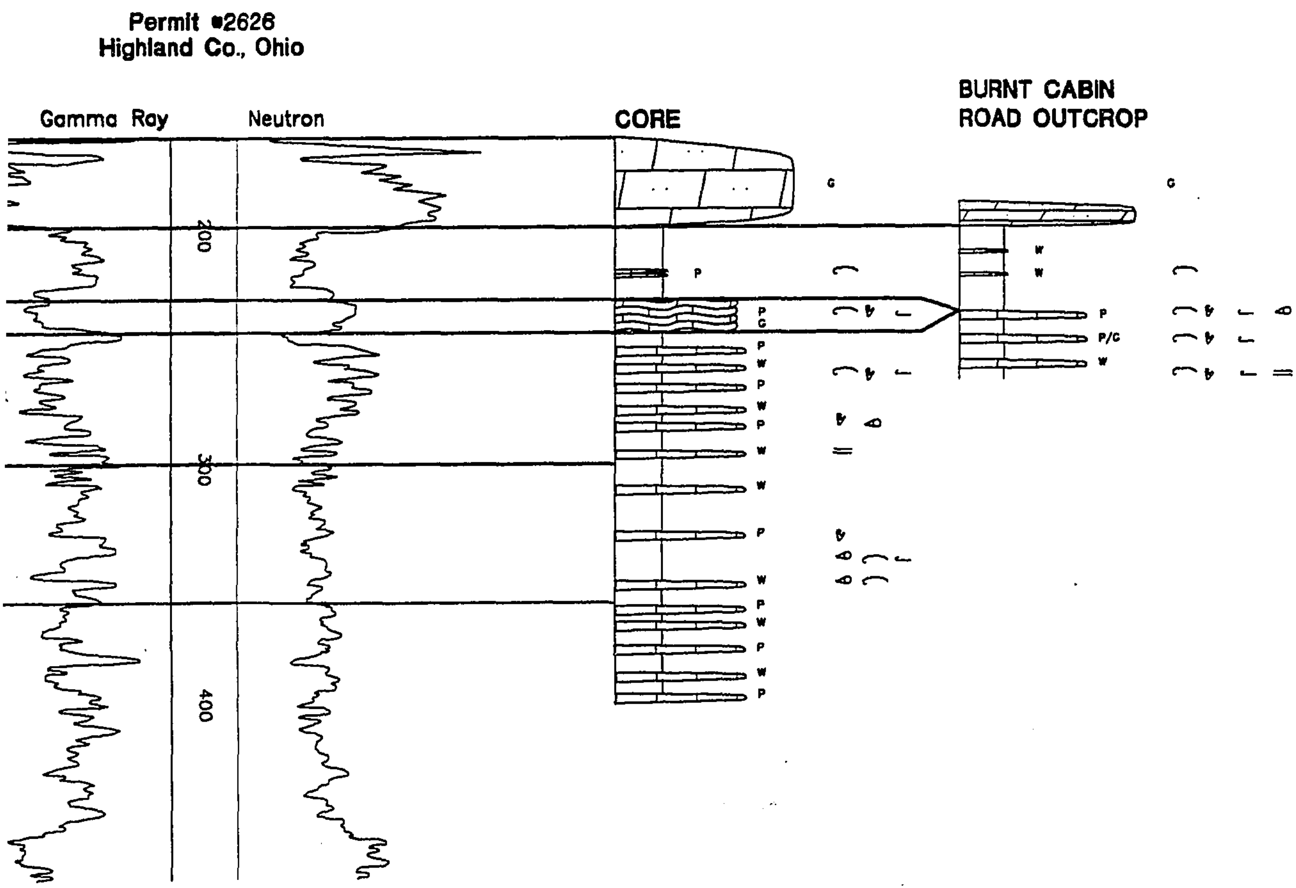
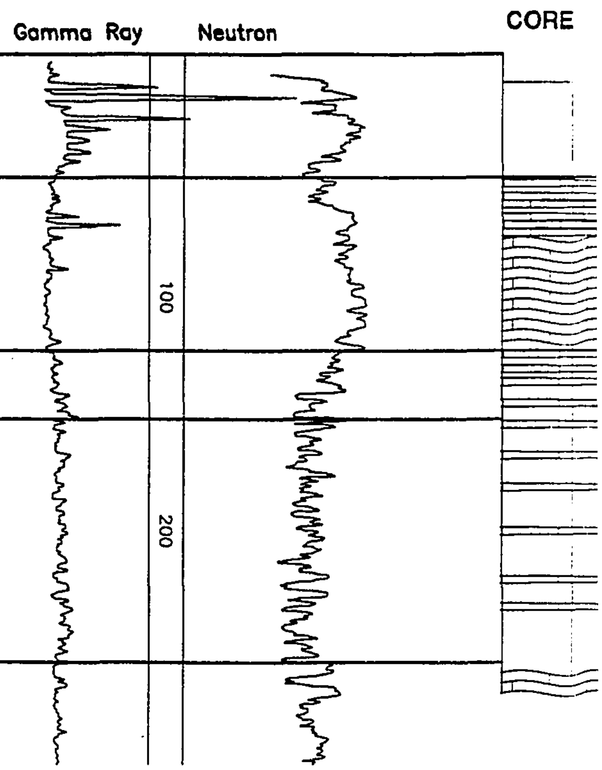


FIGURE 10

Facies Correlations
ODS Core #2626
Highland County, Ohio

DGS #2627
Warren Co., Ohio

FACIES	DESCRIPTION
D	Clay shale, grayish green, fossiliferous layers, intensely bioturbated, mudcracks 1 – 3 cm banded dolosiltstones.
B	Interbedded wackestones, packestones, grainstones, and shales, medium gray to dark greenish gray, abundant bryozoans, irregular to wavy bedded at base, increasing shale content at top, but interval is dominantly carbonate, 1 to 4 cm bedding.
A_2	Interbedded shales with wackestones, packestones, and grainstones, olive gray with dark gray carbonates, carbonates fine upwards, are planar bedded, horizontally burrowed, more carbonates than below, 1 to 4 cm bedding.
A_1	Interbedded fossiliferous mudstones and clay shales wackestones, olive gray shales with dark greenish gray wackestones, horizontal burrows, abundant brachiopods, bryozoans, and trilobites, wackestone beds to 4 cm.



Note: Core described on a bed by bed scale to 106 bgs, then desribed in general.

FIGURE 11

Facies Correlations
DGS #2627
Warren Co., Ohio

7
Ohio

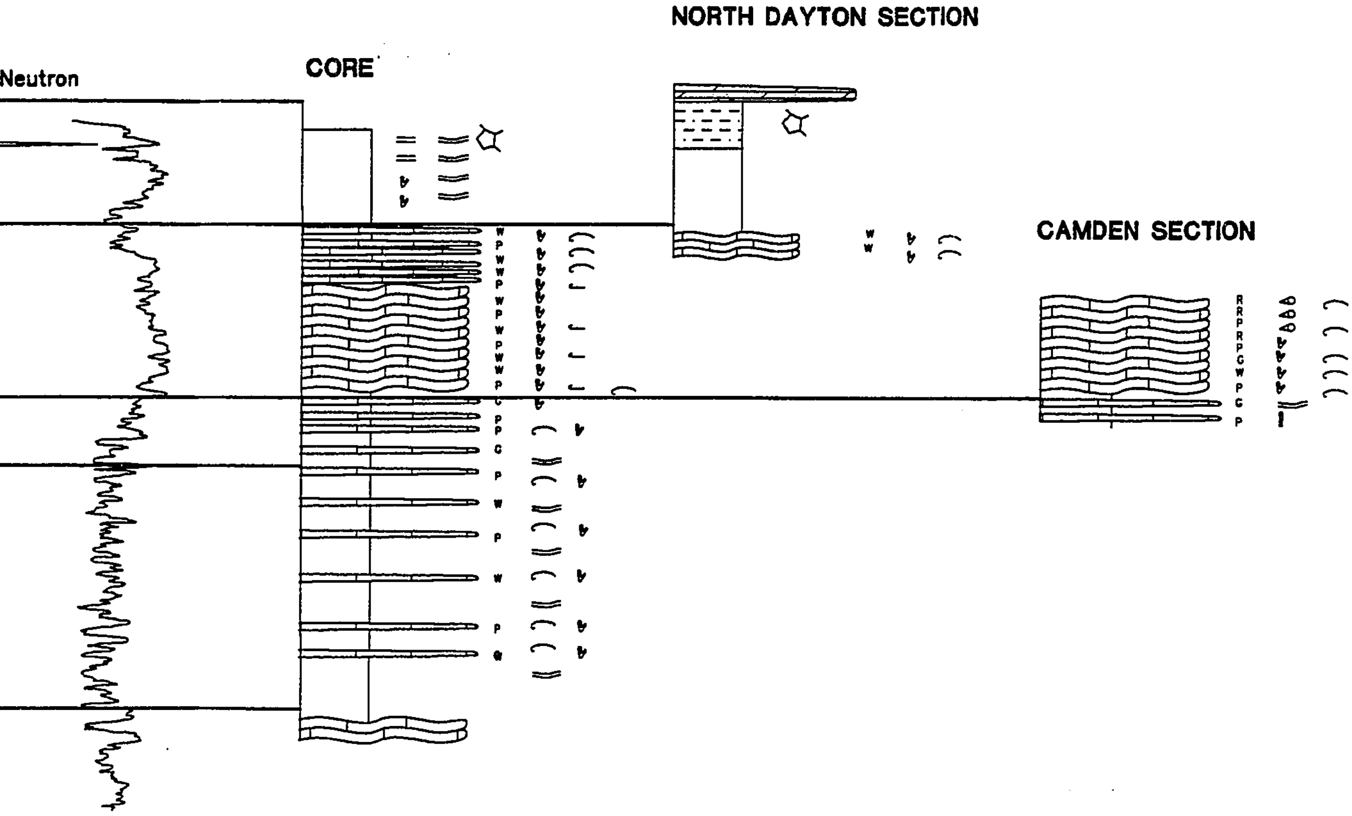
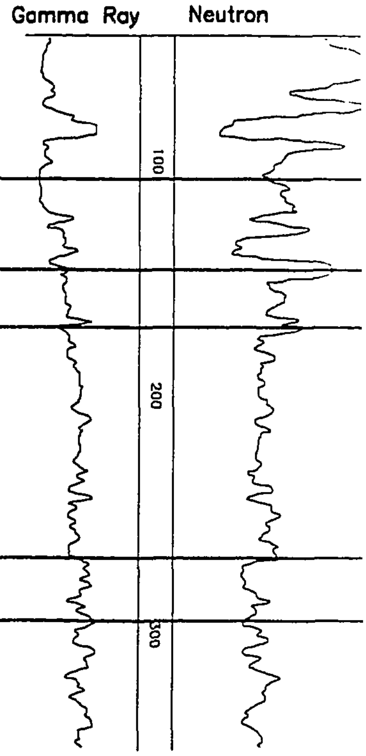


FIGURE 11

Facies Correlations
DGS #2627
Warren Co., Ohio

Permit #27387
Clark Co., Indiana



FACIES	DESCRIPTION
Silurian	Dolomitic grainstones, dark yellowish brown, glauconitic, recrystalized, thin bedded to massive.
C	Dolosiltstone, greenish gray, occasional micstones, unfossiliferous, vertical burrows, styolites, massive.
B	Interbedded wackestones, micstones, and dolomitic siltstones, abundant fossils, bioturbation, bedding 2 to 10 cm.
A	Interbedded shales, wackestones, and packestones, olive green shales, bioturbatd, 2 to 10 cm beds,

FIGURE 12

Facies Corelations
Core SDH #332
Clark County, Indiana

Permit #27387
Clark Co., Indiana

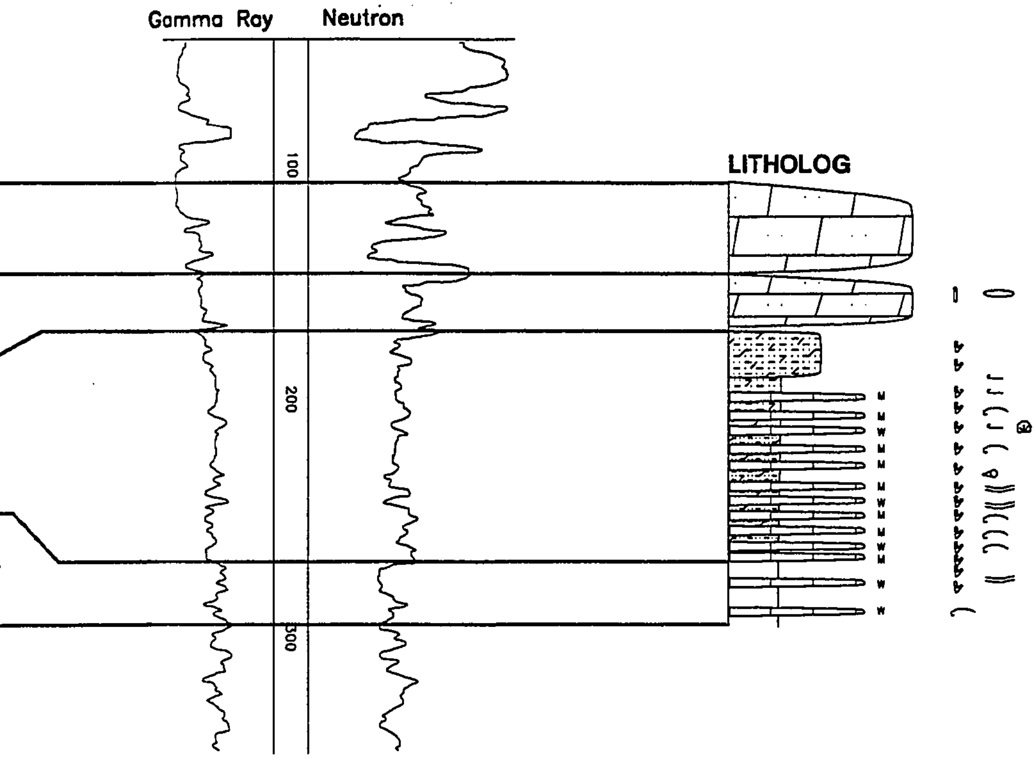


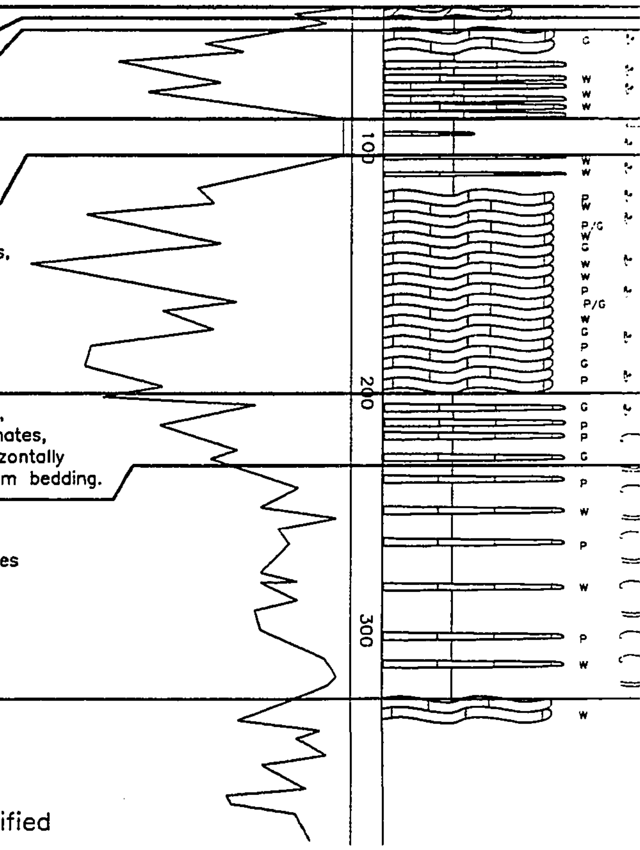
FIGURE 12

Facies Corelations
Core SDH #332
Clark County, Indiana

SDH #57
Wayne Co., Indiana

FACIES	DESCRIPTION
Silurian	
D	Clay shale, as D below.
E	Interbedded wackestones and clay shales, grayish green, irregular bedded, glacuonite at base, bedding less than 5 cm.
D	Clay shale, grayish green, fossiliferous 1 cm packestone/grainstone beds. fossiliferous trace of silt.
B	Interbedded wackestones, packestones, grainstones, and shales, medium gray to dark greenish gray, abundant fossils, irregular to wavy bedded, increasing shale content at top, but interval is dominantly carbonate, 1 to 4 cm bedding.
A_2	Interbedded shales with wackestones, packestones, and grainstones, olive gray with dark gray carbonates, carbonates fine upwards, are planar bedded, horizontally burrowed, more carbonates than below, 1 to 4 cm bedding.
A_1	Interbedded fossiliferous mudstones and clay shales wackestones, olive gray shales with dark greenish gray wackestones, horizontal burrows, abundant brachiopods, bryozoans, and trilobites, wackestone beds to 4 cm.

Percent Shale Core



Notes: Composite Brookville Section Modified From Tobin (1982).

Shale Percentage Log Obtained From The Indiana Geological Survey.

FIGURE 13

Facies Correlations
Core SDH #57
Wayne County, Indiana

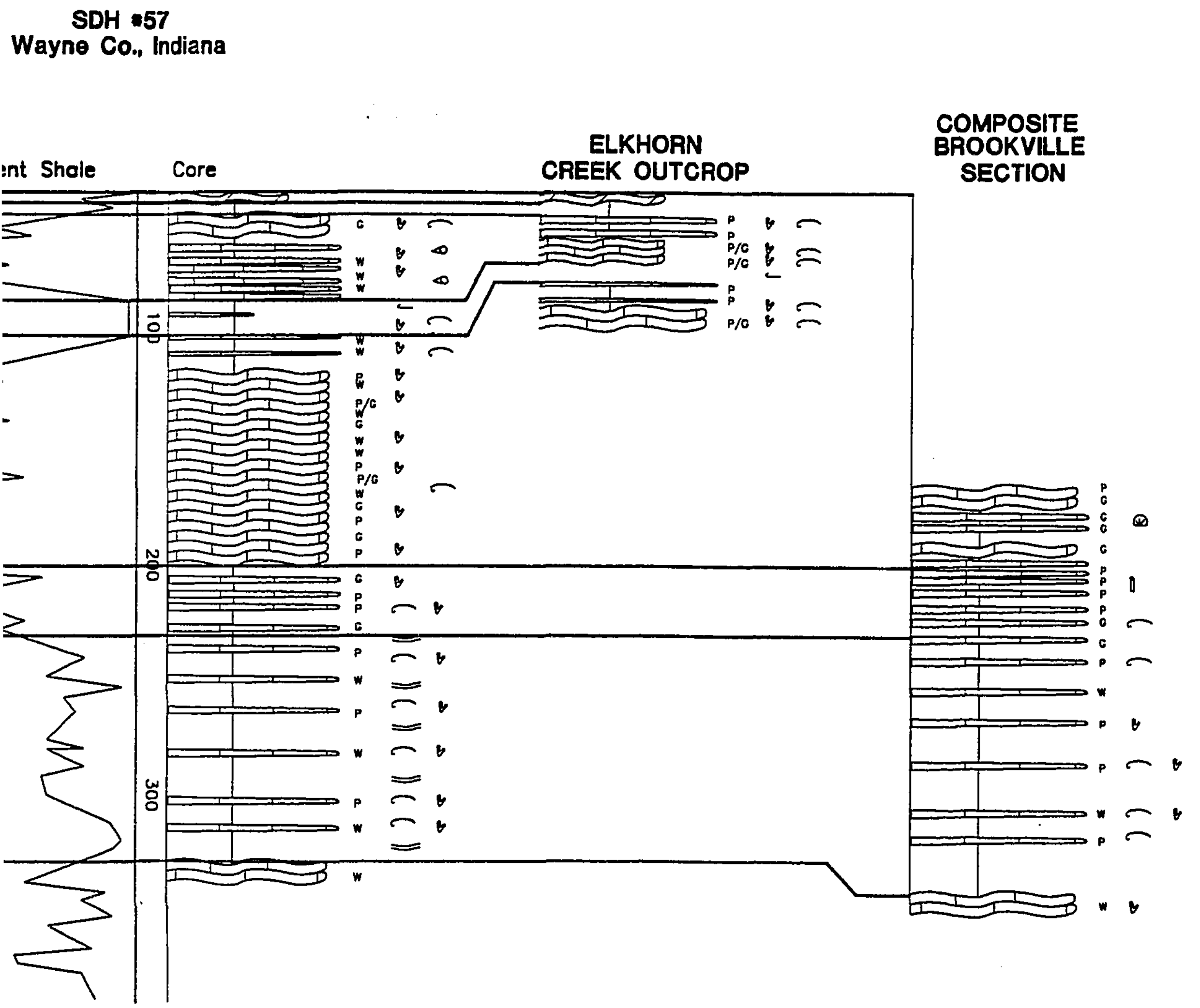


FIGURE 13

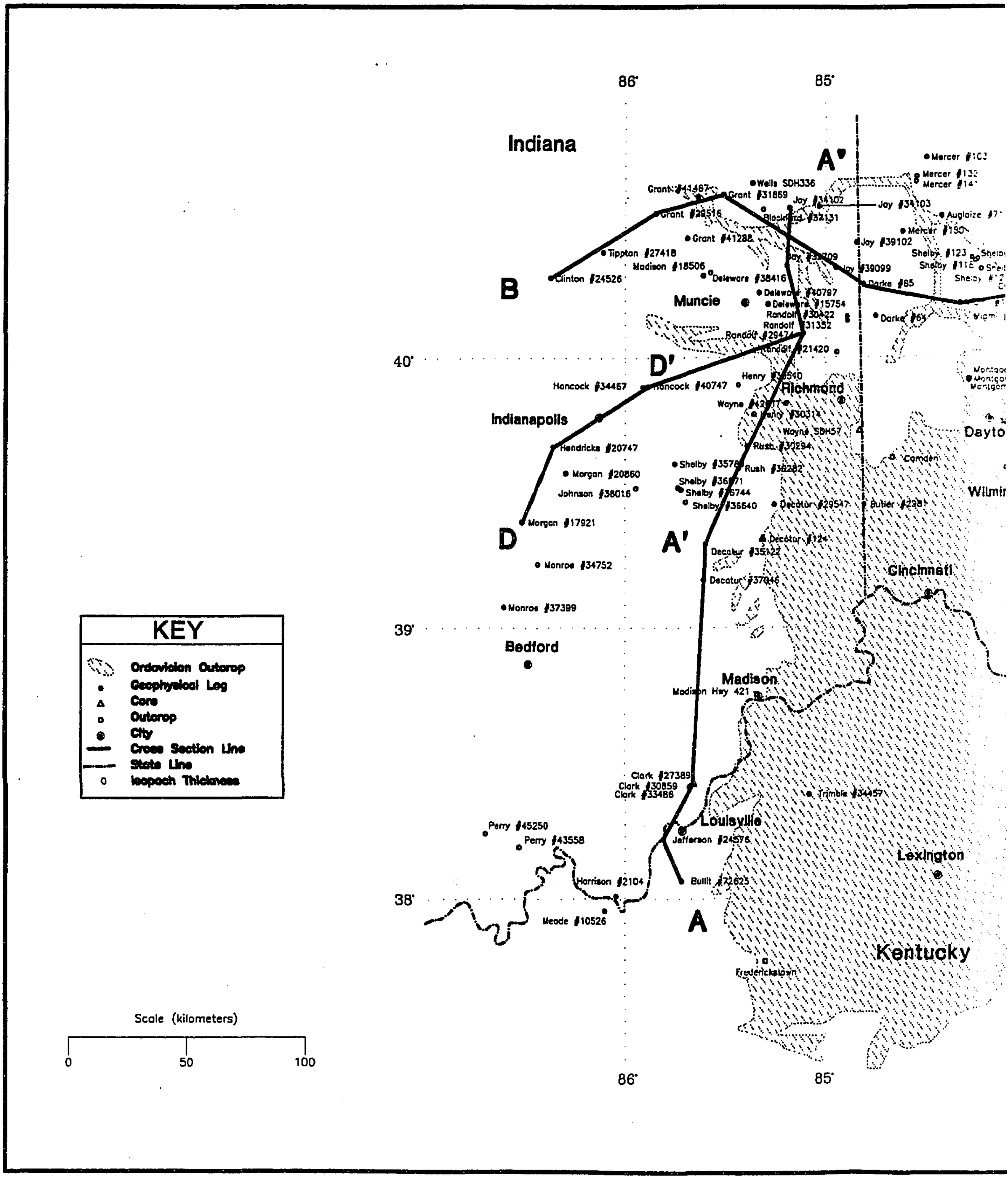
Facies Correlations
Core SDH #57
Wayne County, Indiana

limestone content occurs from south-central Ohio to southwestern Ohio in the Richmond strata.

The relationship between the geophysical log signature and the lithologic character of Clark County Core SDH #332 is illustrated on Figure 12. The facies identified in the core include Facies A, B, and C. Shale content decreases southward as illustrated in comparison of Figure 12 with Figures 10, 11, and 13.

The correlation of Richmond sections to the Wayne County Core SDH #57 is shown on Figure 12. The shale percentage log from this core was correlated to the nearby geophysical logs to assimilate the subsurface data. The core contains Facies A, B, D, and E are and exhibits the continued increase in limestone content towards the west and an interfingering of Facies D shales with the limestones.

The locations of the cross sections that were constructed from the correlated geophysical logs are included on the base map included as Figure 14. In addition, cross sections that show the stratigraphic relationships of the facies are illustrated



86°
85°
Indiana
A"
B
Muncie
40°
D'
Indianapolis
Richmond
D
A'
39°
Bedford
Madison
Cincinnati
Louisville
Lexington
38°
A
Kentucky
KEY
Ordovician Outcrop
Geophysical Log
Core
Outcrop
City
Cross Section Line
State Line
Isopach Thickness
Scale (kilometers)
0
50
100
Clinton #24526
Tippton #27418
Madison #18506
Delaware #38416
Grant #41288
Hancock #34467
Hancock #40747
Hendricks #20747
Morgan #20860
Johnson #38016
Morgan #17921
Monroe #34752
Monroe #37399
Perry #45250
Perry #43558
Harrison #2104
Meade #10526
Clark #27389
Clark #30859
Clark #33486
Jefferson #24576
Madison Hwy 421
Trimble #34457
Frederickstown
Wells SDH336
Joy #39102
Joy #39099
Darke #65
Mercer #132
Shelby #123

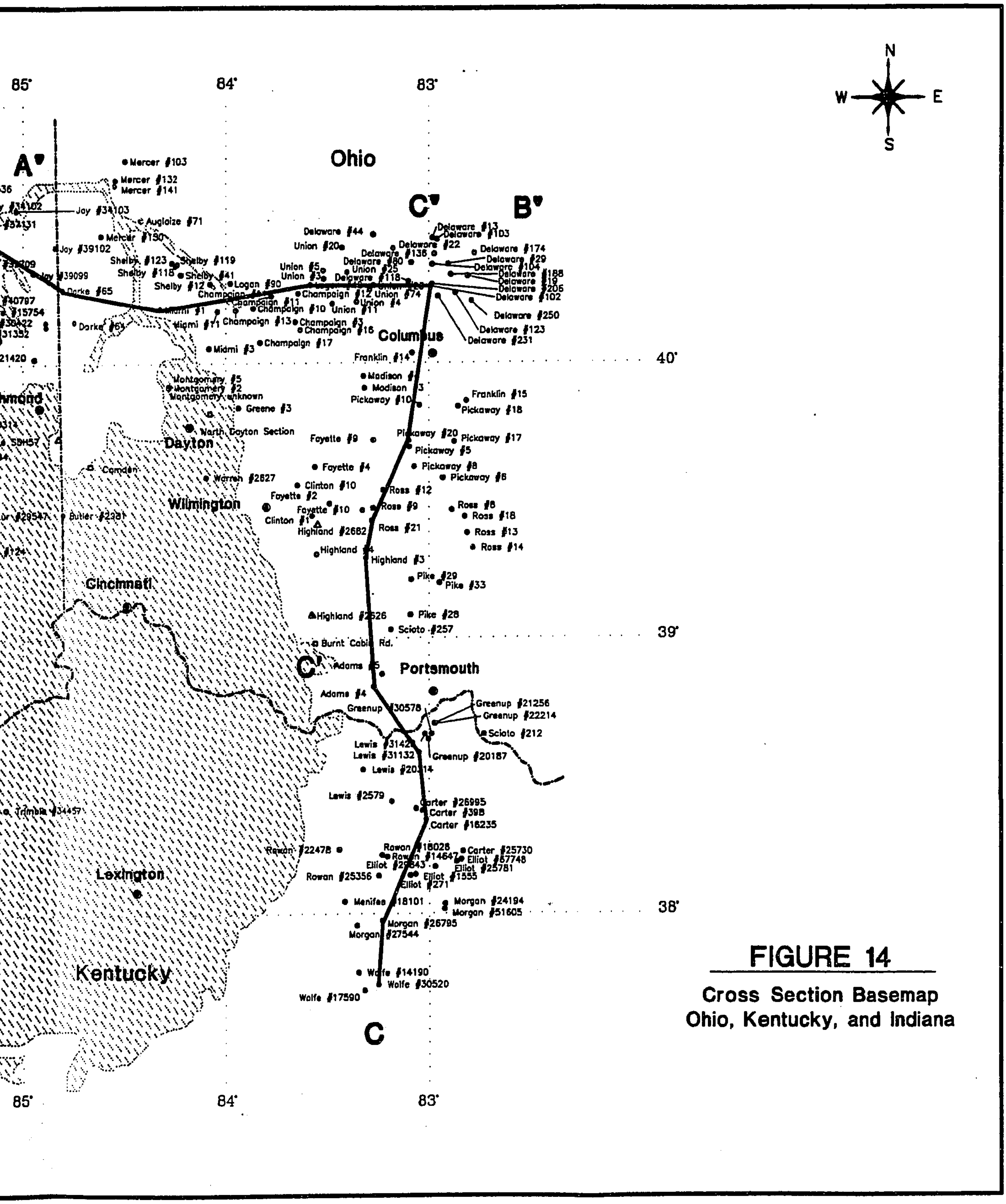


FIGURE 14

Cross Section Basemap Ohio, Kentucky, and Indiana

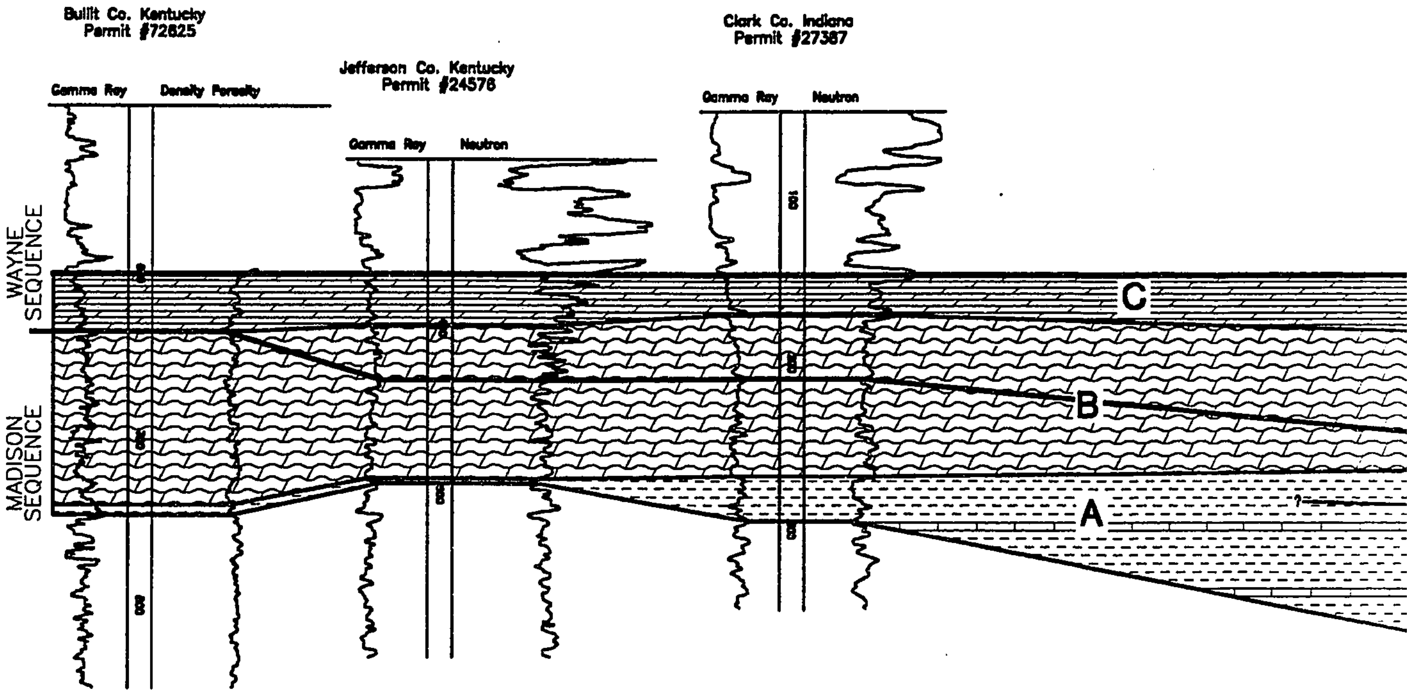
on Figures 15 through 21. These cross sections are referenced to detailed description of the sedimentologic and paleontologic character of each of the facies, which is included in the following sections. A south to north cross section located to the west of the Cincinnati Arch is shown of Figures 15 and 16. As indicated on both of these sections, Facies A thickens northward and Facies D, E, and F thin southward.

A west to east cross section located to the north of the Cincinnati Arch is illustrated on Figures 17 and 18. As shown on these figures, Facies D interbeds with and progrades over Facies A, B, and E. Again, general decrease in shale content to the west is demonstrated in these figures.

A south to north cross section situated to the east of the Cincinnati Arch is illustrated on Figures 19 and 20. Because this section is located along depositional strike of the westward prograding clastic wedge, few facies trends are observable. However, this section shows a thickening of Facies A and correlates strata in Kentucky with those in Ohio.

South

A



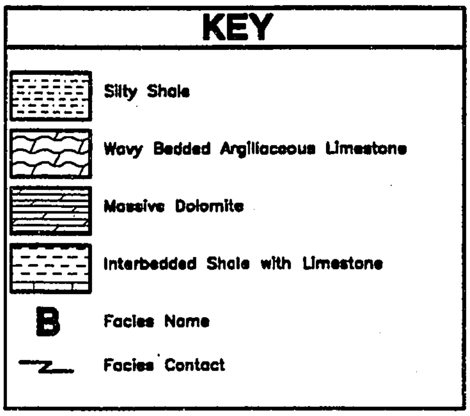
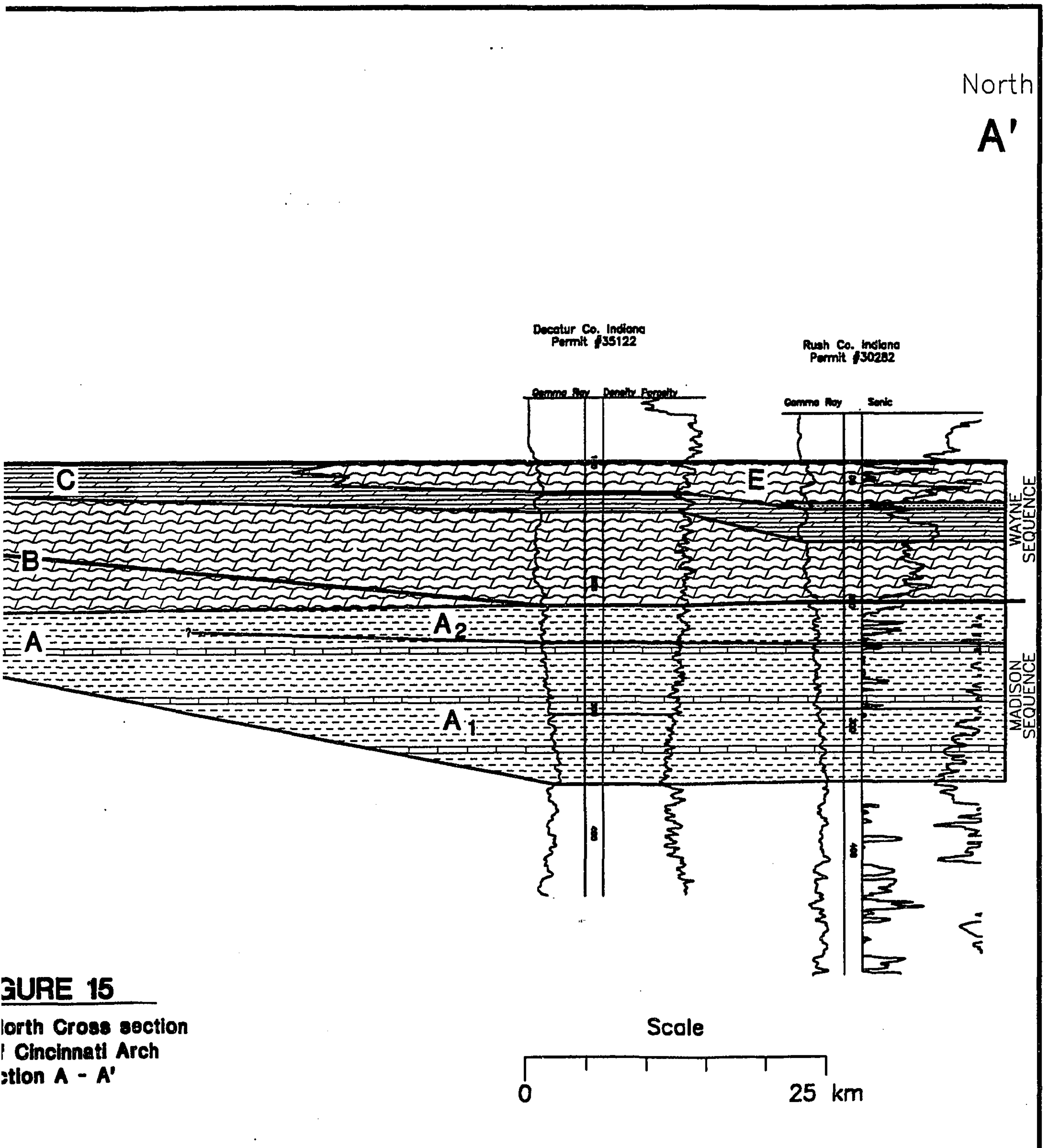


FIGURE 15

South to North Cross section West of Cincinnati Arch Section A - A'



GURE 15

lorth Cross section
f Cincinnati Arch
ction A - A'

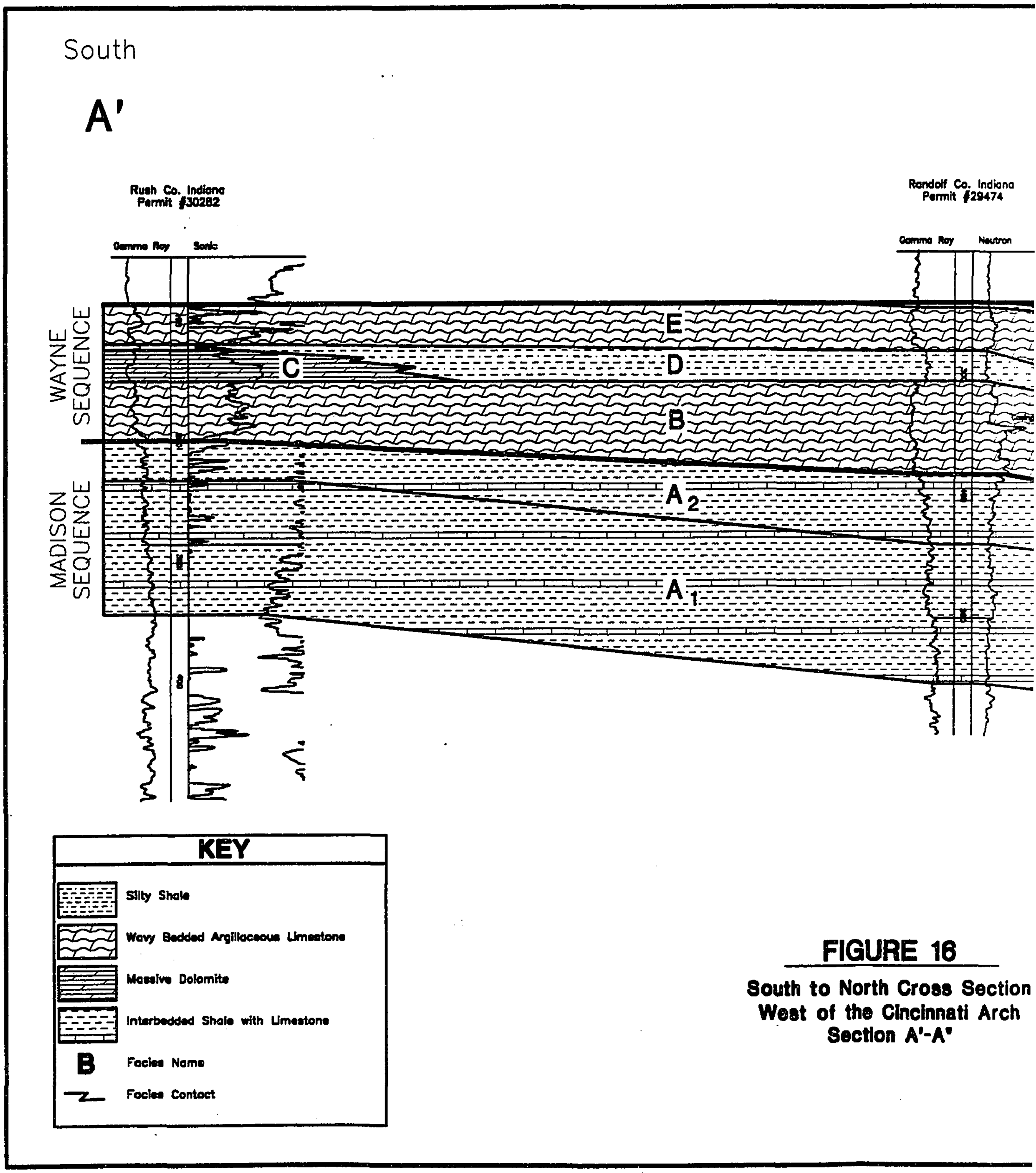


FIGURE 16

South to North Cross Section
West of the Cincinnati Arch
Section A'-A"

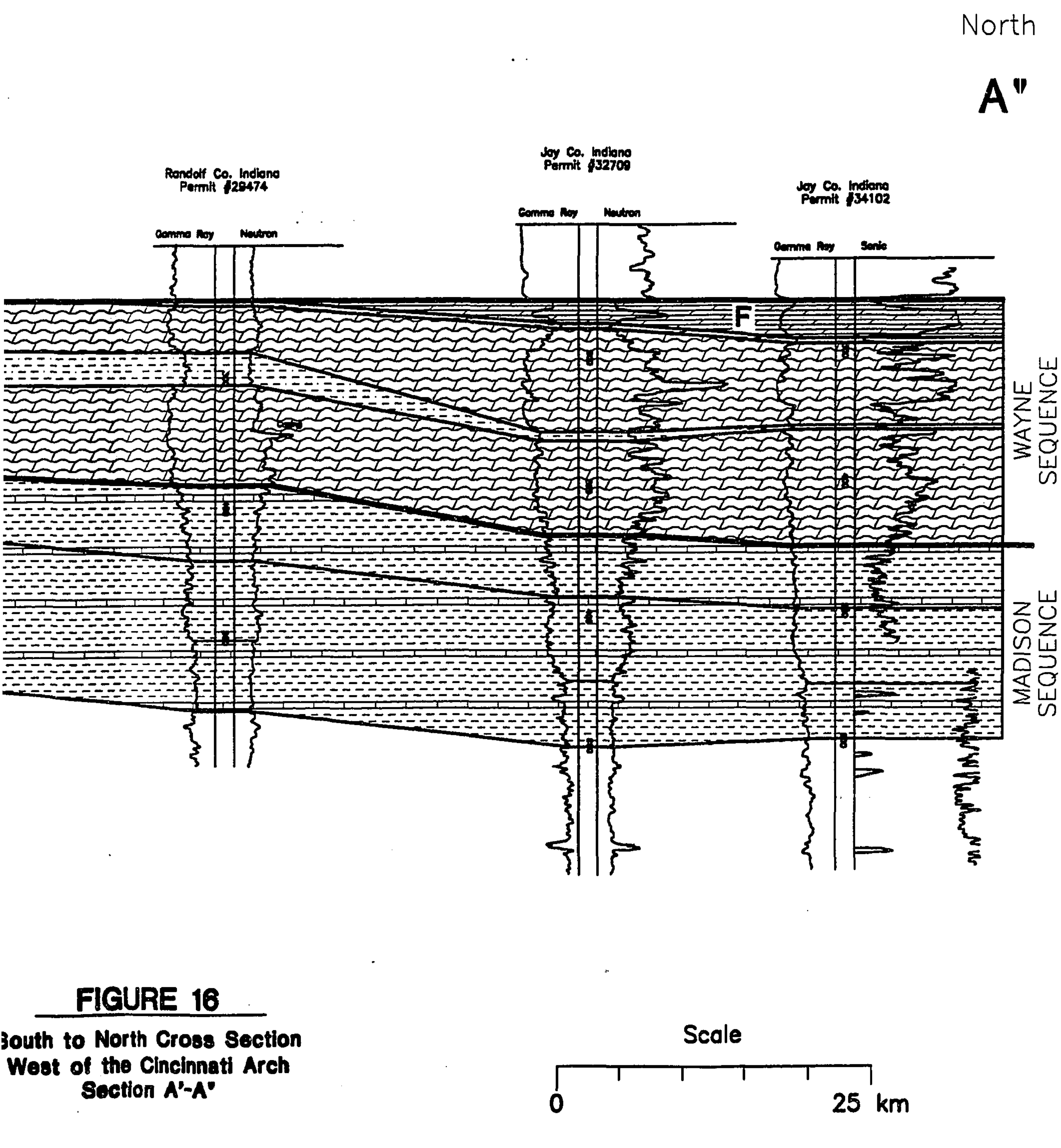


FIGURE 16

South to North Cross Section West of the Cincinnati Arch Section A'-A"

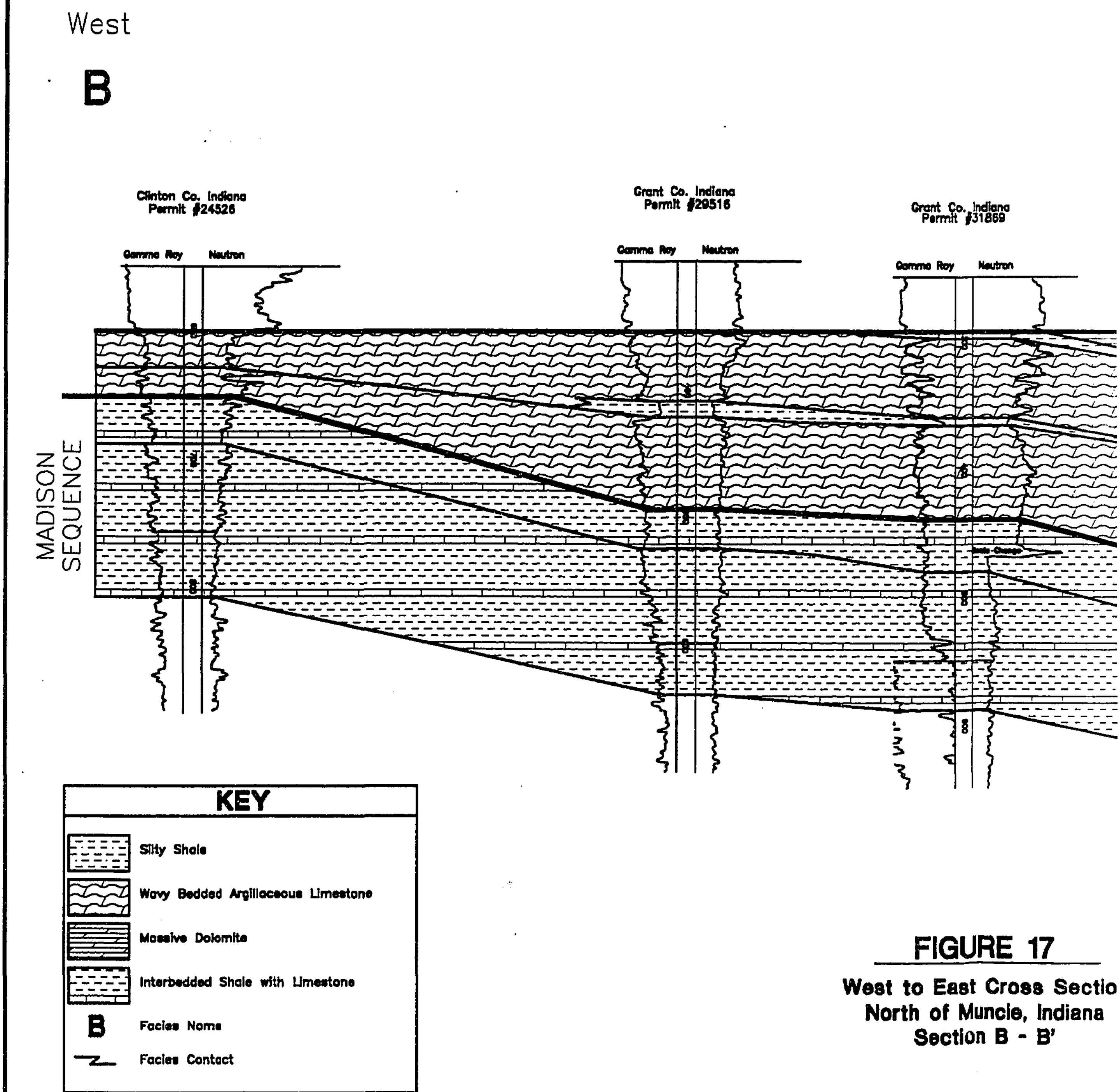


FIGURE 17

West to East Cross Sectio
North of Muncie, Indiana
Section B - B'

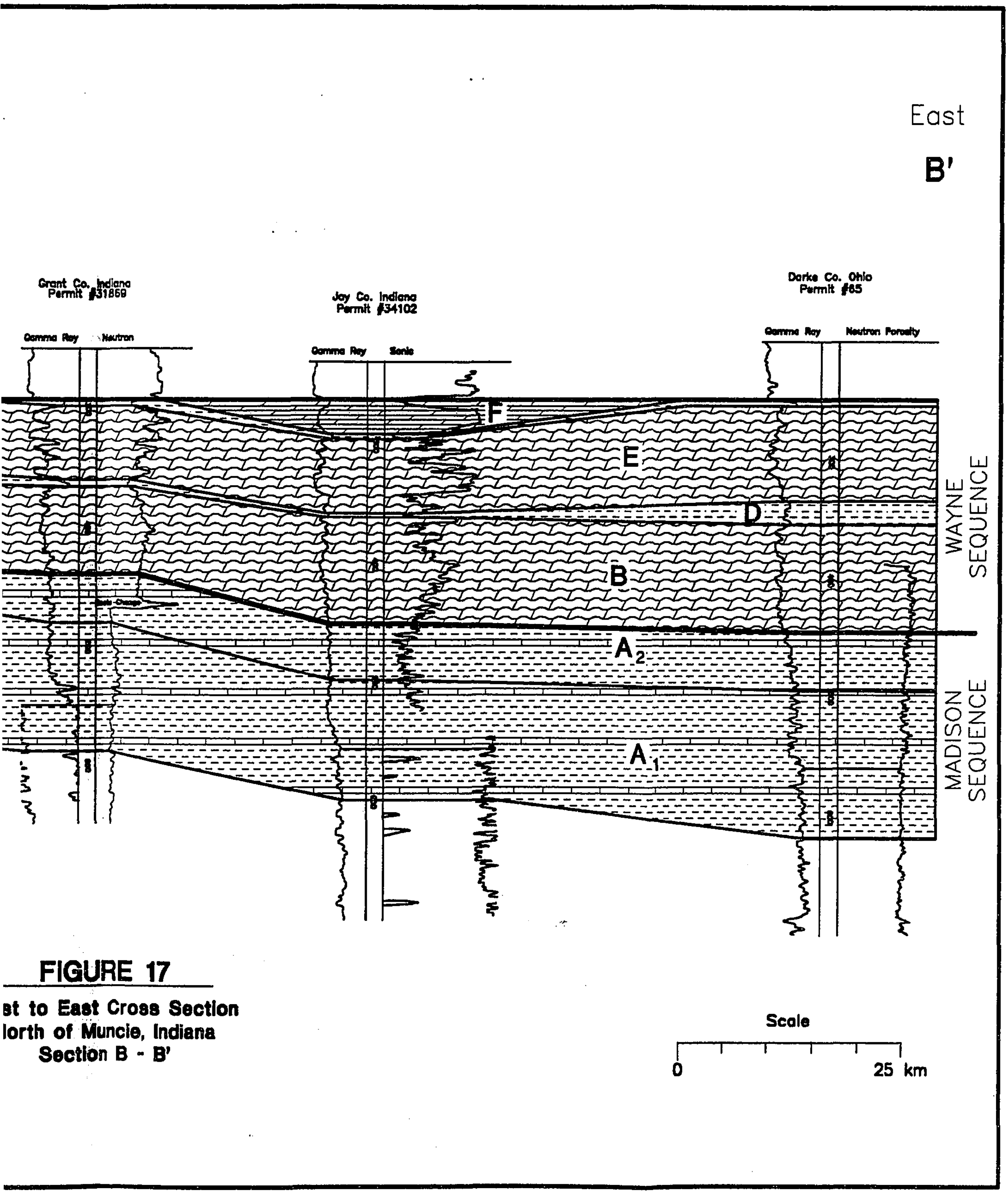
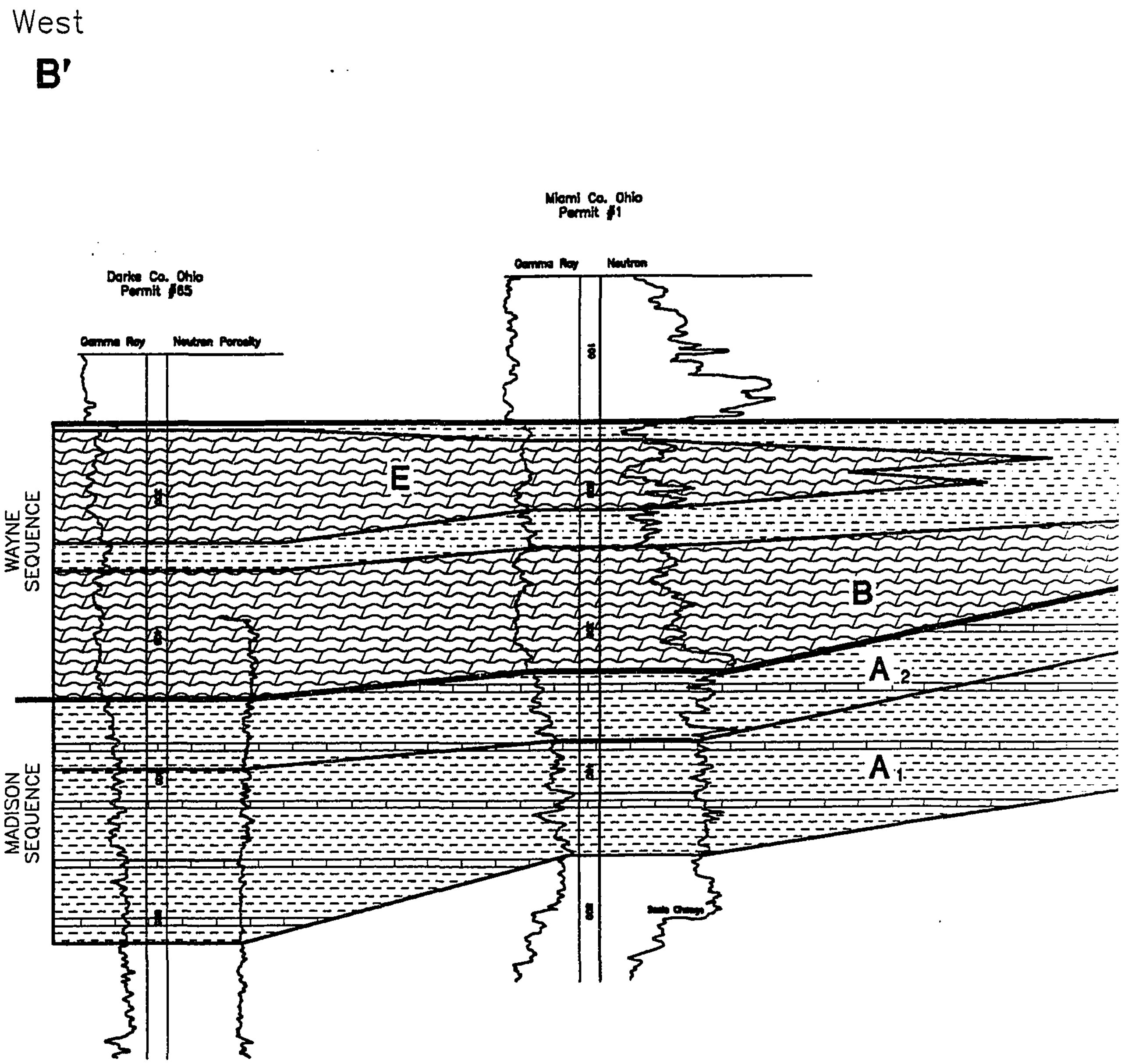


FIGURE 17

st to East Cross Section
lorth of Muncie, Indiana
Section B - B'



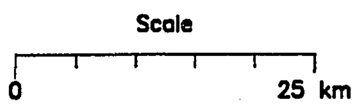
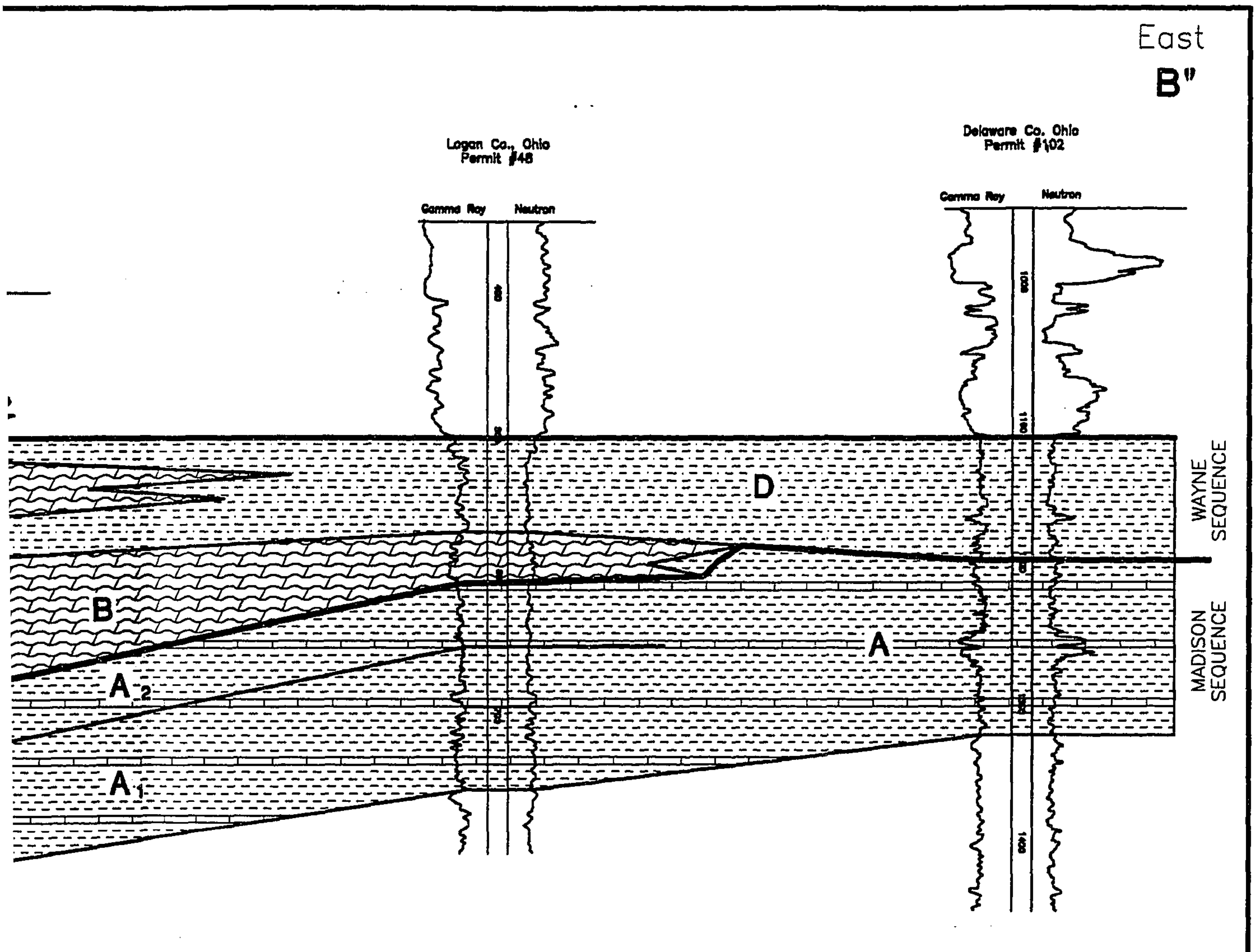


FIGURE 18

West to East Cross Sectio
North of Muncie Indiana
Section B' - B'

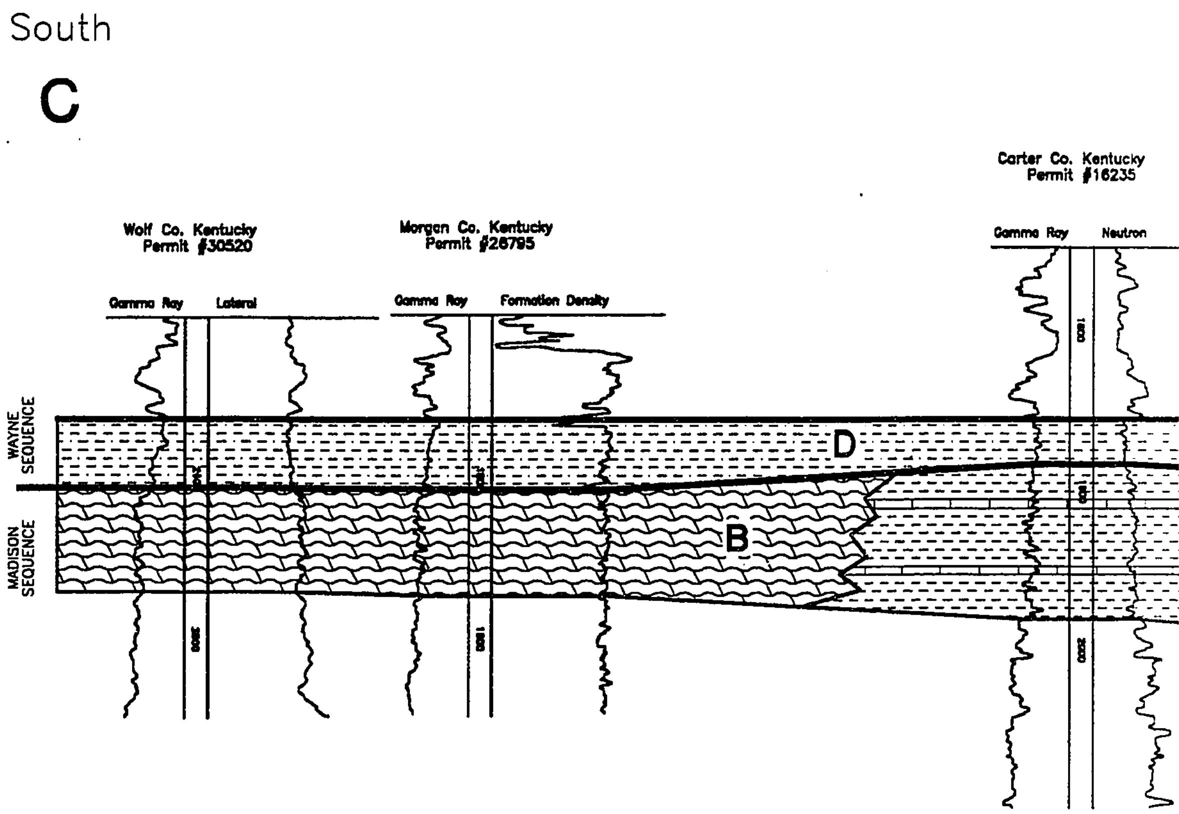


KEY

- Silty Shale
- Wavy Bedded Argillaceous Limestone
- Massive Dolomite
- Interbedded Shale with Limestone
- **B** Facies Name
- Facies Contact

FIGURE 18

West to East Cross Section North of Muncie Indiana Section B' - B"



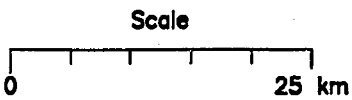
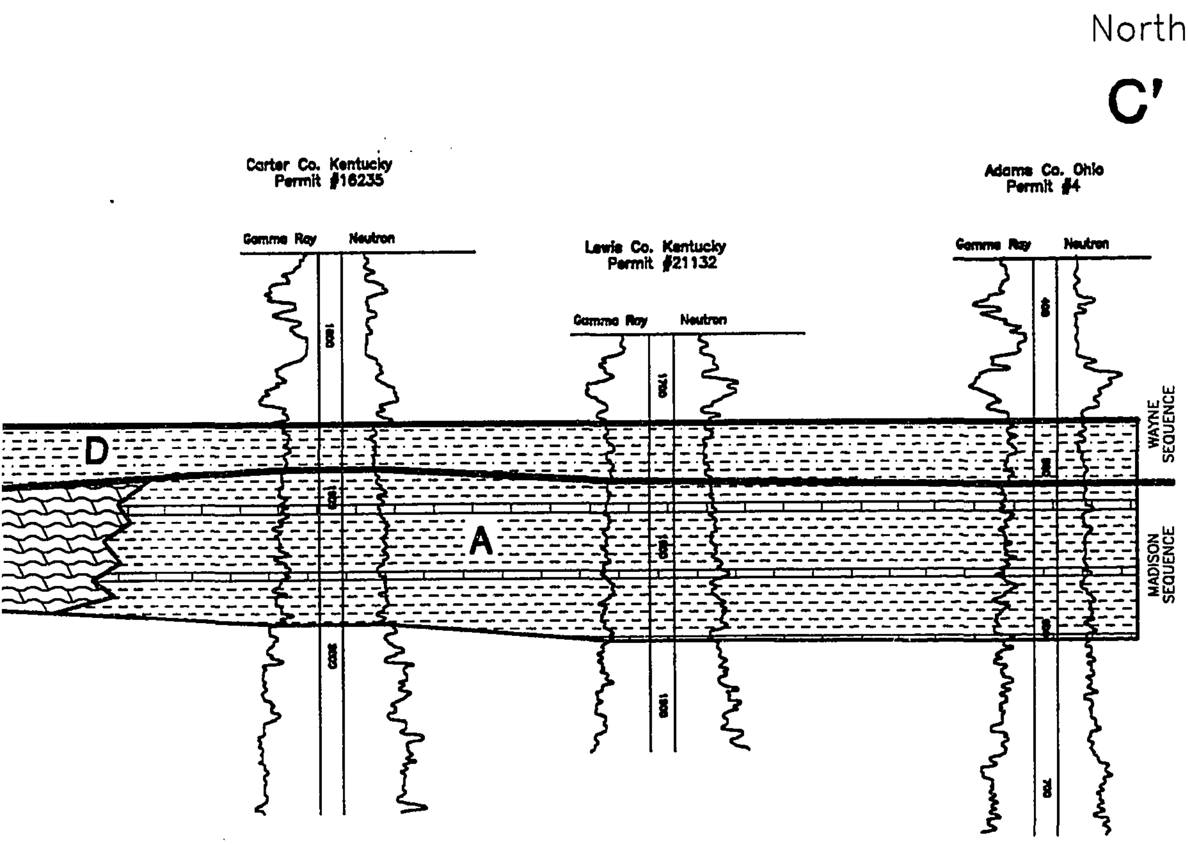


FIGURE 19

South to North Cross Section East of the Cincinnati Arch Section C - C'



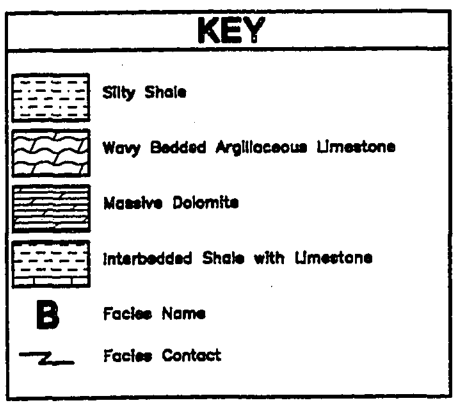


FIGURE 19

South to North Cross Section
East of the Cincinnati Arch
Section C - C'

South

C'

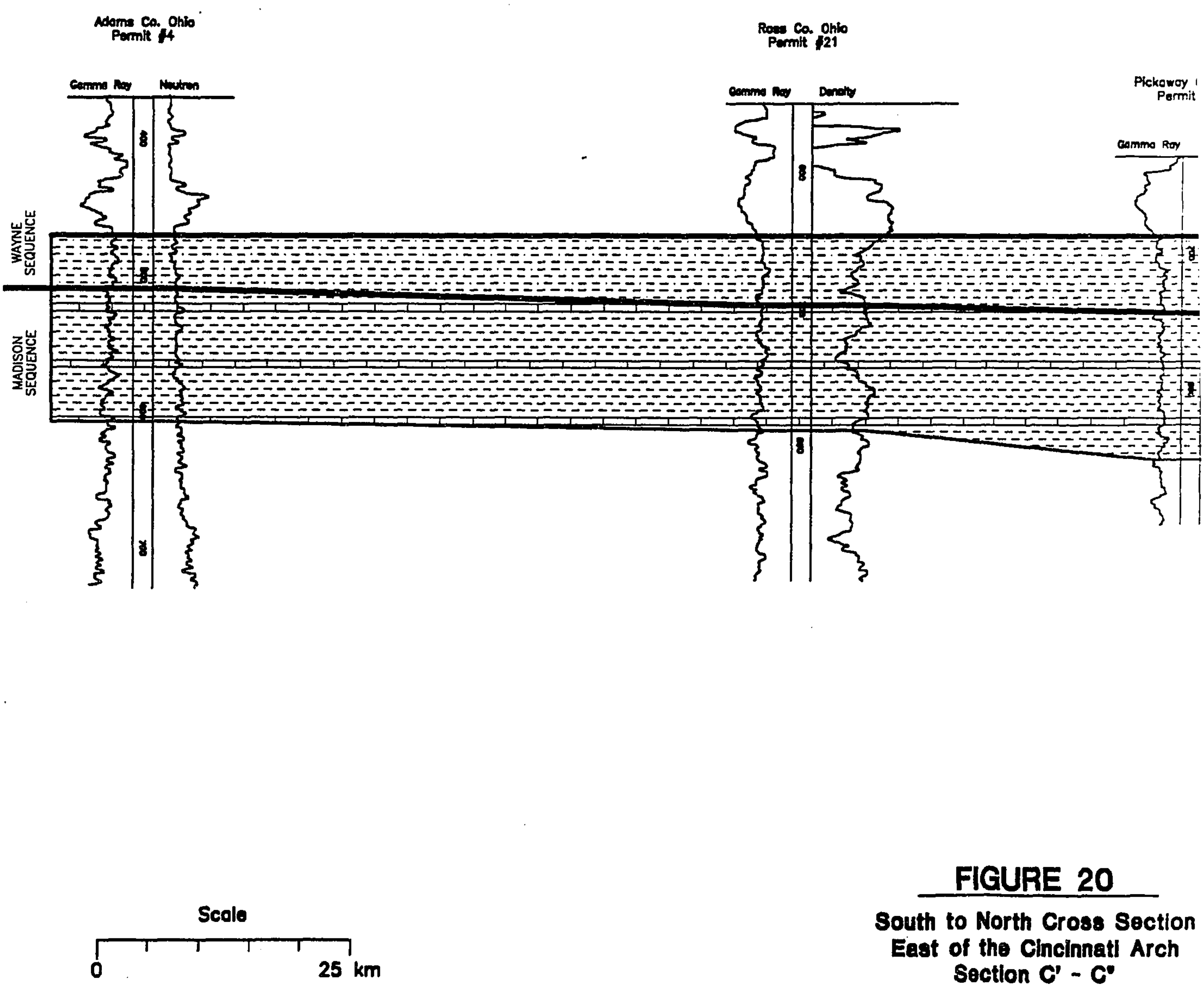


FIGURE 20

South to North Cross Section East of the Cincinnati Arch Section C' - C"

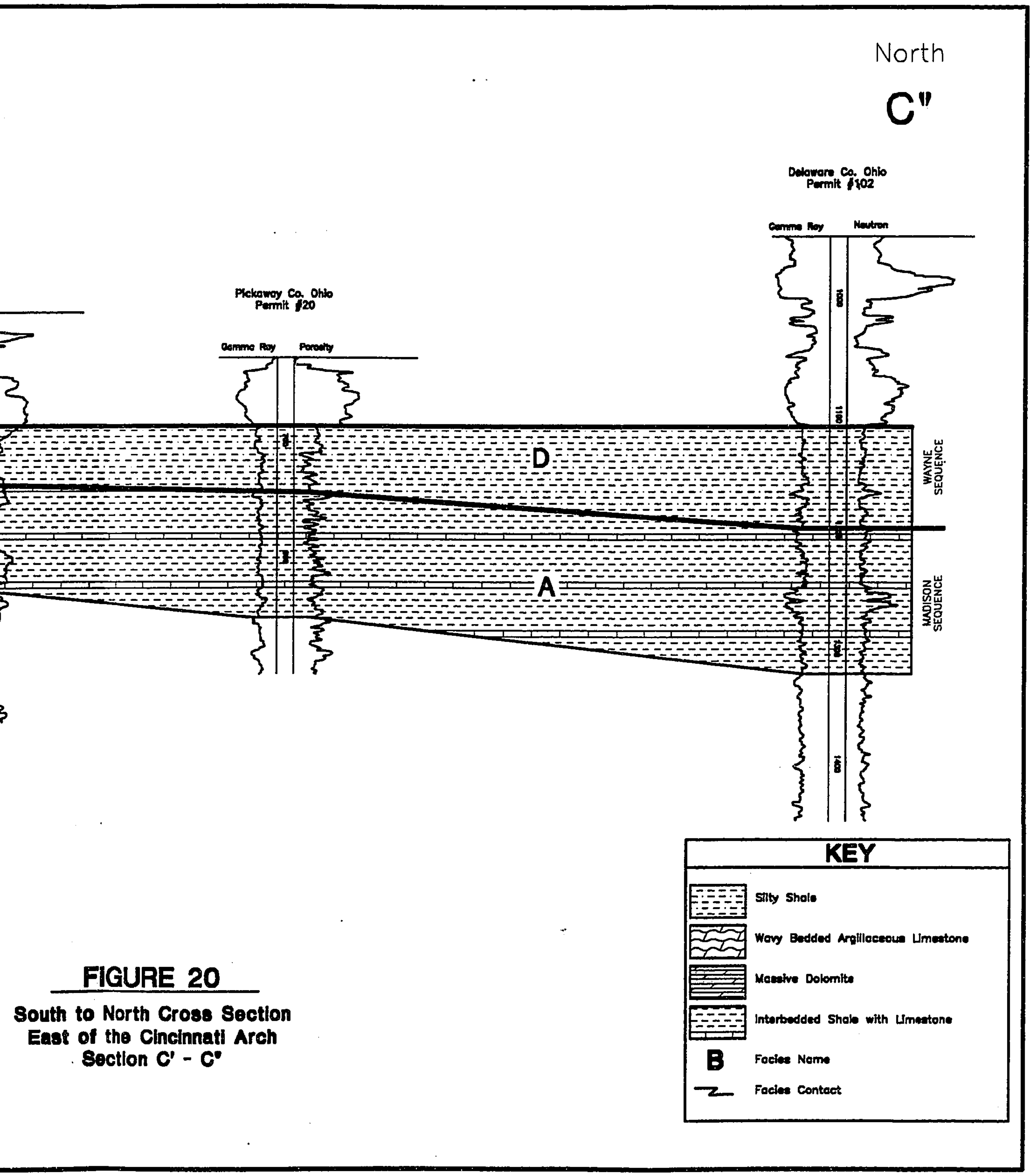
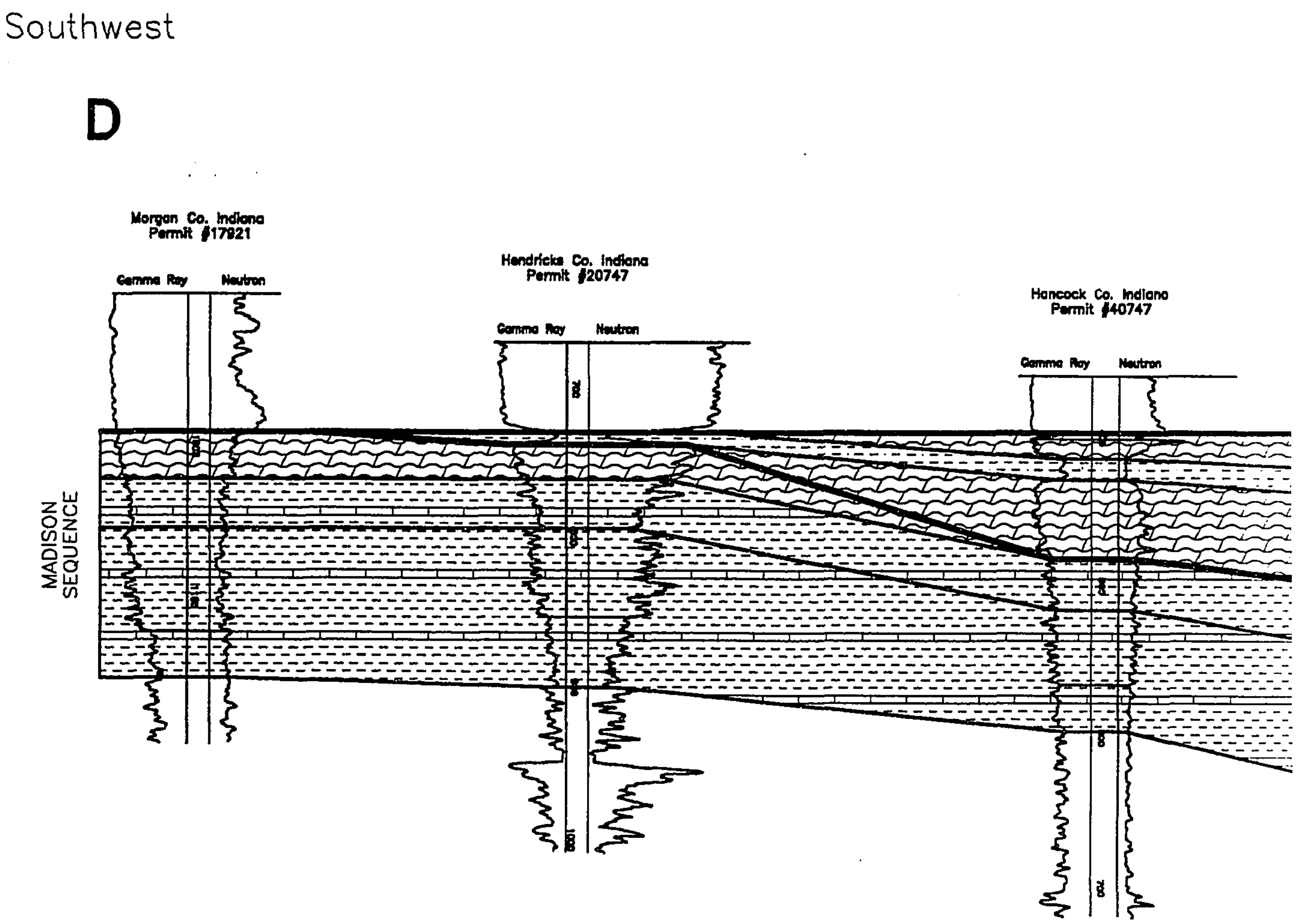


FIGURE 20

South to North Cross Section East of the Cincinnati Arch Section C' - C"



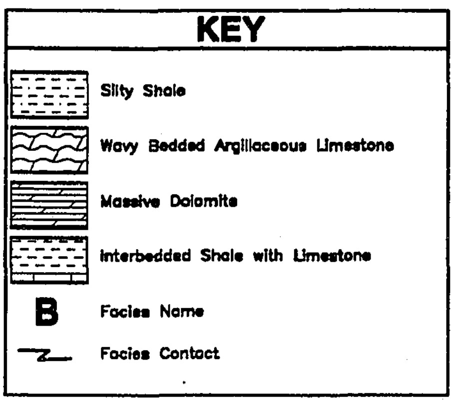


FIGURE 21

Southwest To Northeast Cross S
West of Cincinnati Arch
South of Indianapolis
Section D - D'

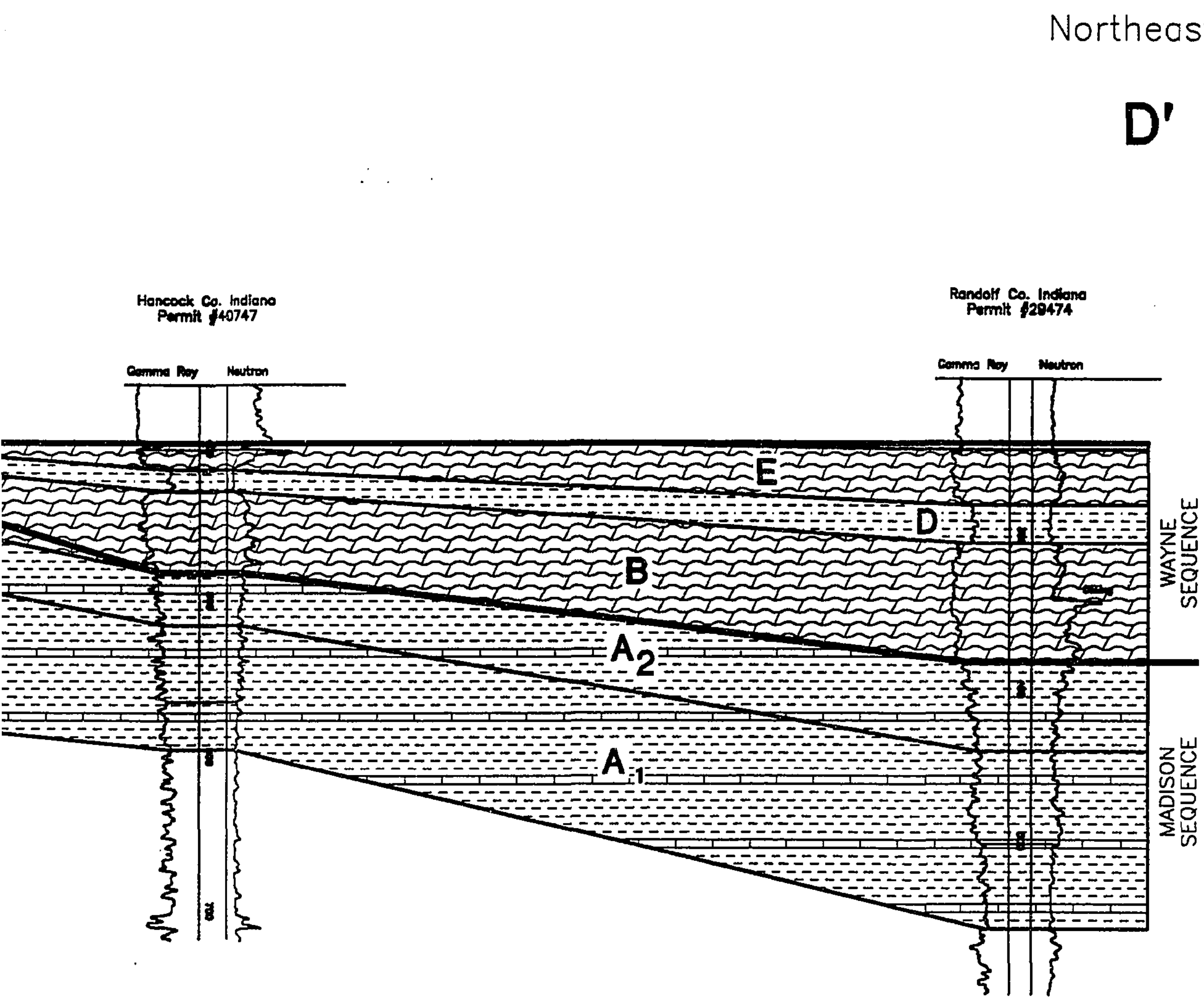


FIGURE 21

Southwest To Northeast Cross Section
West of Cincinnati Arch
South of Indianapolis
Section D - D'

Scale

0 25 km

A west to east cross section in central Indiana, which is shown on Figure 21, illustrates the complexity of lithologic variations in facies at the top of the section toward the western edge of the tristate region. Because these strata are furthest from clastic influx to the east, the facies become more carbonate-rich and are more difficult to correlate. Because cores in the western edge of the field area were not available for examination, further interpretations are difficult.

After a detailed examination of outcrop, core, and geophysical log data, a depositional environment was assigned to each facies based on the paleontologic and sedimentologic data collected during this and previous studies. Facies A through F were assigned to the following depositional regimes and stratigraphic sequences in alphabetical order:

- Facies A: Mixed clastic/carbonate intracratonic ramp - distal facies (first sequence - initial flooding and *highstand systems tract*);
- Facies B: Mixed carbonate/clastic intracratonic ramp - proximal facies (first sequence - *highstand systems tract*);

- Facies C: Mixed carbonate/clastic intracratonic ramp - shallow subtidal to supratidal deposition (first sequence - *highstand systems tract* and second sequence - *lowstand systems tract*);
- Facies D: Distal clastic wedge (second sequence - *lowstand -systems tract*);
- Facies E: Mixed carbonate/clastic intracratonic ramp - proximal facies (second sequence - *transgressive systems tract*); and
- Facies F: Mixed carbonate/clastic intracratonic ramp - shallow subtidal to supratidal facies (unknown but possible second sequence *transgressive systems tract*).

The paleontologic and sedimentologic characteristics of each facies are summarized on Table 4. Facies C is grouped into two sequences based on its initial development as an *HST* and later progradation to a *LST*. The first and second sequences were delineated by stratal stacking patterns as discussed in Section 11.

Table 4
Lithologic and Palentologic Summary of Facies

Facies	Bedding/Lithology	Distinguishing Sedimentary Structures	Distinguishing Paleontology	Trace Fossils	Depositional Regime
A	Abundant shales, with thin, planar-bedded wackestones, packstones, and grainstones.	Gutter casts Graded beds	Small fragile fossils, such as trilobites and branching bryozoans, well preserved.	*Skolithos* *Cruziana*	Mixed carbonate/clastic ramp offshore
B	Wavy- to nodular-bedded wackestones, packstones and grainstones , with lesser amounts of shales.	Irregular bedding Carbonates	Robust fossils and corals. Fossils are abraded and/or bored.	Trace fossils not commonly pre dominant but *Skolithos* and *cruziana* present.	Mixed cratonic shelf to subtidal deep
C	Banded dolomudstones	Desication cracks, ripple cross laminations, birds eye structures, intra clasts, occluded trace fossils	Less fossiliferous, most prominent fossils are colonial corals.	*Skolithos*	Mixed upper subtial to supratidal
D	Dolomitic claystones with siltstones with occasional wackestones and packstones.	Laminated, occasional purple variegated shales, and cross bedded to cross-laminated siltstones , desication cracks.	Generally unfossiliferous with occasional abundant trilobite and ostracods.	Trace fossils not well preserved.	Distal clastic wedge
E	Wavy- to nodular-bedded grainstones, wackestones and packstones.	Irregular bedding and abundance of carbonates	Abundant robust fossils including abundant brachiopods, bryozoans and stromotoporoids.	Burrow mottled	Cratonic shelf to subtidal
F	Banded dolomudstones	Algal laminites	Generally unfossiliferous	Burrow mottled	Shallow subtidal to supratidal

5.0 FACIES A: INTERBEDDED, PLANAR TO LENTICULAR SHALES AND CARBONATES

The first sequence is a prograding intracratonic ramp characterized by the presence of Facies A, B, and C. These facies are interpreted to represent distal, proximal and shallow subtidal to supratidal intracratonic deposition , respectively. This prograding intracratonic ramp is similar to the mixed carbonate-clastic, shoaling-upward cycle described by Tobin (1982) and is roughly equivalent to the C_4 sequence of Holland (1993). In this study, the strata are subdivided based on sedimentologic and paleontologic characteristics that are recognizable in outcrop and their resulting lithologic characteristics, most of which are discernable in geophysical logs. This division de-emphasizes the transitional nature of the facies and small differences in lithologic or paleontologic character while emphasizing gross similarities and differences in the strata.

Facies A is the lowermost unit encountered in this study. It overlies a mixed carbonate-clastic distal facies that is characterized by its increased carbonate content, more irregular bedding, and greater abundance of robust fossils.

Tobin (1982) and Holland (1993) recognize the base of Facies A as a flooding surface reflected by the increase in shale content, the change of the fauna to deeper water fauna, and the presence of distal storm beds. This study recognizes this surface as a regional flooding surface and as a regional unconformity. Layers of oxidized fossil hash are present immediately below 299 feet in Core SDH #332 and 268 feet in Core SDH #124 in southeastern Indiana. Immediately above these two intervals is an intensely bioturbated zone. In addition, a quartz pebble conglomerate in the Butler County Core DGS #2981 was shown to me by Doug Shrake of the Ohio Geological Survey. This surface was not observed in other cores in Ohio because of the increase of shale influx to the east combined with deeper water levels.

5.1 Sedimentologic and Paleontologic Characteristics

In general, Facies A is characterized by:

- A relative abundance of shales;
- Continuous, planar-bedded, thin wackestone, packstone,

and grainstone beds separated by equally thick and often thicker beds of shales;

- Small, fragile fossils such as trilobites and branching bryozoan colonies that are usually well preserved and show little abrasion, boring, and encrustation; and
- Trace fossils indicative of episodic storm deposition such as escape burrows of the *Skolithos* trace fossil assemblage, and indicative of quieter water deposition, such as those found in the *Cruziana* trace fossil assemblage.

This facies is best observed in outcrops in East Central Indiana and southwest Ohio.

Based on the outcrop and core descriptions included in Appendices A and B, Facies A is composed predominantly of shales that range in color from dusky yellow green (5GY 5/2) to grayish olive (10Y 4/2). Many of the shales are extremely fossiliferous, although some may be non-fossiliferous. *Skolithos* and other trace fossils are common in many of the shales. The shales are interbedded with planar- to lenticular-bedded, medium to dark gray wackestones, packstones, and grainstones that are composed of abraded and/or whole fossil fragments. Intervals of nodular- bedded wackestones and packstones are common near the top of Facies A. The bedding thickness of the carbonates ranges from less than a centimeter to over 10 centimeters. The number of limestone beds, and the thickness of limestone beds increases toward the top of the facies in the cores examined. Many of the limestone beds were graded with *Chondrites* trace fossils occurring at the top of the beds and *Skolithos* trace fossils filled with shale common through the entire bed near the top of Facies A at the Camden outcrop. Symmetrical ripples and clay-pebble conglomerates are present in the Burnt Cabin Road outcrop and imbricate brachiopods were observed in several beds of core SDH #57. Other features reported by Tobin (1982) include gutter casts, asymmetric ripples and tool marks.

Undifferentiated Facies A was described at the Burnt Cabin Road and Madison outcrops which are illustrated on the photographs included in Figure 22. In addition, well preserved branching bryozoan fronds were observed in carbonate beds from the Burnt Cabin Road outcrop in Facies A (Figure 23).

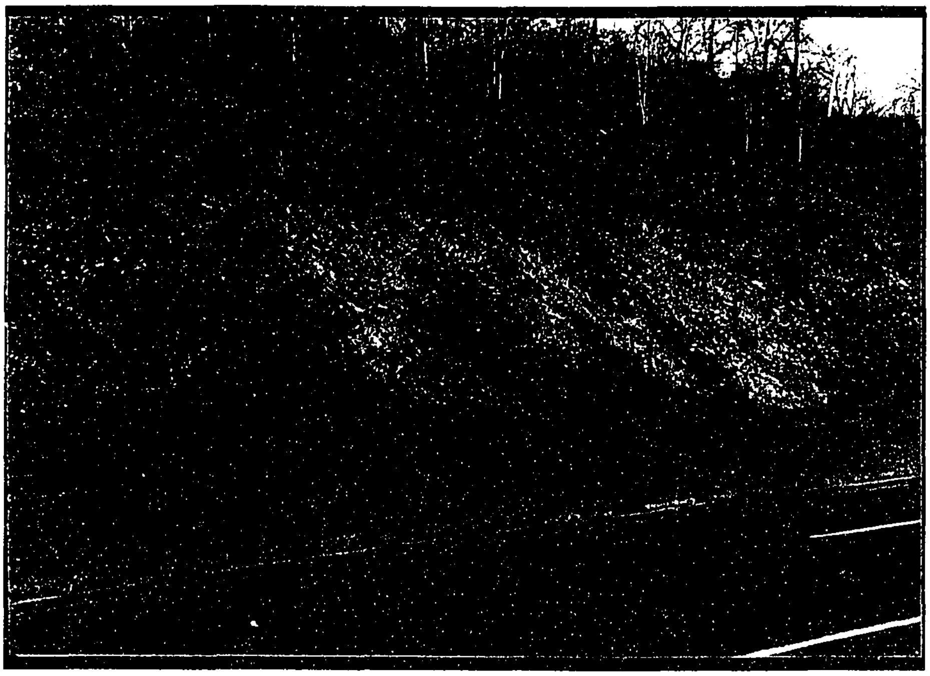


Figure 22a - South facing view of Facies A photographed at the Burnt Cabin Road Outcrop showing the shale dominated nature of the facies.

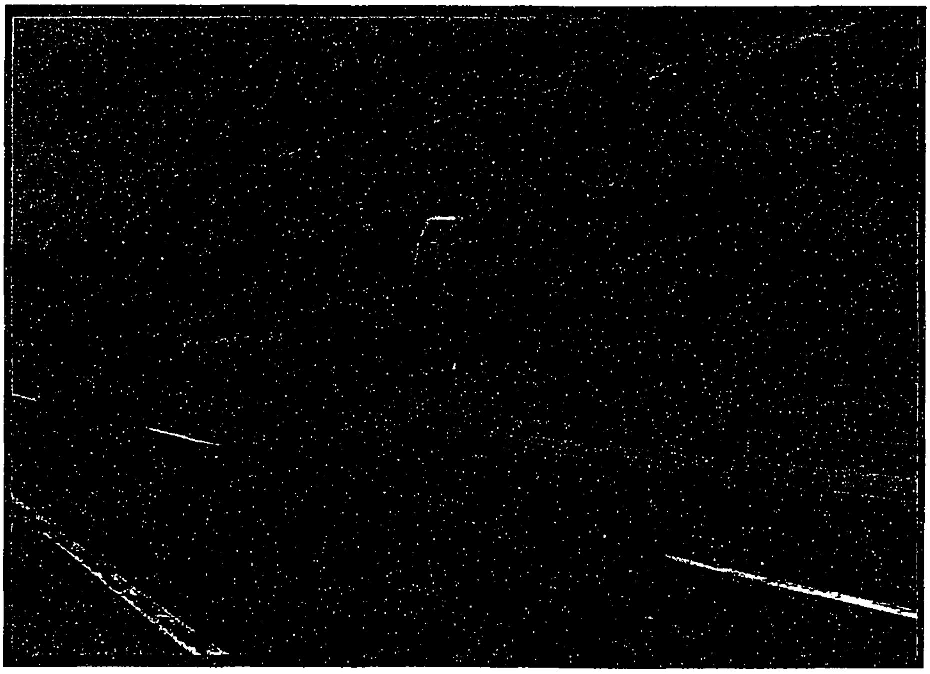


Figure 22b - East facing photograph of the Madison, Indiana outcrop showing the planar-bedded, shale dominated, Facies A.

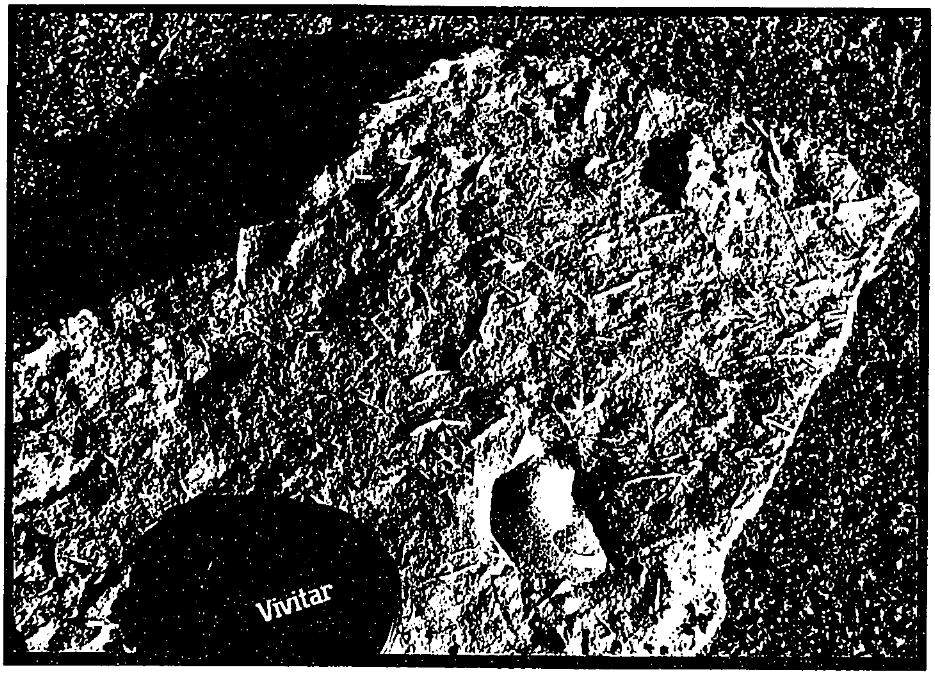


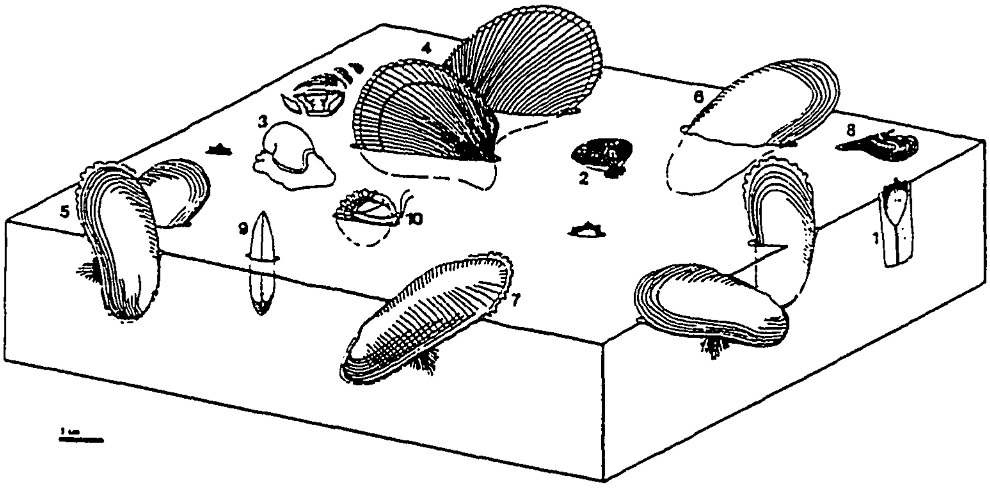
Figure 23 - Hand specimen of Facies A from the Burnt Cabin Road Outcrop showing well preserved, delicate branching bryozoans on top of a graded grainstone bed.

Many of the outcrops in the tristate region were not completely accessible at the time of this study because of slump and lose rock debris. Therefore, detailed descriptions of this facies by Tobin (1982) and Fox (1962) were also used to assess Facies A in addition to the Burnt Cabin Road and Camden outcrops and cores described in this study.

The fossils found in this facies include, but are not limited to small brachiopods (*i.e.*, *Leptaena*), thin shelled brachiopods (*i.e.*, *Onniella* and *Rafinesquina*), as well as thicker shelled brachiopods (*i.e.*, *Hebertella* and *Platystrophia*), branching bryozoans (*i.e.*, *Hallopora*), endobyssate filter feeding mollusks (*i.e.*, *Ambonychia* and *Modiolopsis*) and trilobites (*i.e.*, *Flexycalamene* and *Isotelus*) The horned coral *Grewingkia canadensis* was found in strata at the top of this facies during this research and by others including Tobin (1982) and Fox (1961). Well preserved trilobites, crinoids and bryozoans were observed in cores SDH #57, SDH #124, SDH #332 and/or the Burnt Cabin Road outcrop. According to Tobin (1982), most of the fossils in his correlative Waynesville Formation are unabraded and well preserved. In addition, studies by Frey (1983) confirmed the well-preserved nature of the fossils for some intervals in the lower part of Facies A.

Frey (1983,1987) conducted studies on the paleontology and paleoecology of a Late Ordovician molluskan fauna and noted the dominance of endobyssate and semi-infaunal, filter-feeding taxa present in the fine clastic offshore shelf facies of the Late Ordovician. A paleocommunity reconstruction assembled by Frey (1987) is shown on Figure 24. Frey's (1983) Waynesville paleocommunities represent only a small interval of the Facies A. According to Brandt (1985), the presence of the filter-feeding organisms and the relatively low organic content of the shales suggest that the bottom conditions of the offshore shales were subjected to well-oxygenated conditions.

During the research conducted by this author, Tobin (1982), and Walters (1988), trace fossils found in Facies A (or correlative Waynesville and Liberty Formations) included *Chondrites*, *Trichophycus*, *Paleophycus*, *Rusophycus*, and unnamed vertical tubes. An abundance of *Chondrites* and *Skolithos* trace fossils were present at the top of Facies A. Tobin



A reconstruction of the paleocommunity associated with the claystone lithology of the Trilobite shale unit within the Waynesville Formation (Late Ordovician, early Richmondian) exposed at the Rt. 101 roadcut at Bon Well Hill, Franklin County, Indiana. Note the abundance of large, endobyssate filter-feeding pelecypods. Pelecypods present include 4) the ambonychiid *Ambonychia suberecta*; 5) the modiomorphid *Corallidomus versaillesensis*; 6) the modiomorphid *Modiolopsis valida*; 7) the modiomorphid *Pholadomorpha pholadiformis*; 8) the pterineid *Cantodens demissa*; and 9) the anomalodesmatid *Rhytimya* cf. *R. byrnesi*. Other elements of the fauna include linguloid and trematid inarticulate brachiopods (1, 2), a monoplacophoran (3), and a calymenid trilobite (10). Refer to Table 2 for the mode of life of these pelecypod taxa and Appendix ID for a complete list of taxa present.

SOURCE: Frey, 1987.

Figure 24

Paleocommunity Reconstruction Of Facies A

(1982) and the information derived from this study, indicate that the base of Facies A is characterized by trace fossils from the *Cruziana* assemblage while the top is characterized by trace fossils from *Cruziana* and *Skolithos* assemblages.

Based on the overall abundance of shale, the well-preserved, small, fragile fossils, and the excellent preservation of sedimentary layers and trace fossils, Facies A was deposited in a relatively low energy depositional environment. The lack of features indicating subaerial exposure, such as occluded trace fossils and algal laminates in the carbonate beds, preclude assignment to a lagoonal or other restricted shallow water environment. Thus, a low-energy distal intracratonic ramp is postulated for this facies. Although, the exact depth of the ramp is unclear, the general characteristics of the fossils and sediments suggest a deposition below the storm wavebase. The abundance of *Chondrites* trace fossils at the base of this facies is interpreted to represent initial flooding. According to Tobin (1982), the switch of trace fossil assemblages from a dominant *Cruziana* assemblage at the base of this facies, to a mixed *Cruziana*/*Skolithos* assemblage at the top of this facies, represents an increase in wave energy that signifies a decrease in water depth.

Extensive work by Tobin (1982) and Jennette and Pryor (1993) has demonstrated that the laterally extensive, even-bedded carbonates and shales with silt-filled gutter casts and graded carbonate beds are often indicative of episodic storm deposition. This author and Tobin (1982) believe that the gutter casts, and laterally extensive graded packstones and grainstones of Facies A represent distal storm deposition.

The cratonic shelf facies is approximately equivalent to Tobin's (1982) offshore shelf and transition zone. Tobin's (1982) description of the Brookville Dam Spillway and Fox's (1962) description of the Tanners Creek sections provide excellent detailed sedimentologic and paleontologic descriptions of this facies. Detailed description of cores SDH #57, #124 and #332 are included in Appendix B.

Facies A is further subdivided into Subfacies A_1 and A_2 based on variations in the lithologic, paleontologic, and geophysical log response characteristics in the northern portion of the study area. Subfacies A_1 and A_2 are grouped together under Facies A for the following reasons:

- Their similar sedimentologic and paleontologic character,
- The subfacies are difficult to distinguish in some areas, and
- To permit a comparison of thicknesses of similar strata in places where the facies are too thin or difficult to differentiate.

Subfacies A_1 is distinguishable from Subfacies A_2, especially in cores SDH #124 and #332 because it generally contains more packstone carbonate beds; thinner carbonate beds; thicker shales; the least amount of abrasion, boring, and encrustation of fossils; only the *Cruziana* trace fossil assemblage; and more fragile fossils. The well-preserved crinoids and trilobites present in Wayne County Core SDH #57 are typical of Facies A fossils. Figure 25 contains photographs taken at the base of Facies A_1 from SDH #57 and #124 which show the transition from nodular-bedded limestones to even-bedded shales. The most similar lithostratigraphic facies for the distal shelf subfacies is the Waynesville Formation as described by Tobin (1982). This facies is best differentiated in east-central Indiana, although it is also found in southwestern Ohio.

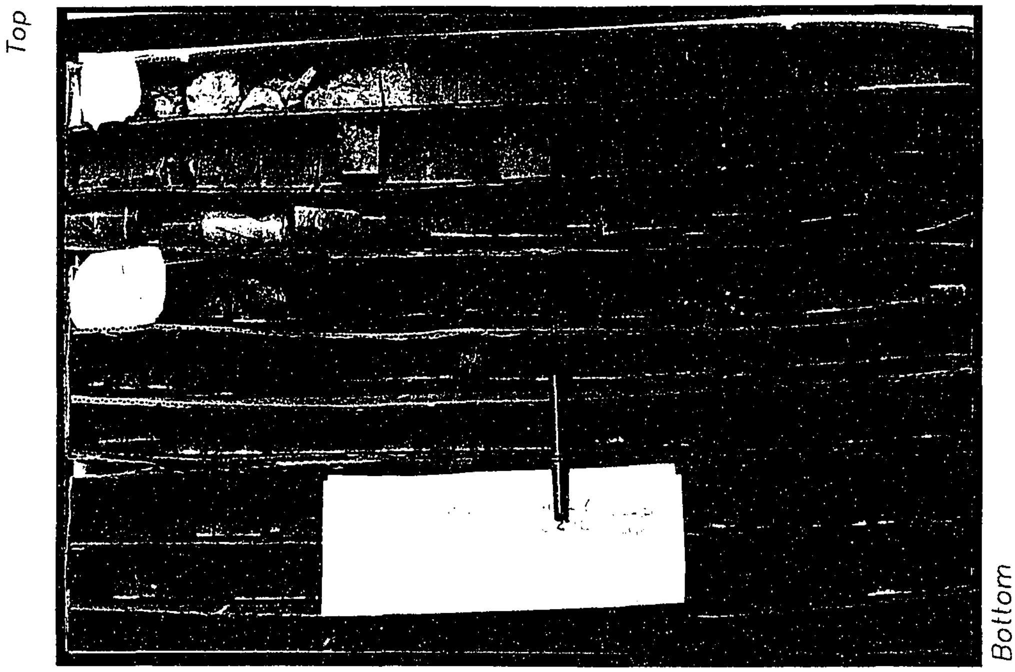


Figure 25a - Base of Facies A1 in Decatur County Core SDH #124, contact is at tip of pin. The even bedded shale-dominated strata on the lower left are extremely burrowed, while the underlying Arnheim Formation on the right is carbonate-dominated and irregular-bedded. Note: the arrow actually points to increasing depths and the fossil hash is not recorded by the photograph.

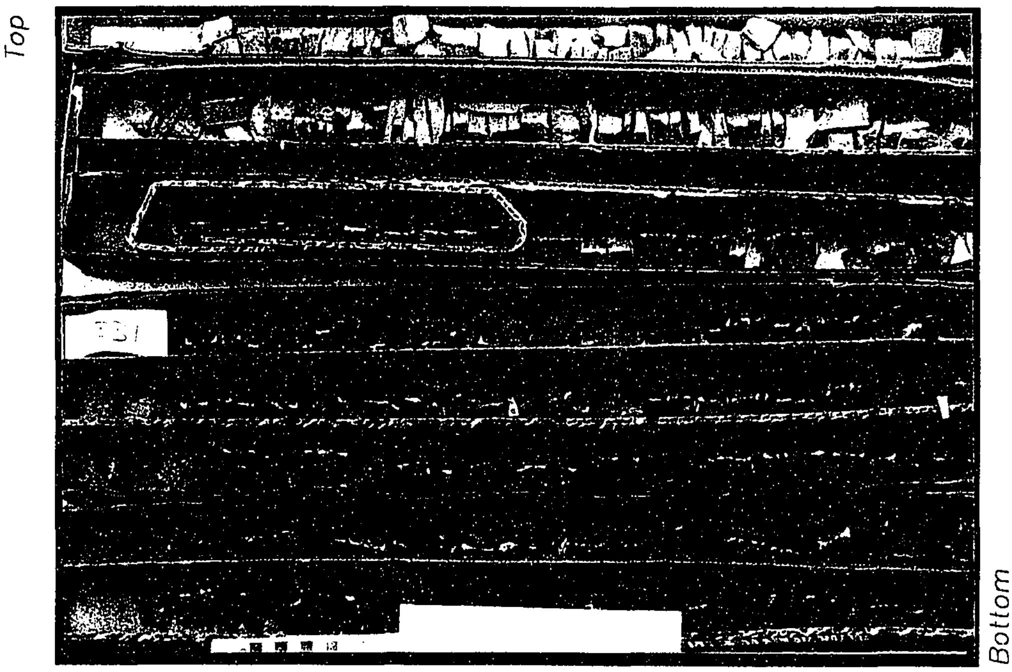


Figure 25b - Base of Facies A1 in Wayne County Core SDH #57 again documenting the planar bedded, highly burrowed, shale-dominated, strata overlying the irregular-bedded, carbonate-enriched Arnheim Formation.

According to Tobin (1982), fossils found in his correlative Waynesville Formation include small, thin brachiopods such as *Rafinesquina* and *Onniella* at the base, as well as, larger, more robust brachiopods such as *Hebertella* and *Platystrophia* at the top. The endobyssate mollusks *Ambonychia* and *Modiolopsis* are prevalent in many intervals and small, delicate, branching bryozoans are common. For the most part, these fossils are generally unabraded, not encrusted and well preserved.

Trace fossils in this subfacies found by Tobin (1982) and in this study include *Chondrites*, *Trichophycus*, *Paleophycus*, and *Rusophycus*. These trace fossils are commonly assigned to the *Cruziana* trace fossil assemblage and are representative of quieter water deposition (Tobin, 1982).

The Subfacies A_2 is distinguished from the Subfacies A_1 by containing more grainstone carbonate beds; thicker carbonate beds; thinner shale layers; slightly increased abrasion, boring, and encrustation of fossils; and the presence of *Skolithos* fossils. The generally even-bedded nature of Subfacies A_2 compared to Facies B and the abundant *Skolithos*

Facies A_2 in the Camden outcrop are shown on the photographs included as Figure 26. Some wavy-bedded intervals are present near the top of Facies A_2. The most representative lithostratigraphic facies for Subfacies A_2 is the Liberty Formation as defined by Tobin (1982). The lithostratigraphic nomenclature defined by various authors and the corresponding facies equivalent assigned by this author are indicated in Figure 5.

Fossils found in Subfacies A_2 are similar to those observed in Subfacies A_1 with the following notable exceptions: the horned coral *Grewingkia canadensis* and the brachiopod *Glyptorthis* was commonly reported by Tobin (1982). Frey (1987) assigned fossils from the Liberty Formation to the skeletal carbonate assemblage, which is dominated by diverse articulate brachiopods and trepostome bryozoan faunas. According to Frey (1987), the communities are most prevalent in the Maysvillian assemblages but also occur in the Whitewater Formation assemblages (correlative to Facies B). The results of this study show that Subfacies A_2 is transitional to the carbonate shoreface facies and contains fossil assemblages common to both the offshore facies and nearshore facies.

Figure 26a - Photograph of Camden Outcrop showing the planar- to wavy-bedded top of Facies A2, overlain by the wavy- to nodular-bedded Facies B. The contact is near the top of the photograph.

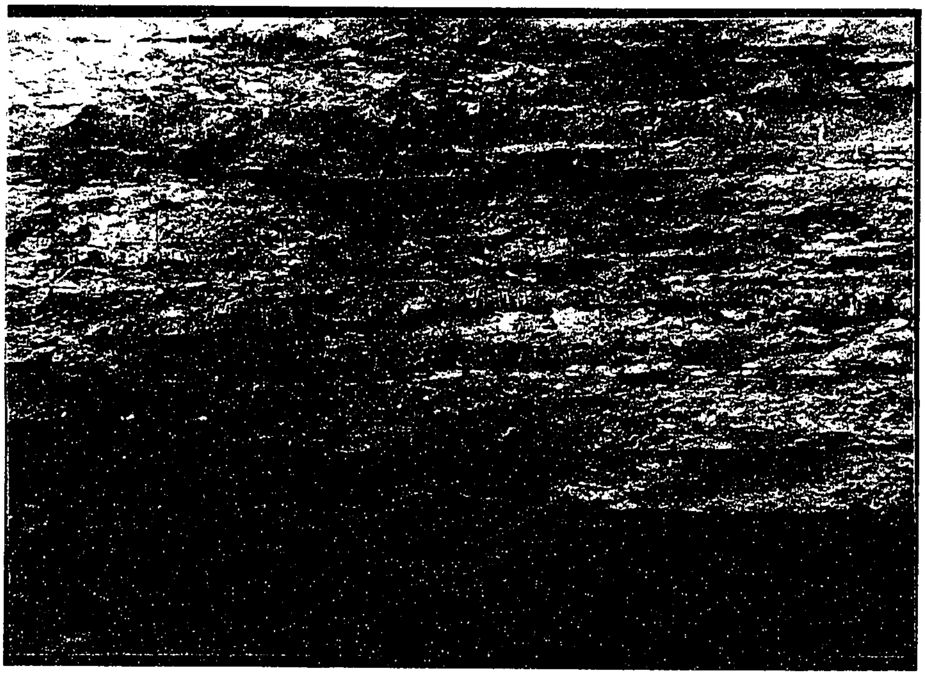


Figure 26b - Closeup of Camden outcrop showing Skolithos burrows up to 5 cm in length and wavy bedding near the top of Facies A2.

The trace fossil assemblage in Subfacies A_2 is similar to that of Subfacies A_1 except for the abundance of *Skolithos* and *Diplocraterion* trace fossils at the top of Facies A_2 as documented at the Camden outcrop (Appendix A). The trace fossil assemblage is representative of a mixed *Skolithos/Cruziana* assemblage.

Subfacies A_1 represents distal intracratonic ramp deposition while Subfacies A_2 represents medial intracratonic ramp deposition and is transitional with the proximal intracratonic ramp facies. This assessment was based upon the following data:

- The sedimentologic character of distal ramp deposits influenced by episodic storms should contain thinner carbonate beds and thicker shales than proximal deposits owing to the decrease in energy of a storm deposit away from the shoreline (Jennette and Pryor, 1993);
- The *Cruziana* trace fossil assemblage of Subfacies A_1 is representative of deeper, quieter water deposition than the mixed *Skolithos/Cruziana* trace fossil assemblage of Subfacies A_2, which is more likely to represent higher energy (thus, shallower water) environments;

- The increase in carbonate content and corresponding decrease in shale content from Subfacies A_1 to A_2 is representative of increasing energy and shallower water; and
- The presence of the horn coral *Grewingkia canadensis* and other fauna prevalent in the carbonate-rich, nearshore environments whether transported or *in situ* is indicative of the close proximity of Subfacies A_2 to shallower water environments.

5.2 Geophysical Log Correlation

Facies A is recognized in geophysical logs by having a high gamma ray deflection, a low neutron density deflection and few limestone "kicks" (See Figures 10 through 13). The lithologic character of the facies corresponds to the geophysical character on the log in that the facies has a high gamma ray deflection with few limestone "kicks" indicative of a shale sequence with few limestone interbeds. In general, Facies A is the first thick shale sequence beneath the Ordovician-Silurian contact in east-central Indiana and western Kentucky and is the second thick shale sequence beneath the Ordovician-

Silurian contact (the Elkhorn being the first shale) in southwestern Ohio. Its interpretation in geophysical logs from eastern Kentucky is based on lateral correlations.

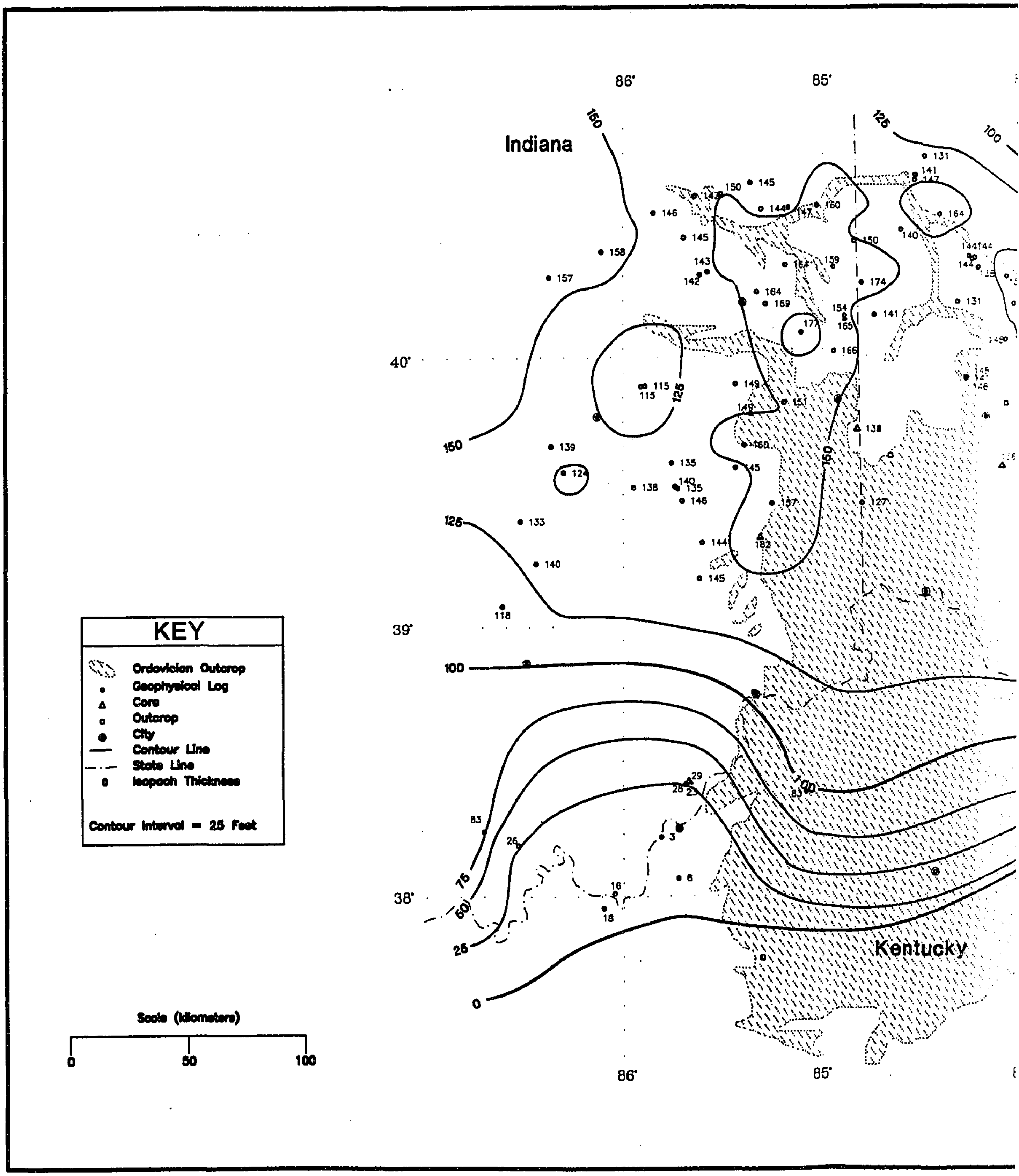
Because of the lithologic similarities and a lack of available core and outcrop data, correlations at the extreme eastern margin of the study area are made somewhat tenuously. On the eastern edge of the tristate region, the clastic Facies D, which is also shale dominated, has a similar geophysical signature and overlies Facies A. The signature differs slightly in that Facies A contains more limestone "kicks" and has a slightly lower gamma ray deflection than the overlying Facies D. In addition, the strata underlying Facies A in this area is of a similar lithologic character. This contact was picked by looking for key limestone beds from known picks on geophysical log's with associated cores.

According to geophysical log data, the thickness of Facies A corresponds to the thicknesses observed in nearby cores and outcrops. For example Tobin's (1982) measured thickness of Facies A (*i.e.* the Waynesville and Liberty Formations) at the Brookville Dam Spillway is approximately 150 feet (46 meters) thick and the thickness derived from geophysical logs and cores obtained Wayne County, Indiana range from 144 to 151 feet (44 to 46 meters). Although Tobin (1982) does not consider the Liberty Formation to be complete at Brookville, these thickness are clearly very similar. Finally, cores with logs such as the DGS #2626 and DGS #2627 and a sand/shale log of the Core SDH #57 correlated with the suggested pick.

5.3 Thickness and Distribution

An isopach map of Facies A constructed from geophysical log correlation is shown on Figure 27. The cross hatch pattern shown on this and subsequent figures represents erosion at the crest of the Cincinnati Arch, where the facies may be missing. Facies A, which ranges in thickness from 0 to 174 feet (0 to 53 meters) is the thickest and best defined on geophysical logs in southeastern Indiana and west-central Ohio. The facies is thinnest and most difficult to correlate in north-central Kentucky because it thins southward as shown on Figures 15 and 16.

On the eastern edge of the study area, Facies A thins to the



Indiana
Kentucky
86°
85°
40°
39°
38°
150
125
100
75
50
25
0
KEY
Ordovician Outcrop
Geophysical Log
Core
Outcrop
City
Contour Line
State Line
Isopach Thickness
Contour Interval = 25 Feet
Scale (kilometers)
0
50
100

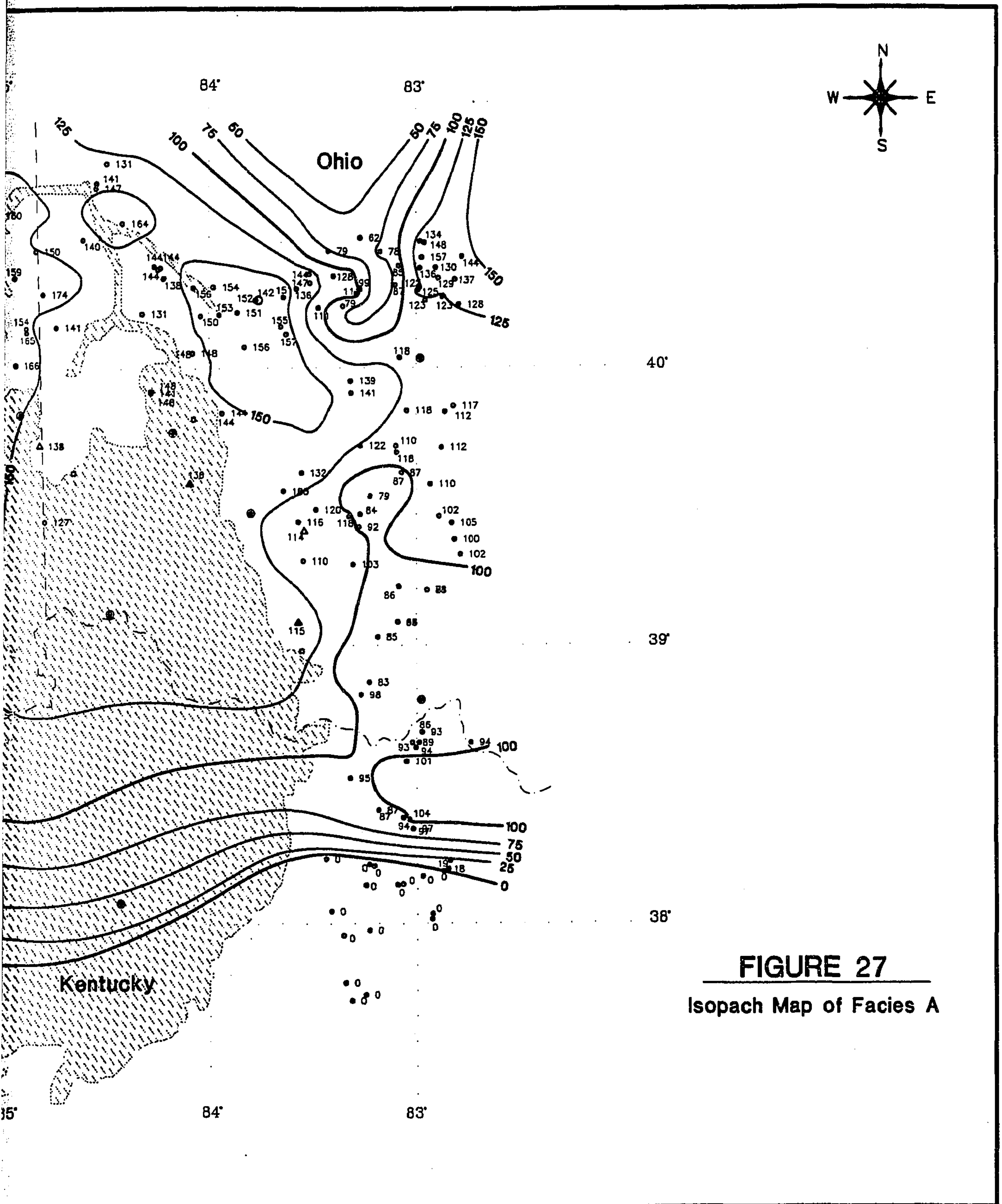


FIGURE 27

Isopach Map of Facies A

east of 83° longitude as result of a transition from the Eastern Interior Basin sedimentation to Appalachian Basin sedimentation. Although a topographic high was likely present east of the study area during deposition of Facies A, the thinning may be an artificial result owing to the difficulty of correlating this facies at the transition to the Appalachian Basin. As shown on Figure 27, the depocenter and deepest part of the basin were in central Indiana and southwestern Ohio.

5.4 Geophysical Log Correlation of Subfacies A_1

Subfacies A_1 is recognized in geophysical logs by having the highest gamma ray deflection, the lowest neutron deflection and the fewest limestone "kicks" of the cratonic shelf Facies A (Figure 11). When it is distinguishable in the geophysical log, it always occurs at the base of the cratonic shelf facies.

The high gamma ray deflections and few limestone "kicks" of Subfacies A_1 are indicative of a shale sequence with few limestone interbeds. The geophysical log response, its stratigraphic position, and its thickness correspond to the strata observed at nearby cores and outcrops. In general, it is the lowermost shale sequence in the cratonic shelf facies in east central Indiana and southwestern Ohio. For example, Tobin's (1982) measured thickness of the interbedded shales and limestones assigned to the Waynesville Formation at the Brookville Dam Spillway is approximately 116 feet (35 meters) and the thickness of Facies A_1 in the closest geophysical log (*i.e.*, The Wayne County, Indiana Permit #42617) was 103 feet (31 meters). It is likely that the difference in thickness between Tobin and this study represents a slight difference in the pick of the top of a gradational sedimentologic sequence or differences in thickness related to the distance of the outcrop to the section.

The log response of subfacies A_1 shows that the subfacies has a similar lithologic character from its base to top except for an increase in limestone content near the top in southeastern Indiana.

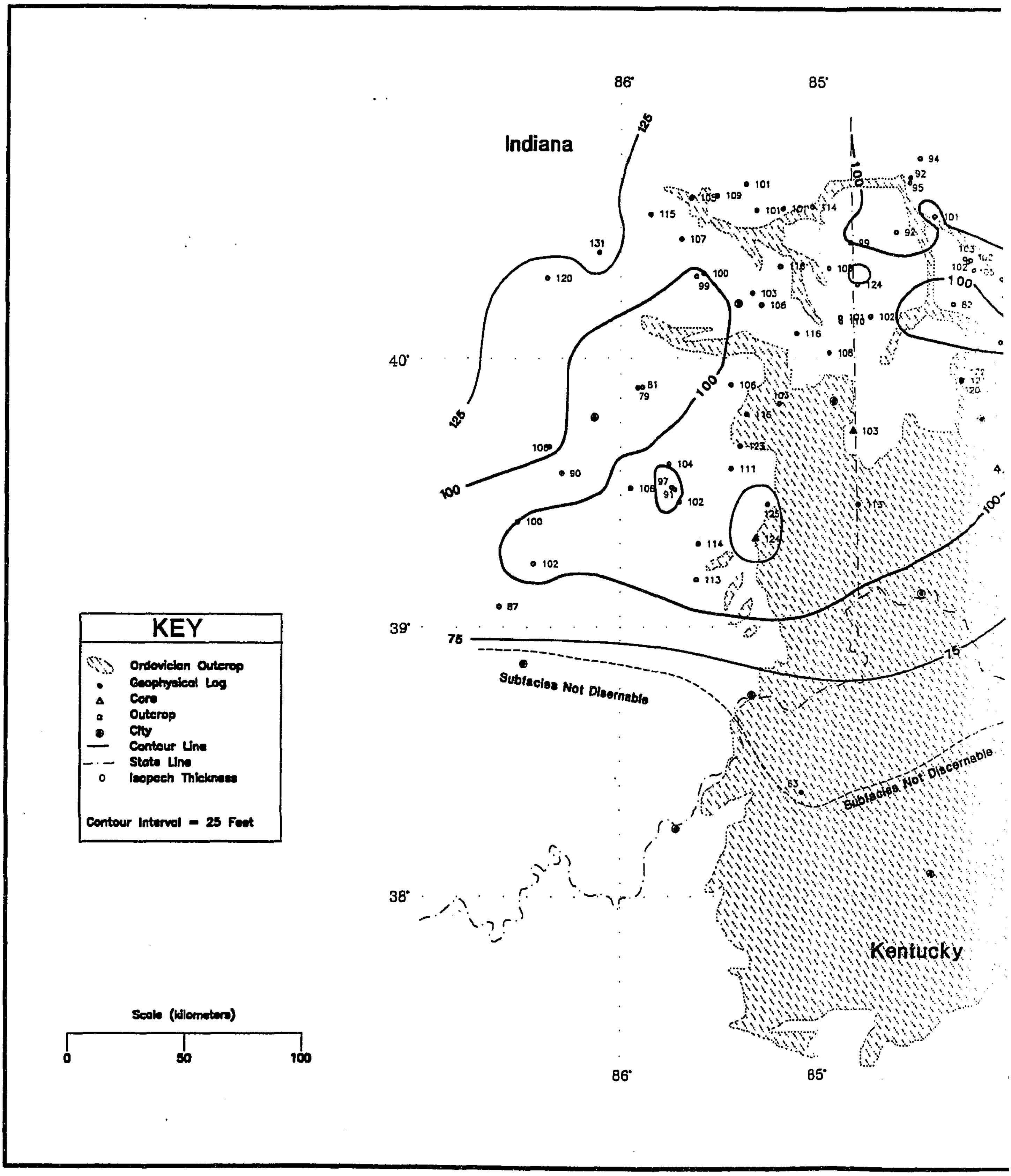
5.5 Thickness and Distribution of Subfacies A_1

As illustrated on the isopach map of the Subfacies A_1 included as Figure 28, Subfacies A_1 thins southward where it is not discernable and towards the east where the transition to the Appalachian Basin occurs and clastic facies are more difficult to distinguish. Subfacies A_1 ranges in thickness from 45 to 153 feet (14 to 46 metes) and is thickest in the center of the study area.

5.6 Geophysical Log Correlation of Subfacies A_2

Subfacies A_2 is distinguished from Subfacies A_1 in geophysical logs by having a slightly lower gamma ray deflection, a slightly higher neutron deflection, and more limestone "kicks." The overall character of the subfacies varies from the base to the top and includes a generalized decrease in gamma deflection and thicker, more numerous limestone "kicks" toward the top.

The geophysical log response is indicative of a shale sequence with limestone interbeds. The increase in the number and thickness of limestone "kicks" as well as the generally decreasing gamma ray deflection are interpreted as an increase in thickness and quantity of limestone layers and decreasing


Indiana
Kentucky
86°
85°
40°
39°
38°
125
100
75
Subfacies Not Disernable
Subfacies Not Discernable
KEY
Ordovician Outcrop
Geophysical Log
Core
Outcrop
City
Contour Line
State Line
Isopach Thickness
Contour Interval = 25 Feet
Scale (kilometers)
0
50
100

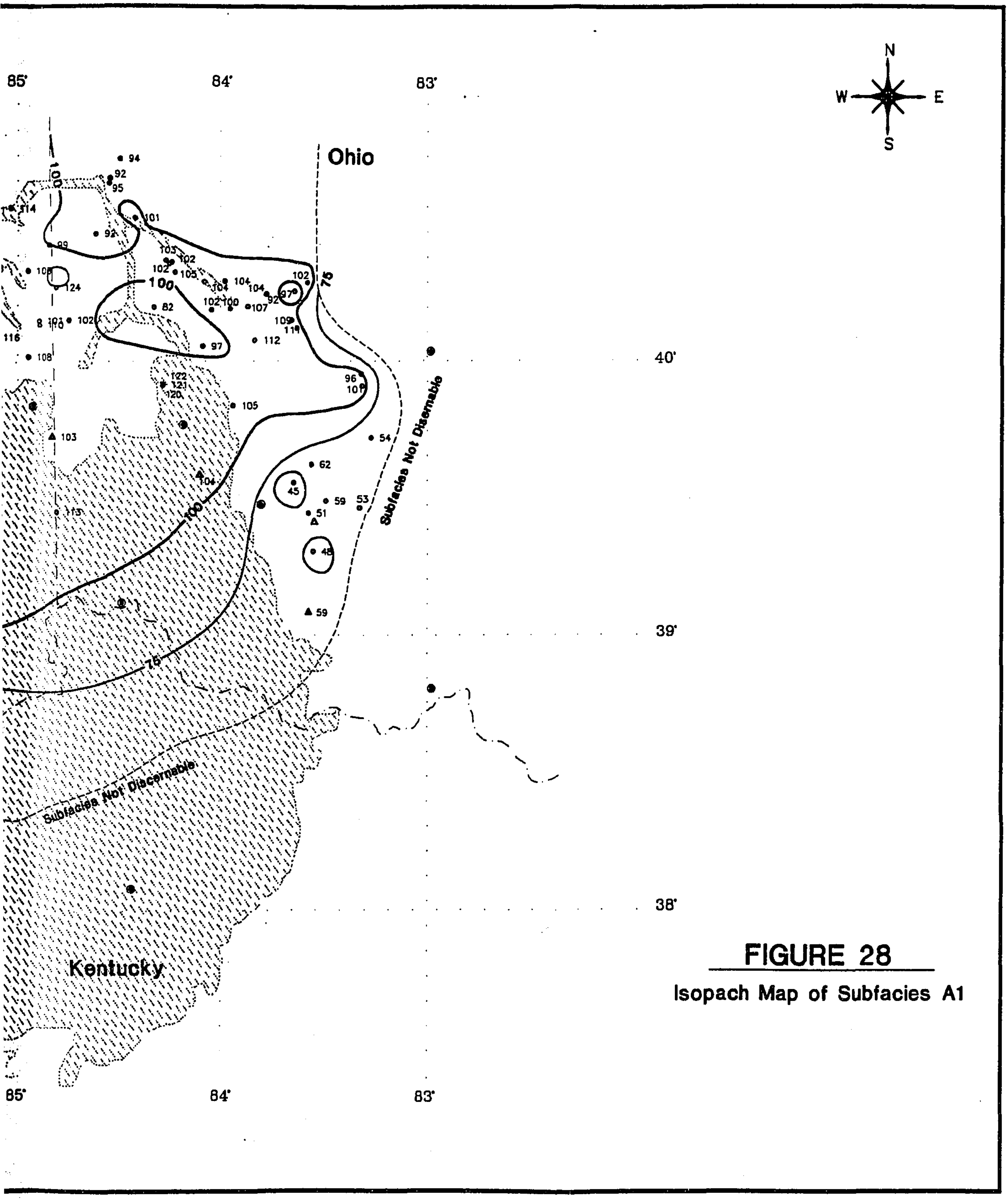
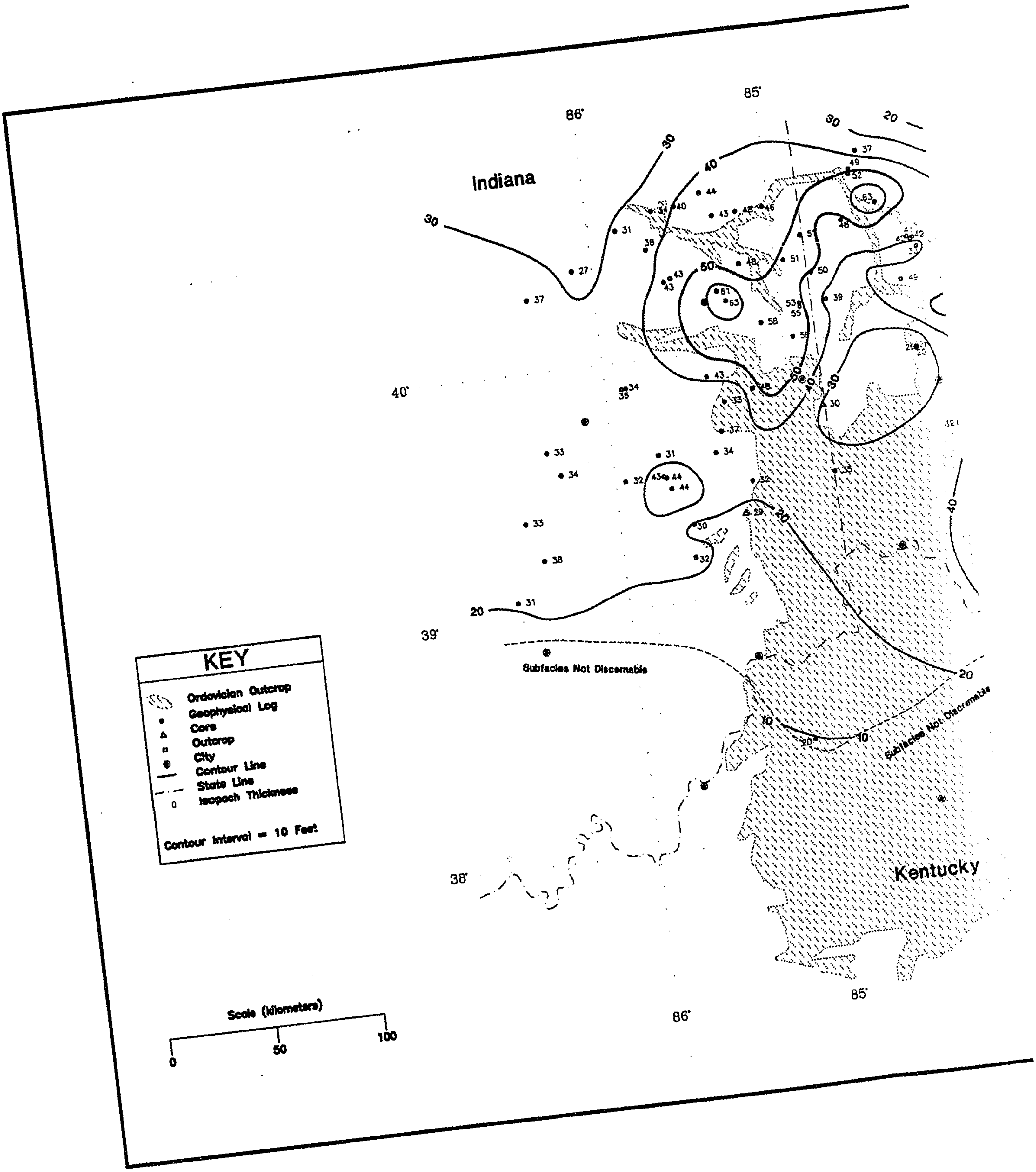


FIGURE 28

Isopach Map of Subfacies A1

5.7 Thickness and Distribution of Subfacies A_2

As shown on the isopach map of Subfacies A_2 included on Figure 29, Subfacies A_2, is limited by the Appalachian Basin to the east and the shelf-margin. Subfacies A_2, whose thickness ranges from 20 to 70 feet (6 to 21 meters), is thickest and most pronounced according to the available geophysical log data in north-central Indiana and southwestern Ohio. The thickness trends of Subfacies A_2 roughly parallels that of Subfacies A_1.


85°
86°
Indiana
40°
39°
38°
Subfacies Not Discernable
Kentucky
85°
86°
KEY
Ordovician Outcrop
Geophysical Log
Core
Outcrop
City
Contour Line
State Line
Isopach Thickness
Contour Interval = 10 Feet
Scale (kilometers)
0
50
100

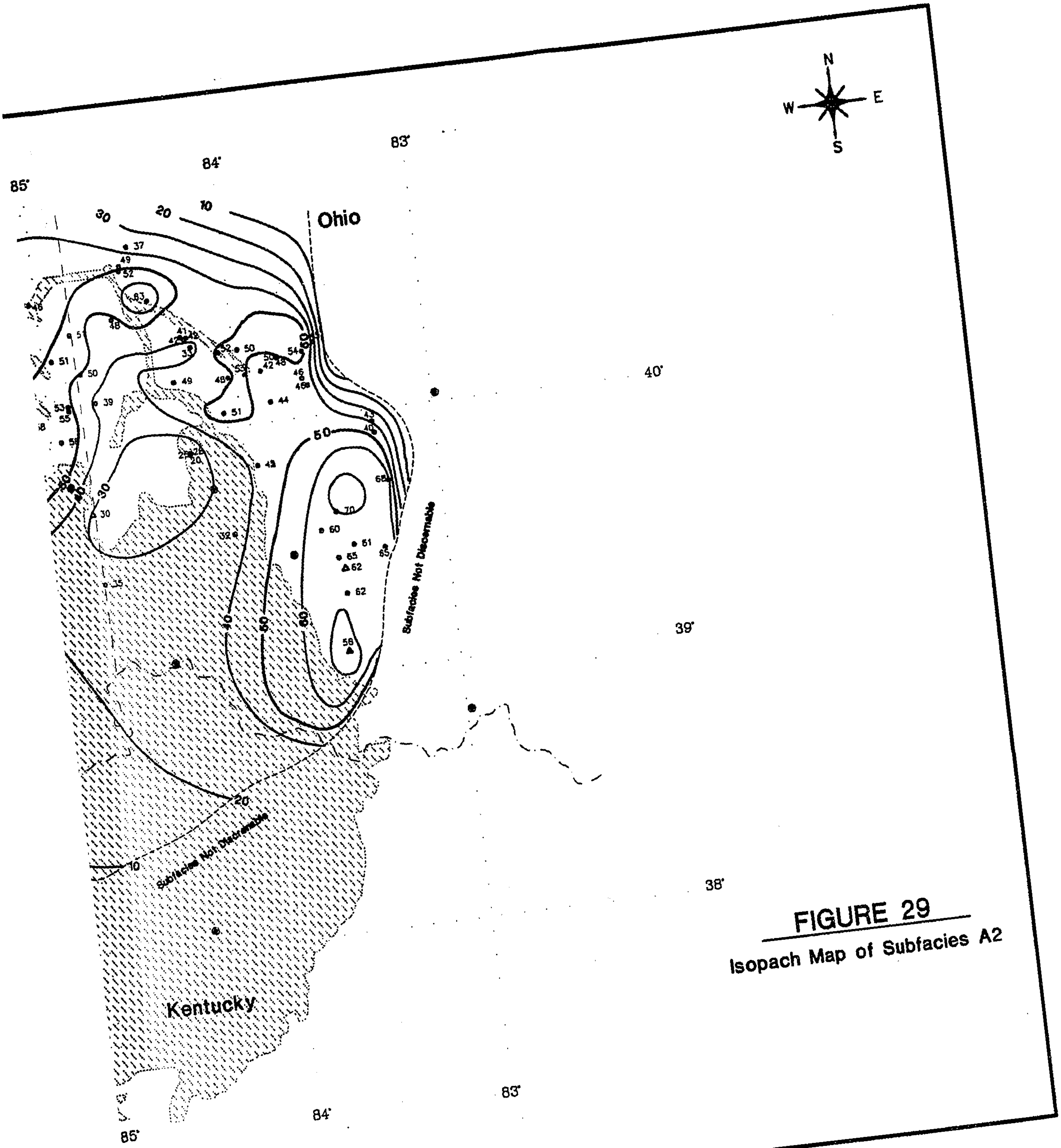


FIGURE 29

Isopach Map of Subfacies A2

bryozoan and brachiopod fragments and to a lesser extent mollusk, crinoid, and trilobite fragments. Micrite is the chief matrix component of the limestones. Based on visual estimations, the clastic content of the unit ranges from approximately 10 to 50%. Much of the shale contains an abundance of articulate brachiopods and solitary rugosan corals, as well as other skeletal remains. The wavy- to nodular-bedded nature of the limestone combined with discontinuous, skeletal-rich nature of the shales results in a distinct rubbly appearance in many of the Facies B outcrops (see Figure 30). The irregular-bedded appearance of Facies B resembles flaser bedding generally attributed to tidal sequences. In addition, the following three prominent variations were observed in Facies B:

- Bryozoan-rich, nodular-bedded wackestones interbedded with 20 - 40% shale;
- Brachiopod- and bryozoan-rich, nodular-bedded wackestones, packstones, and grainstones interbedded with 20 to 50% shale; and
- Less fossiliferous, brachiopod- and bryozoan-dominated, nodular-bedded wackestones, micstones and packstones with abundant siltstones.

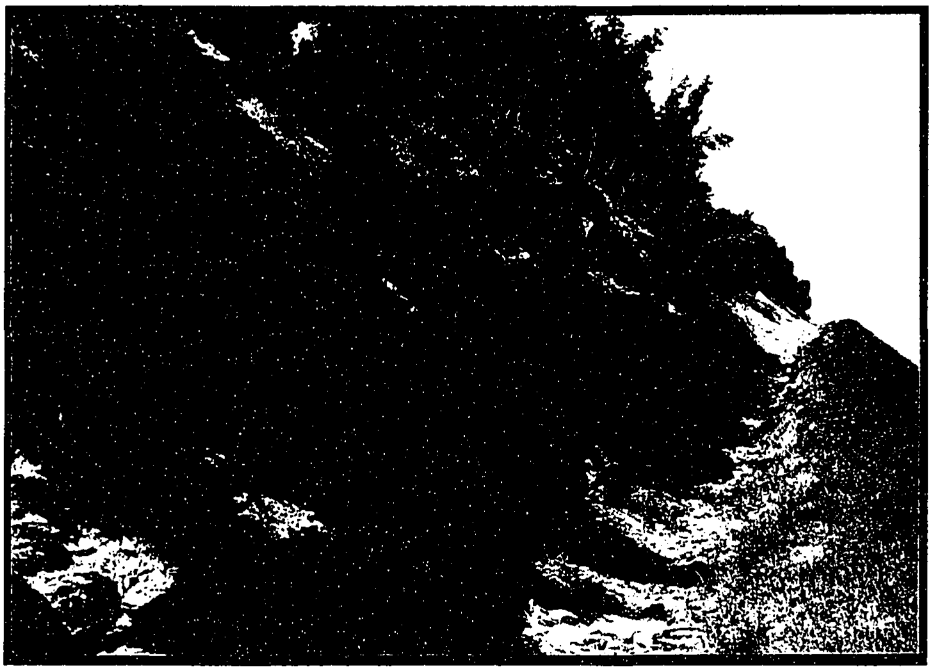


Figure 30a - Irregular- to nodular-bedded calcisiltites and wackestones of Facies B at the Fredericktown Section. The light colored talus slop at the top of the hill is assigned to Facies C.

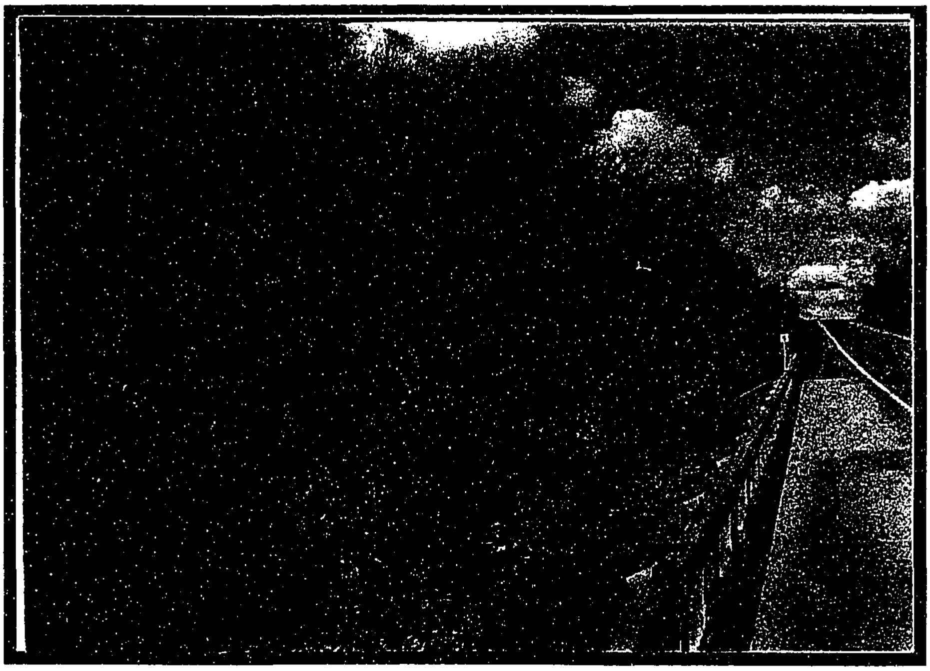


Figure 30b - Typical wavy- to nodular-bedded wackestones and packestones of Facies B at the Camden Outcrop. The rugosan coral illustrated on the next photograph is from this rubbly zone.

The bryozoan-rich, nodular-bedded wackestones interbedded with shale were observed in cores DGS #2626 and #2627 from the eastern margin of Facies B. The brachiopod- and bryozoan-rich, nodular-bedded wackestones, packstones, and grainstones were observed in the North Dayton and Camden Sections and cores SDH #57 and #124. The less fossiliferous, brachiopod- and bryozoan-dominated, nodular-bedded wackestones, micstones, and packstones with siltstones were common in the Madison and Fredericktown Outcrops and Clark County Core SDH #332 on the southwestern edge of the tristate region.

The fossils commonly found in Facies B at the North Dayton and Camden Sections include: *Grewingkia canadensis, Hebertella sp., Platystrophia clarksvillensis, Rafinesquina alternata, Protarea richmondensis, Loxoplocus sp.,* and *Lepidocyclus capax*. Many unidentified fragments of trilobites, crinoids, and bryozoans were also observed, as well as occasional coral heads of *Tetradium sp*. Unidentified borings were found on many of the fossils in Facies B contained unidentified borings. The most commonly bored fossil observed in Facies B was *Grewingkia canadensis*. The borings were commonly up to 2 millimeters in diameter and were located on all surfaces of the fossils. Many of the brachiopods and horn corals were encrusted on one side with *Protarea richmondensis* and unidentified bryozoans. Photographs of the bored and encrusted fossils from Facies B are included on Figure 31.

Frey's (1987) study on Late Ordovician plecypod assemblages included at least one and possibly two communities from Facies B. However, it was unclear whether Frey's Whitewater Formation skeletal community from Richmond, Indiana was from Facies B or E. Frey's community from the Cowan Lake Spillway is from Facies B, and not Facies E, because Facies E is not present in that area. An illustration of Frey's (1987) trepostome-thicket community reconstruction from the Cowan Lake Spillway is provided on Figure 32. Frey (1987) found a diverse assemblage of articulate brachiopods, trepostome bryozoans, solitary corals, pelmetozoan echinoderms, and epibyssate and endobyssate filter-feeding bivalves in the strata and that the fossilized specimens were commonly large and robust.

Both Frey's (1987) research and observations from this study indicate that wave energy was low to moderate and mud

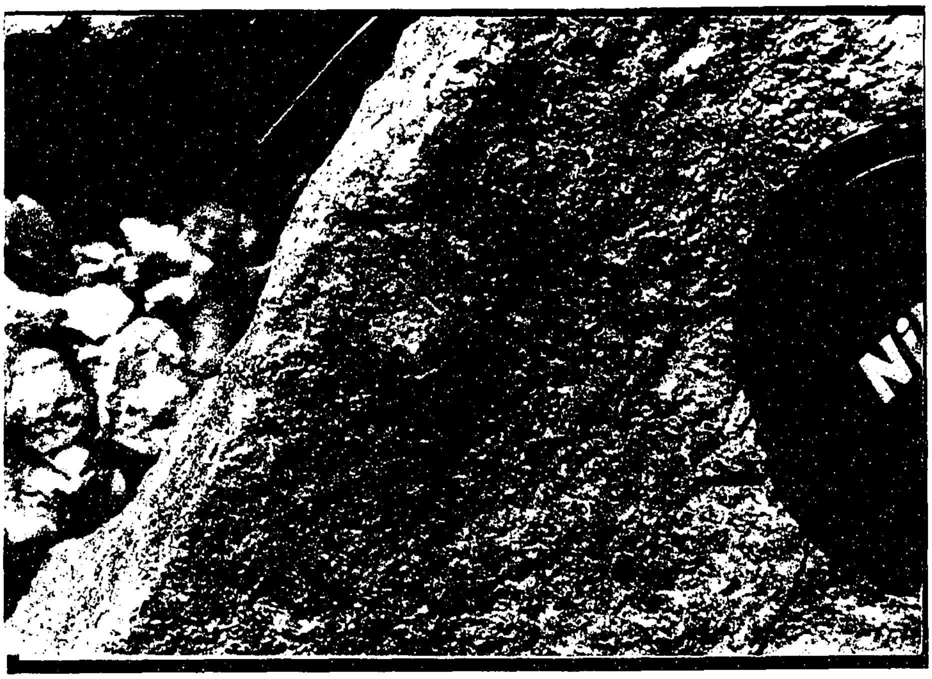


Figure 31a - A burrowed and coral encrusted brachiopod from Facies B collected at the Fredericktown Section.

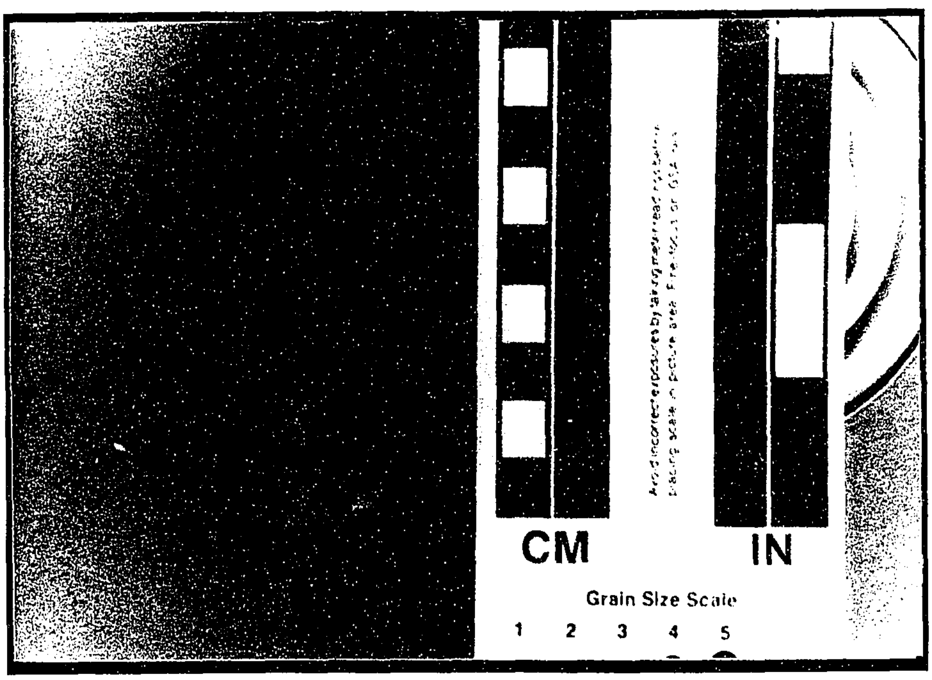
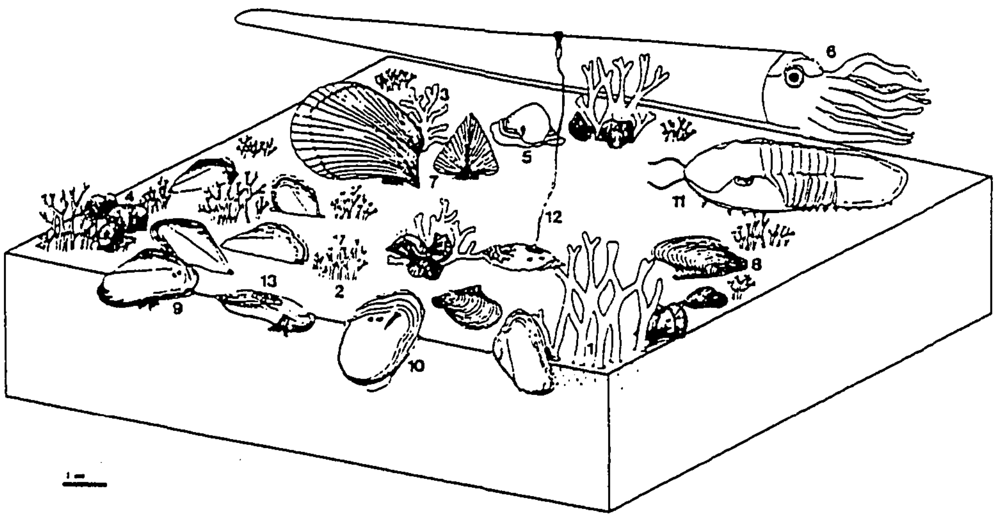
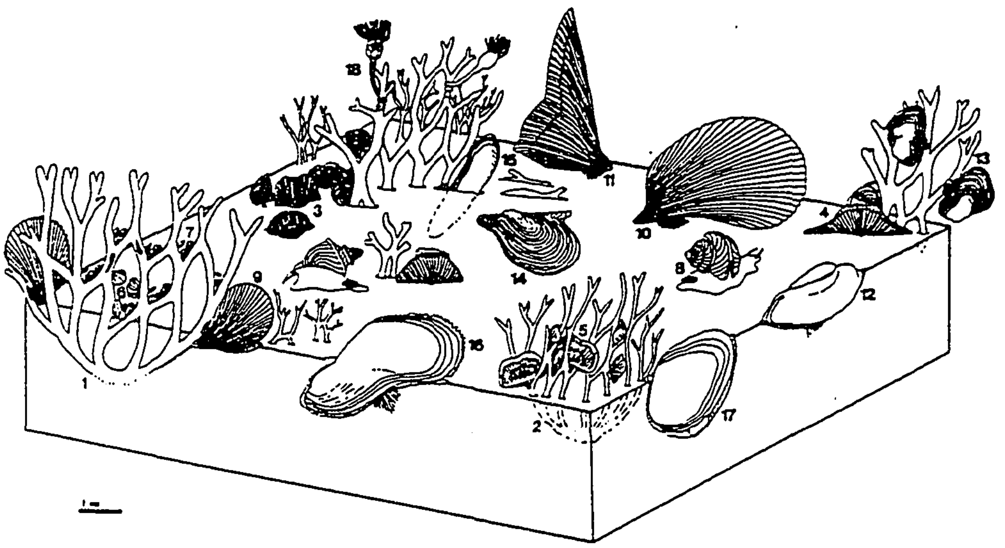


Figure 31b - A coral encrusted, bored rugosan coral from collected from the Camden Outcrop in the rubbly zone above the bridge.



A reconstruction of the trepostome-thicket community associated with the interbedded, thin skeletal wackestone and shale of the upper Bull Fork Formation (Late Ordovician, Richmondian) exposed at the Cowan Lake spillway, Clinton County, Ohio. The pelecypod fauna is abundant and includes 7) the ambonychiid *Ambonychia richmondensis*; 8) the pterineid *Caritodens demissa*; 9) the colpomyid *Pseudocolpomya miseneri*; and 10) the heteroconch *Ischyrodonta truncata*. Other elements of this fauna include numerous ramose trepostomes (1, 2, 3), the orthid brachiopod *Hebertella* (4), the bellerophontid *Bucania* (5), nautiloids (6), the asaphid trilobite *Isotelus* (11), and small crinoids (12). Refer to Table 4 for the mode of life of these pelecypod taxa and Appendix I-I for a complete list of the taxa present.



A reconstruction of the trepostome-thicket community associated with the rubbly skeletal wackestones of the Whitewater Formation (Late Ordovician, Richmondian) exposed at the Rt. 27 roadcut, 4 km south of Richmond, Wayne County, Indiana. The pelecypod fauna is diverse and includes 9) the ambonychiid *Ambonychia obesa*; 10) the ambonychiid *Ambonychia richmondensis*; 11) the ambonychiid *Opisthoptera casei*; 12) the cyrtodontid *Cyrtodontula sterlingensis*; 13) the cyrtodontid *Ortonella hainesi*; 14) the pterineid *Caritodens demissa*; 15) the modiomorphid *Orthodesma curvatum*; 16) the colpomyid *Pseudocolpomya elongata*; and 17) the heteroconch *Ischyrodonta truncata*. Other elements of this fauna include abundant ramose trepostomes (1, 2), a diverse group of articulate brachiopods (3, 4, 5, 6, 7), a pleurotomariacean gastropod (8), and a rhombiferan cystoid (18). Refer to Table 4 for the mode of life of these pelecypod taxa and Appendix IH for a complete list of taxa present.

Figure 32

Paleocommunity Reconstruction Of Facies B

accumulation was decreased. The encrustation and boring of these fossils indicate that the fossils were not immediately buried after death but rather were resting on the sea floor prior to burial. Several encrusted brachiopods and rugose corals were observed at the North Dayton Section and more prominently in the Camden section. The encrusting corals and bryozoans were found on one side of the horned corals and brachiopods indicating that the fossils were resting on the bottom and not rolling on the sea floor after death. The skeletal condition of shells including breakage, articulation, and abrasion, is generally recognized as a method of assessing shell post-mortem transport (Fagerstrom, 1964). Articulated, unabraded shells are likely to have been subjected to minimal transport, while disarticulated and abraded shells are likely to have been subjected to sea floor conditions for longer periods of time. Fragmented and abraded shells are thought to represent highest energy and duration on the seafloor. Fossils found in Facies B include the entire spectrum of skeletal preservation ranging from articulated brachiopods to abraded shell fragments. Thus, the conditions of this facies must have been variable over time and include low-energy and high-energy periods or areas. The higher energy strata may represent proximal storm events that resulted in the deposition of the planar-bedded sequences characteristic of Facies A.

Facies B is roughly equivalent to the Lower and part of the Upper Whitewater Formation as defined by Tobin (1982), the Rowland Member of the Preachersville Formation as defined by Weir *et al.* (1984) and a combination of the skeletal-packstone and wackestone facies of Betz (1984).

Tobin (1982) examined the sedimentologic and paleoecologic character of the Whitewater Formation and concluded that it was the result of deposition in a high-energy, lower shoreface environment. According to Betz (1984), the formation was the result of deposition in an inner to middle carbonate ramp as well as tidal channel environments. Both of these authors developed similar models of moderate- to high-energy, generally open-marine conditions where fossils were subject to abrasion and encrustation, and finer sediments are commonly winnowed away. The basic difference between the two models is in the paleogeographic setting interpreted by the authors. Tobin (1982) based his model on a localized shelf with varying geometric configurations while Betz (1984) based his model on a monoclinal ramp striking north-south and dipping westward from the eastern edge of the Taconic Orogen.

Facies B has been assigned to the proximal intracratonic ramp for the following reasons:

- The large, more robust fossils such as *Grewingkia canadensis*, and *Rafinesquina alternata* are characteristic of open-marine conditions;
- The high degree of abrasion of some of the fossils, the presence of borings on the horn coral, and the encrustation of many of the brachiopods and rugose corals with bryozoans and corals indicate that the fossils were exposed to sea floor conditions for extended periods of time and that enough wave energy must have been present to prevent fines from accumulating over the fossils;
- The presence of the two corals *Tetradium sp.* and *Grewingkia canadensis,* indicate that the depth of water and clastic influx may have decreased; and
- The lack of thick accumulations of shales and the general decrease of the shale in the strata indicate that the shales were not deposited but rather winnowed and

transported away from this facies and deposited in other locations such as the offshore cratonic shelf facies. The accumulation of calcisiltites in the southwestern part of the study area may be the result of a lack of shale influx resulting from restriction on top of the Lexington platform and trapping of clastic by the bryozoan-rich communities to the east.

Hatfield (1968), Hay (1981) and Tobin (1982) assigned the *Tetradium* and *Favistella* coral zones present in the Richmond strata to the Saluda Formation (Facies C) because these zones commonly occur with and below sediments deposited in the shallow subtidal to supratidal depositional environment. This study disagrees with their position for several reasons. First, because the Saluda Formation (Facies C) is dominantly a tidal flat facies, the assignment of a coral zone to them seems dubious. Modern corals are generally not found on tidal flats or in the upper shoreface, but tend to prefer the lower shoreface and shallow-shelf environment. For example, coral reefs off the shores of the Florida Keys (Multer and Hoffmeister, 1975) are found in a zone several miles offshore. Corals are sparse near the shore and a rarely observed in tidal flats. Hatfield (1968) concluded that the Saluda Formation was deposited behind a massive barrier formed by these corals. To date, no stratigraphic evidence in either outcrop or geophysical logs has confirmed the existence of such a barrier.

By observing the general morphology of these corals, it becomes obvious that these corals do not grow on top of each other to form great barriers, but rather grow next to each other and may form very localized sediment shadows. These coral heads are rarely larger than 40 centimeters in diameter and are often quite smaller. In addition, at the Madison and Fredrickstown Sections, it appears that many of the corals have been overturned. This study concurs with Walters (1988) in attributing minor, fine-sediment accumulation in areas immediately adjacent to the corals. This study assigns the corals to a transitional position as evidenced by their occurrence in or adjacent to obvious Facies C strata at Madison, Fredericktown, and cores SDH #124 and #332. There is no evidence to counter the possibility some of these corals may be quite distant from the tidal flat and that their growth may be the result of deposition during times of low clastic influx.

6.2 Geophysical Log Correlation

Facies B is best recognized in geophysical logs as having a low gamma ray deflection, a high neutron deflection with many limestone "kicks," and some shale breaks (see Figures 10 and 11). In southeastern Indiana, Facies B is overlain by Facies C and is distinguished in the geophysical logs by a very low gamma ray log response and very high neutron log response characteristic of Facies C (Figure 12). The base of Facies B is recognizable by the gradational decrease in gamma ray response characteristic of the top of Facies A.

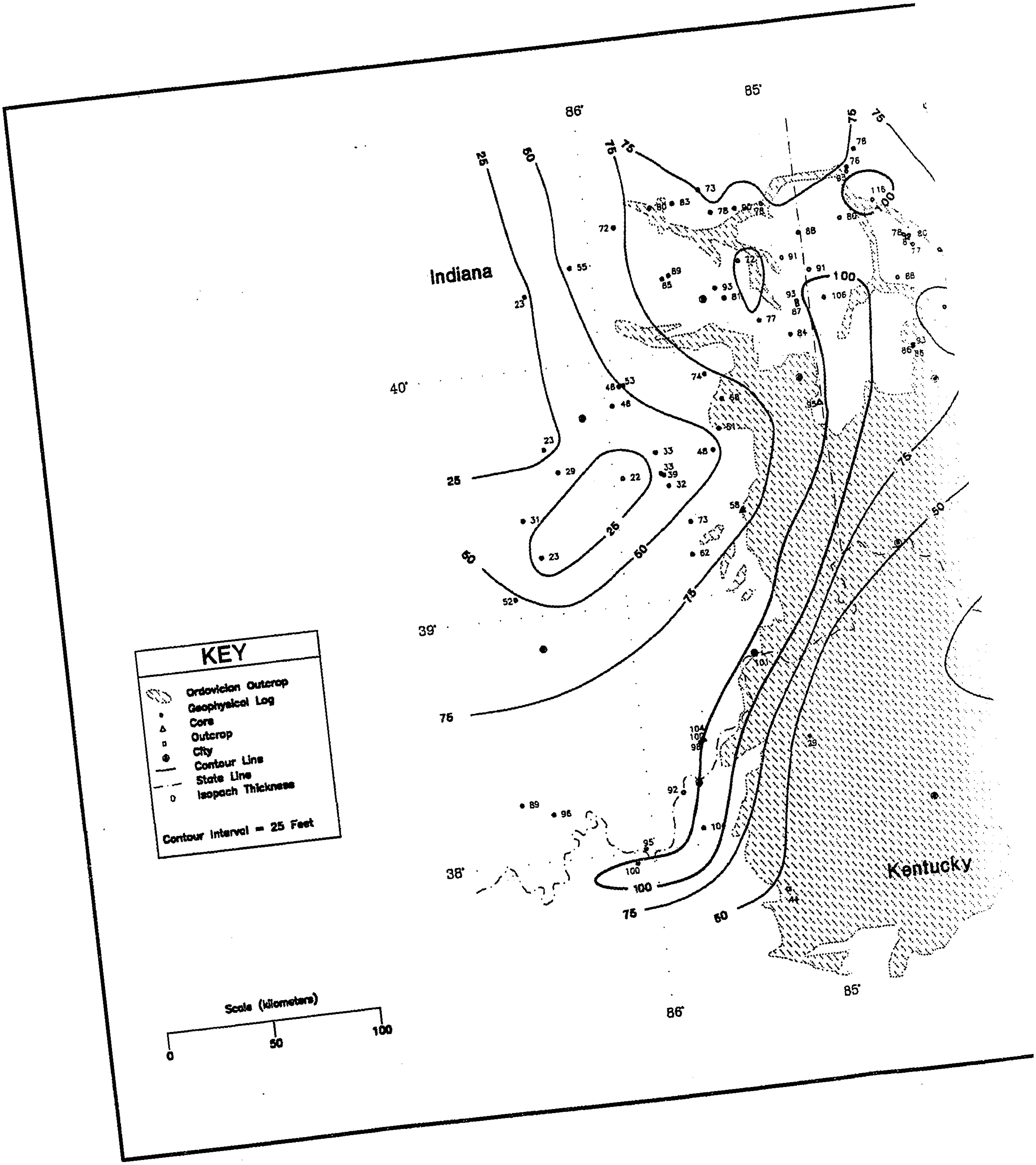
The higher carbonate content of Facies B outcrops and cores is reflected in the relatively low gamma ray and high neutron log responses. The marked decrease in shale compared to the underlying Facies A is evidenced by the decrease in gamma ray response from Facies B to Facies A.

The stratigraphic position of the geophysical signature of Facies B corresponds to the lithologic relations observed in nearby outcrops and cores. It is the first carbonate-rich interval overlying the uppermost interbedded shale and carbonate layer in east-central Indiana and western Kentucky.

6.3 Thickness and Distribution of Facies B

As shown on Figure 33, Facies B is thickest in west-central Kentucky and along the border of Ohio and Indiana. Facies B ranges in thickness from 0 feet (0 meters) in north-central and east-central Ohio to 106 feet (32 meters) along the Ohio and Indiana border. Geophysical log correlations show that Facies B laterally interbeds with Facies A in east-central Ohio.

According to conodont correlations by Sweet (1979), Facies A through C are oldest in north-central Kentucky, and youngest in southeastern Indiana. Based on Sweet's (1979) correlations, it is likely that this carbonate ramp originally formed from the south on the Lexington Platform and then prograded northward into Indiana. At its furthest lateral extents, Facies B prograded across the study area and covered the central portion of the basin. However, it is unclear


Indiana
Kentucky
KEY
Ordovician Outcrop
Geophysical Log
Core
Outcrop
City
Contour Line
State Line
Isopach Thickness
Contour Interval = 25 Feet
Scale (kilometers)
0
50
100
86°
85°
40°
39°
38°

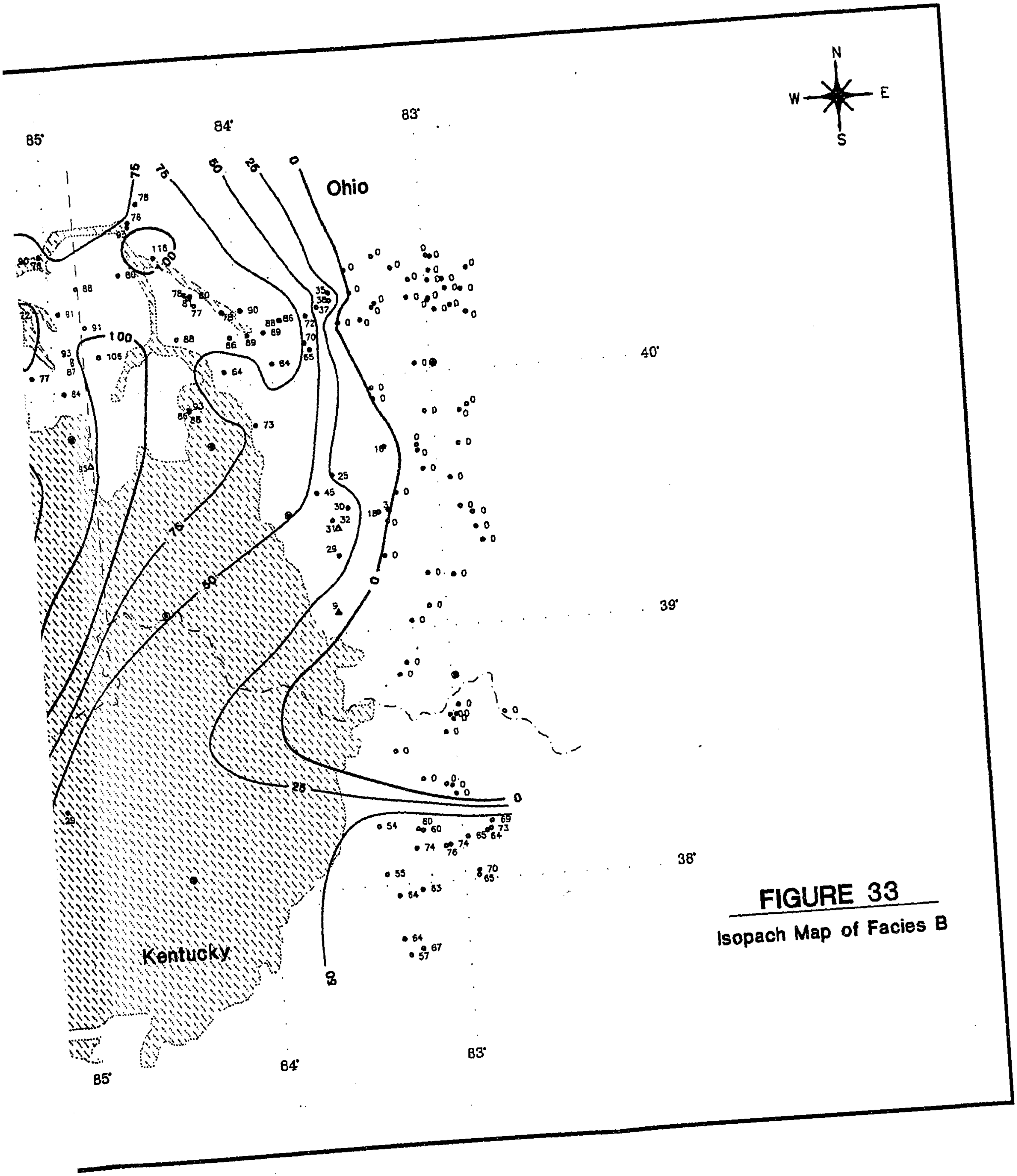


FIGURE 33

Isopach Map of Facies B

whether it prograded as a result of sea level changes or filling of the sediment accommodation space. The correlative carbonate increase in Facies A at the lateral extents of Facies B in eastern Ohio clearly demonstrates that at least parts of Facies A are offshore lateral equivalents of Facies B. According to Gray (1972) the Galena Platform was present north of the tristate region and likely contained shallow-shelf carbonates (Gray, 1971).

The thick accumulation of Facies B in a peninsular shape in Ohio is likely the result of its position at the transition to the Appalachian Basin as a result of:

- Increased clastic sedimentation rates caused by higher clastic influx;
- Increased carbonate growth rates caused by more open circulation and increased nutrients;
- Increased sediment accommodation space caused by subsidence related to the Taconic Orogen.

As discussed previously, the accumulation of Facies B in this area is characterized by abundant bryozoan. It appears that the bryozoan-rich communities were most abundant at the transition between clastic-rich sediments from the Appalachian Basin and the carbonate-rich shelf of the tristate region.

7.0 FACIES C: MASSIVE DOLOMUDSTONES

Facies C, which is composed predominantly of massive, unfossiliferous, banded dolomudstones is always underlain by and laterally interbeds with Facies B. Facies C is paraconformably overlain by Facies E in southeastern Indiana and unconformably by the Silurian Brassfield Formation in most parts of Kentucky. Based on data collected from other studies and this study, Facies C was deposited in a shallow subtidal to intertidal environment.

7.1 Sedimentologic and Paleontologic Characteristics

Facies C is composed of massive to thin-bedded, often-banded, generally unfossiliferous dolomudstones, laminated dolomudstones, and dolosiltstones. Sedimentary features observed in core SDH #124 and #332 and the Madison and Fredericktown outcrops include: desiccation cracks, ripple cross laminations, trace fossils, birdseye structures, intraclasts, and terrigenous detritus. According to Hatfield (1964), the amplitude of ripple cross laminations were up to 3 centimeters, and their wavelengths up to 30 centimeters.

Walters (1998) has reported fining-upwards beds consisting of approximately 80 percent intraclasts. Trace fossils observed in this facies were almost entirely *Skolithos* and were reported by Walters (1988) to be occluded at the top of Facies C in Madison. During this study, these occluded trace fossils were observed at the Madison outcrop as described by Walters (1988) and near the top of Facies C in Clark County Core SDH #332. Photographs of outcrops and specimens that exhibit Facies C characteristics are shown on Figures 34 and 35.

Numerous studies including Walters (1988), Bloemaker (1981), and Hatfield (1964) document the origin of Facies C (as the correlative Saluda Formation) as being deposited in the shallow subtidal to supratidal environment. The origin of Facies C is illustrated on Figure 36, which was modified from Walters (1988) to account for differences in facies contacts and terminology.

The massive dolomudstones of Facies C are approximately equivalent to Lithofacies B and C of the Saluda Formation as defined by Walters (1988), the Middle and Upper Saluda Members described by Tobin (1982) and the Saluda Formation as

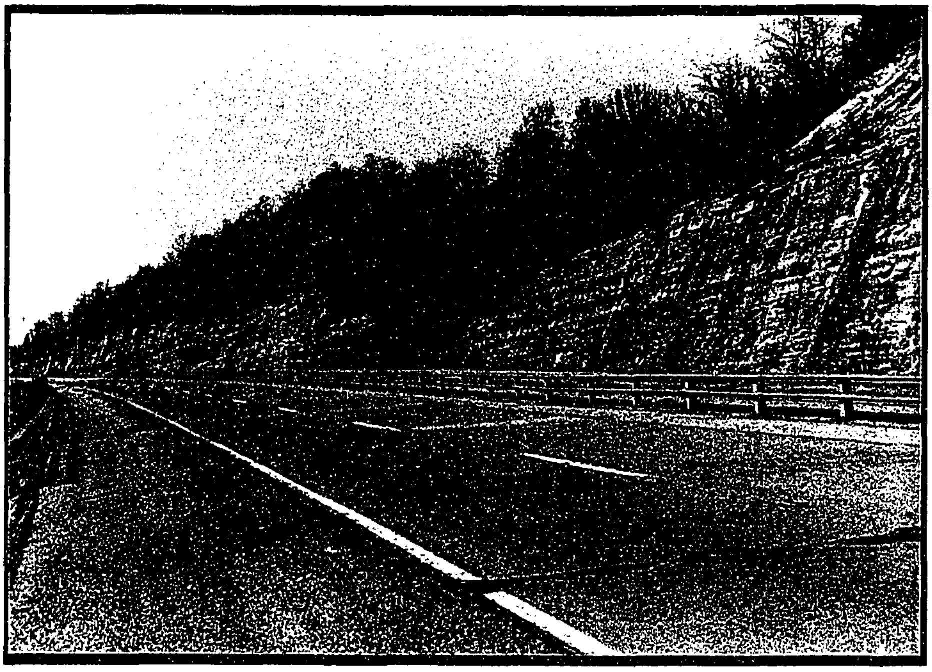


Figure 34a - The massive, banded dolomudstones typical of the Facies C strata photographed at the Madison Outcrop on Highway 421.

Up

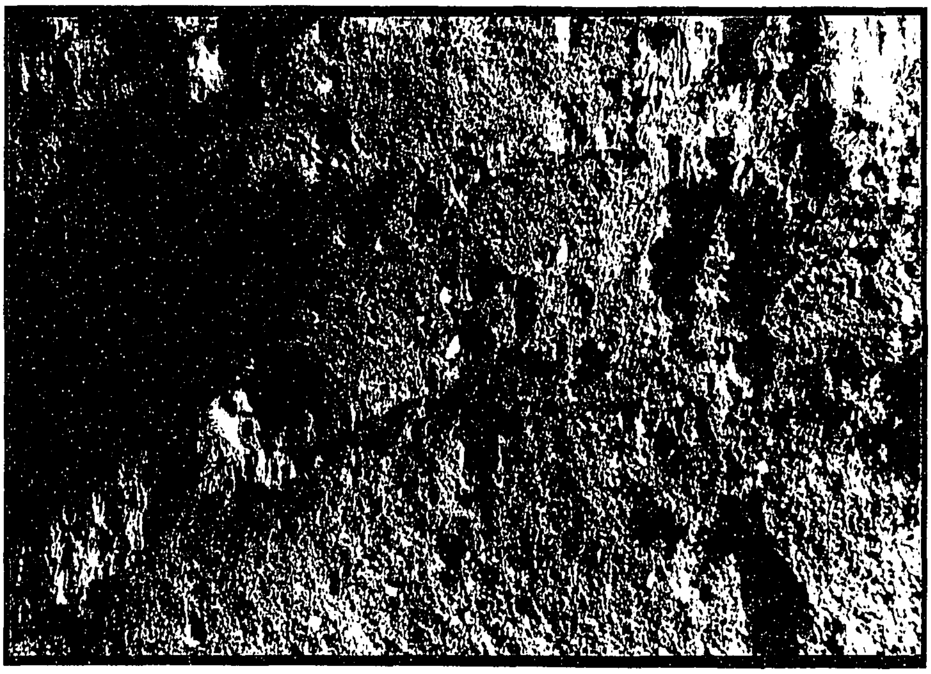


Figure 34b - A coral zone near the top of Facies C at the Fredericktown Outcrop. Note the scattered distribution of the abundant coral in the argillaceous siltstone matrix.

Up

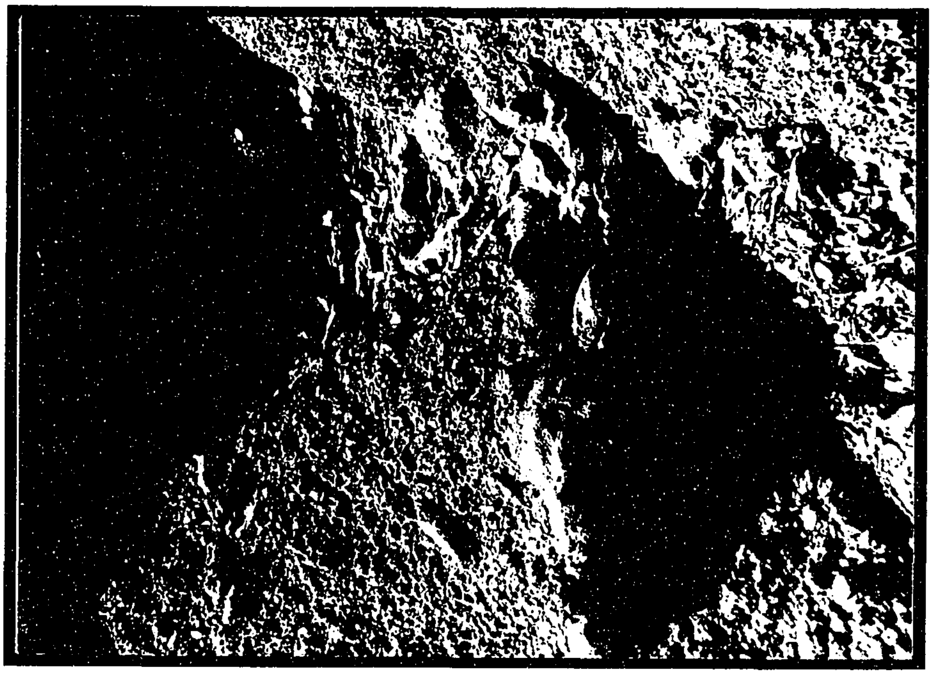


Figure 35a - Close-up photograph of the coral zone at the Fredericktown Section.

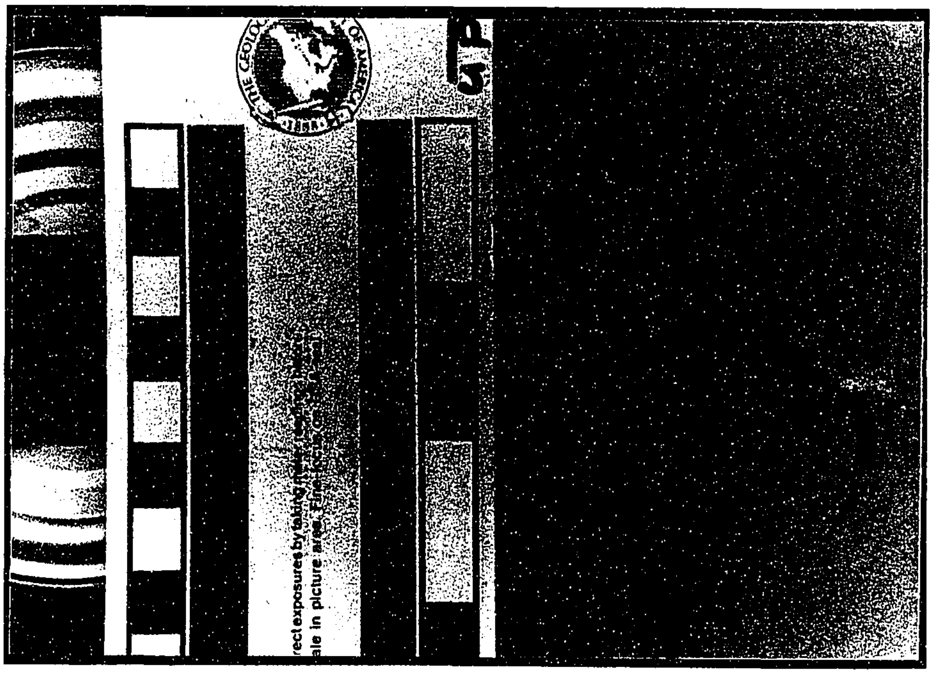


Figure 35b - Photograph of occluded burrows in Facies C of Clark County Core SDH #332.

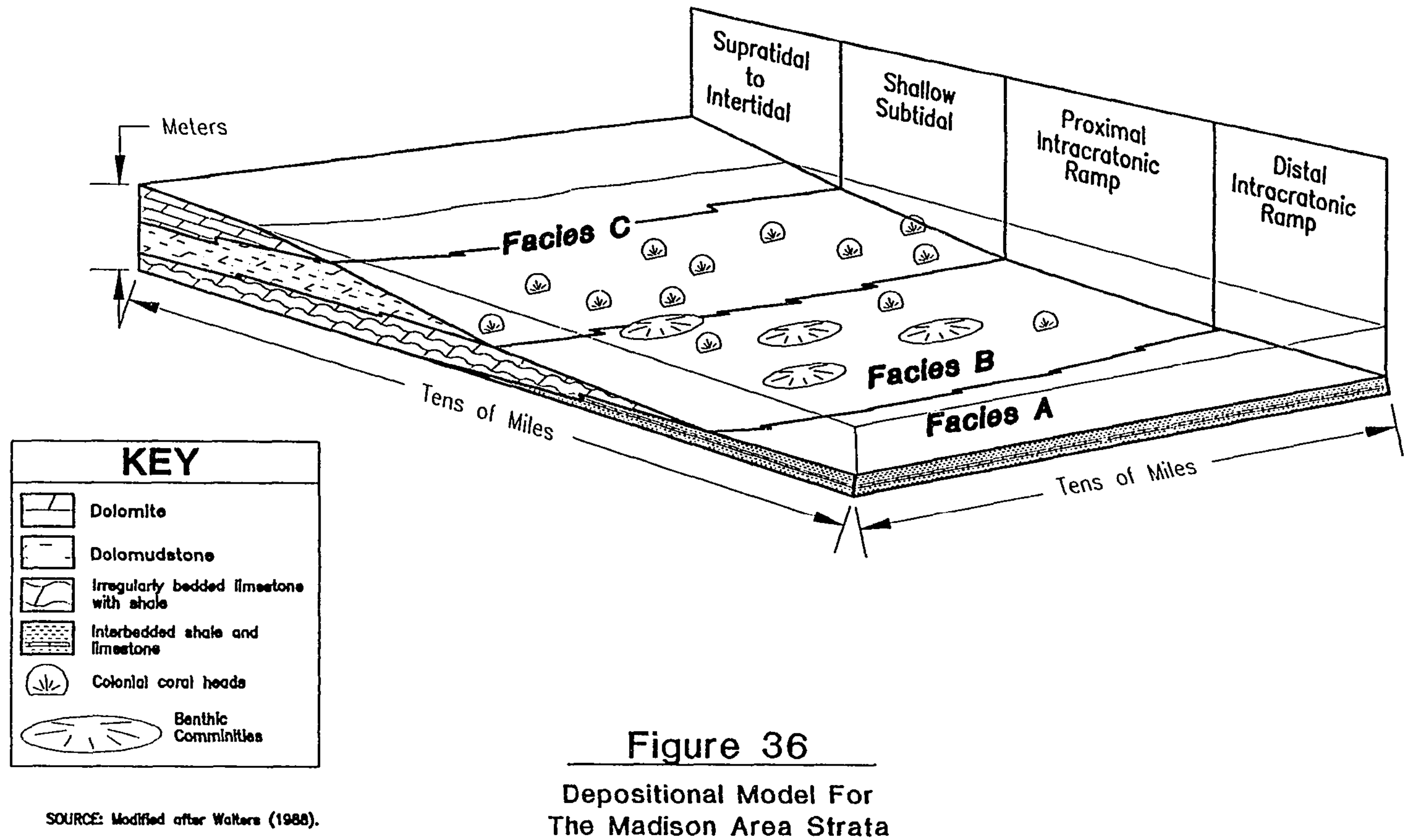


Figure 36

Depositional Model For
The Madison Area Strata
Facies A through Facies C

interpreted by Bloemker (1981). This study differs from Bloemker because it considers the *Tetradium* zone to be transitional and assigns the wavy-bedded dolomitic grainstones, packstones, and wackestones below the corals to Facies B instead of Facies C. The *Tetradium* zone is an easily identified marker bed, and the dolomitic nature of the overlying sediments indicate significant shallowing. The strata below these beds more closely resemble Facies B because they contain fossil fragments, are wavy-bedded and are generally extremely fossiliferous.

Because Tobin (1982) and Hay (1981) appear to assign any *Tetradium* zone present in the strata to the Saluda Formation, associated tidal environments were extended by these authors into Wayne County, Indiana and southwestern Ohio. Both authors then named an Upper Whitewater Formation as wavy-bedded limestones above the Saluda. Although, this study recognizes that dolomudstones and the *Tetradium* corals are an indicator of shallower environments, these could also represent isochronous marker beds formed during a period of minimal shale influx, quiet water conditions or increased nutrients that promote coralline growth. Because these zones are thin, they are not identifiable in geophysical logs.

As previously discussed, this study found no evidence of carbonate buildups of *Tetradium* or any other corals that would cause the restriction of circulation and deposition of lower energy, fine dolomudstones of the massive-bedded Facies C as proposed by Hatfield (1964).

Facies C is differentiated from the underlying Facies B and overlying Facies D, where present, by being a fine-grained, thick- to massive-bedded, dolomite that contains few shales. This study contradicts Bloemker's (1981) and Gray's (1972) contention that the massive-banded dolomudstone facies is not mappable in subsurface geophysical logs. Bloemker (1981) demonstrated that the massive banded dolomudstones were identifiable in the subsurface and mappable on a regional scale in subsurface cores. In the same study, Bloemker (1981) also concluded that these dolomudstones were not identifiable in geophysical logs based upon personal communications with Gray. However, Gray (1972) concluded that this facies was not identifiable in the geophysical logs which were chiefly composed of spontaneous-potential and resistivity logs.

During a personal discussions with Gray (1988), he indicated that this unit was not identifiable because of the type of logs available to him and their widespread distribution. During this study, Facies C was delineated using gamma ray and neutron logs which are commonly available today, but were rarely available during Gray's (1972) research.

7.2 Geophysical Log Correlation

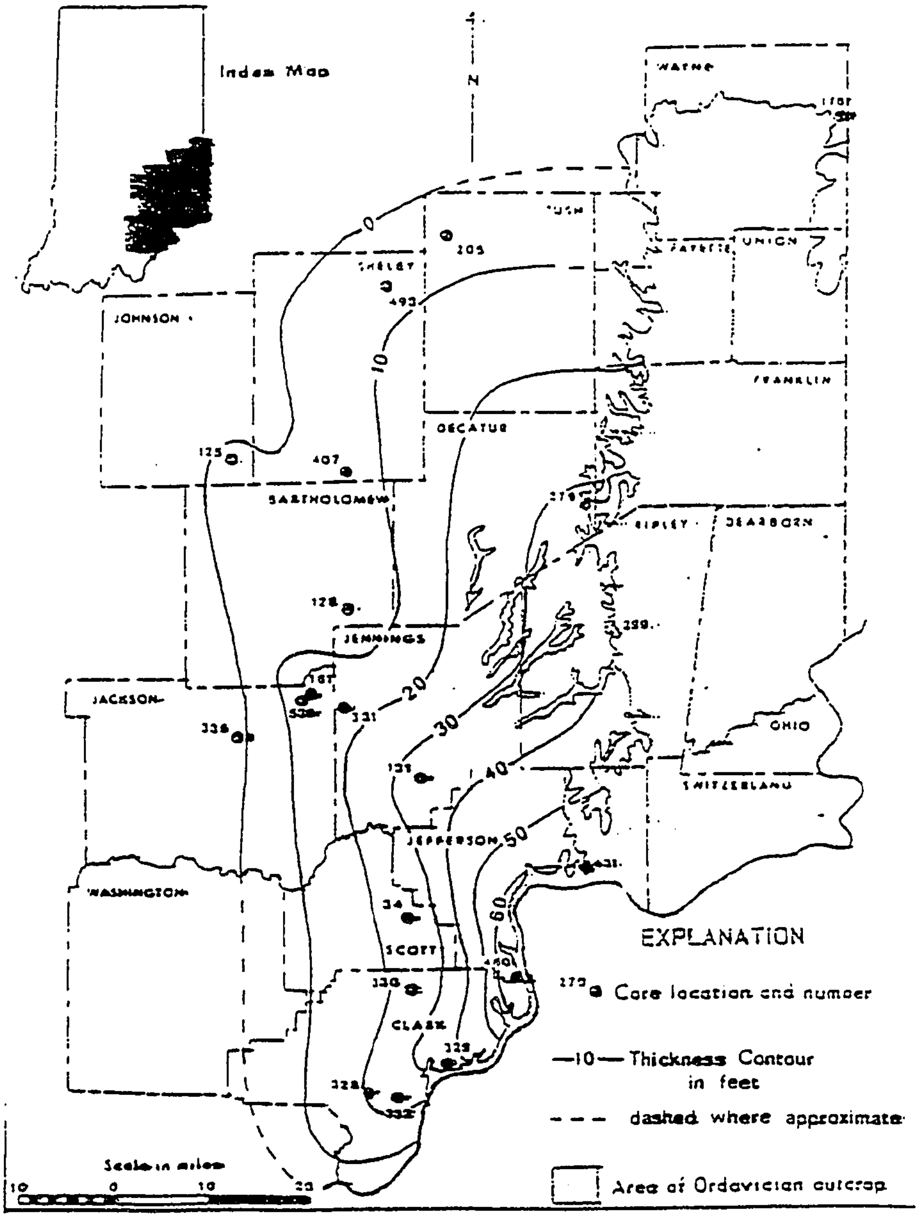
Facies C has the lowest gamma ray and highest neutron density response of the Cincinnatian strata as shown in Figure 12. In areas where Facies C is directly overlain by the Silurian Brassfield Formation, the contact was differentiated by the slightly lower gamma ray and slightly higher neutron response of the overlying Brassfield Formation. The Ordovician-Silurian contact is easily identified in well cuttings because of the characteristic change from pink crinoid-rich dolomites of the Brassfield Formation to tan to the green carbonates of the Facies C. Picks made by personnel at the Indiana and Ohio Geological survey from cuttings were compared to correlated picks from well logs to confirm the exact depth of the contact.

The lithologic character of the facies corresponds to the geophysical log response because the facies has very low gamma ray and very high neutron density responses characteristic of massive carbonates. A gamma ray spike corresponding to the organic-rich shale near the base of the Facies C was observed in the geophysical log from Clark County. Facies C exhibits a marked decrease in shale compared to the underlying Facies B as evidenced by the significant decrease in gamma ray response from Facies B to Facies C.

Many authors including Hatfield (1964) and Bloemker (1981) have mapped this facies in outcrops and cores. Figure 37 is an isopach map of the Saluda Formation constructed by Bloemker (1981). In comparison to the isopach map of Facies C derived from this study (Figure 38), the thicknesses and distribution of the facies as delineated by core and geophysical logs are similar.

7.3 Thickness and Distribution of Facies C

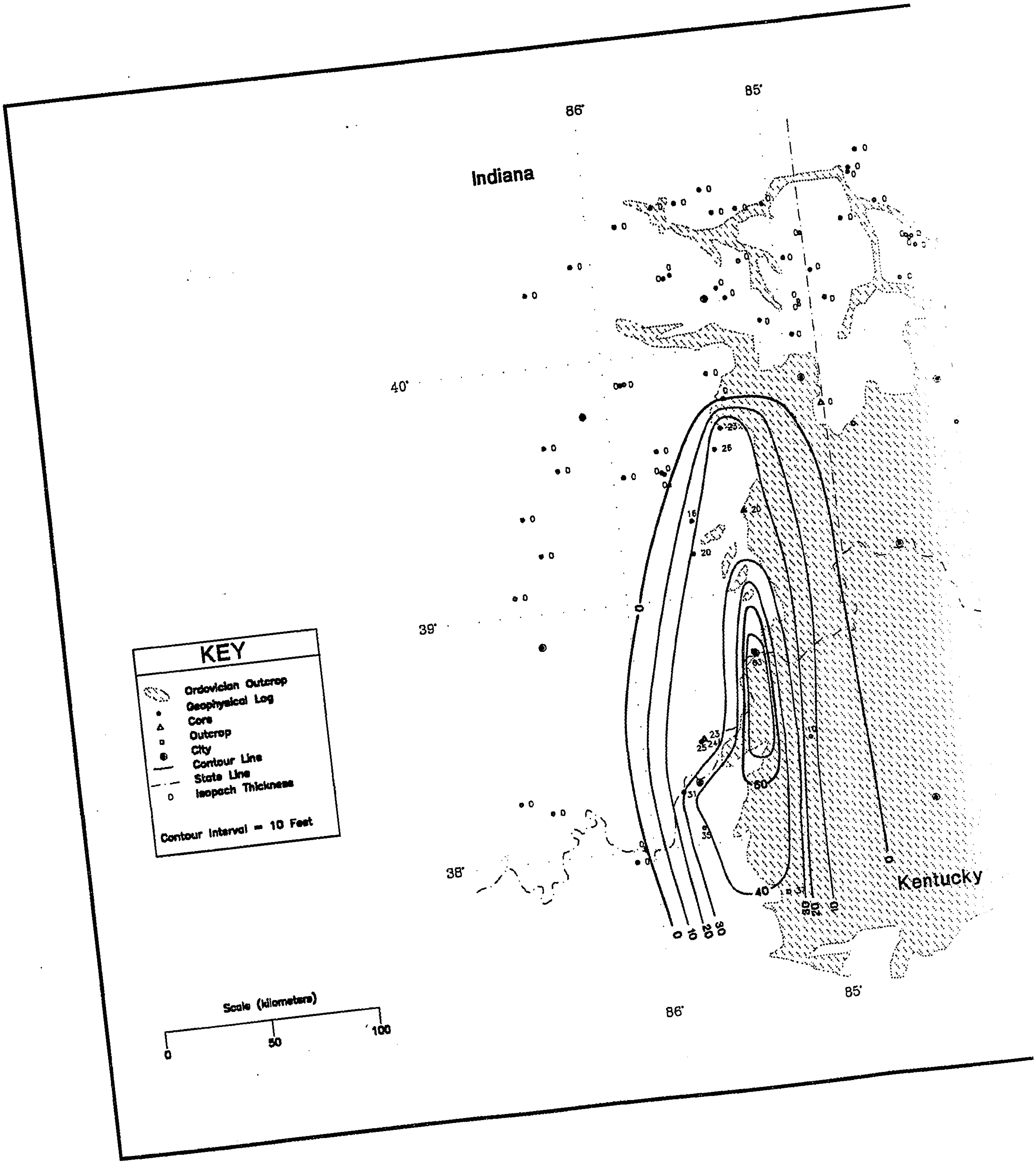
As shown on Figure 38, the thickness of Facies C ranges up to 63 feet (19 meters) along the Kentucky-Indiana border and is



SOURCE: Bloemkr 1981.

Figure 37

Ispach Map Of The Saluda Constructed From Core Data



Indiana
Kentucky
86°
85°
40°
39°
38°
KEY
Ordovician Outcrop
Geophysical Log
Core
Outcrop
City
Contour Line
State Line
Isopach Thickness
Contour Interval = 10 Feet
Scale (kilometers)
0
50
100

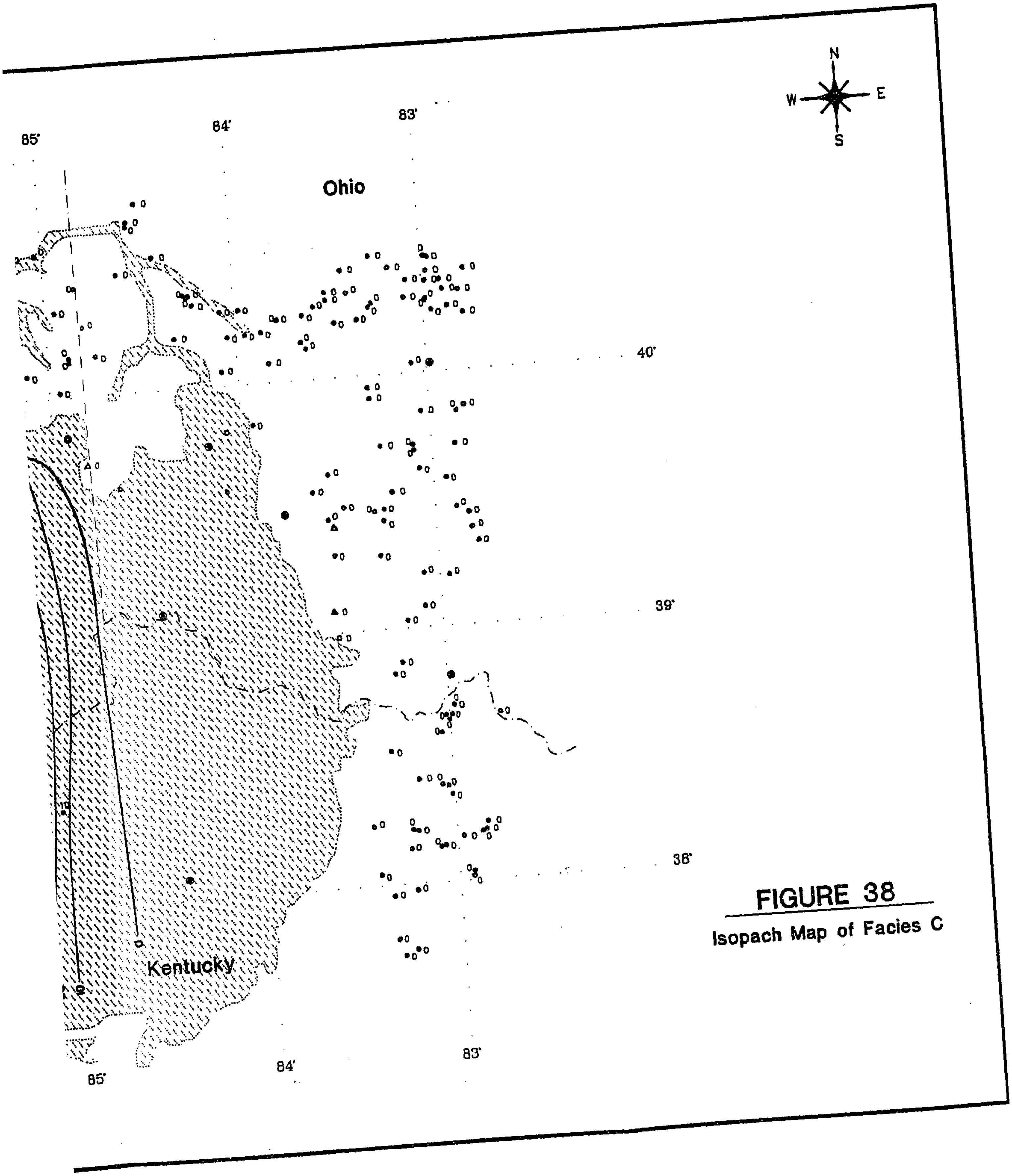


FIGURE 38

Isopach Map of Facies C

distributed in a peninsular shape that trends south to north approximately 31 miles (50 kilometers) to the west of the Ohio-Indiana border. The peninsular shape of the facies may be influenced by eroded strata along the western margin of the Cincinnati Arch. According to regional cross sections, Facies C is thickest along the northern margin of the Lexington Platform. The buildup of Facies B on the shelf infers that a high sea level stand occurred during deposition which resulted in the thick buildup of tidal flat deposits.

The maximum northward extent of Facies C is near Decatur County, Indiana. As illustrated on the south to north cross section west of the Cincinnati Arch shown on Figures 15 and 16, Facies C thins towards the north and grades into Facies B and E.

8.0 FACIES D: DOLOMITIC CLAYSTONE AND SILTSTONE

Facies D gradationally overlies Facies A in the easternmost part of the field area and Facies B to the west into Indiana. Facies B is characterized by homogenous to laminated siltstones, dolosiltstones, and dolomitic claystones with sparse fossils, including *Isotelus* and unidentified ostracods.

8.1 Sedimentologic and Paleontologic Characteristics of Facies D

Two lithologic variations are present in Facies D. The first is composed of predominantly grayish olive (10Y 4/2) to greenish grey (10GY 5/2) dolomitic claystones with medium gray (N5) siltstone, wackestone, and packstone beds. Bands of variegated, grayish red (5R 4/2) and moderate brown claystones and carbonaceous layers are common at the top of the section in the eastern half of the field area. The 0.5- to 3-cm thick siltstone beds are often cross bedded or cross laminated and contain gutter casts at the Burnt Cabin Road Outcrop (Figure 39). The wackestone and micstone beds are usually burrowed, and the burrows are filled with pale olive (10Y 6/2) shale.

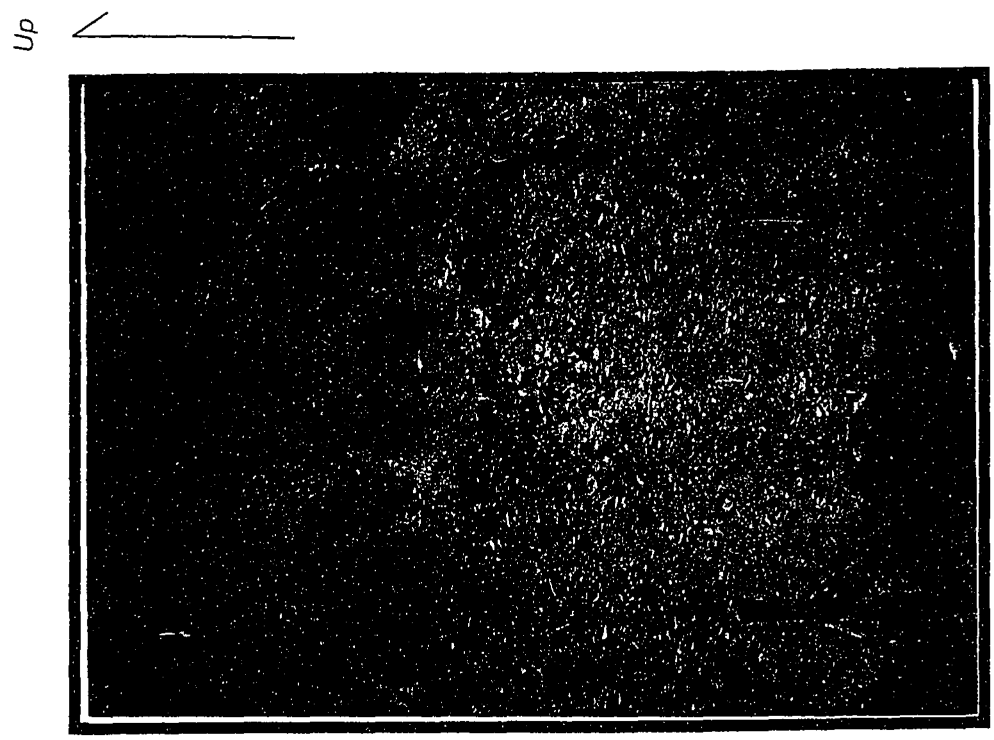


Figure 39a - Photograph of North Dayton Section illustrating the shale-rich Facies D overlying the nodular- to wavy-bedded carbonates of Facies B. The contact is the first set of carbonate beds beneath the shale.

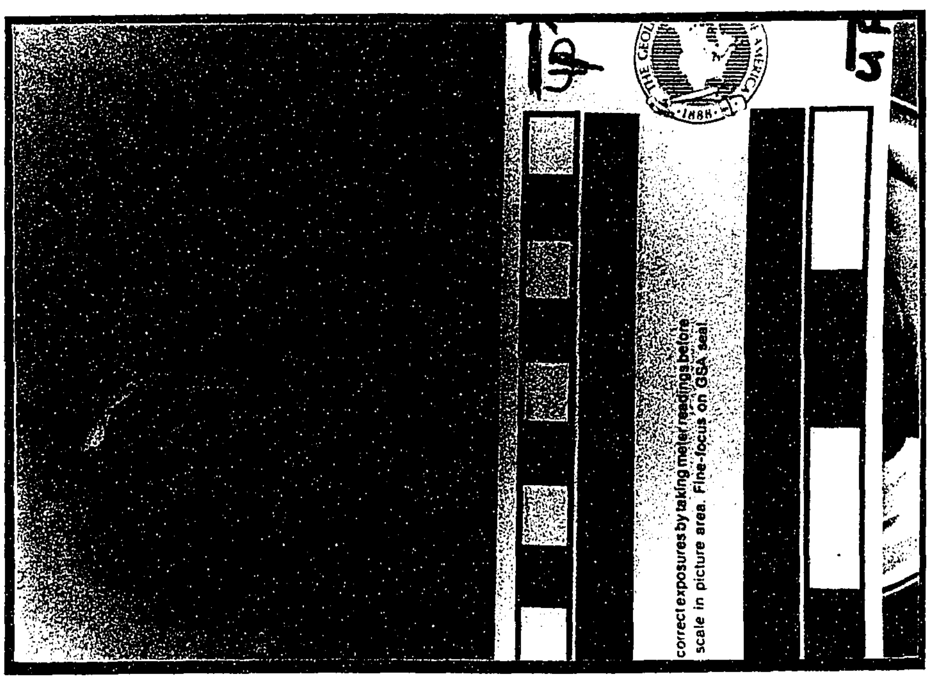


Figure 39b - Closeup of wavy laminated siltstones present near the top of Facies D at the North Dayton Section.

Many of the carbonate beds had ripples with amplitudes up to 1.5 cm and wavelengths to 4 cm at the Burnt Cabin Road Outcrop. The strike of the ripples ranged from 58 to 74° azimuth and fossil fragments were common at the crest of the ripples.

The frequency and thickness of carbonate beds gradually increase toward the base of the Facies D at the Burnt Cabin Road Outcrop, whereas at the North Dayton Section the change is more abrupt (Figure 39). The first series of carbonate beds at the base of Facies D in the North Dayton section is nearly 1 meter thick. Additional thin shale units are present beneath this carbonate layer. Betz (1984) completed a petrographic analysis of shales from Facies D which indicated that the claystones may contain up to 38 percent dolomite.

Isotelus sp. and unidentified ostracods were identified in the claystone and trepostome bryozoans, *Platystrophia moritura,* and other unidentified brachiopods occurred in thin limestone lenses within the shale. The fossils are commonly slightly abraded, occasionally fragmented. In general, the fossils are not very abundant except at certain horizons within each outcrop.

A second lithologic variation composed predominantly of thinly laminated, non-fossiliferous dolosiltstones with argillaceous seams is present at the top of the North Dayton Section. The beds, which range from 1 to 2 cm thick with occasional 0.5- to 2-cm silty-shale layers, contain some low angle cross bedding in a number of horizons. Its contact with the overlying Brassfield Formation is sharp and wavy. According to Betz (1984), the dolosiltstones are composed predominantly of silt-sized dolomite rhombs. The quartz content ranges up to 12% and desiccation cracks were observed in some horizons. This unit is nearly 4 meters thick at the North Dayton Section.

Facies D was observed in outcrops from the eastern edge of the field area to as far west as Elkhorn Creek, Indiana. Bloemker's (1981) description of Core SDH #205 in Rush County, Indiana includes a olive green to gray, calcareous shale that is likely associated with Facies D.

In contrast to Tobin (1982), and Betz (1984) this study correlates the siltstones and claystones of the Preachersville

Member of the Drakes Formation in Adams County with the claystones and siltstones from the Elkhorn Formation in Dayton and Elkhorn Creek and group them together as Facies D. The reddish banding present in both the North Dayton and the Burnt Cabin Road sections and the cores collected from locations between this two sections (*i.e.*, DGS #2626 and #2627) show a distinct lithologic similarity. Hay (1981) suggests that these two shale intervals may be correlative and the geophysical logs correlations discussed later in this section further document this correlation.

According to Weir *et al.* (1984) and Betz (1984), the source of the dolomitic shales was likely the Taconic Highlands to the east which were being uplifted during the Late Ordovician. Evidence that Facies D sediments were probably deposited in a well-oxygenated, intertidal to shallow-water, clastic-dominated environment include: ripple marks, thin limestone lenses, desiccation cracks, and a paucity of marine fossils. During a petrographic examination of this facies, Betz (1984) found algal laminites in some strata, which he associated with a mud-dominated tidal flat at the western margin of the clastic wedge shed from the Taconic Highlands. In addition, Dennison (1976) traced the Upper Ordovician redbeds into central Ohio from the Taconic Highlands.

The reddish shales observed in the North Dayton and Burnt Cabin Road Sections and reported in many cores are an indicator of the well-oxygenated conditions present in the sediments of Facies D. Maynard (1982) geochemically classified sedimentary environments of shales in the Appalachian Basin based upon Berner's (1981) sedimentary environments. In his study, Maynard (1982) found that red shales were indicative of "oxic environments" where both the sediments and water were well oxygenated, bioturbation was high, and organic carbon was readily oxidized. Gray to green shales were indicative of "post oxic environments" in which the oxygen content was lower because of increased water depths. This facies is assigned as a marine equivalent of the distal alluvial fans and described by Dennison (1976) based on their stratigraphic position at the top of the section.

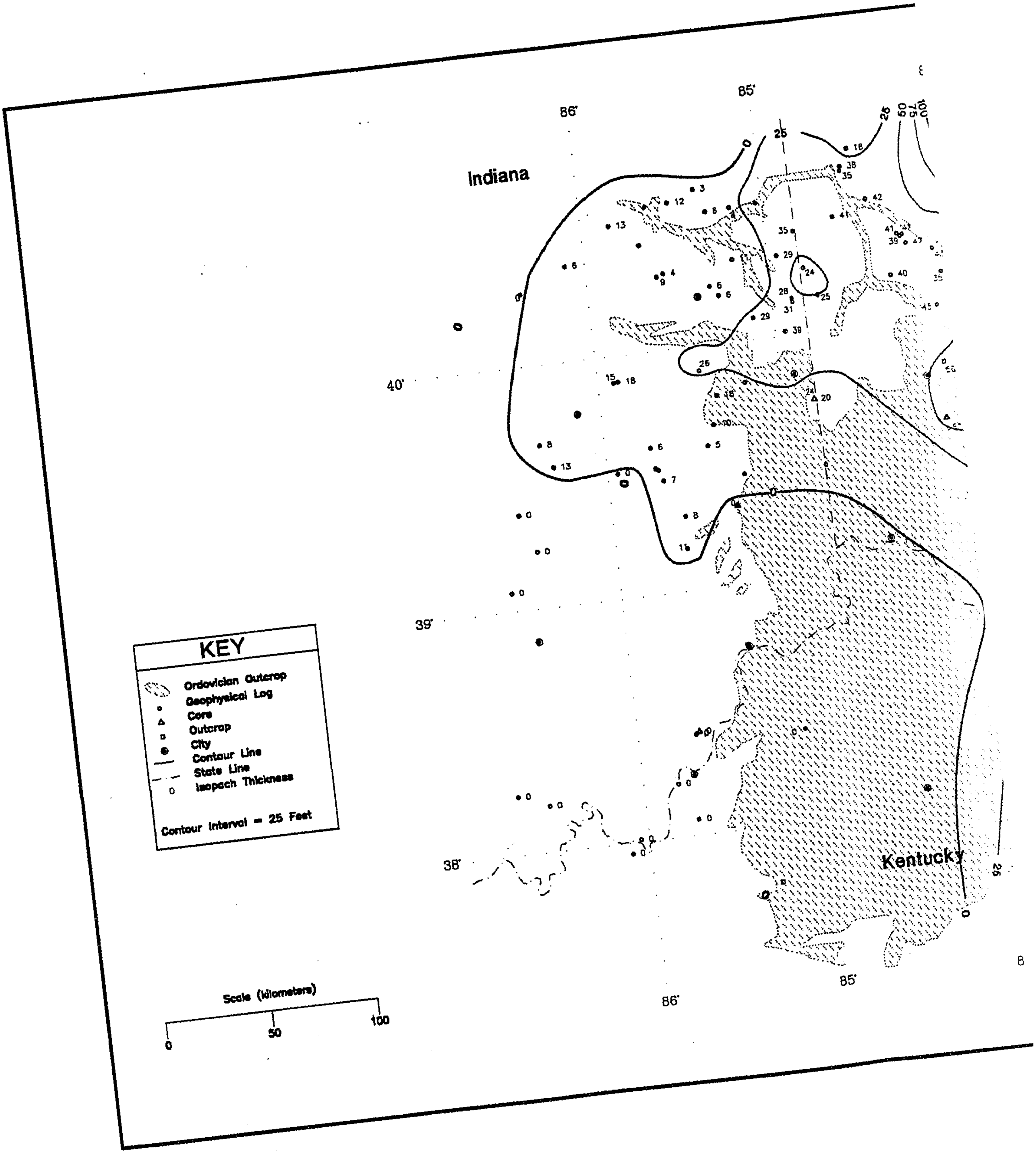
Facies D provides an excellent example of a shallowing-upwards, prograding shale unit. The gray to green shales are found at the base of the facies and towards the western extent of the unit represent distal clastic deposition and the reddish shales that overlie the gray to green shales that represent shallow subtidal to supratidal deposition are found in the eastern half of the field area. Thus, based on a Taconic Highlands source to the east, the red shales are proximal to the gray shales and Facies D prograded to the west across Facies A and B. In addition Facies D is not part of the carbonate ramp associated with Facies A, B, and C, but rather a distal portion of a clastic wedge that prograded westward across the Richmond epicontinental shelf from the Appalachian Basin. Conodont correlations by Sweet (1979) indicate that the base of this clastic facies is younger toward the west, which supports the inferred westward progradation.

8.2 Geophysical Log Correlation

Facies D is easily recognizable in geophysical logs where Facies B is present by its high gamma ray deflection and correspondingly low neutron deflection. It always overlies Facies B and intertongues with Facies B and or Facies E. Thus, where Facies B or E occur Facies D's high gamma ray and low neutron deflection strikingly contrasts the low gamma ray and high neutron deflections of the carbonate-rich Facies B and E. However, where Facies D overlies the shale-rich Facies A, the contact is more difficult to identify because of similarities in the geophysical log response. The overall character of the gamma ray deflection must be examined to differentiate the two facies. More specifically, Facies A contains more limestone beds, and thus, has more limestone "kicks" in the geophysical logs than Facies D. As a result, geophysical log correlations to cores and nearby outcrops were used to delineate this facies in the subsurface as shown on Figures 10 and 11. The correlations in Kentucky were based upon geophysical log picks in Highland County, Ohio.

8.3 Thickness and Distribution of Facies D

The isopach map of Facies D provided in Figure 40 shows that Facies D ranges in thickness up to 152 feet (46 meters) and is commonly 30 to 50 feet (9 to 15 meters) thick. Facies D is thickest along the northeastern margin of the tristate region and thins progressively westward. Facies D is most distinctive in the eastern portion of the field area where it


Indiana
Kentucky
86°
85°
40°
39°
38°
KEY
Ordovician Outcrop
Geophysical Log
Core
Outcrop
City
Contour Line
State Line
Isopach Thickness
Contour Interval = 25 Feet
Scale (kilometers)
0
50
100

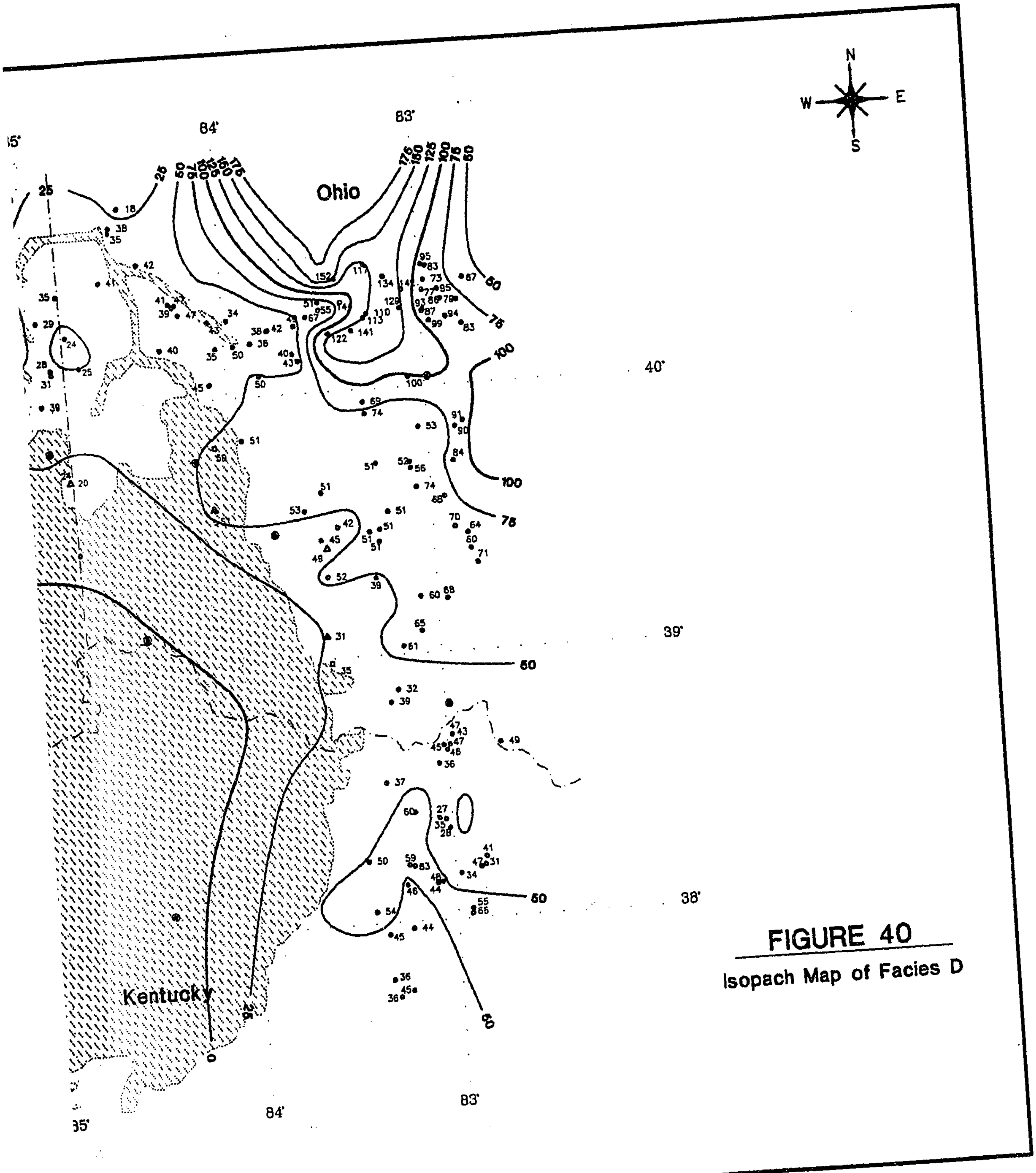


FIGURE 40

Isopach Map of Facies D

is contains grayish red banding. Toward the west, it thins to less than 20 feet (6 meters) and looses its reddish banding and siltstone content. The west to east cross section illustrated on Figures 17 and 18 shows the east to west gradation of Facies D with Facies B and E. However, the similarity between Facies A and D geophysical log signatures on the eastern margin of the study area makes mapping of these intervals difficult.

9.0 FACIES E - FOSSILIFEROUS, WAVY- TO NODULAR-BEDDED CARBONATES MIXED WITH CLASTICS

Facies E is characterized by wavy- to nodular-bedded grainstones, wackestones, and packstones that contain abundant fossils, many of which are large, robust, and well preserved. This facies has a high shale content in Ohio and east-central Indiana, and a lower shale content in southwestern Ohio and southernmost Indiana. Facies E overlies the massive-banded dolomudstone facies (Facies C) in southwestern Indiana and gradationally intertongues with the dolomite claystone and siltstone facies (Facies D) in east-central Indiana and Ohio. However, Facies E is distinguishable from Facies C by being fossiliferous, bedded, and less dolomitic and from Facies D by containing abundant thick carbonate beds.

Throughout much of the study area, the top of Facies E is the Ordovician-Silurian unconformity with the exceptions of:

- Northeastern Indiana, where Facies F overlies Facies E; and
- East-central Indiana and Ohio where Facies D overlies Facies E.

Based on lithologic, paleontologic, and stratigraphic data collected from this study and others, Facies E sediments were deposited in a proximal intracratonic ramp depositional environment.

9.1 Sedimentologic and Paleontologic Characteristics

Facies E, which is the most variable unit examined during this study, is similar in lithologic and paleontologic character to Facies B. Both units are dominantly composed of wavy- to nodular-bedded wackestones, packstones, and grainstones that generally contain large and robust fossils. However, Facies E has a higher shale content in east-central Indiana and in southwestern Ohio where it intertongues with the dolomitic claystone and siltstone facies. In areas where Facies E is shale rich, it consists of yellowish gray (5Y 7/2) grainstones composed of bryozoan, brachiopod, and fossil fragments overlying grayish green (5G 5/7) to grayish olive green (5 GY 3/2) extremely fossiliferous wackestones and bioturbated, fossiliferous, shales.

In southeastern Indiana, the facies is dominated by bioturbated, fossiliferous dolomite; brown- to tan-colored wackestones; packstones; and grainstones containing abundant bryozoans and brachiopods with shale. Much of the carbonate appears to be bryozoan colonies covered with lime mud. Because Facies E interfingers with Facies C in southeastern Indiana, the contact between these two facies is often difficult to identify. During this study, the contact was determined to be the point at which the strata become more fossiliferous and bedded. Like the contact between Facies B and C, this contact was chosen because it is discernible on geophysical logs. Photographs of Facies E in core and outcrop are included as Figures 41 and 42.

Only a limited amount of paleontological data were available for Facies E because this facies was primarily described in core. The fossils found in the core samples include many unidentified brachiopods, trepostome bryozoans, gastropods, and echinoderms. The genera identified at the Elkhorn Falls locality include the brachiopods *Hebertella*, *Leptaena*, and *Platystrophia*, the trilobite *Isotelus*, and the rod-shaped stromotoporoid *Beatrecia*. Hay (1982) reported the horned

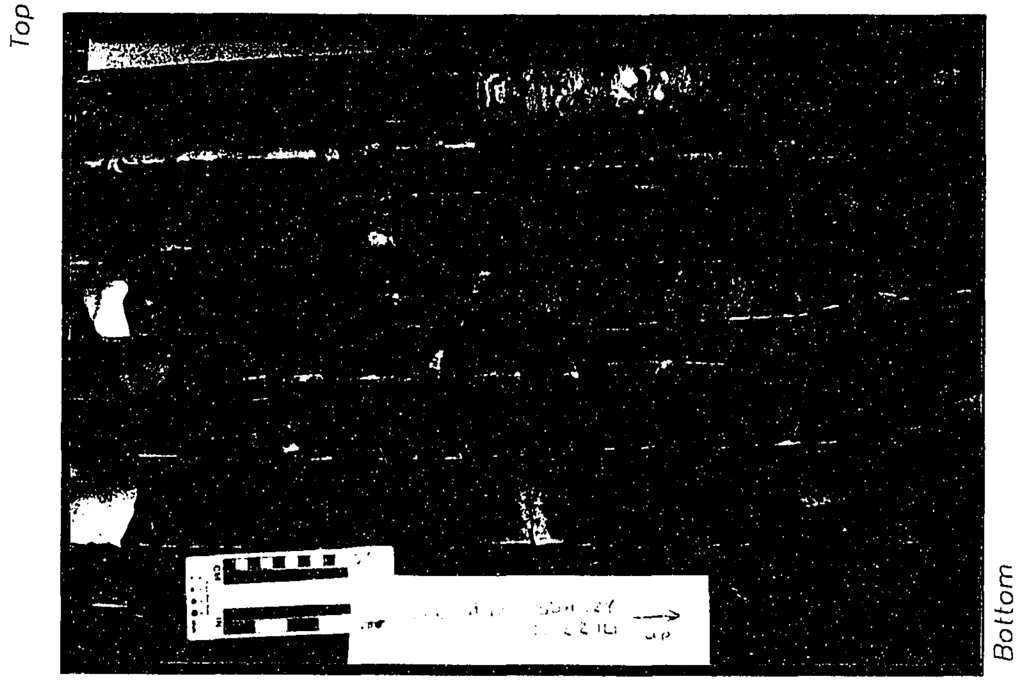


Figure 41 - Photograph of Decatur County Core SDH #124, which illustrates the irregular-bedded nature of the carbonate-rich interval. Arrow points to increasing depths.

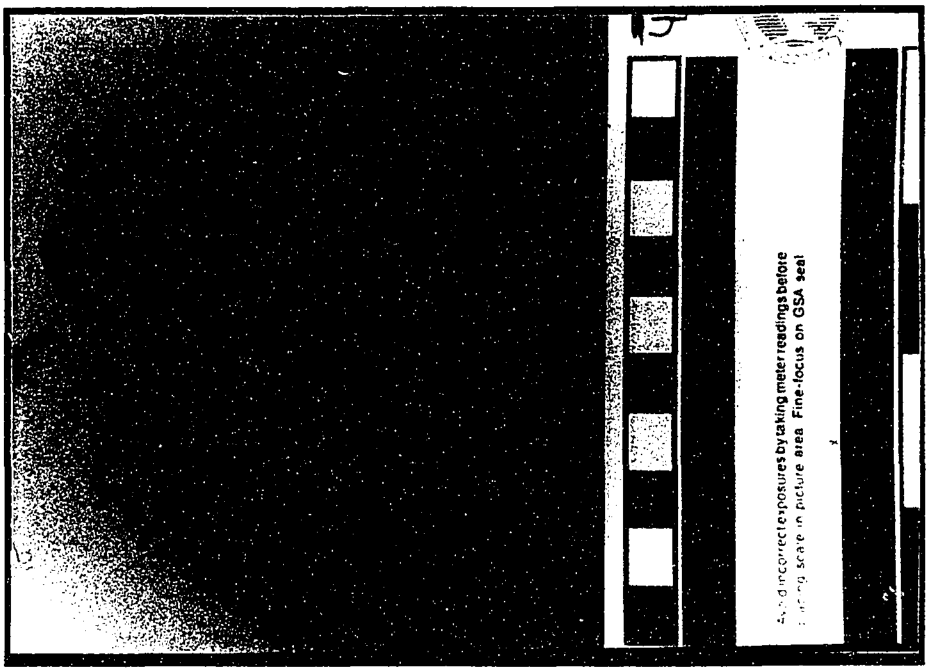


Figure 42a - Algal laminated wackestone from Facies E collected at the Elkhorn Falls Section.

Figure 42b - Burrowed micstone from Facies E collected at the Elkhorn Falls Section.

coral *Grewingkia canadensis* and the colonial coral *Tetradium* in this section.

In general, the lithology and paleontology of Facies E are similar to those of Facies B in that they are both generally fossil-rich, nodular- to wavy-bedded carbonate-rich facies. Most of the fossils are bryozoans and brachiopods and the depositional environment assigned to these facies is that of a proximal intracratonic ramp. However, a greater lithologic variability exists within Facies E as a result of more complex interactions between the distal clastic wedge from the east and the carbonate-dominated proximal cratonic ramp to the north and south and decreased water depths within the basin. In addition, a decreasing shale content toward the south is likely caused by the restriction of clastic influx by the prograding carbonate ramp. The increased, fine-grained dolomite content towards the south and the presence of *Tetradium* corals and stromatoporoids throughout the section reported by Betz (1984) suggest that this facies was shallower than Facies B.

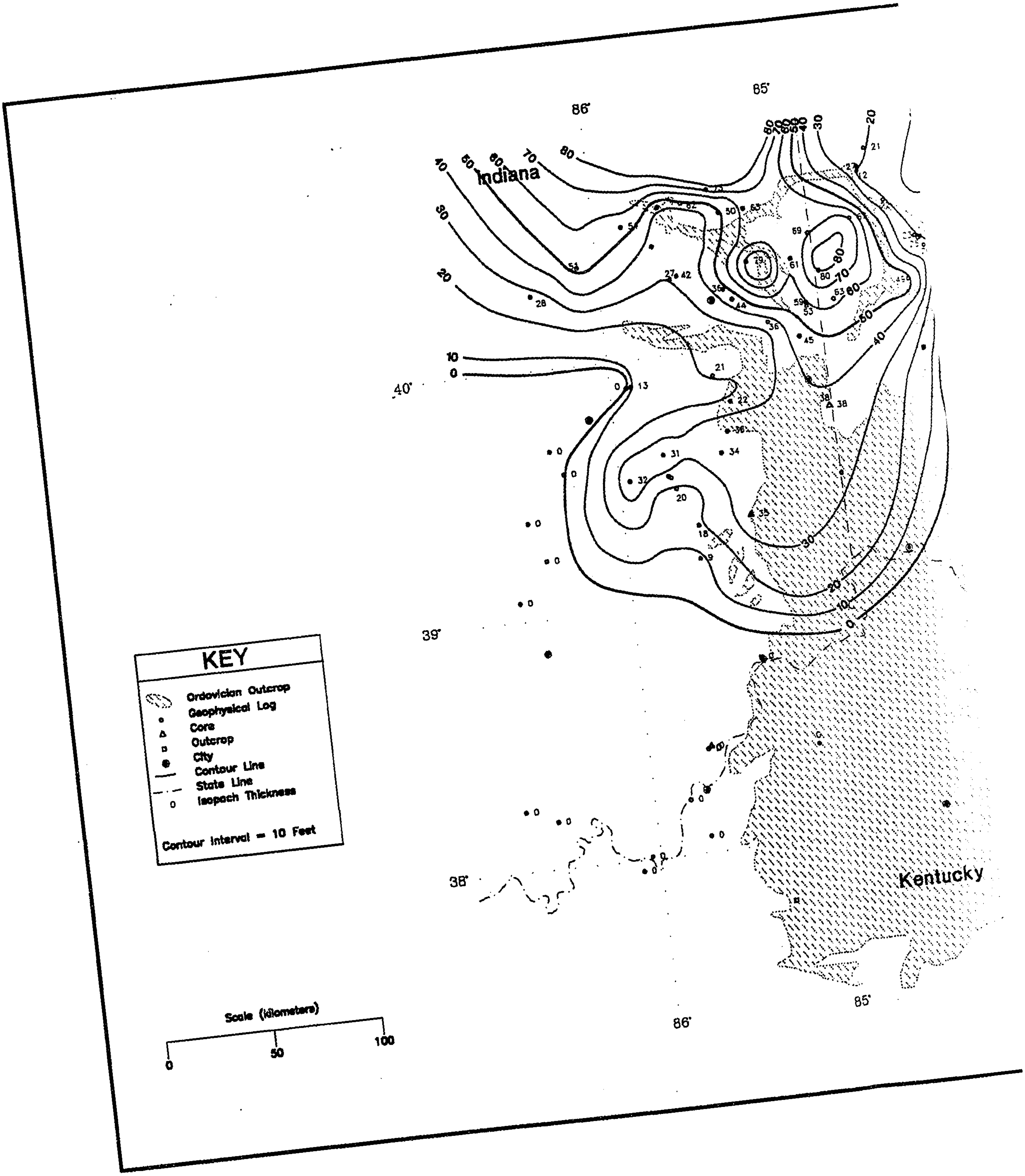
In contrast to Betz (1984), this study considers Facies D to represent a distal clastic wedge prograding from the east during low sea level stands and not part of a natural succession of the intracratonic ramp. Thus, the retrogradation of Facies E over the shallow-water to supratidal Facies C and D is the result of a relative sea level rise. This study differs from Tobin (1982) in that it considers Facies E (*i.e.*, Tobin's Upper Whitewater Formation) as a separate transgressive unit that occurs above Facies D (*i.e.*, Tobin's Elkhorn Formation) or Facies C (*i.e.*, Tobin's Saluda Formation).

9.2 Geophysical Log Correlation

Facies E is recognizable in geophysical logs by low gamma ray and high neutron log deflections. Although its geophysical log signature is similar in appearance to Facies B, Facies E can be differentiated by its higher shale content and that it its position which is always above Facies C or Facies D.

9.3 Thickness and Distribution of Facies E

An isopach map of Facies E compiled from geophysical logs, outcrops, and cores is provided on Figure 43. The map shows that Facies E ranges up to 73 feet (22 meters) thick, and trends in a peninsular shape from the north to south along the Ohio-Indiana border. The easternmost extent of Facies E is near Dayton, Ohio, and the westernmost extent is near Indianapolis, Indiana. Facies E thins rapidly southward and westward as shown on Figures 15, 16, and 21. These correlations show an increase in relative sea level as evidenced by proximal ramp carbonates being deposited over tidal flat and distal clastic wedge shales.


86°
85°
Indiana
Kentucky
40°
39°
38°
KEY
Ordovician Outcrop
Geophysical Log
Core
Outcrop
City
Contour Line
State Line
Isopach Thickness
Contour Interval = 10 Feet
Scale (kilometers)
0
50
100

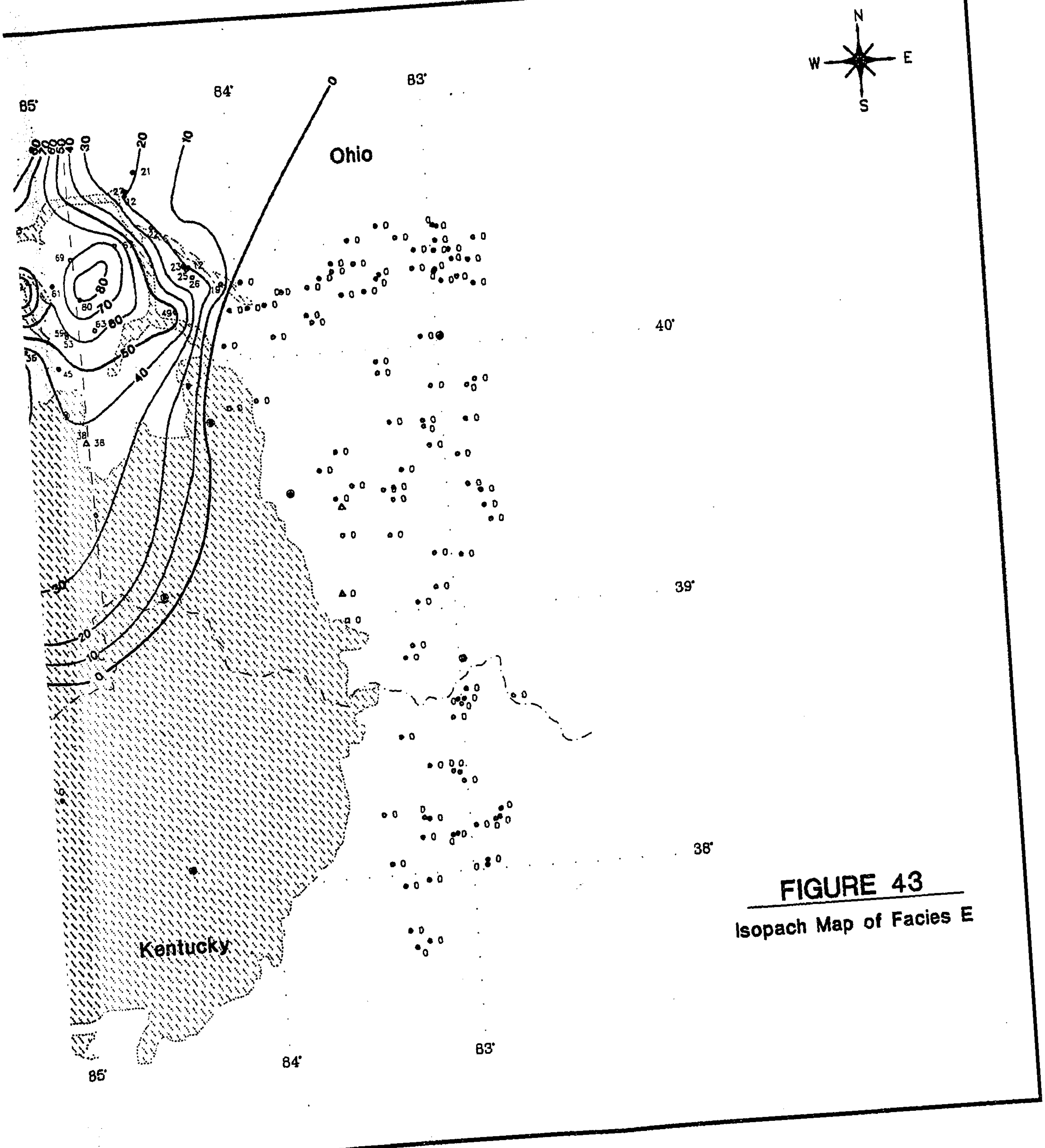


FIGURE 43

Isopach Map of Facies E

10.0 FACIES F: MASSIVE DOLOMUDSTONES

Facies F is characterized by massive, banded, generally unfossiliferous dolomudstones. Because Facies F was only observed in one core (*i.e.*, SDH #236), only limited information is available to determine its lithologic variability and faunal content. Facies F appears to overlie or interbed with Facies E and based upon the limited data available, Facies F represents intertidal to supratidal deposition. No information is available about biostratigraphic time correlations within this facies.

10.1 Sedimentologic and Paleontologic Characteristics

Facies F consists of massive, banded, yellowish gray (5Y 7/2) and olive gray (5Y 3/2) dolomudstones. The olive gray laminae are less than 3 mm thick and may exhibit a frequency of up to 10 laminae per cm. The yellowish gray bands are range from 1 to 5 cm in thickness. At the top of the facies, the banding is not present and the dolomudstones are olive gray (5Y 3/2) to grayish olive green (5GY 3/2), and bedded up to 20 cm thick. The entire facies is generally unfossiliferous except for a few brachiopods and bryozoans that occur in some of the yellowish gray layers. However, it appears that some of the olive gray layers may be algal laminates.

Based on the limited amount of data available, this facies is assigned to in a intertidal to supratidal depositional environment. The massive, banded dolomudstones, which contain algal laminites, are by characteristic a typical lithology expected from a tidal flat environment. Facies F has several lithologic, sedimentologic, and paleontologic characteristics similar to the tidal flat depositional environment characterized in Facies C including:

- Massive dolomudstones lithologies,
- Paucity of few fossils, and
- Laminations and banding.

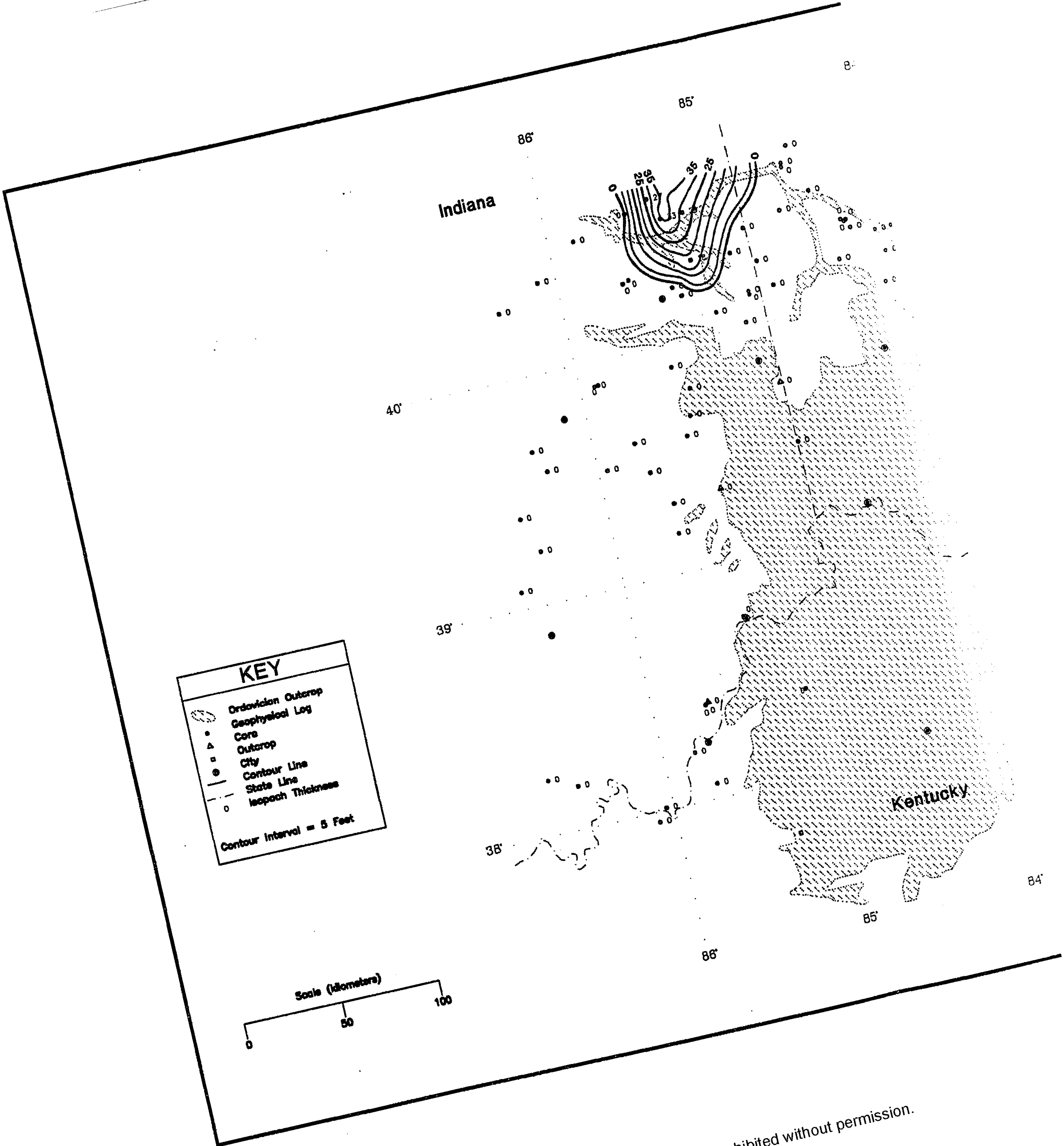
Facies F may be the tidal flat facies shoreward of Facies E or a third regressive sequence. During this study, it was assigned to be a lateral equivalent of Facies E because of a lack of data and a recognition that sequences should not be delineated from a single core.

10.2 Geophysical Log Correlation

Facies F is characterized by a low gamma ray and a high neutron deflection. Because Facies F always overlies Facies E, the lowest gamma ray deflection above Facies E is always chosen as Facies F.

10.3 Thickness and Distribution of Facies F

As shown on the isopach map of presented in (Figure 44), the thickness of Facies F ranges up to 33 feet (11 meters) and the areal extent is limited to the northern portion of the study area near the Ohio-Indiana border. Because this facies is only present in a few geophysical logs and one core at the margin of the study area, additional efforts are needed to discern Facies F thickness trends and distributions. The top of this facies marks the final regression at the end of Richmondian deposition as characterized by a 2^{nd} order regional unconformity (*i.e.*, the Ordovician-Silurian Unconformity).


Indiana
Kentucky
86°
85°
84°
40°
39°
38°
KEY
Ordovician Outcrop
Geophysical Log
Core
Outcrop
City
Contour Line
State Line
Isopach Thickness
Contour Interval = 5 Feet
Scale (kilometers)
0
50
100

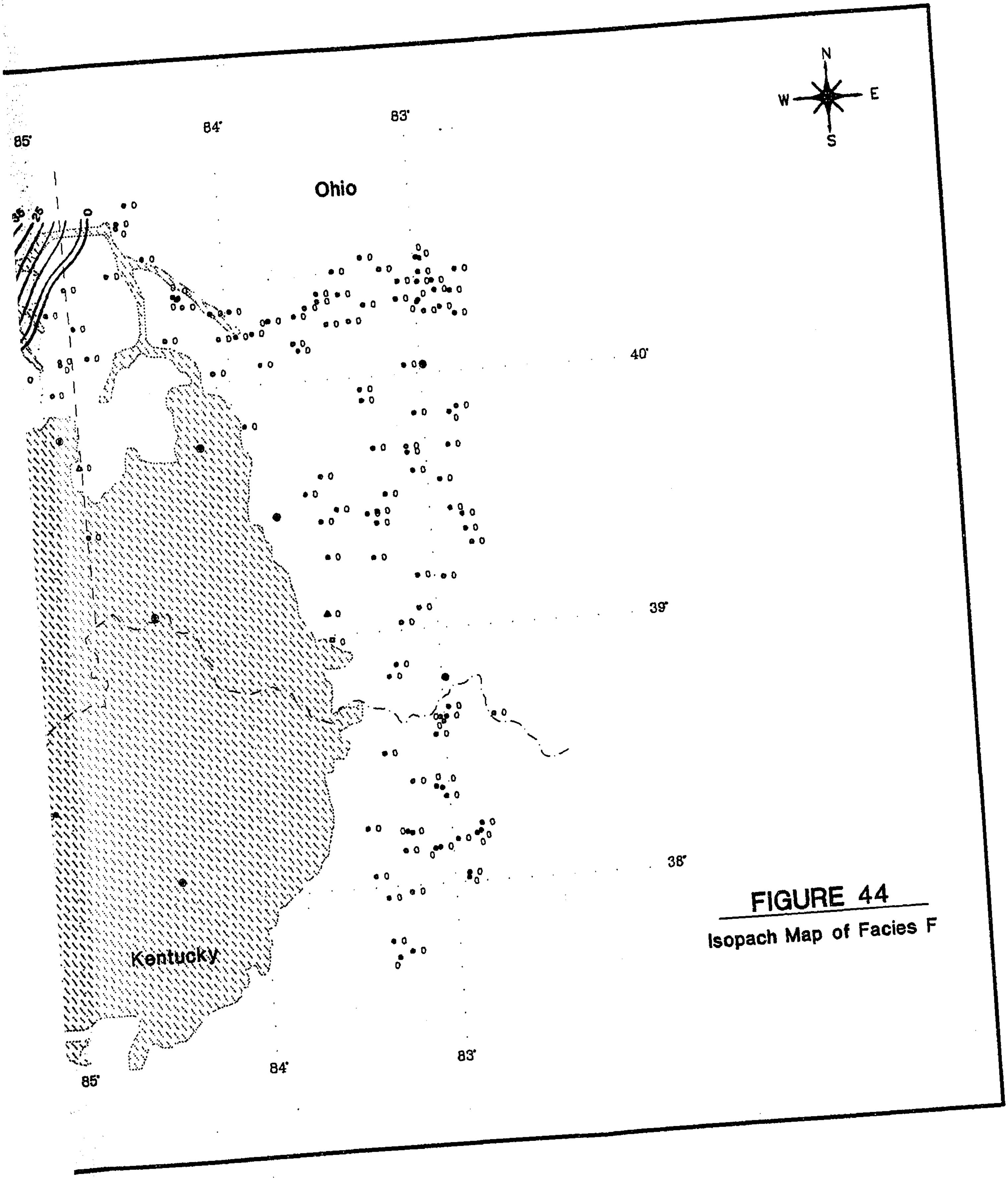


FIGURE 44

Isopach Map of Facies F

11.0 SEQUENCE STRATIGRAPHY OF THE RICHMOND

The various stratal units identified in the Richmond are discussed in the following subsections to provide a basis for the sequence stratigraphic interpretation of the associated geophysical logs.

11.1 Identified Sequence Stratigraphic Units

The stratal units outlined by Van Wagoner *et al.* (1990) include laminae, laminae sets, beds, bedsets, parasequences, parasequence sets, and sequences. As shown in Appendices C and D, laminae, laminae sets, and beds were observed in outcrops and core samples examined during this study. Laminae and laminae sets were most commonly observed in: shales, siltstones, and carbonate layers as cross beds, storm beds and tidal deposits. Although individual beds were observed in all of the cores and outcrops, they were not identifiable in geophysical logs because of the lack of sensitivity of the logging tool. Bedsets are common in Facies A and occur as shale-carbonate storm bed couplets as indicated by Tobin (1982). These bedsets conform to the definition of Van

Wagoner *et al.* (1990) in that they are genetically related, relatively conformable, and bounded by surfaces of erosion or their correlative conformities. As with individual beds, bedset were not identified in geophysical logs because of the lower sensitivity of the gamma ray tool.

The stratal stacking of these bedsets form the parasequences used to delineate sequences in this study. Parasequences were observed in all geophysical logs examined. These parasequences, which range from a few feet thick to tens of feet thick are composed of rhythmically arranged beds and bedsets. Only some of the parasequences thicker than 3 feet (1 meter) were directly identified on the geophysical logs as shown on Figure 45 which documents smaller parasequences in Clark County Core SDH #332 and on the associated geophysical log. In addition parasequences of similar lithologic composition could not be identified. The parasequences of this study correspond to the 5^{th} order cycles of Jennette and Pryor (1993) and are of the same order as Tobin's (1982) megacycles. However the distances between the geophysical logs prohibited correlations of individual parasequences within the study area.

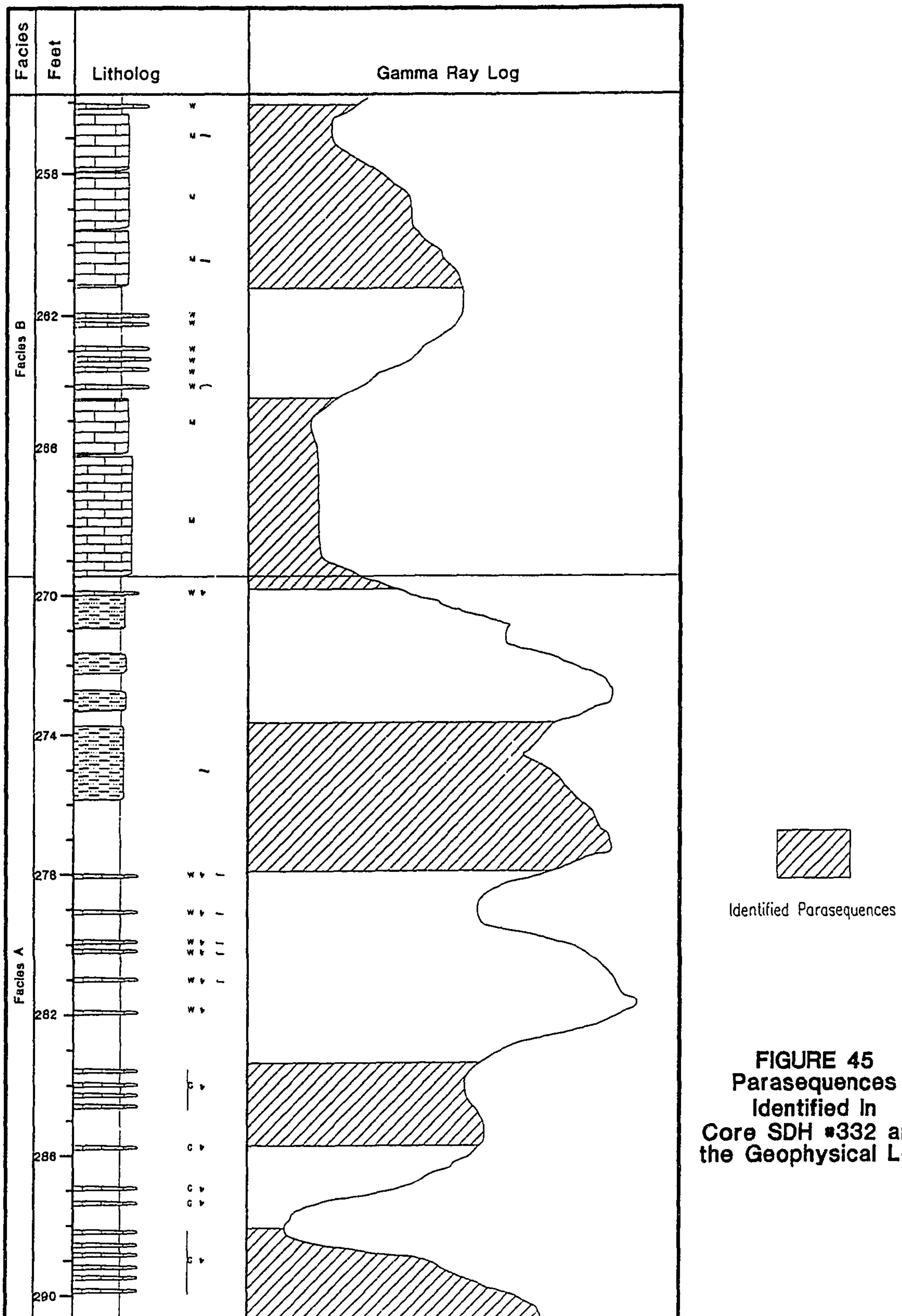


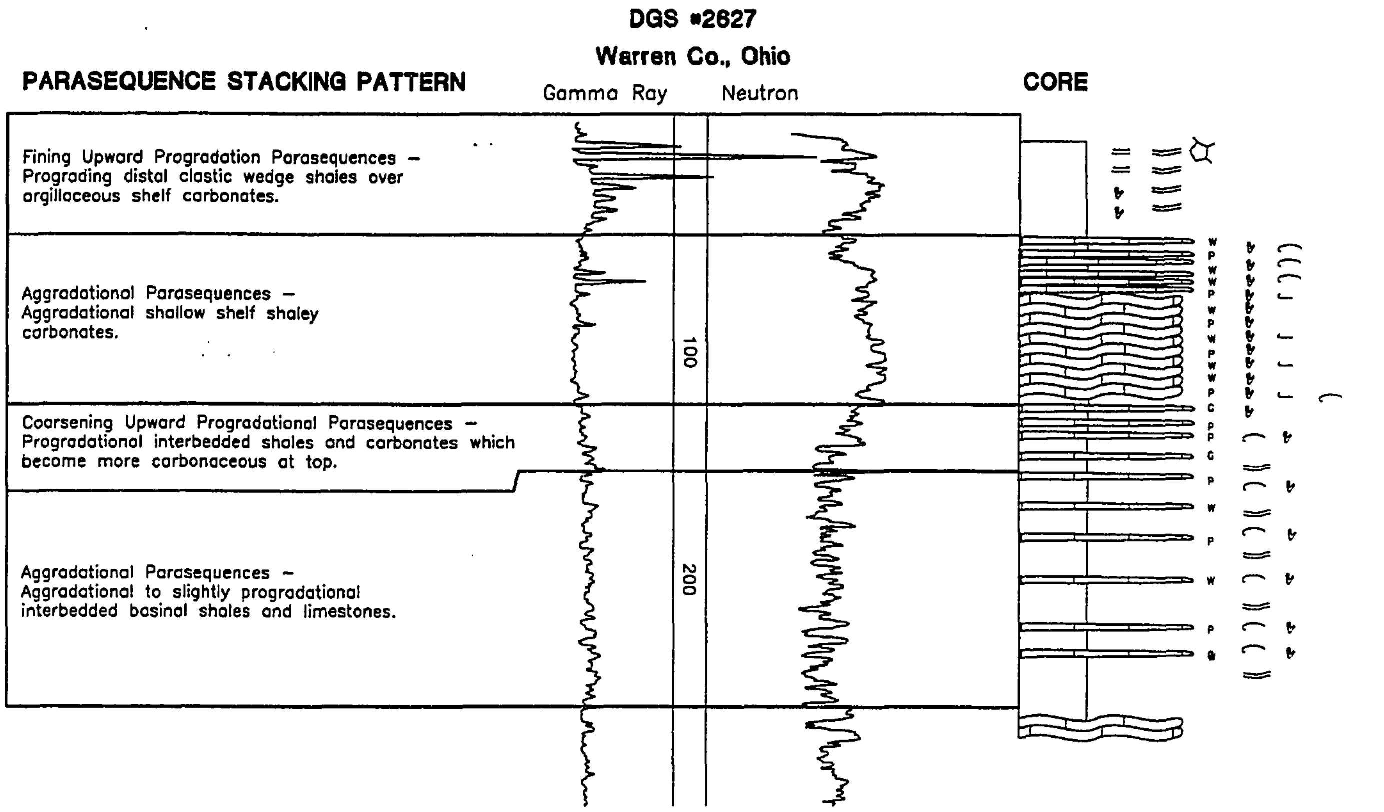
FIGURE 45
Parasequences Identified In Core SDH #332 and the Geophysical Log

The following five parasequence set stratal stacking patterns were identified during this study:

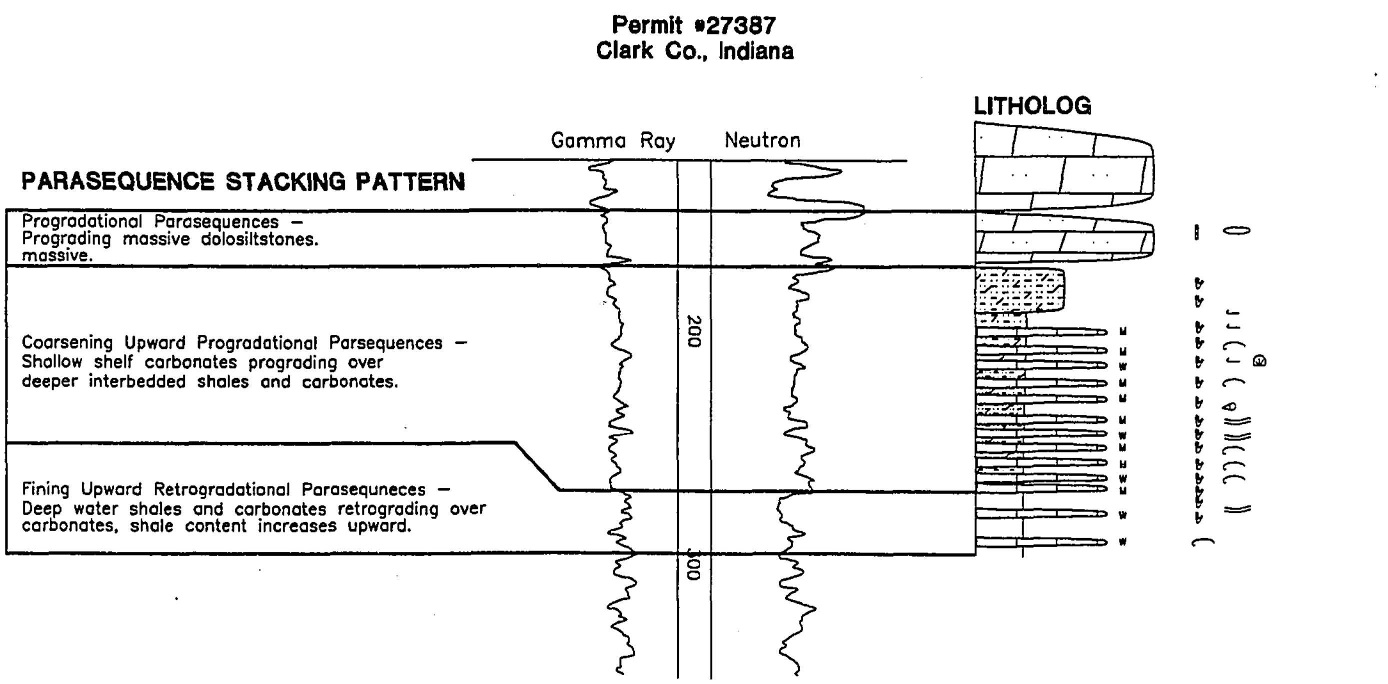
- Fining upward progradational,
- Fining upward retrogradational,
- Coarsening upward progradational,
- Coarsening upward retrogradational, and
- Aggradational.

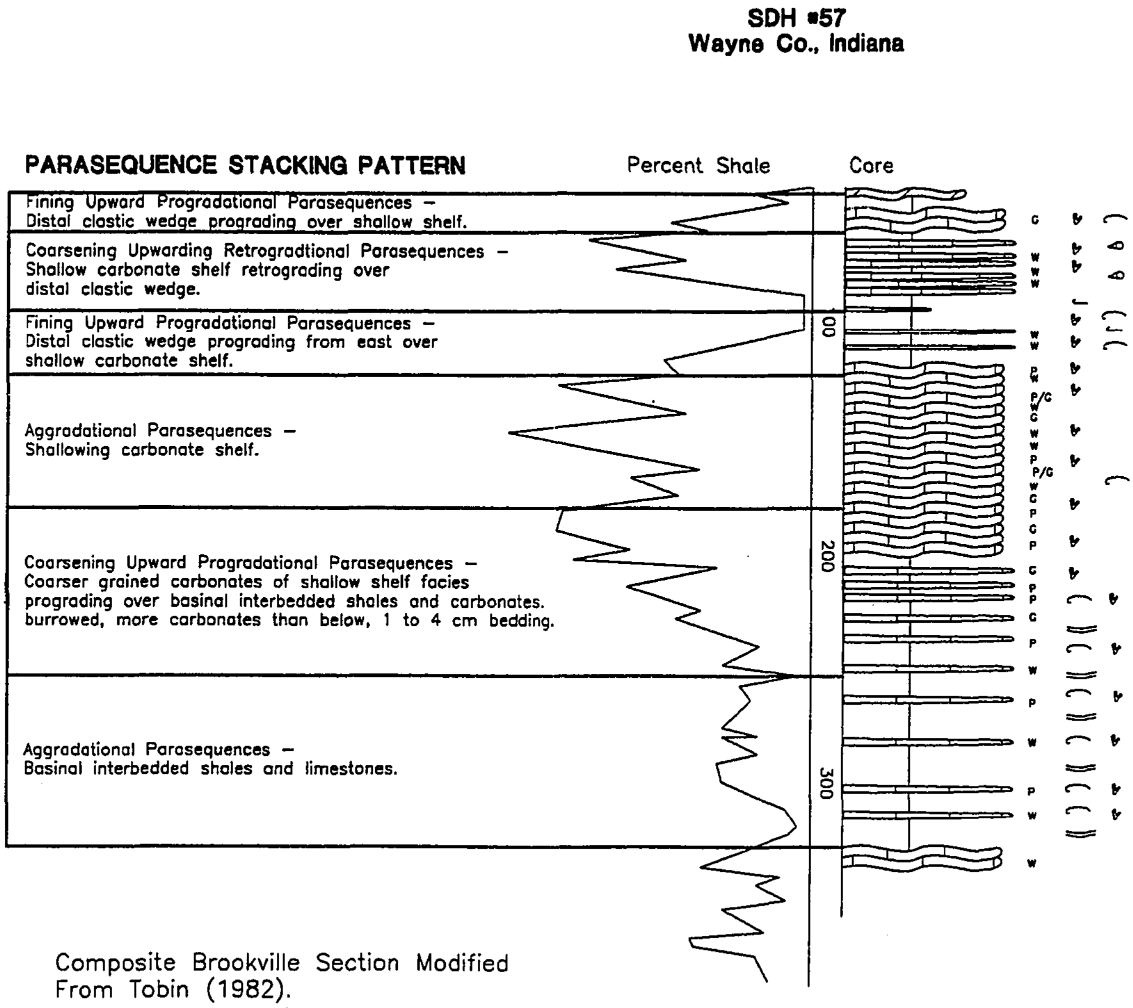
Characteristic log responses to each of these parasequence set stacking patterns are illustrated on Figure 46. These patterns were used to: correlate stratal stacking patterns in the geophysical logs, identify regional surfaces, and infer sea level changes.

Fining-upward progradational and retrogradational parasequence sets have similar geophysical log responses consisting of a low basal gamma ray deflection which increases upwards. Cores DGS #2627 and DGS #332 demonstrate these stacking patterns as shown in Figure 46. During this study, these two parasequence sets were differentiated by their inferred depositional environments as interpreted from core and outcrop data. Fining-upward progradational packages are common in Facies D in the eastern half of the study area. This stacking pattern



Note: Core described on a bed by bed scale to 106 bgs, then desribed in general.





Notes: Composite Brookville Section Modified From Tobin (1982).

Shale Percentage Log Obtained From The Indiana Geological Survey.

Figure 46

Parasequence Stacking Patterns In the Richmond Determined From Cores and Cross Sections

is the result of the progradation of the distal clastic wedge over the proximal intracratonic ramp carbonates of Facies B. The retrogradational parasequence stacking occurs in southeastern Indiana where increasing water depths result in the retrogradation of shale-rich Facies A over the carbonate-rich Arnheim Formation.

The shoaling progradational parasequence set is common in the upper half of the Richmond strata. Its characteristic log response includes a high gamma ray response at its base which decreases upward (Figure 46). The progradation of the proximal ramp carbonates over the distal ramp shales which are characteristic Subfacies A_2 is an excellent example of this stacking pattern. This stacking pattern was likely caused by either a sea level fall or the progradation of the intracratonic ramp during a sea level standstill. The progradation of the ramp during a standstill was chosen during this investigation because there was not an associated progradation of clastics from the east.

Coarsening-upward retrogradational parasequence sets superficially resemble shoaling parasequence sets because the log response is characteristic of a shale shoaling into a carbonate upward. However, near the top of the Richmond strata, shallow water carbonates prograde over intertidal to supratidal shales of Facies D giving a similar log response. The two parasequences are distinguished using depositional environment interpretations from core and outcrop data. This parasequence set marks a change from relatively low sea level to an increasing sea level as the result of increasing eustatic sea level or basin subsidence. Figures 17 and 18 demonstrate this stacking pattern with the shallow-shelf Facies E retrograding over clastic wedge Facies D.

The aggradational parasequence sets show no trend toward fining or coarsening and are likely the result of balance between sedimentation, basin subsidence, and sea level fluctuations (Van Wagoner *et al.*, 1990). This pattern is common near the base of Facies A and in Facies B where thick sequences of similar strata are deposited in this manner.

Based on these stratal stacking patterns, two sequences were delineated in the Richmond. As described in detail in the next subsections, both of these sequences have significant sedimentologic and paleontologic characteristics.

11.2 Delineation of Sequence Boundaries

According to Van Wagoner *et al.* (1990), the base of the sequence should correspond to the base of the *lowstand systems tract.* This selection is based on a shelf break model where sea level falls cause erosion and incised valleys nearshore and the buildup of turbidite fans offshore beyond the shelf break. Data collected by Tobin (1982), Walters (1988), and during this study indicates that deposition in the tristate region during the Late Ordovician more closely resembled a intracratonic ramp which does not have a distinct shelf break in which deep water turbidites and lime mud buildups are deposited. Because, significant buildups of clastic lowstand fans should not generally occur in intracratonic ramp settings, minimal lowstand and shelf-margin deposition is expected for the following reasons:

- Lowering of sea level reduces potential for carbonate production owing to less accommodation space; and
- The low depositional slope prohibits the development of incised valleys.

Based on Van Wagoners's model, the sequence boundary can be placed at either:

- The base of each carbonate rich aggradational system present in the middle of the basin, or
- The sharp contact between that carbonate rich unit and the overlying shale or its correlative aggradational surface.

The selection of the base of the underlying aggradational carbonate assumes that this carbonate is the lowstand or transgressive systems tract resulting from a sea level fall or basin uplift. However, because carbonate ramps may also prograde as a result of the sedimentation rate exceeding the sea level rise or accommodation space, it is unclear at what point the *highstand systems* tract would become the *lowstand systems tract*. However, if a sea level standstill results in a progradation, the selected boundary would be gradational and diachronous.

Another potential choice for the sequence boundary is the contact underlying Facies A which at first inspection, appears to represent the maximum flooding surface. According to Van Wagoner *et al.* (1990), this surface should not be chosen because flooding surfaces are diachronous and commonly overlain by condensed sections.

11.3 Delineation Of Sequences

This study places the beginning of the first sequence at the base of the sharp contact between the underlying carbonate and base of the Facies A shales for the following reasons:

- A sharp contact can be easily identified,
- The base of Facies A is correlatable across the study area, and
- Features at this contact present evidence of erosion or a low sea level stand.

As shown on all of the cross sections (Figures 15 through 21), the sharp contact between the ramp carbonates and basinal shales was easily selected on most geophysical logs by the aggradational stacking patterns at the base of Facies A present in the northern two-thirds of the study area. In addition, cores SDH #124 and #332 contain an oxidized fossil hash immediately below and oxidized silt-filled burrows immediately above this contact. The zone of intense burrowing in these cores was also noted Wayne County Core SDH #57 which is located in the center of the basin. This burrowing is likely the result of the initial, infaunal colonization of the sediments during the transgression. In addition, a sandy pebble conglomerate is present at the base of this contact in the Butler County Core (Ohio Geological Survey files) which indicates the potential presence of an unconformity. Additional studies on the Arnheim Formation need to be completed to verify the selected sequence boundary.

The lower parasequences of the first sequence are aggradational throughout the northern two-thirds of the study area. The aggradational parasequence stacking pattern at the base of Facies A is assigned to the *highstand systems tract* position because the distal ramp shale-dominated sediments were being deposited in the proximal ramp position. However, as shown in Figure 46 and Appendix B, the base of the Clark County Core SDH #332 may be retrogradational, as indicated by a gradual decrease in carbonate content from the fossil hash at approximately 300 feet to the trilobite-dominated, shale-rich interval at 278 feet. Further studies may indicate that the base of Facies A is actually a transgressive systems tract. The slightly progradational to moderately progradational upper portion of the first sequence is also assigned to the *highstand systems tract* because no evidence was found to document a shift in parasequence stacking patterns.

The top of the first sequence is selected as the base of the massive buildups of tidal-flat dolosiltstones and dolomudstones (*i.e.*, Facies C of the Madison outcrop) in the proximal ramp position and the coinciding progradation of the clastic wedge westward (*i.e.*, Facies D of eastern Ohio). The *Tetradium* coral zone at the Brookville roadcuts is a marker bed that coincides with the progradation of Facies C into the basin. The farthest basinward progradation of intertidal to supratidal environments during the Latest Ordovician mark a sea level fall and the start of a new sequence with the deposition of a *lowstand systems tract*. The progradation of intertidal to supratidal facies into southeastern Indiana is unique to the Richmond. The strongly progradational parasequence stacking patterns of Facies C and Facies D are correlative across the basin and form the *lowstand systems tract* of the second sequence. The retrogradational parasequence stacking pattern of the proximal ramp Facies E over the shallow subtidal to supratidal Facies C and the clastic wedge Facies D, marks the *transgressive systems tract* of the second sequence.

The relationship of the tidal flat deposited Facies F to the second sequence is not clear because this facies was observed in only one core. Because the fossiliferous grainstones at the base of the core suggest that it may be progradational, Facies F could represent the base of a third sequence. However, because of the lack of data related to Facies F, this study places Facies F as lateral facies equivalent of Facies E. The top of the sequence is a 2^{nd} order unconformity (*i.e.*, Silurian-Ordovician Unconformity) which is often discernible by its lithology. According to Sweet (1979) the unconformity is smallest in southeast Indiana. However, because Sweet (1979), did not incorporate the subsurface data to the north and east, younger Ordovician strata may be present in these areas.

12.0 SEQUENCE STRATIGRAPHIC DEPOSITIONAL MODEL FOR THE RICHMOND

A detailed sequence stratigraphic model for the genesis of Richmond strata in the tristate area has been constructed from the cores, outcrops, and geophysical logs examined as described previously. The following five events are proposed for the study area:

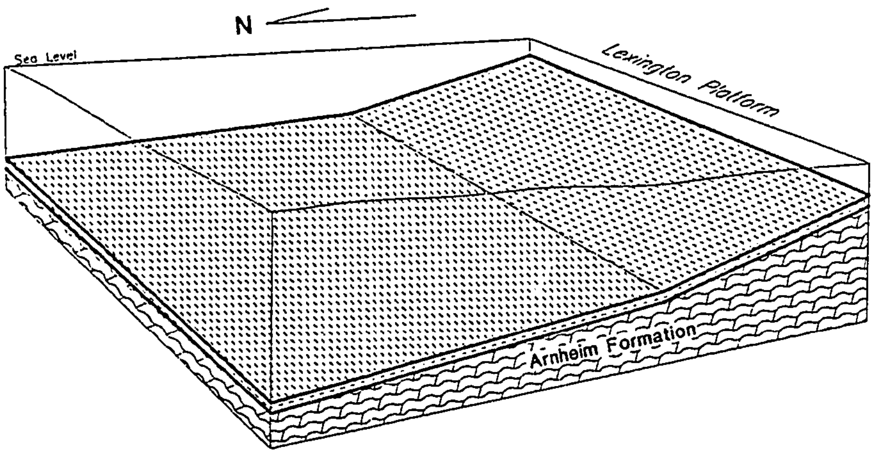
- Initial basin flooding and the deposition of Facies A shales interbedded with thin limestones over a regional unconformity.
- The development of a mixed carbonate/clastic ramp on the Lexington Platform evidenced by the deposition of proximal mixed carbonates and shales.
- A regression resulting in the progradation of the shallow subtidal to supratidal ramp facies into the basin and concurrent progradation of the distal clastic wedge facies westward.
- A second flooding event resulting in migration of the carbonate/clastic ramp shoreward.
- A final regression at the Ordovician-Silurian Boundary marking the end of Late Ordovician sedimentation.

Each of the foregoing events is discussed in detail in the following sections.

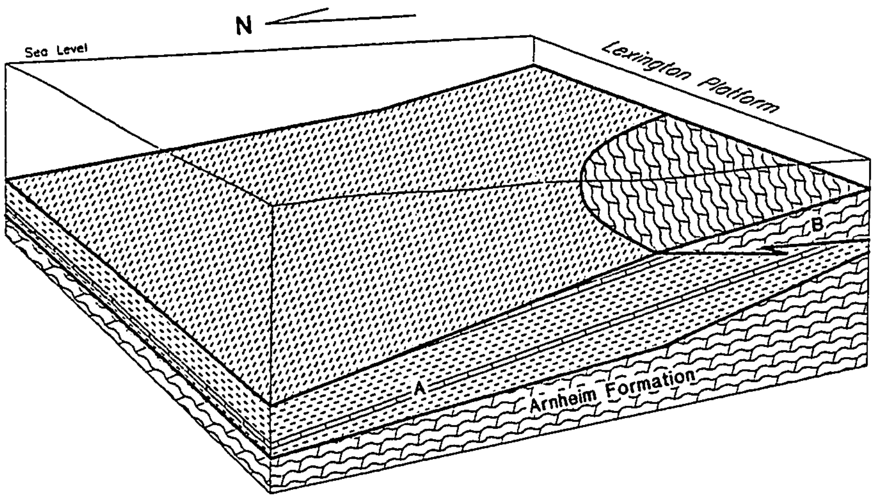
12.1 Initial Flooding

The initial flooding is marked by the onset of basinal shale and carbonate deposition of Facies A on the margin of the Lexington Platform. Figure 47 is a paleogeographic reconstruction that shows the initial flooding of the Lexington Platform. The base of Facies A marks a transition from deposition of shallow water, carbonate-dominated to deeper water, storm-dominated clastics interbedded with thin carbonates (Tobin, 1982). According to the geophysical logs, the underlying sequence was carbonate dominated on the Lexington Platform and shale-rich in the basin. This event marks a sea level rise in the basin. Based upon data collected in this study, the *lowstand systems tract* is thin or absent.

In this study, the base of Facies A is considered to be a Type 2 sequence boundary and the Facies A deposition represents early *highstand systems tract* development because the base of



Initial flooding of the Lexington Platform and the beginning of the deposition of Facies A and the base of the HST.



Development of the carbonate shelf Facies B during high sea level stand.

Figure 47

Paleogeography Of Early Richmondian Depositional Environments

the sequence is not marked by a relative sea level fall accompanied by the deposition of a *lowstand systems tract* but rather a thin-to-absent *transgressive systems tract* followed by the development of a *highstand systems tract*. This study concurs with Holland (1993) that the gastropod coquina beds in the Bedford, Kentucky area mark the base of the sequence and comprise a *transgressive systems tract*. Although the author has examined this outcrop several times, the derived data is not included in this study because: (1) the coquina has a limited areal extent; (2) has been previously mapped (Weir *et al.*, 1984); and (3) the distinctive beds were not identifiable in subsurface logs and cores.

Hohman and Keith (*in press*) designate the aforementioned boundary as a parasequence boundary and group the overlying strata together as a single facies tract. During this study, the strata are subdivided into separate sequences because:

- The rocks were deposited over a time interval exceeding 3 million years, which is consistent with time intervals involved with sequence formation and not facies tracts as shown in Table 1;
- A distinct change in sedimentation patterns occurs as

evidenced by a shallow subtidal to supratidal facies overlying a distal storm-dominated ramp facies;

- Parasequences and parasequence sets are identified in this study and others (i.e. Jennette and Pryor, 1993 and Dattilo, 1994) in Cincinnatian strata from the Richmond Group and lower intervals; and
- The identified boundaries, sequences, and parasequence sets are mappable over a 325 by 350 km study area.

The identification of these stratal patterns in the Richmond strata over the tristate region documents the "sequence-like" architecture of the mixed carbonate/clastic successions. Thus, if a distinct interval has sequence characteristics, it seems logical to designate the interval as a sequence. However, it is also clear after an examination the entire Cincinnatian section in geophysical logs, that there is a distinct carbonate-shoaling upward pattern starting at the base of the Kope Formation and ending at the Ordovician-Silurian Boundary. According to Hohman and Keith (*in press*), this interval also has sequence characteristics. The differences between these cycles is order of magnitude. It is important to determine the hierarchy of sequences in the Cincinnatian because these data are used to construct global sea level curves (Posamentier and Weimer, 1993). Data from this study and other Cincinnatian sequence stratigraphic studies (Holland, 1993; Jennette and Pryor, 1993; Dattilo, 1994; and Hohman and Keith, *in press*) indicate that 3rd, 4th, and 5th order sequences are present in the Cincinnatian strata and have similar features. This study assigns the Richmond cycles to 3rd order sequences because the time interval over which they were deposited (3 million years) is characteristic of the duration of Paleozoic 3rd order sequences (*i.e.*, 1 to 10 million years) as described by Vail *et al.* (1977)

12.2 Development of Carbonate Ramp

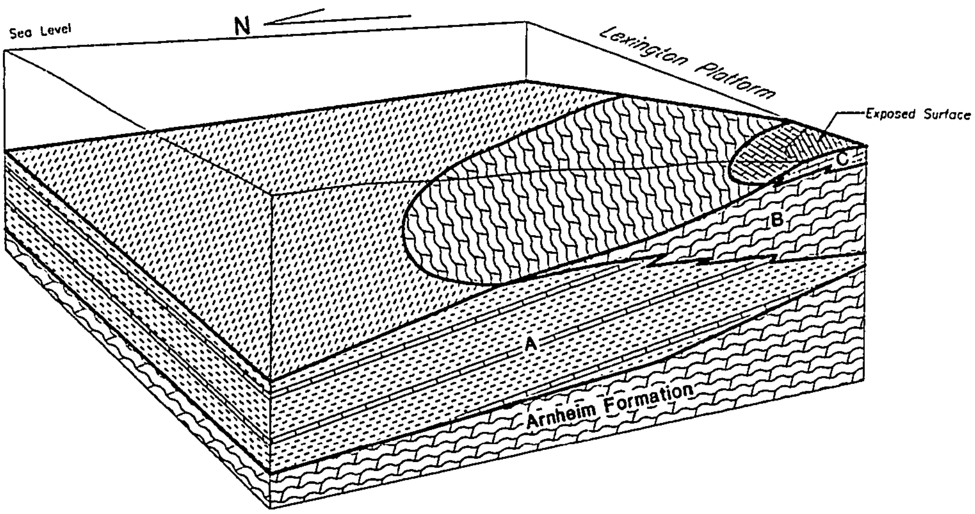
After the brief shale deposition on the basin margin, proximal carbonate ramp sedimentation was again initiated on the Lexington Platform as illustrated in Figure 47. Evidence of this event is shown on the cross sections on Figures 15 and 16, by the deposition of the carbonate-dominated Facies B over the interbedded shales and carbonates of Facies A on the margins of the Lexington Platform. In the center of the basin, continued shale deposition resulted in thick accumulations of Facies A. During the initial formation of the proximal ramp facies (Facies B) on the Lexington Platform, tidal flat deposition (Facies C) was not occurring within the tristate region. Thus, a complete carbonate ramp either did not exist at the time, or the subtidal facies was present outside the study area.

The stratal stacking and sedimentation patterns suggest that deposition of Facies B on the Lexington Platform is representative of a relative high sea level stand as evidenced by the inundation of the shelf and lack of tidal flat development. Strata assigned to Facies A and B, which were deposited during this period, are grouped into the *high stand systems tract*. A relative sea level standstill resulting from a balance of relative sea level rise and sedimentation is postulated for this interval based on the aggradational stacking patterns of the lower half of Facies A in southeastern Indiana.

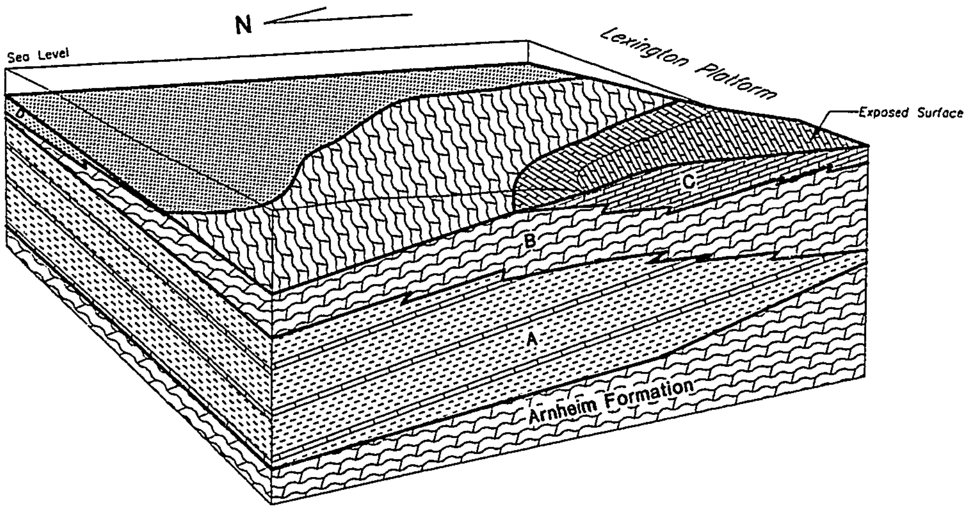
12.3 Progradation of the Carbonate Ramp

After the accumulation of approximately 100 feet of shallow water carbonates on the Lexington Platform, intertidal to supratidal deposition was initiated on the margin of this Platform as evidenced by the overlying tidal flats of Facies C (Figure 48). The deposition of Facies C marks the development of a complete carbonate ramp. As Facies C prograded northward, the proximal ramp facies also prograded basinward. Based upon the stratal stacking patterns observed in the geophysical logs, the development of Facies C and its basinward migration reflect the maximum development of the *highstand systems tract* and a shift of sedimentation towards the basin. The gradual increase in carbonate content over the stratigraphic interval suggest a carbonate ramp that was reacting to a sea level standstill.

A marked shift in sedimentation patterns is evidenced by progradation of Facies C tidal flat carbonates into the basin. As evidenced by the deposition of Facies C in the Madison, Indiana area, this shift marks the development of *a lowstand systems tract* and the base of a Type 1 sequence. At the same time, the distal clastic wedge (Facies D) started prograded westward over Facies A and B as shown in the west to east cross section (Figures 17 and 18). This basin-wide regression was the result of a eustatic sea level fall. The *lowstand*



Progradation of carbonate ramp marked by the development of the tidal flat Facies C resulting from sea level standstill.



Shift of sedimentation to the LST position as evidenced by the thick accumulation of the tidal flat Facies C. The progradion of the distal alluvial fan Facies D supports a relative sea level fall and shifting of facies basinward.

Figure 48

Paleogeography of Middle Richmondian Depositional Environments

systems tract is assigned to this parasequence set because of the strong progradational stacking patterns of Facies C and D. Typically, *lowstand systems tracts* of Type 1 sequences and *shelf-margin systems tracts* of Type 2 sequences superficially resemble each other on ramps except that Type 1 *lowstand systems tracts* are strongly progradational (Van Wagoner *et al.*, 1990). The Type 1 sequence occurs when the sea level fall is greater than the basin subsidence. This study concurs with Dattilo (1994) that *lowstand systems tracts* are present in the Cincinnatian and contrast Holland's (1993) study, which did not identify any *lowstand systems tracts*. The recognition of a eustatic sea level fall at this boundary is evidenced by:

- The nearly isochronous progradation of both Facies C from the south and Facies D over the lateral facies from the east, and
- The development of carbonate-rich proximal ramp sedimentation in southeastern Indiana and southwestern Ohio.

A sustained low sea level resulted in the thick accumulation of Facies C tidal flats in southeastern Indiana as shown in Figure 48.

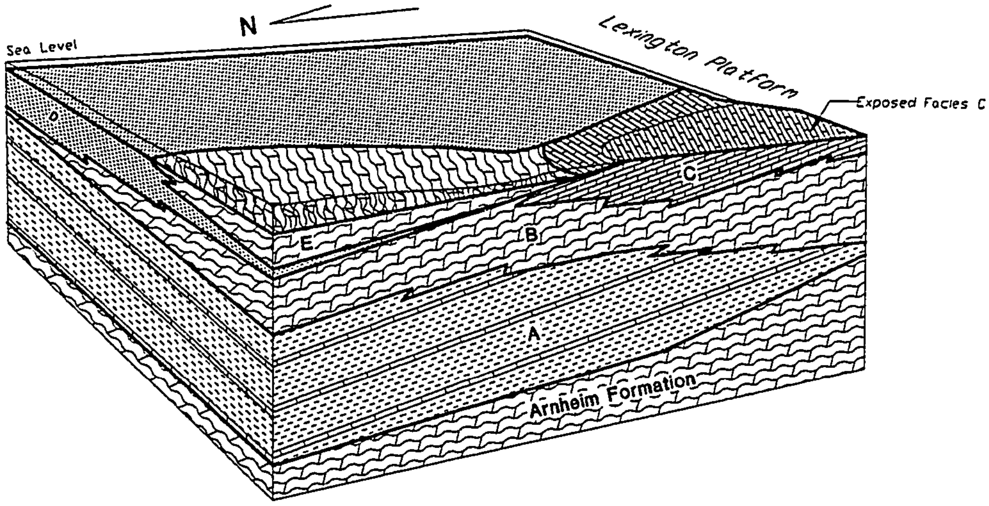
12.4 Basin Flooding

After the progradation of Facies C and D, a second flooding event occurred as documented by the deposition of Facies E. This flooding and relative sea level rise are evidenced by the development of shallow carbonate sedimentation over the tidal flat Facies C and the distal clastic wedge Facies D (Figure 49). However, the sea level rise was probably not as high as the initial flooding of the first sequence as evidenced by the lack of:

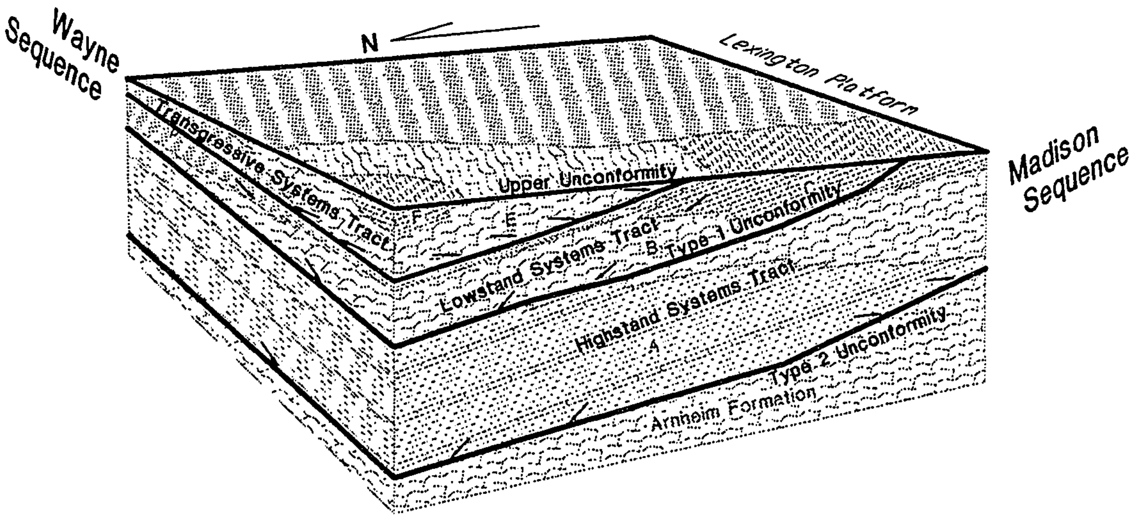
(1) Significant sedimentation on the Lexington Platform, and

(2) Development of a deep-water facies within the basin.

Because the top of this sequence is a second order sequence boundary, it is plausible that these sediments were deposited and eroded at a later time. However, the overall nature of shallowing that occurs during the Late Cincinnatian suggests that this did not occur. Retrogradational parasequences assigned Facies E are assigned to the *transgressive systems tract* because they were deposited during the sea level rise and represent deeper water sedimentation.



Beginning of transgressive systems tract as evidenced by the progradation of the carbonate Facies E over the tidal flat Facies C and the distal alluvial fan Facies D.



Sequence stratigraphic features as proposed by this study. This figure shows the positions of the HST, LST, and TST.

Figure 49

Richmondian Paleogeography And Sequence Stratigraphy

12.5 Final Regression and Progradation of Facies D

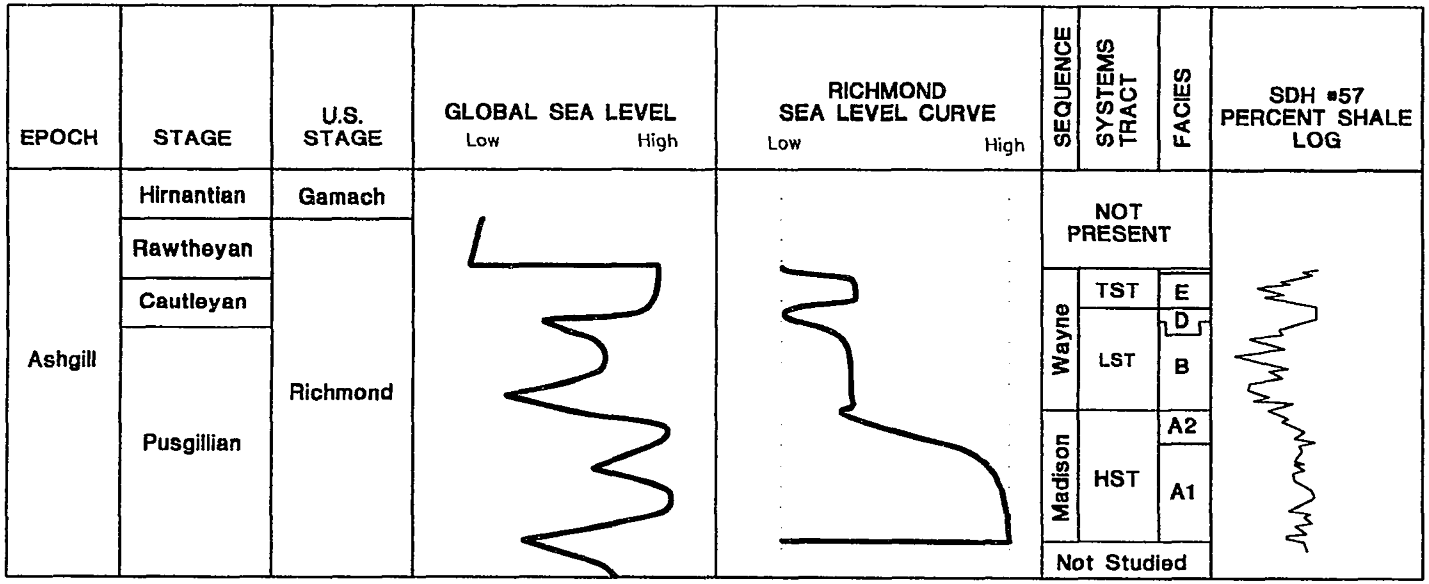
After the sea level rise, the shelf and tidal flat Facies E and F developed in the basin as shown on Figure 49. A regression at the top of the sequence marked the progradation of clastics to the west and the development of a major unconformity at the Ordovician-Silurian Contact.

12.6 Tectonics, Eustacy, and Clastic Influx

Eustatic sea level changes may not be solely responsible for controlling stratal stacking patterns in the Richmond. This study shows that sedimentation was complex at the end of the Ordovician owing to tectonic activity to the east and the location of the study area being transitional between the Appalachian Basin and the Illinois Basin. If the Cincinnati Arch is a peripheral bulge that formed as a result of Paleozoic tectonic events, it is plausible that an incipient uplift may have been occurring during the Latest Ordovician which resulted in the development of tidal flats in southeastern Indiana, and the shallowing of the basin. In addition, the varying rates of clastic influx from the east complicate the sequence stratigraphic interpretation of geophysical logs because carbonate increases may be the result of sea level falls, shoaling, or a lack of clastic influx. If significant changes in clastic influx occur, lithologic, paleontologic, and sedimentologic changes observed in cores, outcrops, and geophysical logs may not precisely reflect sea level falls.

As shown on Figure 50, a sea level curve was constructed from the data presented in this study and compared to the global sea level curve by Ross and Ross (1992). The curve was generated by placing the base of Facies A in core SDH #57 at the low sea level stand shown by Ross and Ross (1992) in the Early Ashgill. The top of the core was correlated to the latest low sea level stand in the Ordovician. At this point, it is unlikely that any further sedimentation occurred because the Cincinnatian strata shows a general shallowing trend upwards and Gamachian strata has not been recorded in the midcontinent. Other sea level curves such as Vail (1977) also recognize this low sea level stand.

Figure 50 shows that the sea level curve generated from this



NOTE:

Global sea level curve from Ross and Ross (1992).

FIGURE 50

RICHMOND SEA LEVEL CURVE
TRISTATE REGION

KEY:

TST = *Transgressive Systems Tract*
LST = *Lowstand Systems Tract*
HST = *Highstand Systems Tract*

study approximates the shape of the curve completed by Ross and Ross (1992). The duration of the highstands and lowstands are similar in length. In addition, the order of highstands, lowstands, and transgressions are also the same. This close approximation indicates that sea level fluctuations recorded in the Richmond strata from the tristate region are similar to those observed globally. Thus, the sequences delineated in this study are further verified by the global distribution of the stratal stacking patterns resulting from eustatic sea level changes

13.0 SUMMARY OF MODEL AND STRATIGRAPHIC IMPLICATIONS

Figure 49 shows a summary of the Richmondian sequence stratigraphic model. The conclusions significant for stratigraphic nomenclature implications from this study are as follows:

- Each sequence is bounded by a surface that is correlative across the study area;
- Regional facies within each sequence, which are recognizable in cores, outcrops, and geophysical logs are delineated; and
- These regional facies contain lithologic and paleontologic characteristics that have been mapped as smaller units, are distinguishable in outcrop, and have sedimentologic significance (i. e. the Waynesville, Liberty, Whitewater, Saluda Formation and Elkhorn Formations).

Because sequences are delineated based upon time discontinuities in the rock record, allostratigraphic principals for classification apply as described in Article 58 of the North American Stratigraphic Code. To determine the appropriate stratigraphic nomenclature for this sequence, an appropriate rank for each of the designated units must be chosen according to Article 7. The selection of the rank can be based on either the time discontinuities or contrasting texture. Because the preservation of established names and the stability of nomenclature should be maintained (Article 7c), this study suggests the rank of alloformation for previously delineated, groups of similar rocks which are single units within the discontinuity bounded sequence (*i. e.* the Waynesville, Whitewater, Saluda, and Elkhorn Formations). Stratigraphic nomenclature grouping together thick sections of strata that cross this sequence boundary should be discarded such as the Maquoketa, the Bullfork, and the Dillsboro Formations because they ignore the discontinuities present in the strata. In addition Holland's (1993) sequential naming of the sequences (*i. e.*, C_1 through C_5) cannot be used for formal Stratigraphic purposes because according to Article 7 of the North American Stratigraphic Code, the name of a unit should consist of a geographic name and a rank.

The most appropriate rank for the sequences delineated in this study is allogroup because it is the next highest rank and would include all of the alloformations within each sequence under a single name. Each sequence should be named for an geographic area where it outcrops and is best developed.

The acceptable alloformation nomenclature and assigned sequence names are presented in Figure 51. The Madison Sequence was named after the well known road cuts in and around the Madison Indiana area including the Highway 421 outcrops north and south of Madison. The Wayne Sequence was named for its occurrence in the Wayne County core.

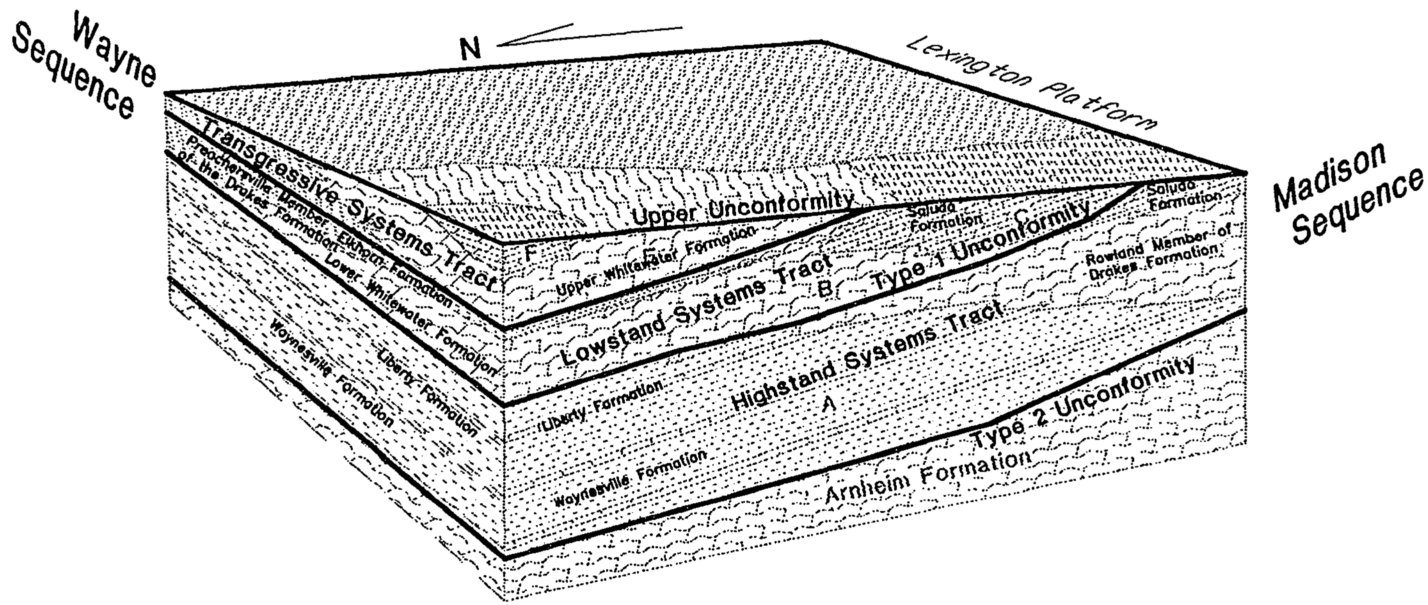


Figure 51

Stratigraphic Units Identified in the Richmond Sequences

14.0 CONCLUSIONS

1. Six regional depositional facies, designated Facies A through F, were identified in the Richmond strata and were correlated between outcrops, cores, and geophysical logs. Depositional environments were assigned to each facies as follows:

   - Facies A: Mixed clastic/carbonate intracratonic ramp - distal facies,
   - Facies B: Mixed carbonate/clastic intracratonic ramp - proximal facies,
   - Facies C: Mixed carbonate/clastic intracratonic ramp - shallow subtidal to supratidal deposition,
   - Facies D: Distal clastic wedge,
   - Facies E: Mixed carbonate/clastic intracratonic ramp - proximal facies, and
   - Facies F: Mixed carbonate/clastic intracratonic ramp - shallow subtidal to supratidal facies.

2. Two sequences were identified in the strata based upon parasequence stacking patterns observed in the logs and interpreted depositional environments the inclusive facies

as follows:

Madison Sequence

- Unconformity, sea level rise, flooding of the basin margins, and development of a *highstand systems tract;* and
- Development of carbonate ramp;

Wayne Sequence

- Sea level fall followed by development of a *lowstand systems tract;*
- Sea level rise marked by development of a *transgressive systems tract;* and
- A final regression at the end of the sequence.

3. The beginning of the first sequence is marked by a correlatable unconformity. Facies A, B, and C form a carbonate ramp in the *highstand systems tract* position. The progradation of Facies C northward into Indiana marks the development of a *lowstand systems tract* and the start of the second sequence. Facies E forms a *transgressive systems tract* which migrated over Facies C and D; while Facies F is an enigmatic unit which probably formed laterally to Facies E.

4. The sea level fluctuations recorded in the Richmond strata of the tristate region approximate those observed globally, indicating eustatic sea level controls and further verification of sequence recognition.

5. Facies D is not part of the intracratonic mixed clastic/carbonate ramp, but rather distal clastic wedge that developed independently of the ramp and responded to relative sea level fluctuations in a similar fashion to Facies A, B, C, E, and F. This study extends the edge of the distal clastic wedge from central Ohio into southeastern Indiana.

6. This study contrasts Hohman and Keith's (*in press*) model by defining two Richmond sequences and Holland (1993), by including a *lowstand systems tract* at the base of the second sequence and not including the eastern clastic facies as part of the intracratonic ramp.

7. Earlier established Ordovician paleogeographic features such as the Seebree Trough and Lexington Platform were significant to Richmond deposition.

BIBLIOGRAPHY

Anstey, R. L. and Fowler, M. L., 1969, Lithostratigraphy and depositional environments of the Eden Shale (Ordovician) in the tri-state areas of Indiana, Kentucky, and Ohio: Journal of Geology, volume 77, pages 668 - 682.

Berner, R.A.,1981, A new geochemical classification of sedimentary environments: Hour. Sed. Petrology, v. 51, p. 359-365.

Betz, C. E., 1984, Facies analysis and depositional environments of the upper part of the Richmond Group (Upper Ordovician) Richmond, Indiana to Xenia, Ohio (unpublished M. S. thesis): Miami University, Oxford, Ohio, 159 pages.

Bloemker, J. M., 1981, Subsurface Stratigraphy and Paleoecology of the Saluda Formation (Upper Ordovician) of Indiana (unpublished M. S. thesis): Ball State University, Indiana, 62 pages.

Brandt, D. B., 1985, Ichnological, taphonomic and sedimentologic clues to the deposition of Cincinnatian Shales (Upper Ordovician) Ohio, U. S. A., *in* A. H. Curran, ed., Biogenic structures: Their use in Interpreting Depositional Environments: SEPM, Special Publication No. 35, pages 299 - 307.

Brown, L. F., and Fisher, W. L., 1977, Seismic-Stratigraphic Interpretation of Depositional Systems: Examples from Brazilian Rift and Pull Apart Basins, *in* Seismic Stratigraphy - application to hydrocarbon exploration, Tulsa, OK: American Association of Petroleum Geologists, pages 213-248.

Dattilo, B. F., 1994, Stratigraphy and Paleoecology of the Miamitown Shale (Upper Ordovician): Ohio, Indiana, and Kentucky (unpublished PhD dissertation): University of Cincinnati, Cincinnati, Ohio, 73 pages.

Dennison, J. M., 1976, Appalachian Queenston Delta related to eustatic sea-level drop accompanying Late Ordovician glaciation centered in Africa, *in* M. G. Bassett, ed., The Ordovician System: Cardiff, England, University of Wales Press, pages 107 - 129.

Fagerstrom, J. A., 1964, Fossil communities in paleoecology, their recognition and significance: Geologic Society of America Bulletin, v. 75, no. 12, pages 1197-1216.

Foerste, A. F., 1904, The Ordovician-Silurian contact in the Ripley Island area of southern Indiana, with notes on the age of the Cincinnati Geanticline: American Journal of Science, v. 18, pages 321 - 342.

_____, 1910, Preliminary Notes on Cincinnatian and Lexington Fossils of Ohio, Indiana, Kentucky, and Tennessee: Den. Univ. Sci. Lab. Bulletin, v. 16, pages 17-100.

Ford, J. P., 1965, Bedrock geology in southwest Hamilton County (unpublished PhD. dissertation): Ohio State University, Columbus, Ohio, 103 pages.

_____, 1967, Cincinnatian Geology in southwest Hamilton County, Ohio American Association of Petroleum Geologists Bulletin, v. 51, pages 918 - 936.

_____, 1968, Upper Ordovician stratigraphic relations between Covington and Clays Ferry, Kentucky: American Association of Petroleum Geologists Bulletin, v. 52, pages 1779 - 1791.

Fox, W. T., 1962, Stratigraphy and paleoecology of the Richmond Group in southeastern Indiana: Geologic Society of American Bulletin, v. 73, pages 621 - 642.

Frey, R. C., 1983, The Paleontology and Paleoecology of the *Treptoceras duseri* shale unit (Late Ordovician, Richmondian) of southwest Ohio (unpublished PhD dissertation): Oxford, Ohio, Miami University, 719 pages.

_____, 1987, The Occurrence of Pelecypods in Early Paleozoic Epeiric-Sea Environments, Late Ordovician of the

Cincinnati: Ohio Area Society of Economic Paleontologists and Mineralogists, v. 2, pages 3-23.

Gray, H. H., 1972. Lithostratigraphy of the Maquoketa Group (Ordovician) in Indiana: Indiana Department of Natural Resources and Geological Survey Special Report, v. 7, pages 1-31.

Hatfield, C. B., 1964, Stratigraphy and paleoecology of the Saluda Formation (Cincinnatian) in Indiana, Ohio and Kentucky (unpublished PhD dissertation): Bloomington, IN., Indiana University. 112 pages.

_____, 1968, Stratigraphy and Paleoecology of the Saluda Formation (Cincinnatian) in Indiana, Ohio and Kentucky: Geologic Society of America Special Paper number 95, 34 pages.

Hay, H. B., 1981, Lithofacies and formations of the Cincinnatian Series (Upper Ordovician), southeastern Indiana and southwestern Ohio (unpublished PhD dissertation): Miami University, Oxford, Ohio, 152 pages.

Holland, S. M., 1993, Sequence stratigraphy of carbonate-clastic ramp: The Cincinnatian Series (Upper Ordovician) in its type area: Geologic Society of America, v. 105, pages 306-322.

Hohman, J. C. and B. D. Keith, in press, Upper Ordovician Sequence Stratigraphy in the southern part of the Illinois Basin *in* Witzke, B. J., G. A. Ludvigson and J. E. Day editors, Paleozoic sequence stratigraphy: North American Perspectives: Geological Society of America Special Publication.

Jennette, D. C., and Pryor, W. A., 1993, Cyclic Alternation of Proximal and Distal Storm Facies: Kope and Fairview Formations (Upper Ordovician), Ohio and Kentucky: Journal of Sed. Petrology, v. 63, No. 2, pages 183-203.

Keith, B. D., 1988, Regional facies of Upper Ordovician Series of eastern North American, *in* B. D. Keith, ed., The Trenton Group (Upper Ordovician Series) of eastern North

America: American Association of Petroleum Geologists Studies in Geology 29, pages 1-16.

Maynard, J. B., 1982, Extension of Berner's "New Geochemical Classification of Sedimentary Environments" to Ancient Sediments: Journal of Sedimentary Petrology, v. 52, no. 4, pages 1325-1331.

Meyer, D. L., Tobin, R. C., Pryor, W. A., Harrison, W. B., and Osgood, R. G., 1981, Stratigraphy, sedimentology and paleoecology of the Cincinnatian Series (Upper Ordovician) in the vicinity of Cincinnati, Ohio, *in* T. G. Roberts, ed., G. S. A. Field Trip Guidebook, 1981 Annual meeting, volume 1, pages 31 - 71.

Mitchell, C. E. and Bergstrom, S. M., 1991, New Graptolite and Lithostratigraphic Evidence from the Cincinnati Region, U.S.A., for the Definition and Correlation of the Base of the Cincinnatian Series (Upper Ordovician), *in* Barnes, C. R. and Williams, S. H., eds., Advances in Ordovician Geology: Geological Survey of Canada, Paper 90-9, pages 59-77.

Mitchum, R. M., P. R. Vail, and S. Thompson, III, 1977, Seismic stratigraphy and global changes of sea level, parts 2, 3, and 4, *in* Payton, C. E. editor, Seismic stratigraphy - Applications to Hydrocarbon Exploration: American Association of Petroleum Geologists Memoir, n. 26, pages 53 - 97.

Multer, H. G. and Hoffmeister, J. E., 1975, Petrology and significance of the Key Largo Limestone, Florida Keys, *in* Multer, H. G., ed., Field guide to some carbonate rock environments Florida Keys and western Bahamas: Sept. Earth Sciences, Farleigh Dickinson Univ., Pages 111-112.

Nickles, J. M., 1902, The Geology of Cincinnati: Cincinnati Society Natural History Journal, volume 20, pages 49-100.

Noger, M. C., 1986, The Upper Ordovician Fredericktown Section, Nelson County, Kentucky: Geologic Society of America, Centennial Field Guide - Southeastern Section, pages 13-15.

North American Commission on Stratigraphic Nomenclature, 1983, North American Stratigraphic Code: American Association of Petroleum Geologists Bulletin, v. 67, pages 841-875.

Pojeta, J., 1971, Review of Ordovician Pelecypods U.S. Geological Survey Professional Paper, v. 695, 46 pages.

Posamentier, H. W. and Weimer, P., 1993, Siliciclastic Sequence Stratigraphy and Petroleum Geology - Where to From Here? American Association of Petroleum Geologist Bulletin, v. 77, no. 5, pages 731-742.

Posamentier, H. W. and Vail, P. R., 1988, Eustatic Controls on Clastic Deposition II-Sequence and Systems Tract Models, *in* C. K. Wilgus, B. S. Hastings, C. G. St. C. Kendall, H. W. Posamentier, C. A. Ross, and J. C. Van Wagoner, eds., Sea level change: and integrated approach: SEPM Special Publication 42, pages 125-154.

Posamentier, H. W., Jervey, M. T. and Vail, P. R., 1988, Eustatic Controls on Clastic Deposition I-Conceptual Framework *in* C. K. Wilgus, B. S. Hastings, C. G. St. C. Kendall, H. W. Posamentier, C. A. Ross, and J. C. Van Wagoner, eds., Sea level change: and integrated approach: SEPM Special Publication 42, pages 110-124.

Posamentier, H. W., James, D. P., in press, An Overview of Sequence Stratigraphic Concepts: Uses and Abuses: IAS Special Publication, pages 1-15.

Rast, N., 1989, The evolution of the Appalachian chain, in Bally, A. W., and Palmer, A. R., eds., The Geology of North America - An overview: Boulder, Colorado, Geological Society of America, The Geology of North America, v. A, pages 323-347.

Read, J. F., 1985, Carbonate platform Facies models: American Association of Petroleum Geologists Bulletin, v. 69, pages 1 - 21.

Ross, J. R. P. and Ross, C. A., 1992, Ordovician sea level fluctuations, *in* Webby amd Lauri, eds., Global prespectives on Ordovician Geology, Balkemana, Rotterdam, Netherlands, pages 327-336.

Schlumberger, 1985, Sedimentary Environments from Wireline Logs.

Schumacher, G. A., 1984, Sedimentology, biostratinomy, and paleoecology of Cincinnatian (Upper Ordovician) *Iocrinus subcrassus* crinoid assemblages (unpublished M. S. thesis): University of Cincinnati, Cincinnati, Ohio, 210 pages.

Scotese, C. R., Bamback, R. K., Barton, C., Van Der Voo, R., and Ziegler, A. M., 1979, Paleozoic Base Maps, Journal of Geology, v. 87, pages 217-277.

Shrake, D. L., Schumacher, G. A., Swinford, E. M., 1988, Field Guidebook to the Stratigraphy, Sedimentology, and Paleontology of the Upper Ordovician Rocks in Southwestern Ohio: Ohio Department of Natural Resources, Division of Geological Survey, 81 pages.

Sloss, L. L., Krumbein, W. C. and Dapples, E. C., 1949, Integrated Facies Analysis, in Longwell, C. R., chairman, Sedimentary Facies in Geologic History: Geological Society of America Memoir 39, pages 91-124.

Sloss, L. L., 1988, Forty years of sequence stratigraphy: American Association of Petroleum Geologists Bulletin, v. 100, pages 1661-1665.

Stith, D. A., 1986, Supplemental Core Investigations for High-Calcium Limestones in Western Ohio and Discussion of natural Gas and Stratigraphic Relationships in the Middle to Upper Ordovician Rocks of Southwestern Ohio: Ohio Department of Natural Resources, division of Geologic Survey, Report of Investigations No. 132, 17 pages.

Sweet, W. C., 1979, Conodonts and Conodont Biostratigraphy of Post-Tyrone Ordovician Rocks of the Cincinnati Region: U.S. Government printing office, 281-359/31, pages G1-G26.

Sweet, W. C., Turco, C. A., Warner, Earl, and Wilkie, L. C., 1959, The American Upper Ordovician Standard, I, Eden conodonts from the Cincinnati region of Ohio and Kentucky: Journal Paleontology, v. 33, pages 1029-1068.

Sweet, W. C., Bergstrom, S. M., and Rust, C. C., 1965, Relative abundance analysis - an aid to Ordovician conodont biostratigraphy in the Cincinnati region of Ohio (Abs.): Geologic Society of America Special Paper 82, 203 pages.

Sweet, W. C. and Bergstrom, S. M., 1971, The American Upper Ordovician standard XIII: A revised time stratigraphic classification of North American Upper and Middle Ordovician rocks: Geologic Society of America Bulletin, v. 82, pages 613 - 629.

Tobin, R. C., 1980, Sedimentology of the Fairview Formation, Miamitown Shale and Bellevue Limestone (Upper Ordovician, Cincinnatian Series) of southwestern Ohio and northern Kentucky (unpublished M. S. thesis): University of Cincinnati, Cincinnati, Ohio, 144 pages.

_____, 1982, A model for cyclic deposition in the Cincinnatian Series of southwestern Ohio, northern Kentucky and southeastern Indiana (unpublished PhD dissertation): University of Cincinnati, Cincinnati, Ohio, 483 pages.

Vail, P. R., Mitchum, R. M. Jr., and Thompspm, S. III, 1977, Seismic Stratigraphy and Global Changes of Sea Level, Part Four: Global Cycles of Relative Changes of Sea Level, *in* Seismic Stratigraphy - application to hydrocarbon exploration, Tulsa, OK: American Association of Petroleum Geologists, pages 83-98.

Vail, P. R. and Wilbur, R. O., 1966, Onlap, key to worldwide unconformities and depositional cycles (abs.): American Association of Petroleum Geologists Bulletin, v. 50, pages 638-639.

Van Wagoner, J. C., Mitchum, R. M., Campion, K. M., and Rahmanian, V. D., 1990, Siliclastic Sequence Stratigraphy in Well Logs, Cores and Outcrops: American Association

Petroleum Geologists Methods in Exploration Series, number 7, 52 pages.

Walters, S. J., 1988, The Sedimentology and Depositional Environment of the Saluda Formation (Upper Ordovician) on Highway 421, Jefferson County, Indiana (unpublished master's thesis): Cincinnati, Ohio, University of Cincinnati, 170 pages.

Weimer, R. J., 1992, Developments in sequence strtigraphy: Foreland and Cratonic Basins: American Association of Petroleum Geologist Memoir 36, pages 7-36.

Weir, G. R., Peterson, W. L., and Swadley, W. C., 1984, Lithostratigraphy of Upper Ordovician Strata Exposed in Kentucky United States Geologic Survey Professional Paper 11151-E, 121 pages.

Wilson, J. L., 1975, Carbonate Facies in Geologic History: New York, Springer-Verlag, 472 pages.

Appendix A

Outcrop Descriptions

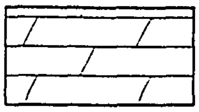
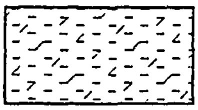
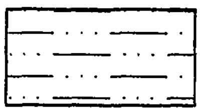
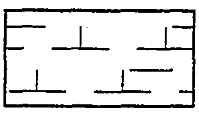
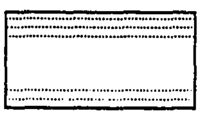
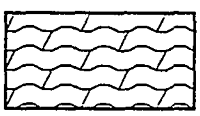
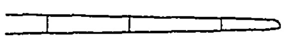
Lithology	Description
	LIMESTONE - Thickbedded to massive.
	DOLOMITE - Thickbedded to massive.
	Dolosiltstone - Silt sized dolomite grains.
	SILTSTONE - Quartz siltstone.
	SILTSTONE - Calcareous siltstone.
	BANDED - Lithology has color banding.
	IRREGULAR BEDDING - Interval of irregular bedded dolomite or limestone.
	Planar carbonate bed.
	Irregular carbonate bed.
M, W, P, G, or R	Micstone, wackestone, packestone, grainstone, or rudstone indentifier.

Figure A1

Lithologic Key

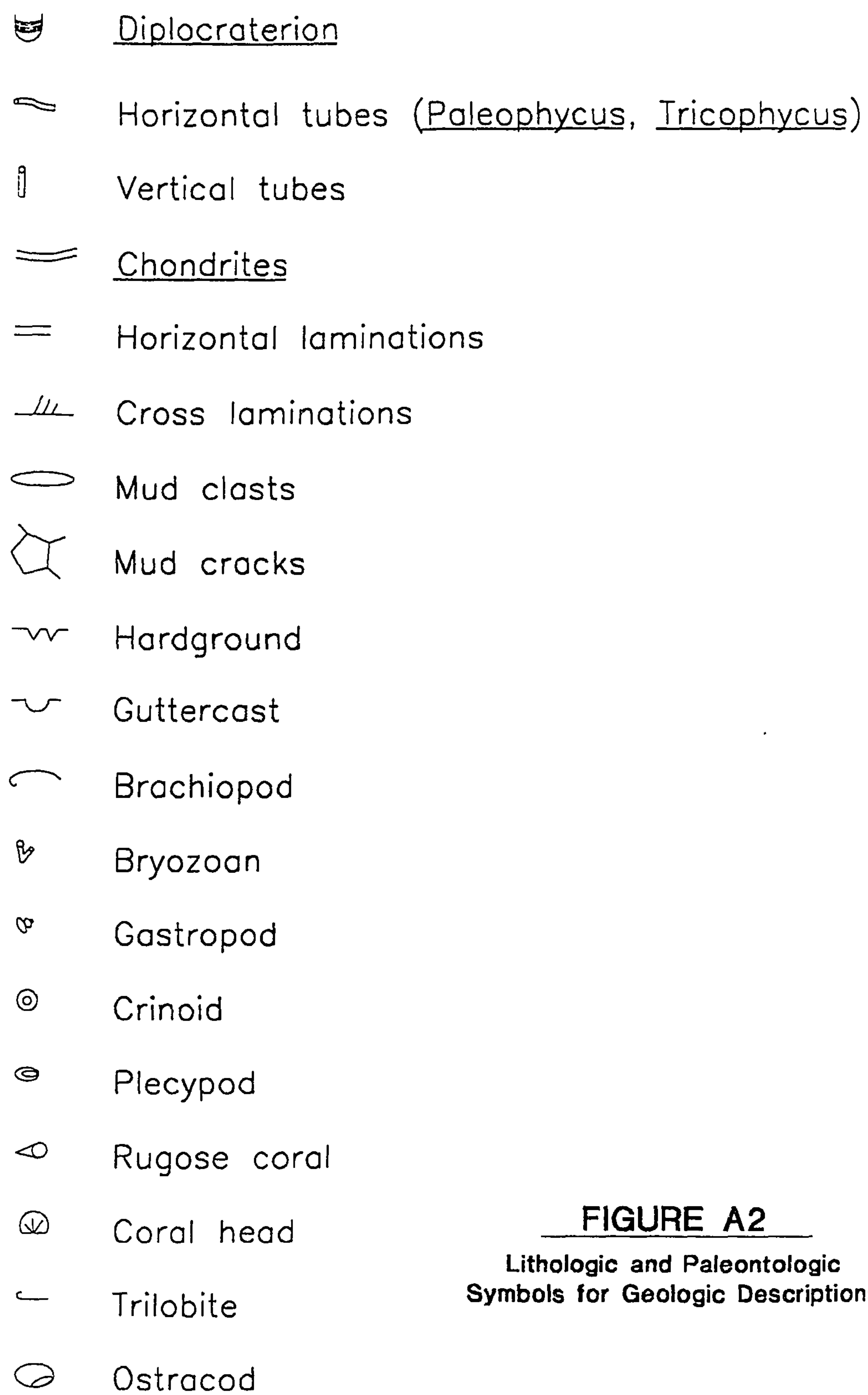


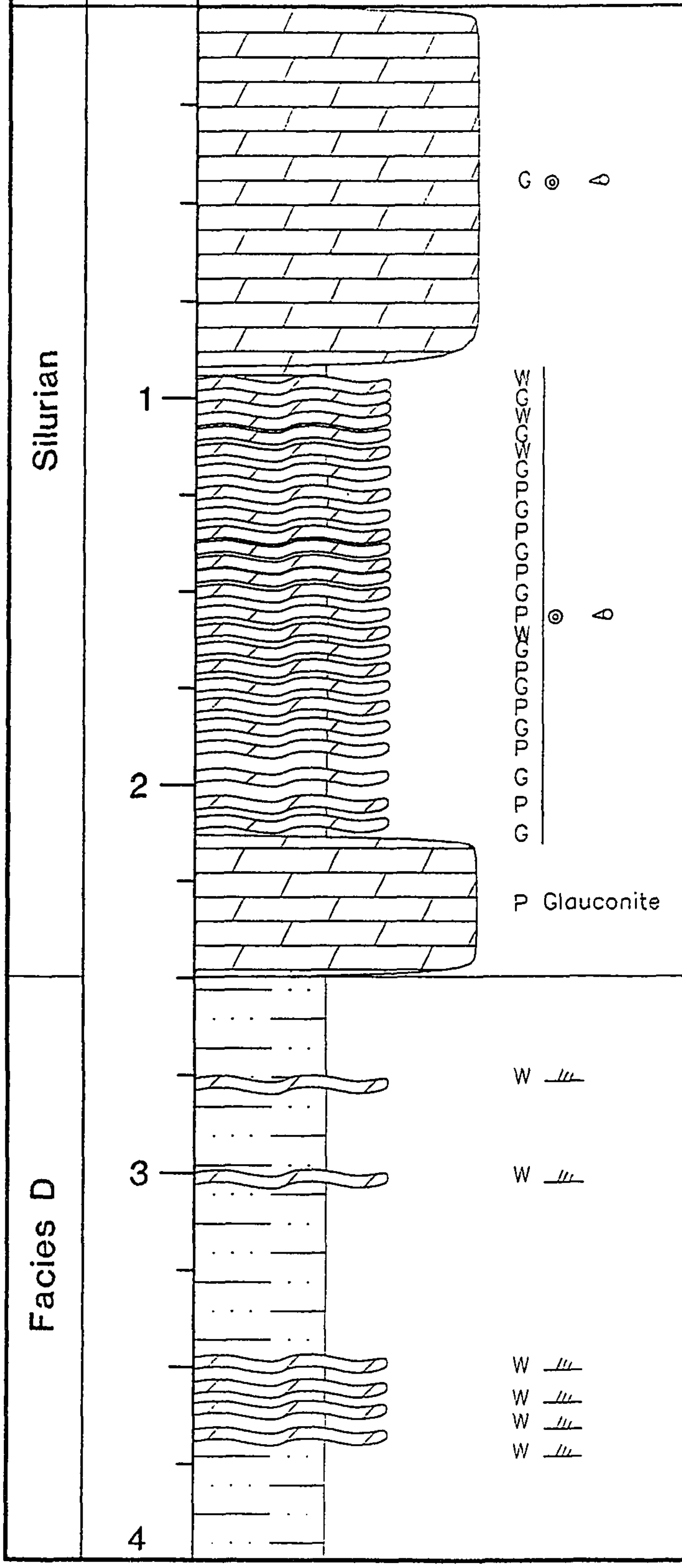
FIGURE A2

Lithologic and Paleontologic Symbols for Geologic Descriptions

Burnt Cabin Road Outcrop

Geological Description

Facies	Meters	Litholog	Comments

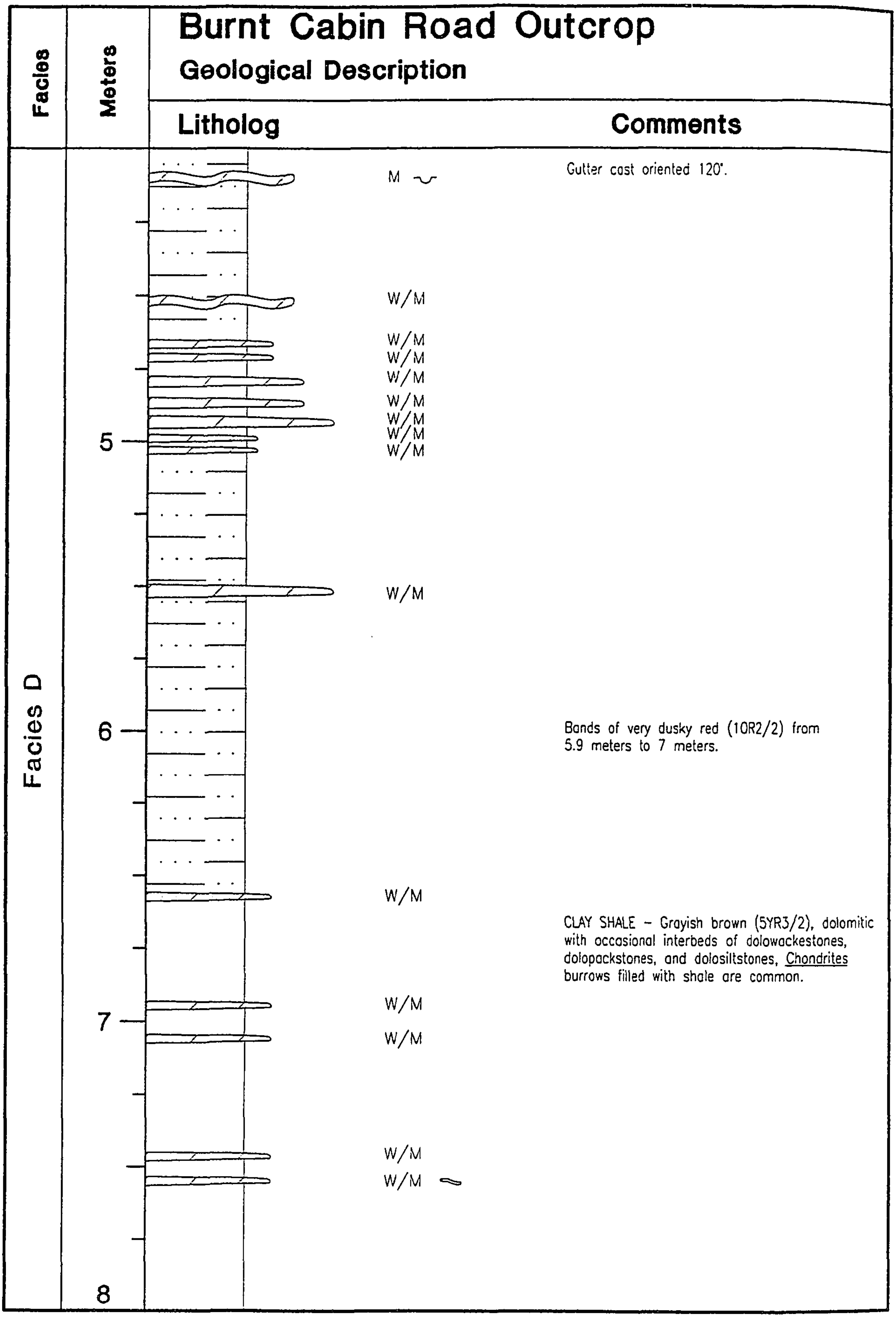


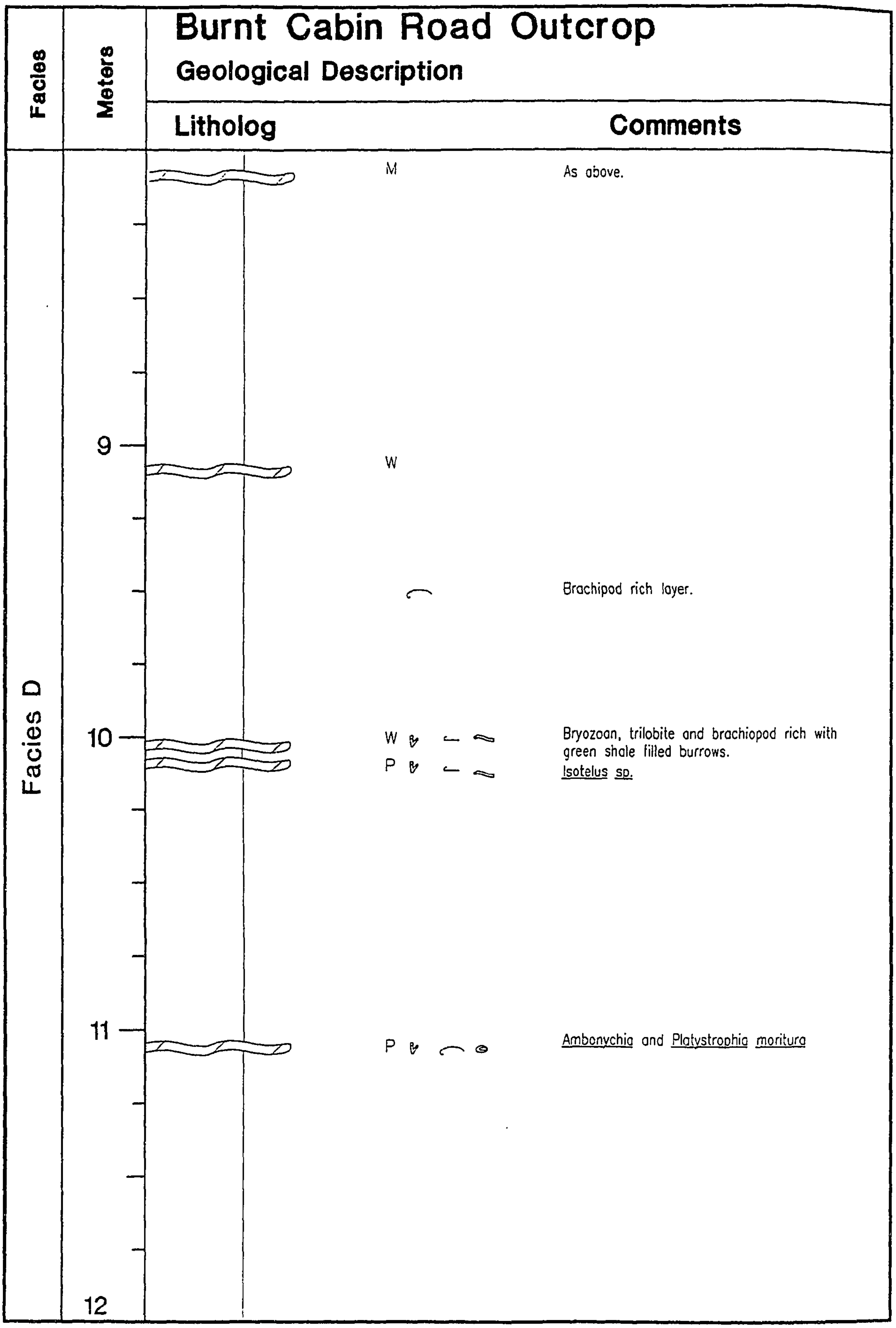
DOLOGRAINSTONES - Pale olive (10Y6/2), crinoid rich, 7 to 25 cm bedding, chert nodules, vuggy, spar cement, 350 to 500 micron grain size, sharp, undulatory contact at base with glauconite and pyrite.

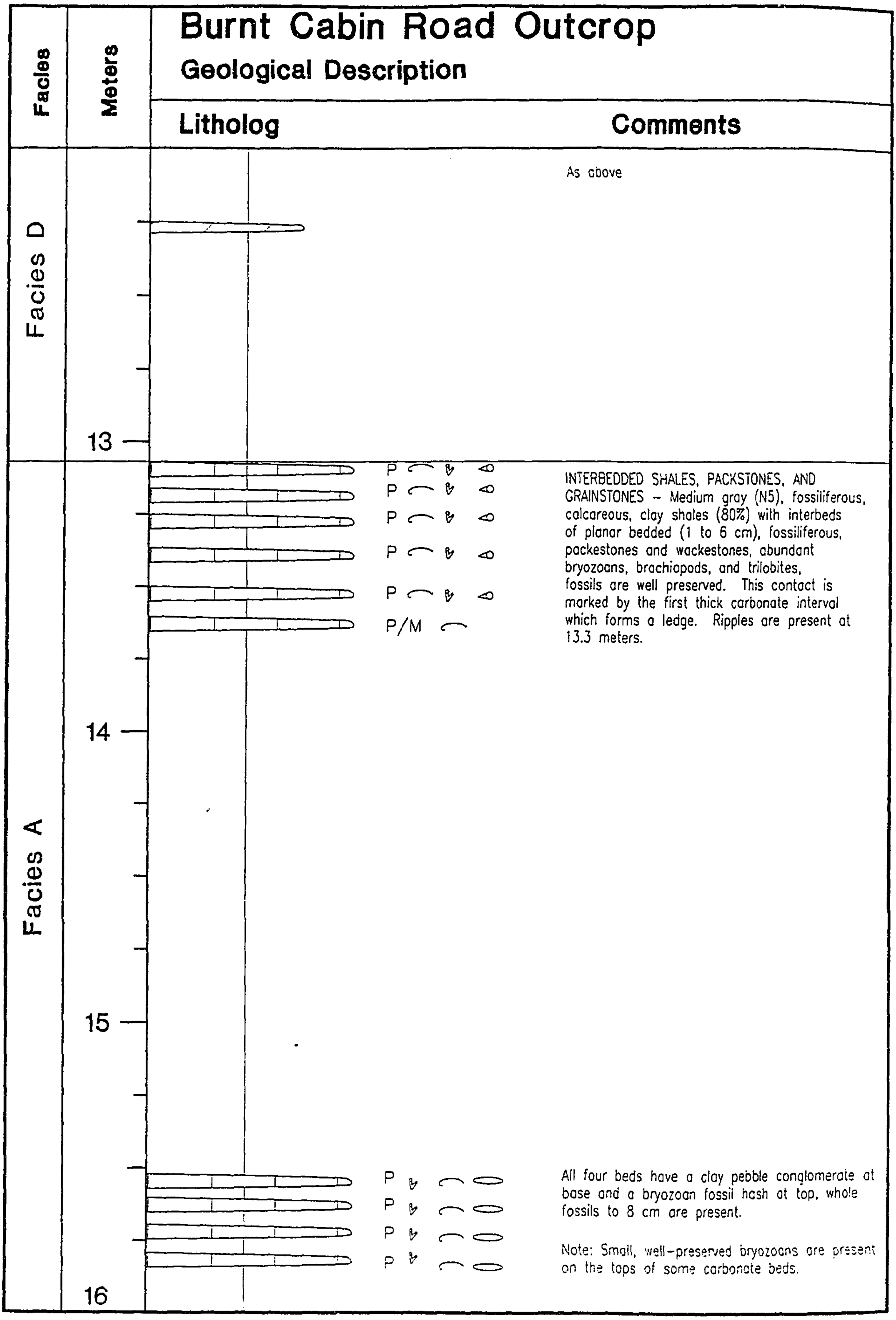
INTERBEDDED DOLOWACKESTONE, DOLOPACKSTONES, AND DOLOGRAINSTONES - Dusky yellow (5Y6/4), 3 to 5 cm, irregular carbonate beds with chort nodules separated by up to 2cm shale partings, shale content increases towards the base, abundant crinoids and rugosan corals.

DOLOPACKSTONES - Dusky yellow (5Y6/4), undulatory, 3 to 12 cm bedding, abundant glauconite, petroliferous.

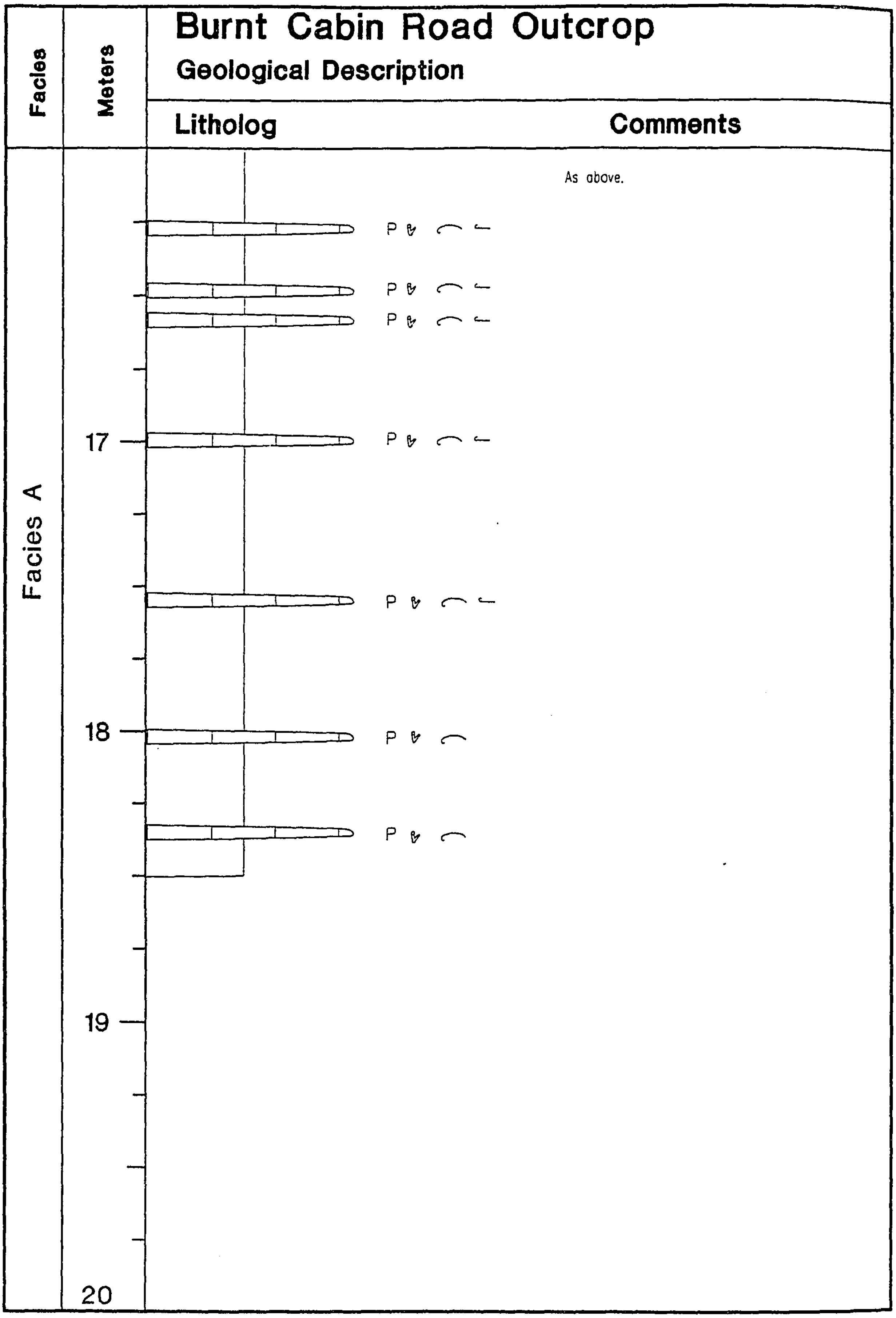
INTERBEDDED DOLOSILTSTONES AND DOLOWACKESTONES - Grayish olive (10Y4/2) siltstones (80%) have sparse fossils and are commonly argillaceous, wackestones are medium gray (N5) ripple to wavy bedded, cross-laminated, 3 to 5 cm bedding, ripples strike from 58° to 74°, sharp contact with overlying strata.


Burnt Cabin Road Outcrop
Geological Description
Facies
Meters
Litholog
Comments
Facies D
5
6
7
8
M
W/M
W/M
W/M
W/M
W/M
W/M
W/M
W/M
W/M
W/M
W/M
W/M
W/M
W/M
Gutter cast oriented 120°.
Bands of very dusky red (10R2/2) from 5.9 meters to 7 meters.
CLAY SHALE – Grayish brown (5YR3/2), dolomitic with occasional interbeds of dolowackestones, dolopackstones, and dolosiltstones, Chondrites burrows filled with shale are common.


Burnt Cabin Road Outcrop
Geological Description
Facies
Meters
Litholog
Comments
Facies D
9
10
11
12
M
W
W
P
P
As above.
Brachipod rich layer.
Bryozoan, trilobite and brachiopod rich with green shale filled burrows.
Isotelus sp.
Ambonychia and Platystrophia moritura



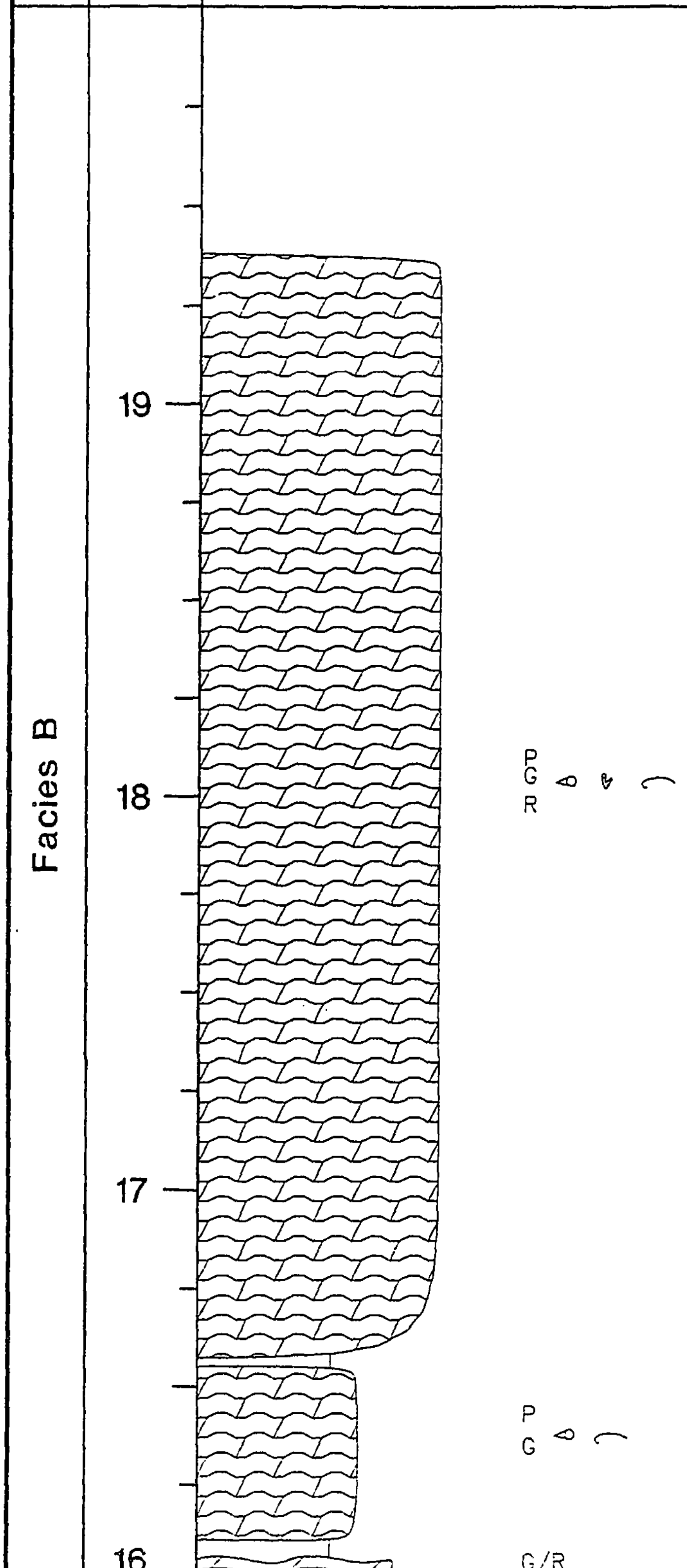
Burnt Cabin Road Outcrop
Geological Description
Facies
Meters
Litholog
Comments
Facies D
Facies A
13
14
15
16
P
P
P
P
P
P/M
P
P
P
P
As above
INTERBEDDED SHALES, PACKSTONES, AND GRAINSTONES - Medium gray (N5), fossiliferous, calcareous, clay shales (80%) with interbeds of planar bedded (1 to 6 cm), fossiliferous, packestones and wackestones, abundant bryozoans, brachiopods, and trilobites, fossils are well preserved. This contact is marked by the first thick carbonate interval which forms a ledge. Ripples are present at 13.3 meters.
All four beds have a clay pebble conglomerate at base and a bryozoan fossil hash at top, whole fossils to 8 cm are present.
Note: Small, well-preserved bryozoans are present on the tops of some carbonate beds.


Burnt Cabin Road Outcrop
Geological Description
Facies
Meters
Litholog
Comments
As above.
Facies A
17
18
19
20
P
P
P
P
P
P
P

Camden Outcrop

Geological Description

Facies	Meters	Litholog	Comments



INTERBEDDED GRAINSTONES, PACKESTONES, RUDSTONES, AND SHALES - Medium dark gray (N3), irregular bedded, discontinuous, extremely fossiliferous, fossils are encrusted, 80 to 90% carbonates, with medium gray (N5) calcareous shales, poorly exposed. Fossils include: Grewingkia canadensis, many species of bryozoans, Platystrophia sp., Ambonychia, Isochrodonta, and and unidentified encrusting tabulate coral.

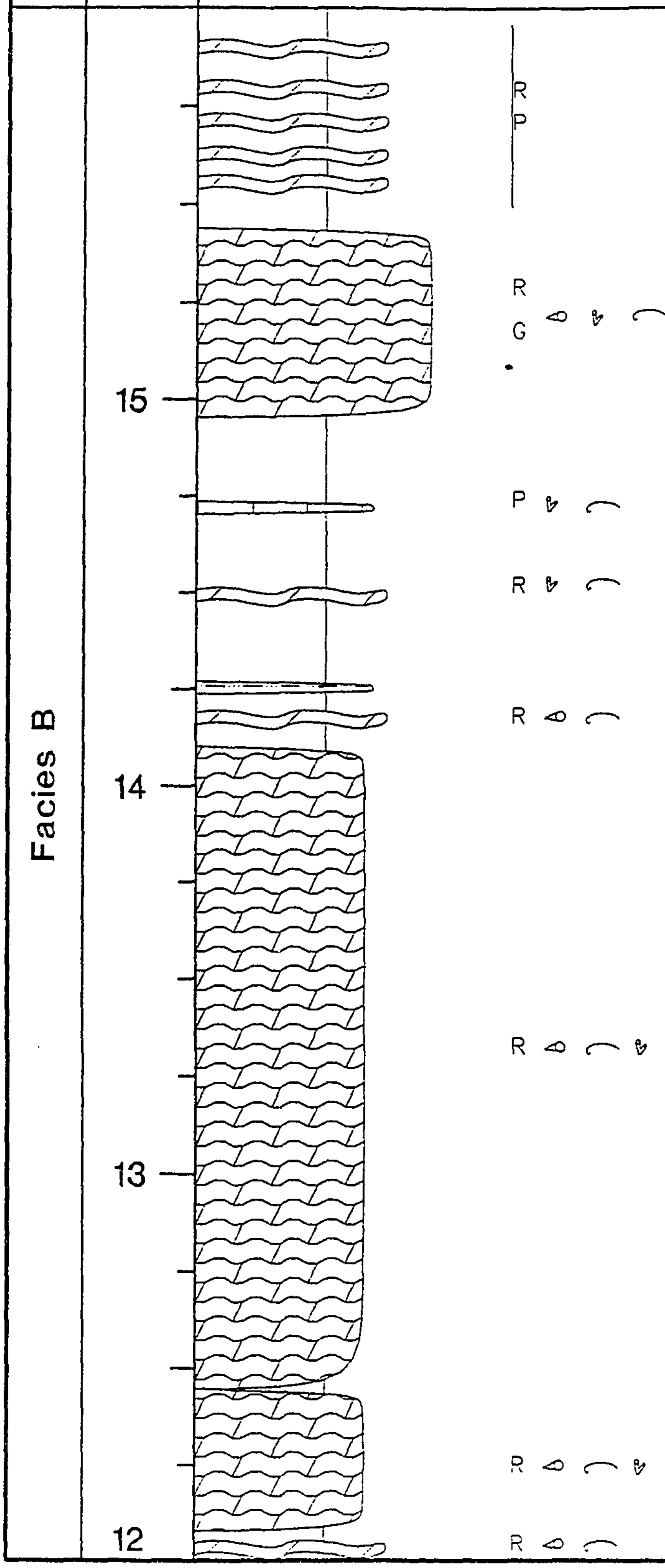
Note: Proterea richmondensis encrsuts both brachiopods and rugosan corals in this interval.

INTERBEDDED SHALES, PACKSTONES, AND GRAINSTONES - Medium gray (N5), irregular to nodular bedded, approximately 30% shale, less fossiliferous than above, very poorly exposed.

Camden Outcrop

Geological Description

Facies	Meters	Litholog	Comments



INTERBEDDED SHALES, RUDSTONES, AND PACKSTONES – Medum dark gray (N4), 85% shales, less fossiliferous than above.

INTERBEDDED RUDSTONES AND GRAINSTONES – Medium gray (N5), irregular bedded, 90% carbonates, fossils are dominantly in shales including rugosan corals, bryozoans, encrusting tabulate corals, and whole brachiopods, species as above.

CLAY SHALE – Medium dark gray (N4) clay shale with occasional discontinuous packstone and rudstone interbeds, shale are non-fossiliferous and the carbonate beds are irreular bedded, 1 to 2 cm thick and contain bryozoan hash with occasional whole and broken brachiopods.

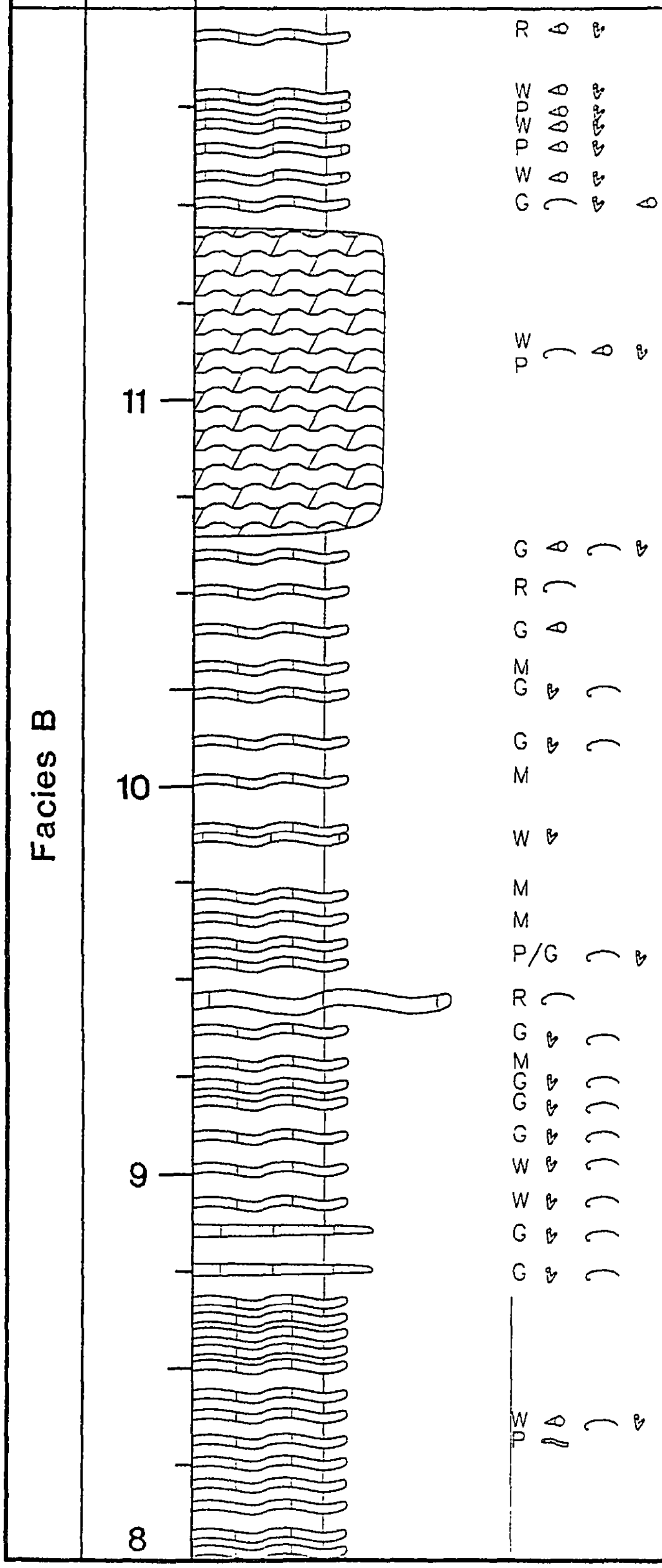
INTERBEDDED SHALES AND RUDSTONES – Medium dark gray (N4), nodular bedded, 50% shales, poorly exposed, occasional encrusted, bored rugosan corals.

INTERBEDDED RUDSTONES AND SHALES – Medium gray (N5), extremely fossiliferous, fossils are fragmented, abundant brachiopods, rugosan corals, and bryozoans.

Camden Outcrop

Geological Description

Facies	Meters	Litholog	Comments



INTERBEDDED WACKESTONES, PACKSTONES, AND SHALES – Medium gray (N5) to light olive gray, 3 to 5 cm, irregular bedding, less fossiliferous than above.

As above but increased carbonate content.

INTERBEDDED CARBONATES AND SHALES – Medium gray (N5) to light olive gray (5Y5/2), irregular bedded, 2 to 13 cm carbonate beds, with up to 10 cm shale layers, extremely fossiliferous, large brachiopods and rugosan corals up to 3 cm, fossils are abraded and often encrusted with bryozoans, some minor bioturbation, grain size of bioclastic fragments ranges from 500 to 4000 microns.

Loxoplocus and Cyclonema sp.

Fossils encrusted and bored – most prominent in this interval including Hebertella and rafinesquina, trace pyrite.

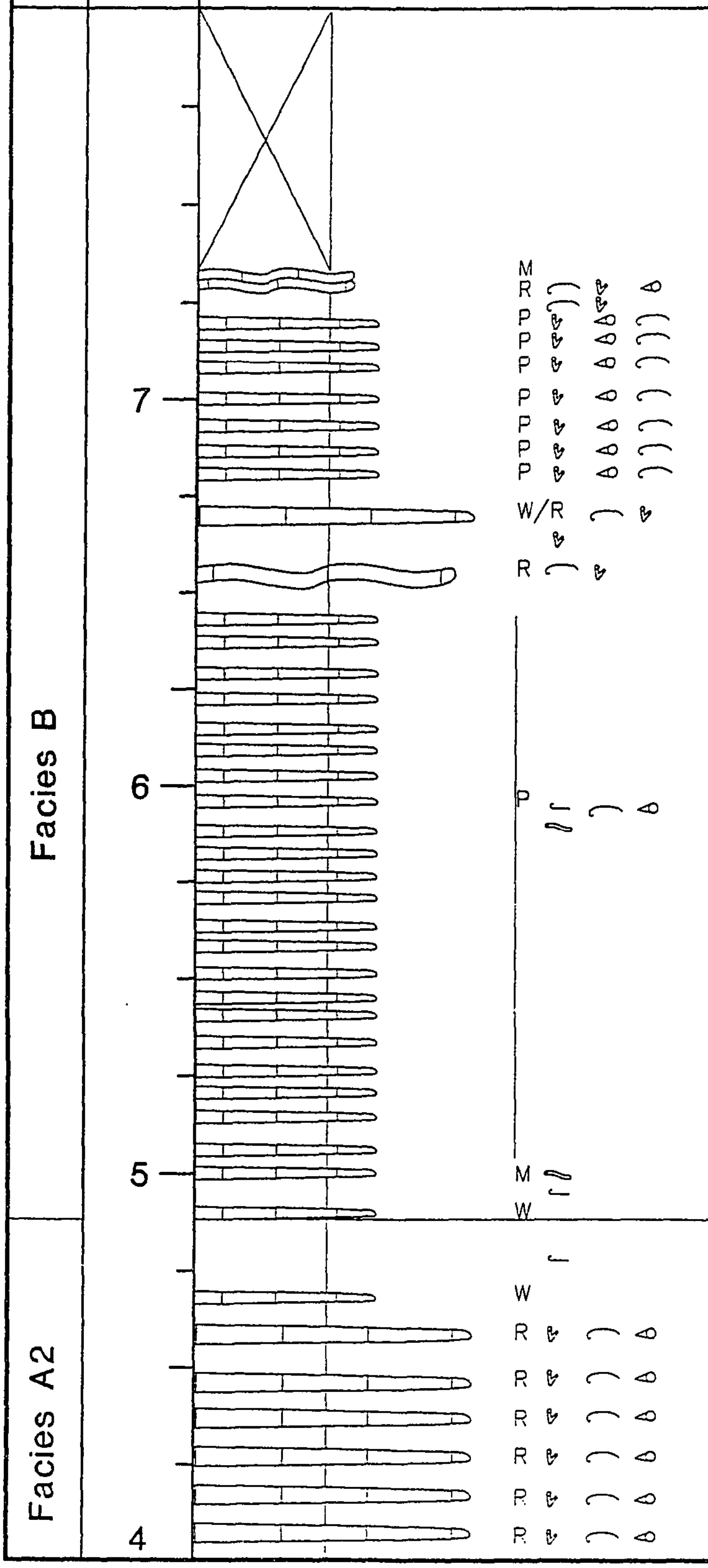
INTERBEDDED WACKESTONES AND PACKSTONES – Medium gray (N5) to light olive gray (5Y5/2), irregular bedded, abundant rugosan corals, brachiopods, and bryozoans, fossils concentrated at the top of many of the beds, Chondrites is present in distinct layers.

Beds coarsen upwards.

Camden Outcrop

Geological Description

Facies	Meters	Litholog	Comments



As above but bryozoans and trilobites are more abundant and less irregular bedded.

Isotelus

INTERBEDDED PACKSTONES AND SHALES – Light olive gray (5Y5/2) to light olive (10Y5/4), planar bedded with occasional irregular beds, abundant trilobites, and whole brachiopods and bryozoans, not abraded, Chondrites present at top of some beds.

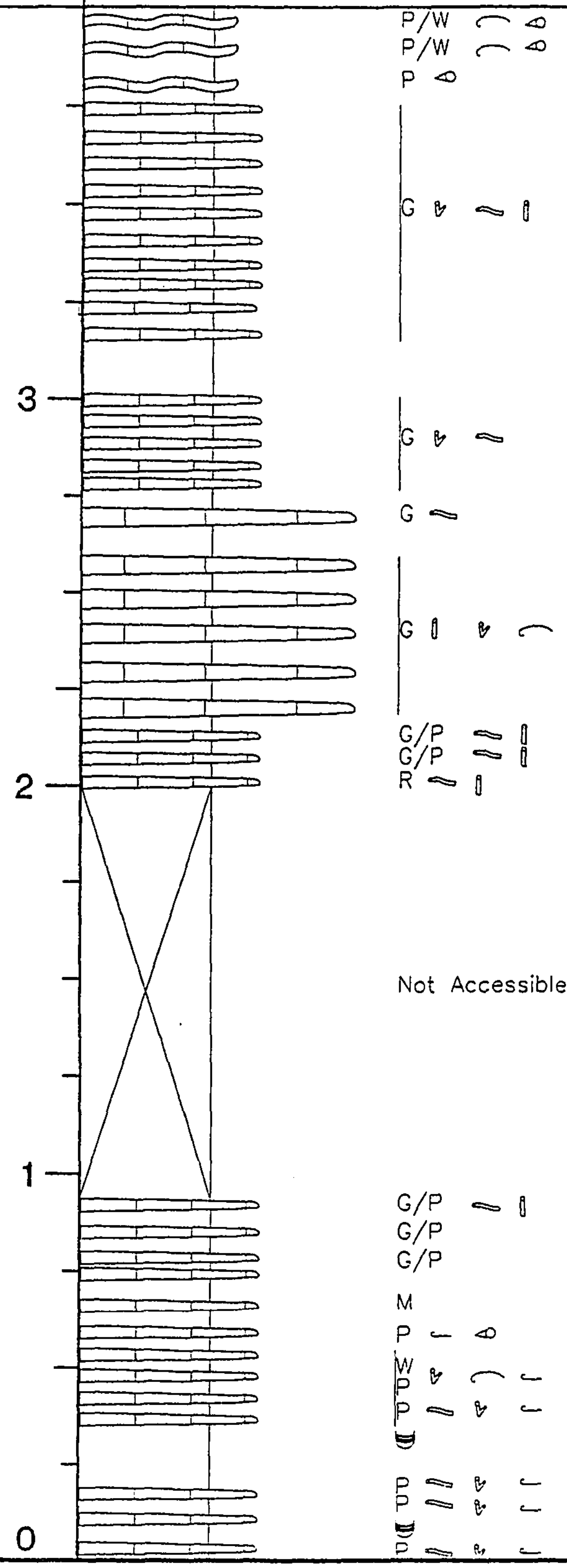
INTERBEDDED RUDSTONES AND SHALE – Medium dark gray (N4) to dark gray (N3), abundant brachiopods, bryozoans, and rugosans, Platystrophia most common brachiopod, beds have sharp contact, facies contact is gradational, base of Facies B is placed at the top of the last prominent shale interval.

Camden Outcrop

Geological Description

Facies | Meters | Litholog | Comments

Facies A2



INTERBEDDED PACKSTONES, GRAINSTONES, AND SHALE - Light olive gray (5Y5/2) to grayish olive (10Y4/2), prominent bioturbation at some intervals, occasional wavy beds, beds fine upward, sharp contacts above and below, fossils are well preserved, carbonate beds are commonly bioturbated at top and infilled with overlying clay lithology.

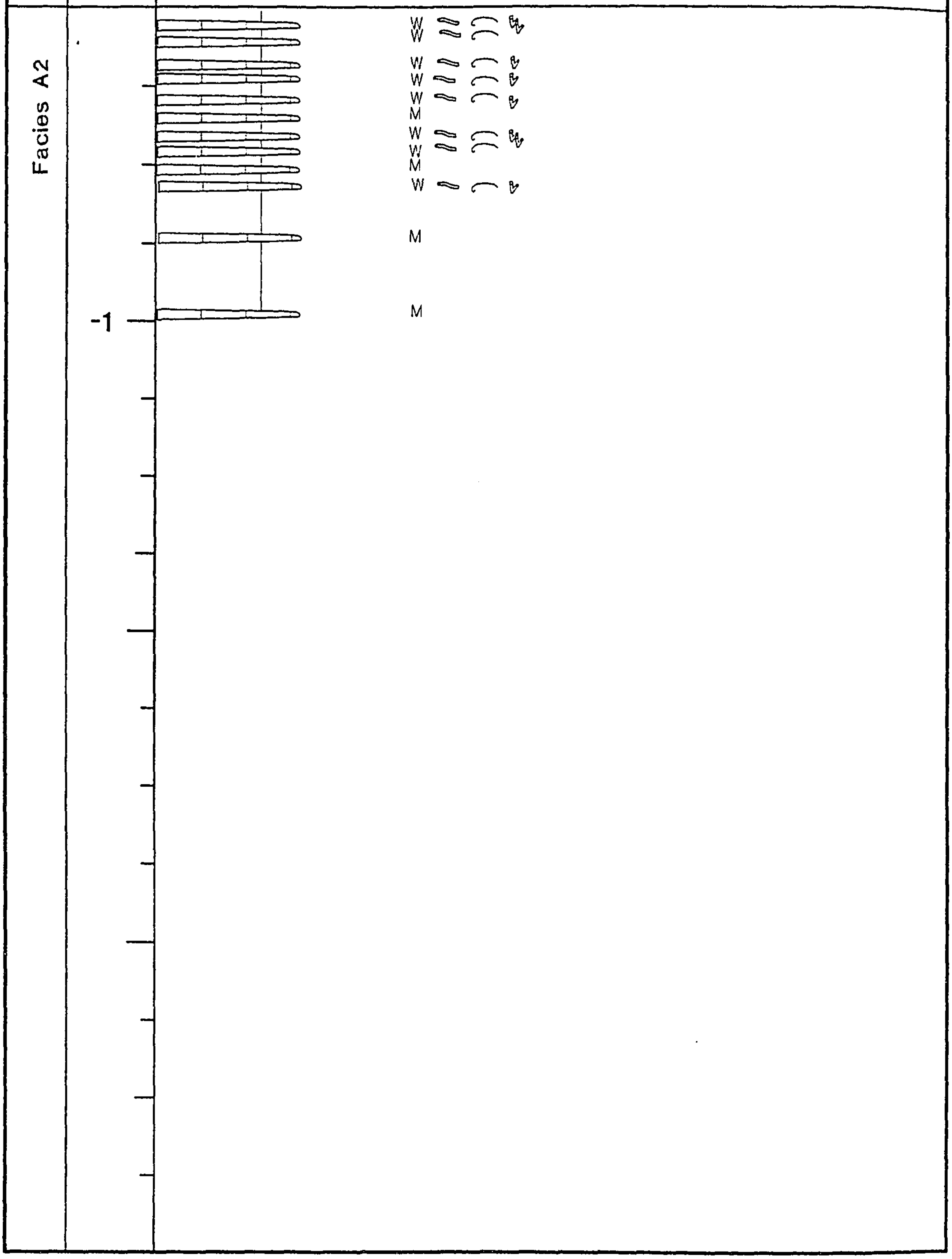
Vertical burrows are common throughout this interval and may extend the entire thickness of the bed. Pictures of this layer are presented in the text.

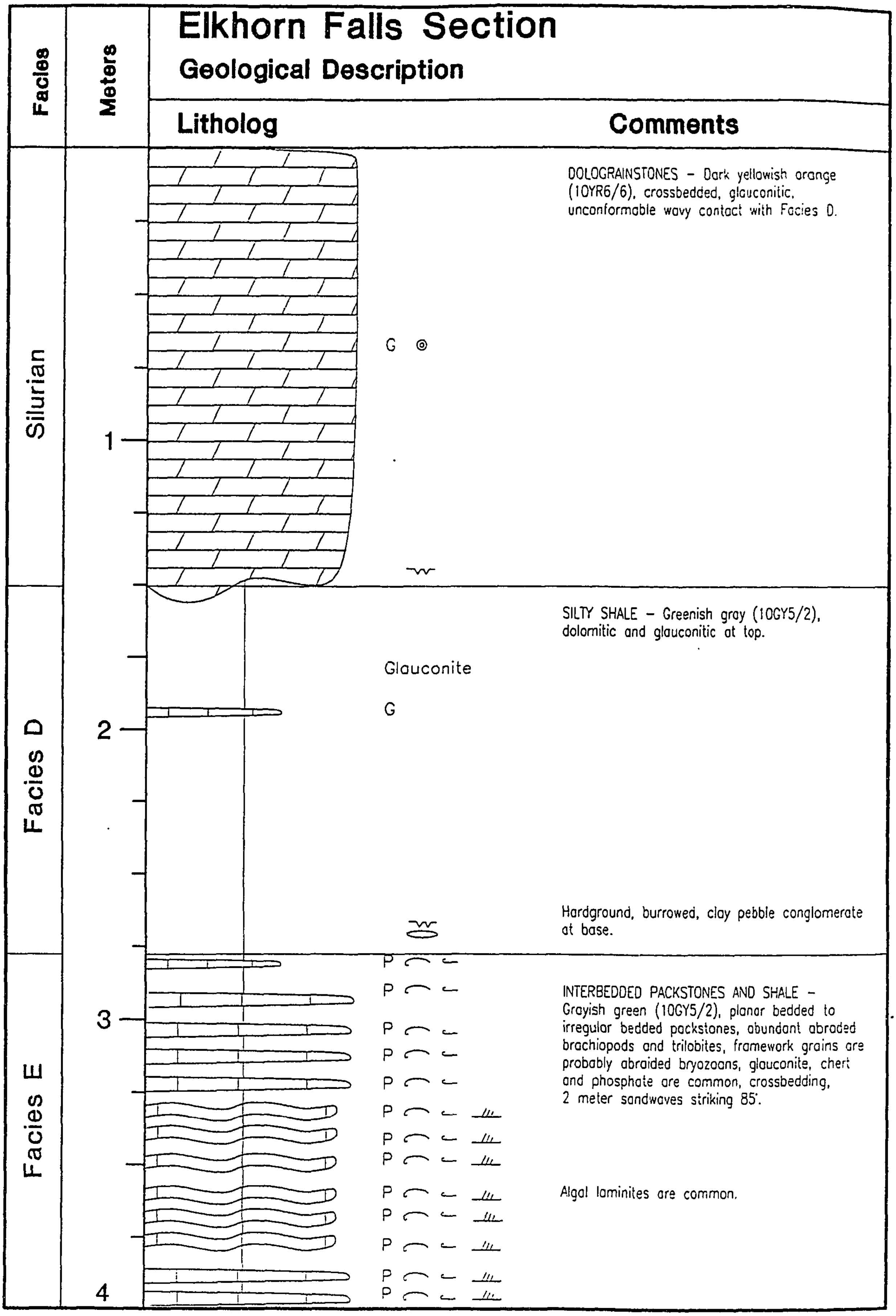
As above.

Camden Outcrop

Geological Description

Facies	Meters	Litholog	Comments



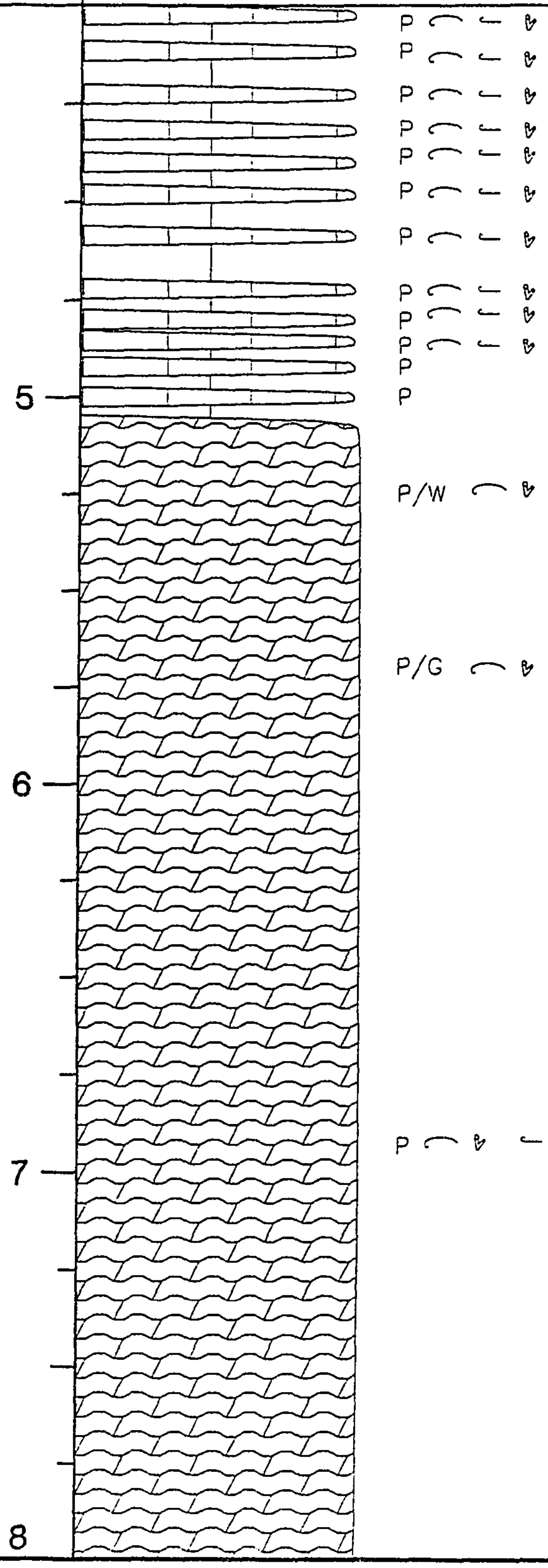

Elkhorn Falls Section
Geological Description
Facies
Meters
Litholog
Comments
Silurian
Facies D
Facies E
1
2
3
4
G
Glauconite
G
P
DOLOGRAINSTONES - Dark yellowish orange (10YR6/6), crossbedded, glauconitic, unconformable wavy contact with Facies D.
SILTY SHALE - Greenish gray (10GY5/2), dolomitic and glauconitic at top.
Hardground, burrowed, clay pebble conglomerate at base.
INTERBEDDED PACKSTONES AND SHALE - Grayish green (10GY5/2), planar bedded to irregular bedded packstones, abundant abraded brachiopods and trilobites, framework grains are probably abraided bryozoans, glauconite, chert and phosphate are common, crossbedding, 2 meter sandwaves striking 85°.
Algal laminites are common.

Elkhorn Falls Section

Geological Description

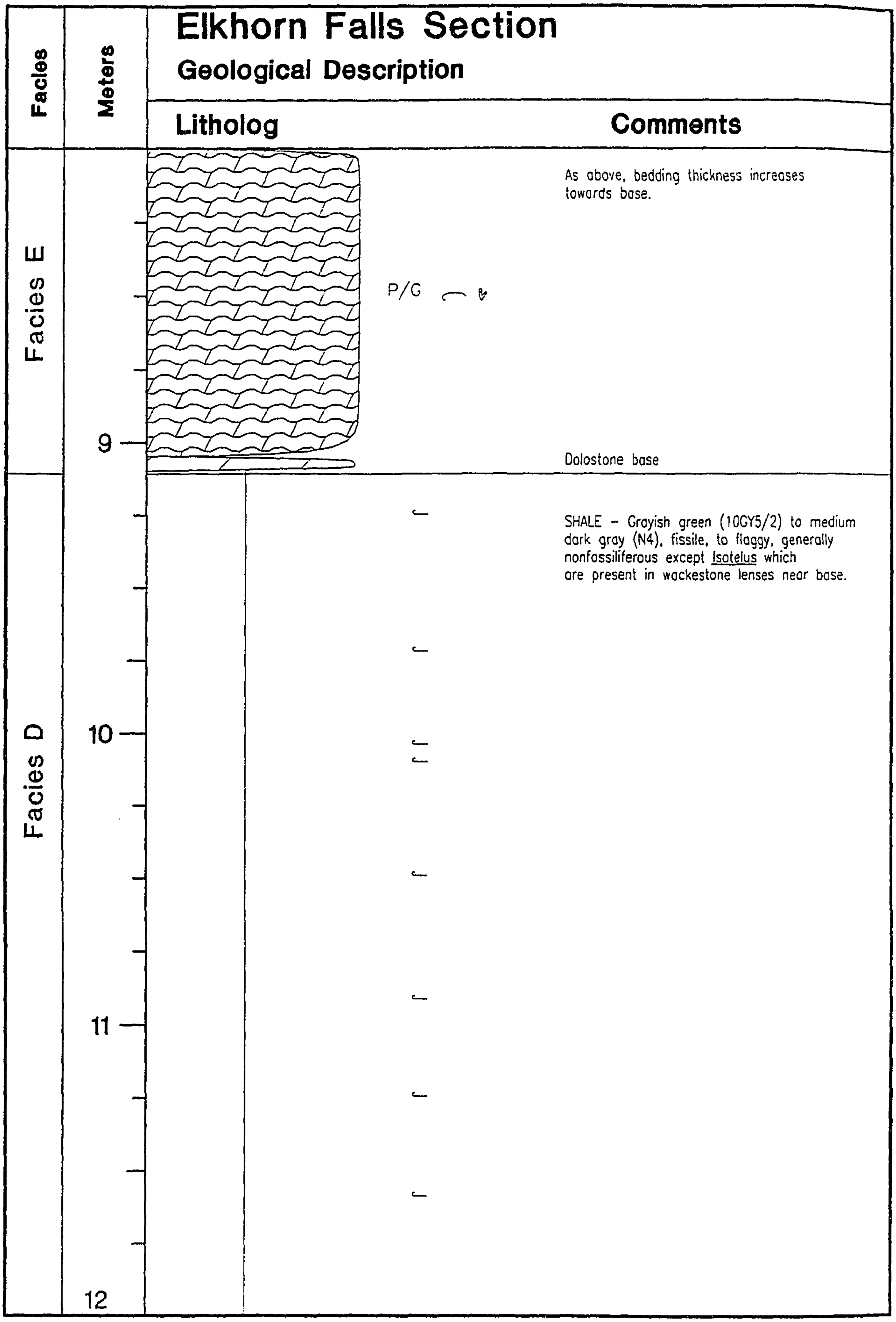
Facies | Meters | Litholog | Comments

Facies E



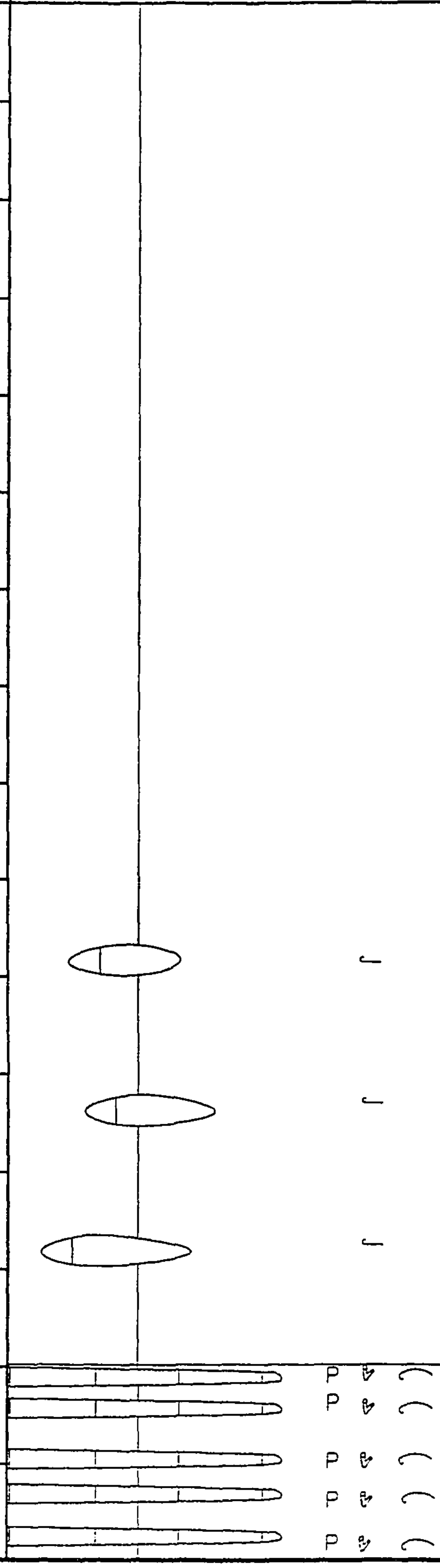
Abundant Beatrecia oriented 315°, one specimen was at least 18 inches long.

INTERBEDDED WACKESTONES AND PACKSTONES – Grayish green (10GY5/2), irregularly bedded wackestones and packstones (80%) separated by dolomitic shale, abundant, poorly sorted fossils, most prominent fossils include a variety of bryozoans, Platystrophia moritura, Isotelus sp., and Hebertella sp.. Fossils are highly abraded.


Facies
Meters
Elkhorn Falls Section
Geological Description
Litholog
Comments
Facies E
Facies D
9
10
11
12
P/G
As above, bedding thickness increases towards base.
Dolostone base
SHALE - Grayish green (10GY5/2) to medium dark gray (N4), fissile, to flaggy, generally nonfossiliferous except Isotelus which are present in wackestone lenses near base.

Elkhorn Falls Section

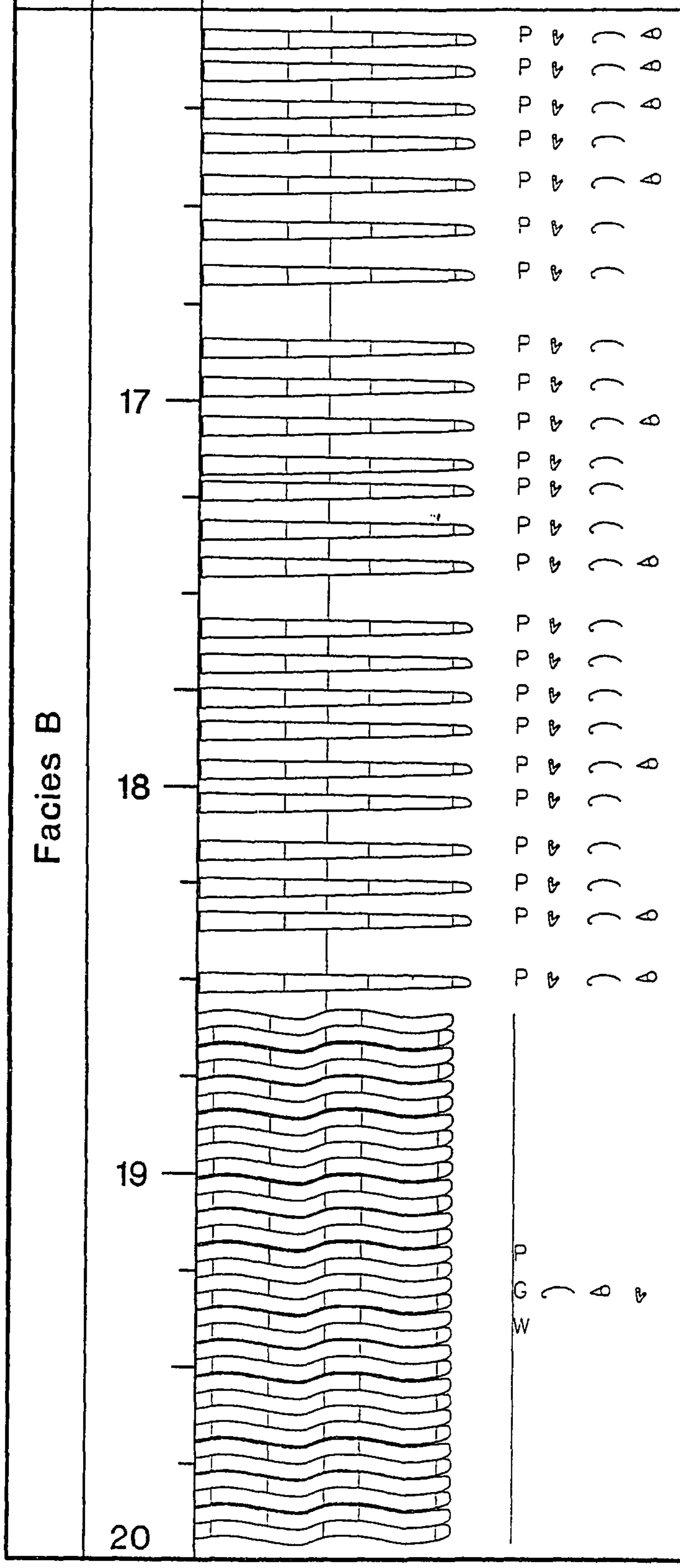
Geological Description

Facies	Meters	Litholog	Comments
Facies D	13, 14, 15		As above
Facies B	16		INTERBEDDED PACKSTONES AND SHALES – Grayish green (10GY5/2), planar bedded, 50% packstones to wackestones, abnduant bryozoans and brachiopods, gradational contact with overlying shales selected as first prominent packstone bed.

Elkhorn Falls Section

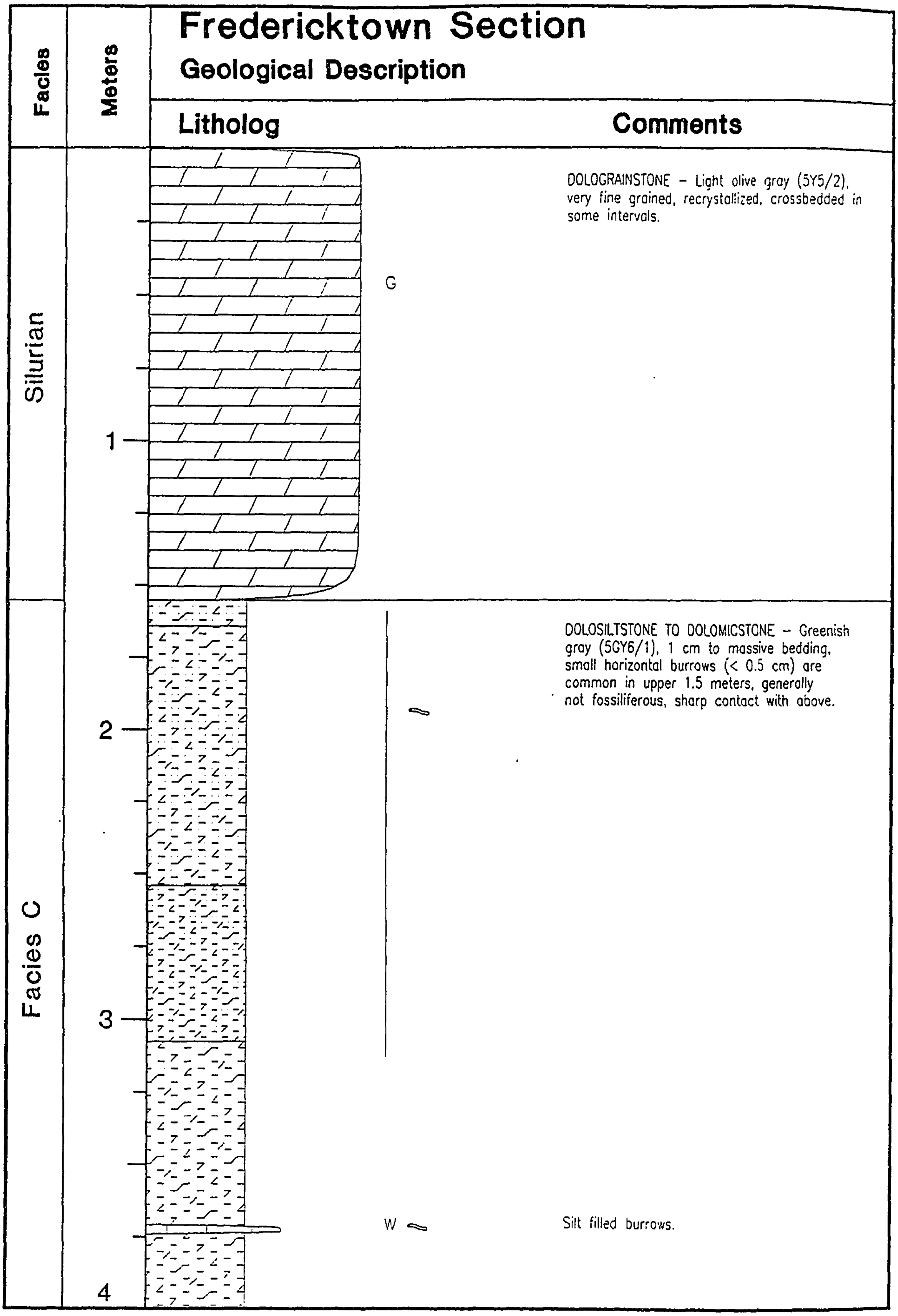
Geological Description

Facies	Meters	Litholog	Comments

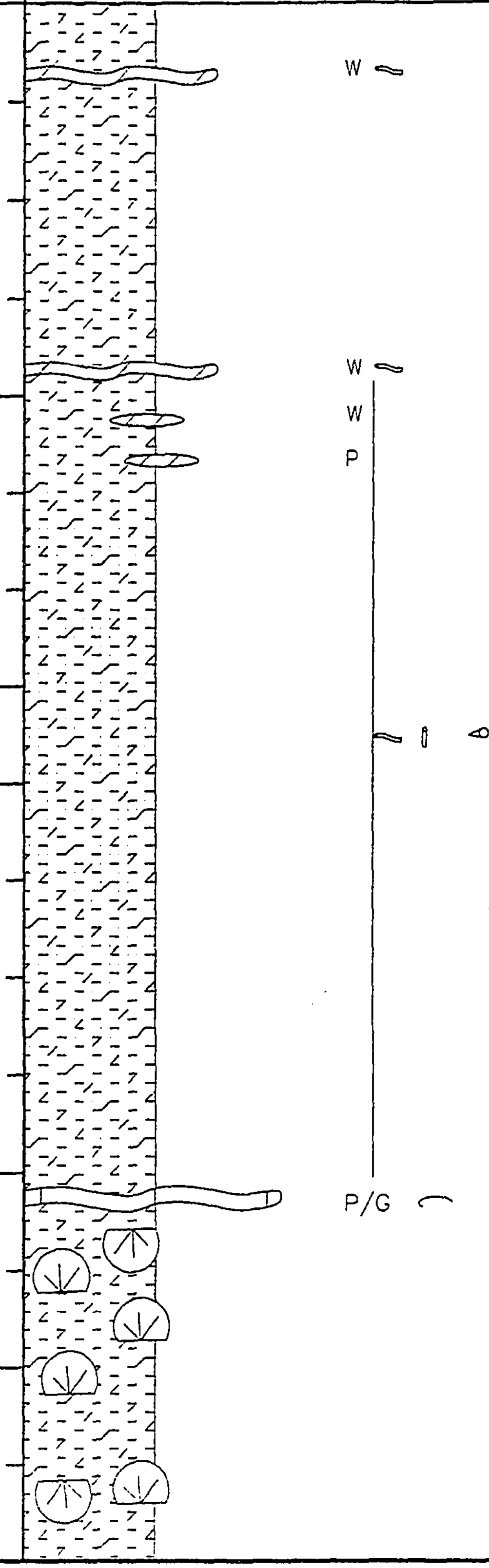


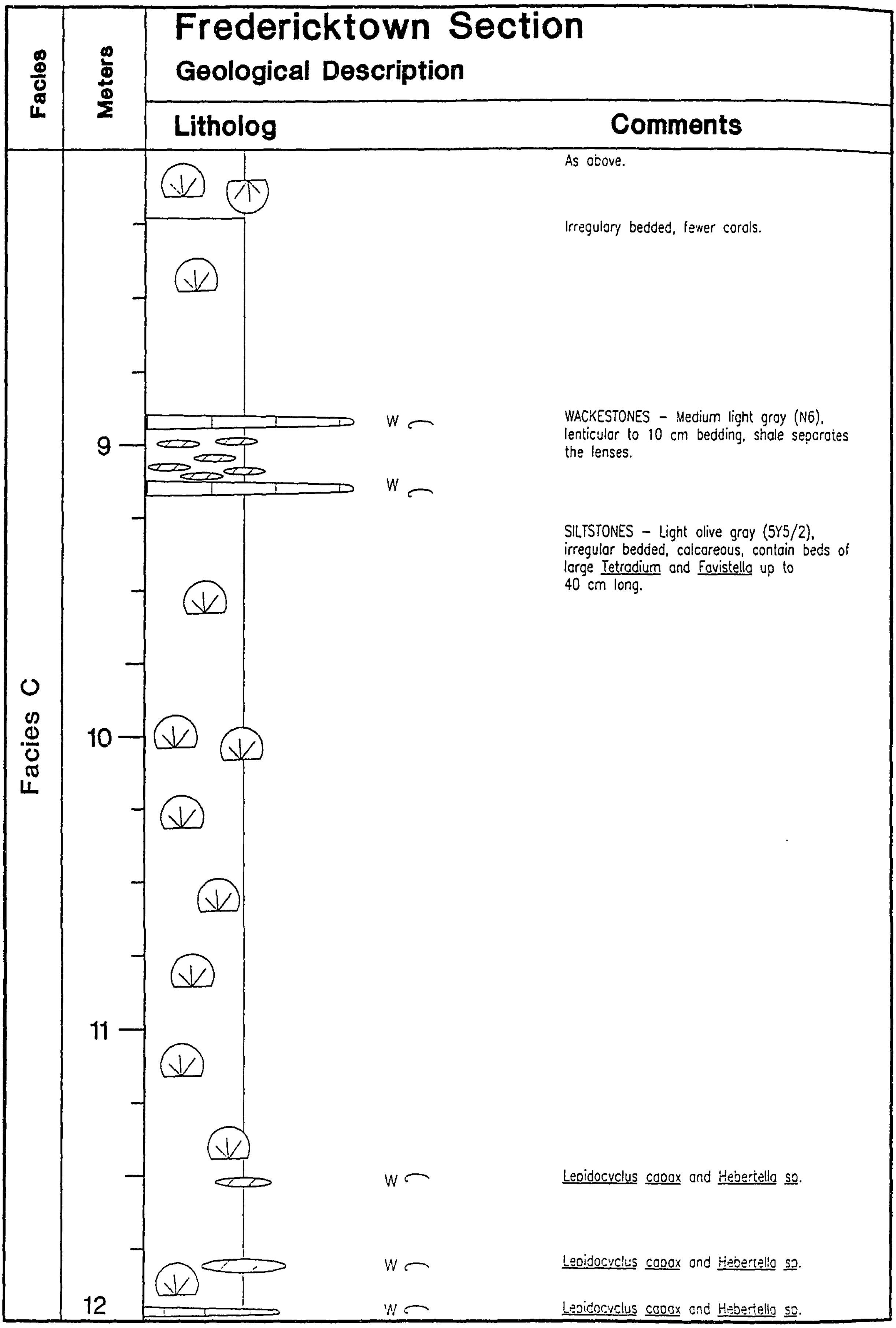
As above, with rugosan corals (Grewingkia canadensis) and increasing shale content towards base.

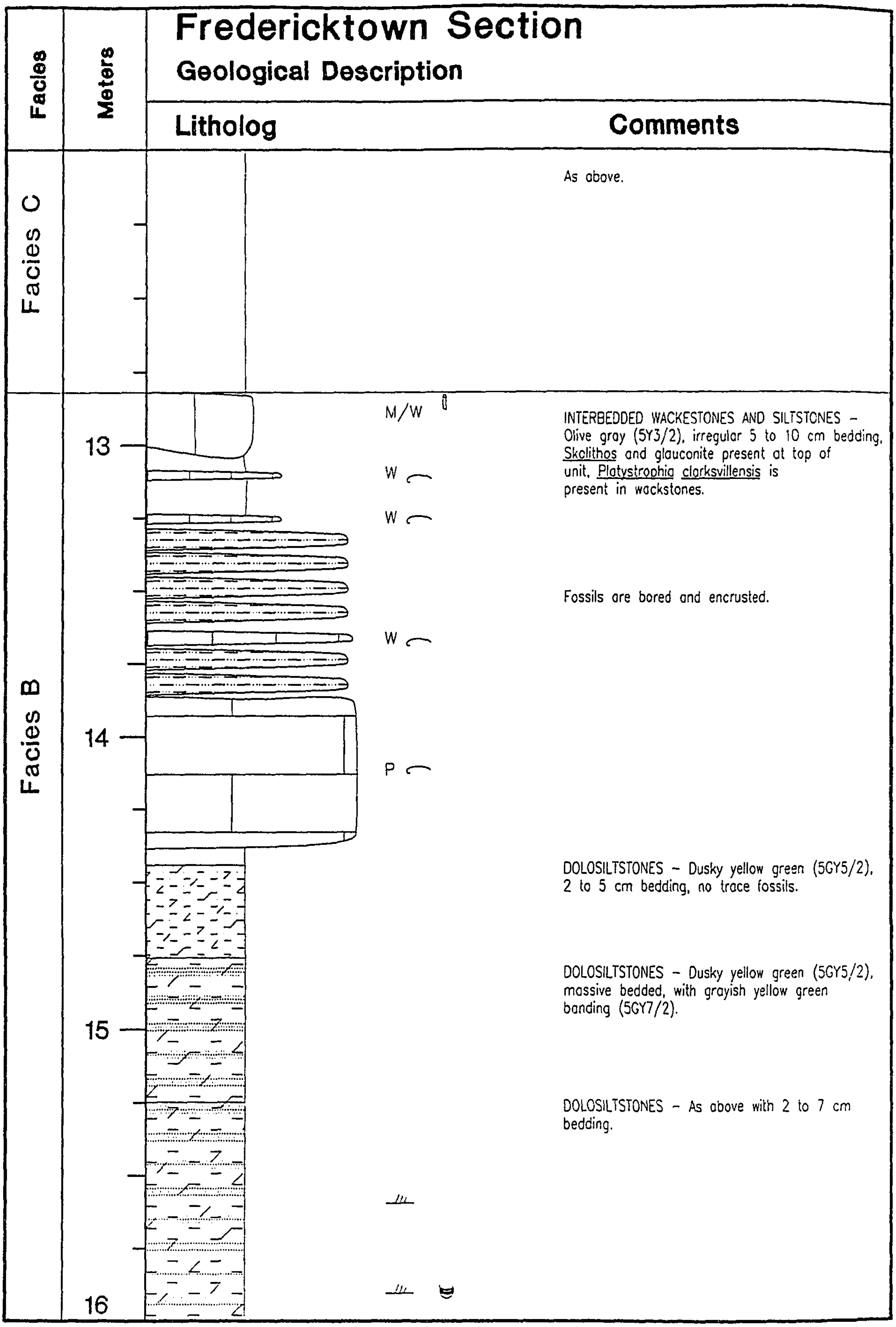
INTERBEDDED PACKSTONES, GRAINSTONES, AND WACKESTONES – Medium dark gray (N4), irreularly bedded, extremely fossiliferous including brachiopods, bryozoans, rugosan corals and intervals of algal rich carbonates.

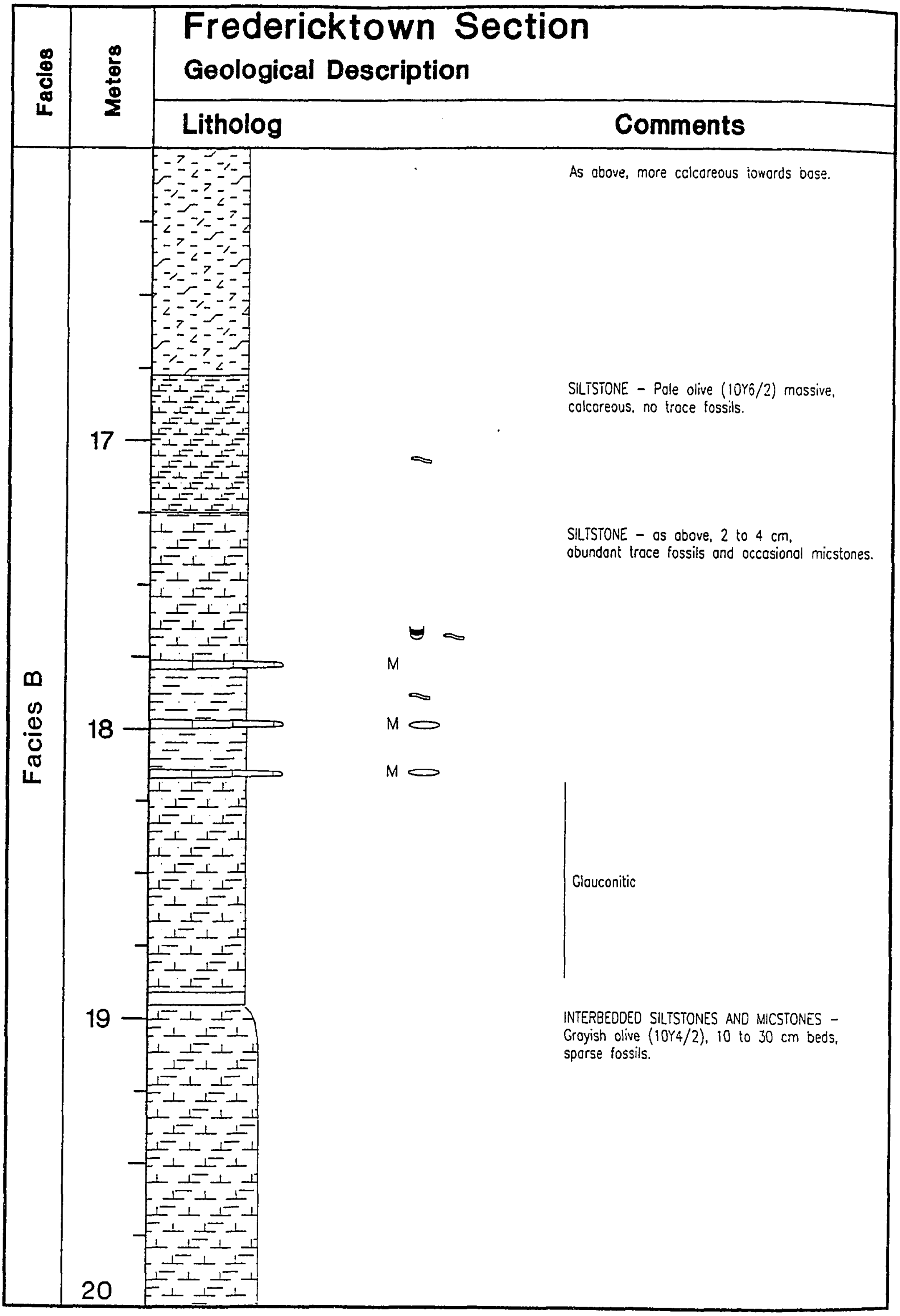


Fredericktown Section
Geological Description
Facies
Meters
Litholog
Comments
Silurian
Facies C
1
2
3
4
G
W
DOLOGRAINSTONE - Light olive gray (5Y5/2), very fine grained, recrystallized, crossbedded in some intervals.
DOLOSILTSTONE TO DOLOMICSTONE - Greenish gray (5GY6/1), 1 cm to massive bedding, small horizontal burrows (< 0.5 cm) are common in upper 1.5 meters, generally not fossiliferous, sharp contact with above.
Silt filled burrows.

Facies	Meters	Fredericktown Section Geological Description	
		Litholog	**Comments**
Facies C	5 6 7 8		As above, becoming more argillaceous towards the base. DOLOSILTSTONE – Greenish gray (5GY6/1), intensely bioturbated with both Skolithos and Chondrites, occasional wackestone and packestone lenses, Grewingkia canadensis is sparsely distributed, 1 to 3 cm bedding. SILTY SHALE – Medium light gray (N6) silty shale with approximately 50% Tetradium and Favistella, approximately 10% are overturned.


Fredericktown Section
Geological Description
Facies
Meters
Litholog
Comments
As above.
Irregulary bedded, fewer corals.
W
WACKESTONES - Medium light gray (N6), lenticular to 10 cm bedding, shale separates the lenses.
9
W
SILTSTONES - Light olive gray (5Y5/2), irregular bedded, calcareous, contain beds of large Tetradium and Favistella up to 40 cm long.
Facies C
10
11
W
Lepidocyclus capax and Hebertella sp.
W
Lepidocyclus capax and Hebertella sp.
12
W
Lepidocyclus capax and Hebertella sp.

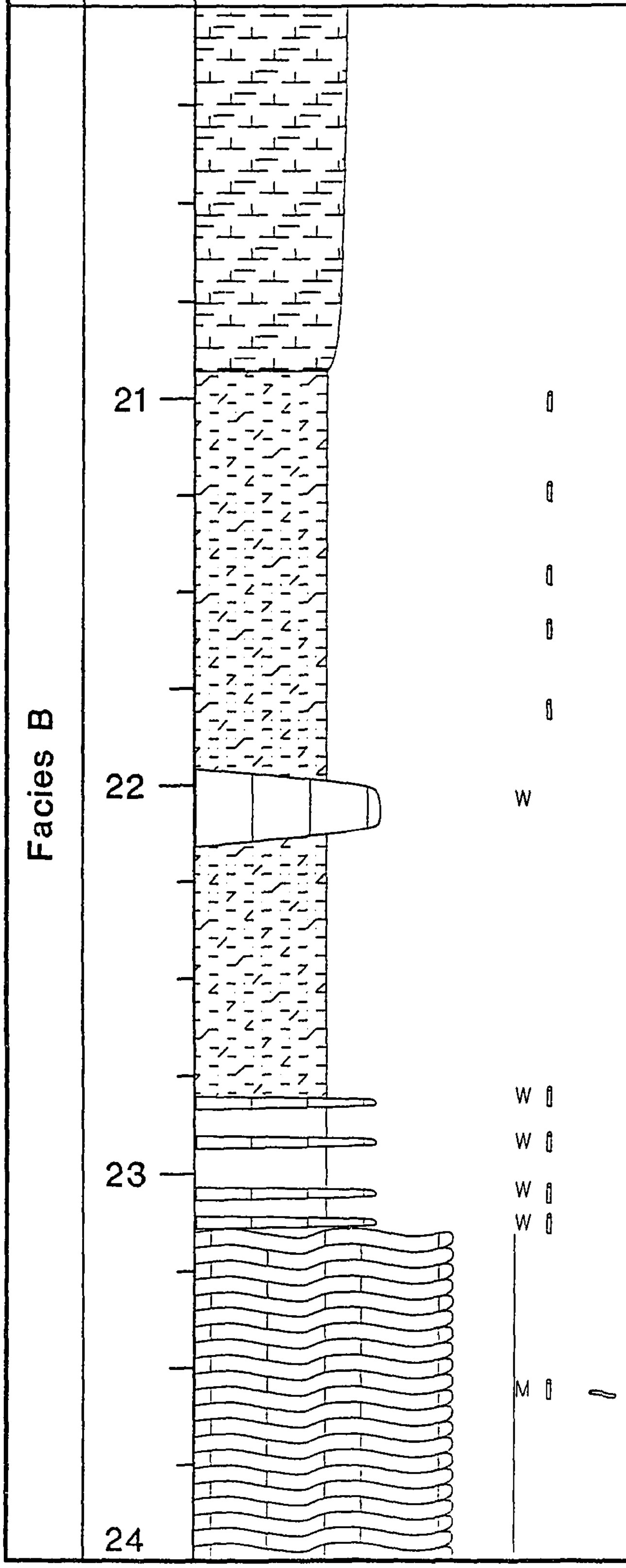

Fredericktown Section
Geological Description
Facies
Meters
Litholog
Comments
Facies C
As above.
Facies B
13
14
15
16
M/W
W
W
W
P
INTERBEDDED WACKESTONES AND SILTSTONES – Olive gray (5Y3/2), irregular 5 to 10 cm bedding, Skolithos and glauconite present at top of unit, Platystrophia clarksvillensis is present in wackstones.
Fossils are bored and encrusted.
DOLOSILTSTONES – Dusky yellow green (5GY5/2), 2 to 5 cm bedding, no trace fossils.
DOLOSILTSTONES – Dusky yellow green (5GY5/2), massive bedded, with grayish yellow green banding (5GY7/2).
DOLOSILTSTONES – As above with 2 to 7 cm bedding.


Fredericktown Section
Geological Description
Facies
Meters
Litholog
Comments
As above, more calcareous towards base.
SILTSTONE - Pale olive (10Y6/2) massive, calcareous, no trace fossils.
17
SILTSTONE - as above, 2 to 4 cm, abundant trace fossils and occasional micstones.
M
M
M
18
Facies B
Glauconitic
19
INTERBEDDED SILTSTONES AND MICSTONES - Grayish olive (10Y4/2), 10 to 30 cm beds, sparse fossils.
20

Fredericktown Section

Geological Description

Facies	Meters	Litholog	Comments



As above.

DOLOSILTSTONES – Pale olive (10Y6/2). 5 to 10 cm bedding, abundant <u>Skolithos</u>.

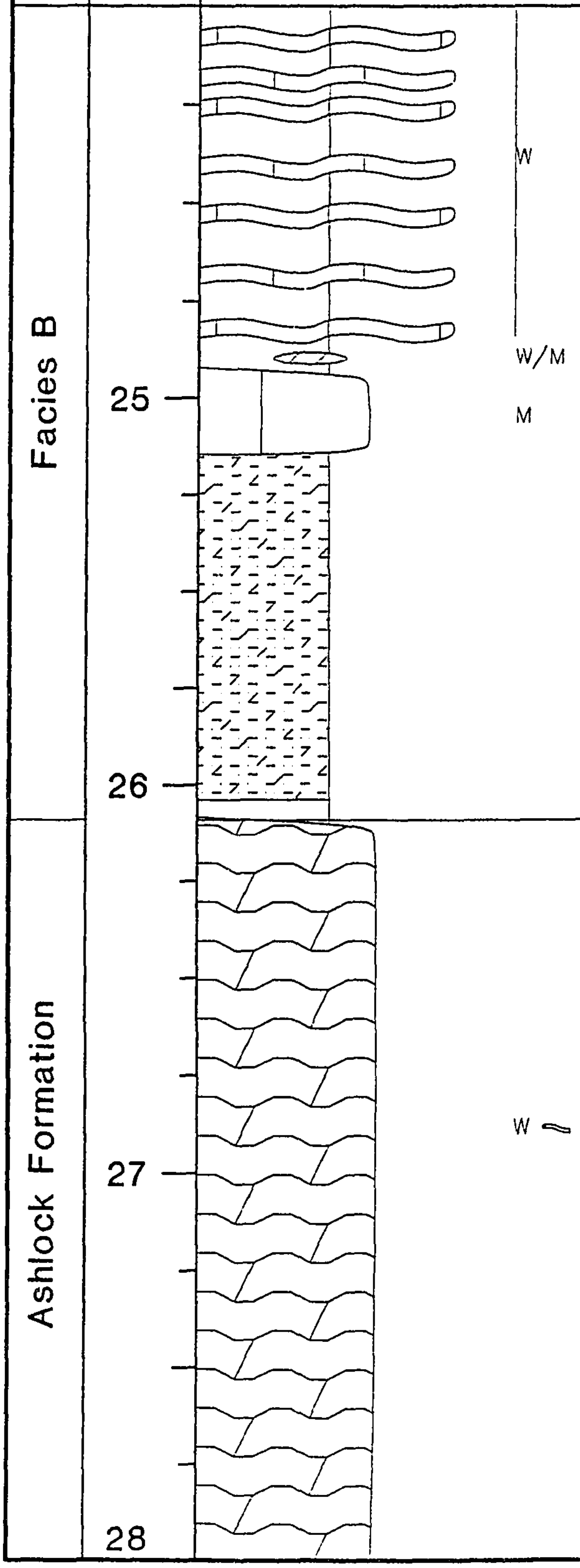
INTERBEDDED WACKESTONES, MICSTONES, AND SHALES – Grayish olive (10Y4/2), planar bedded, abundant <u>Sklolithos</u>

MICSTONES – Grayish olive (10Y4/2), irregular bedding, with 1 to 2 cm shale partings, shale partings have abundant <u>Skolithos</u> and <u>Chondites</u>.

Fredericktown Section

Geological Description

Facies	Meters	Lithology	Comments

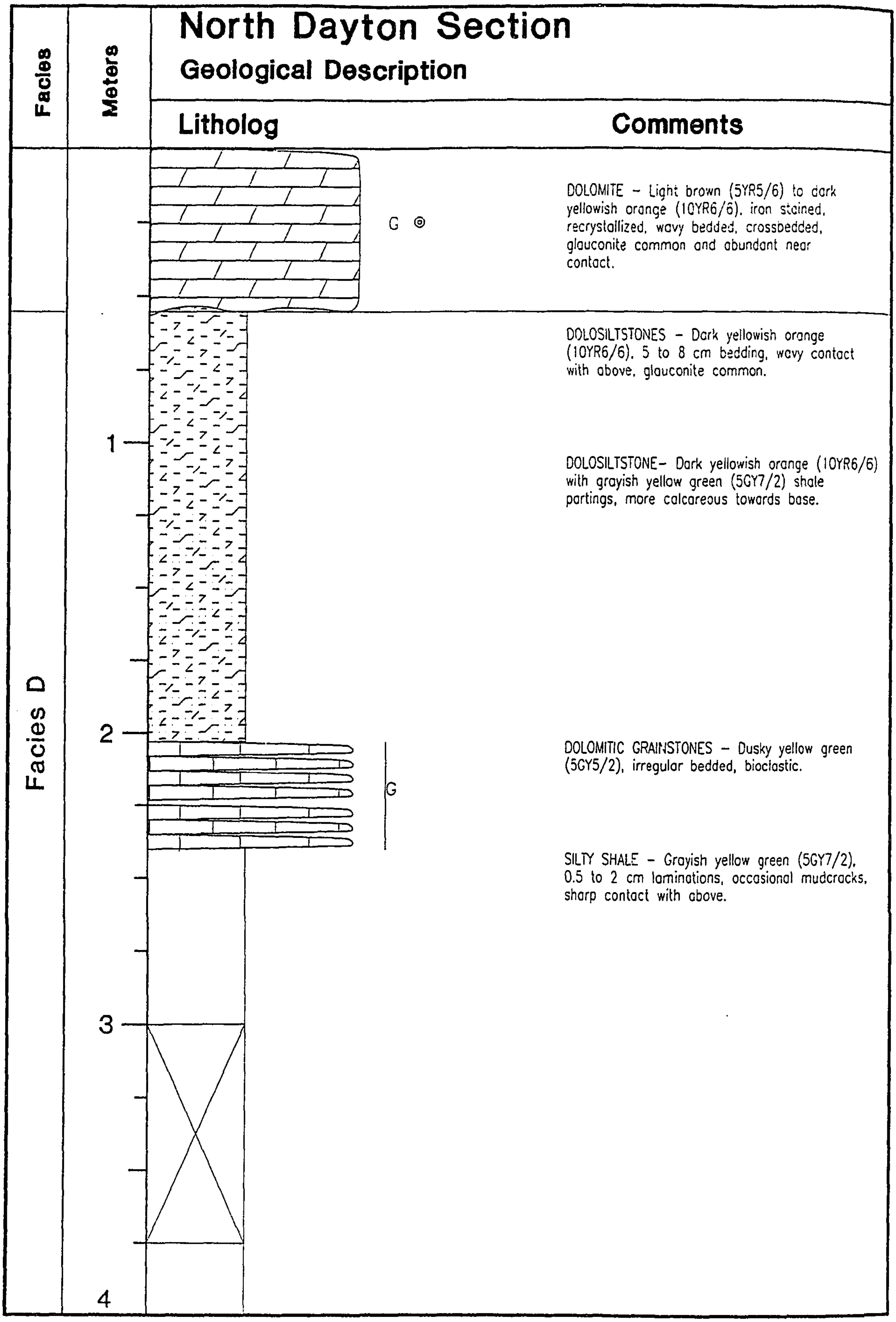


As above with wackstones and increasing shale content towards base.

SILTSTONES – Light olive gray (5Y5/2), 2 to 4 cm bedding, few fossils, occasional ripples.

CLAY SHALE – Olive gray (5Y3/2)

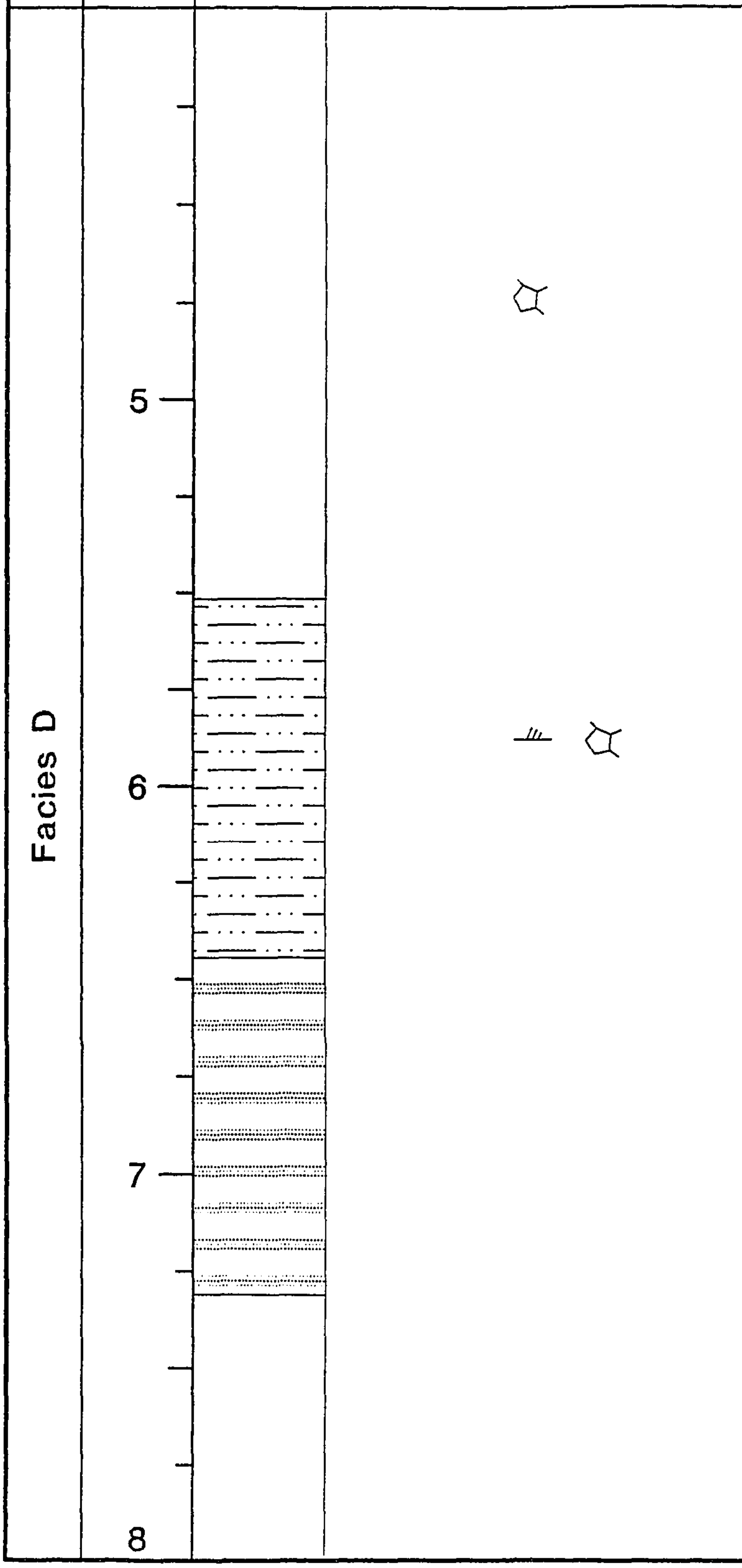
WACKESTONES – Medium gray (N5), irregularly bedded, abundant bryozoans and horizontal burrows.


North Dayton Section
Geological Description
Facies
Meters
Litholog
Comments
DOLOMITE – Light brown (5YR5/6) to dark yellowish orange (10YR6/6), iron stained, recrystallized, wavy bedded, crossbedded, glauconite common and abundant near contact.
G ⊚
DOLOSILTSTONES – Dark yellowish orange (10YR6/6), 5 to 8 cm bedding, wavy contact with above, glauconite common.
1
DOLOSILTSTONE– Dark yellowish orange (10YR6/6) with grayish yellow green (5GY7/2) shale partings, more calcareous towards base.
Facies D
2
DOLOMITIC GRAINSTONES – Dusky yellow green (5GY5/2), irregular bedded, bioclastic.
G
SILTY SHALE – Grayish yellow green (5GY7/2), 0.5 to 2 cm laminations, occasional mudcracks, sharp contact with above.
3
4

North Dayton Section

Geological Description

Facies	Meters	Litholog	Comments



As above

SILTSTONE – Light olive brown (5Y5/6), finely laminated (1 mm), 1 to 2 cm bedding, low angle cross stratification, mudcracks common at base.

SHALEY SILTSTONE – Dusky yellow (5Y6/4) with grayish red (5R4/2) beds of clay shale, gradational contact with above.

CLAY SHALE – Dark greenish gray (5GY4/1) very thin bedded, poorly exposed, generally non-fossiliferous.

North Dayton Section

Geological Description

Facies	Meters	Litholog	Comments
Facies D	9 – 12		As above

North Dayton Section

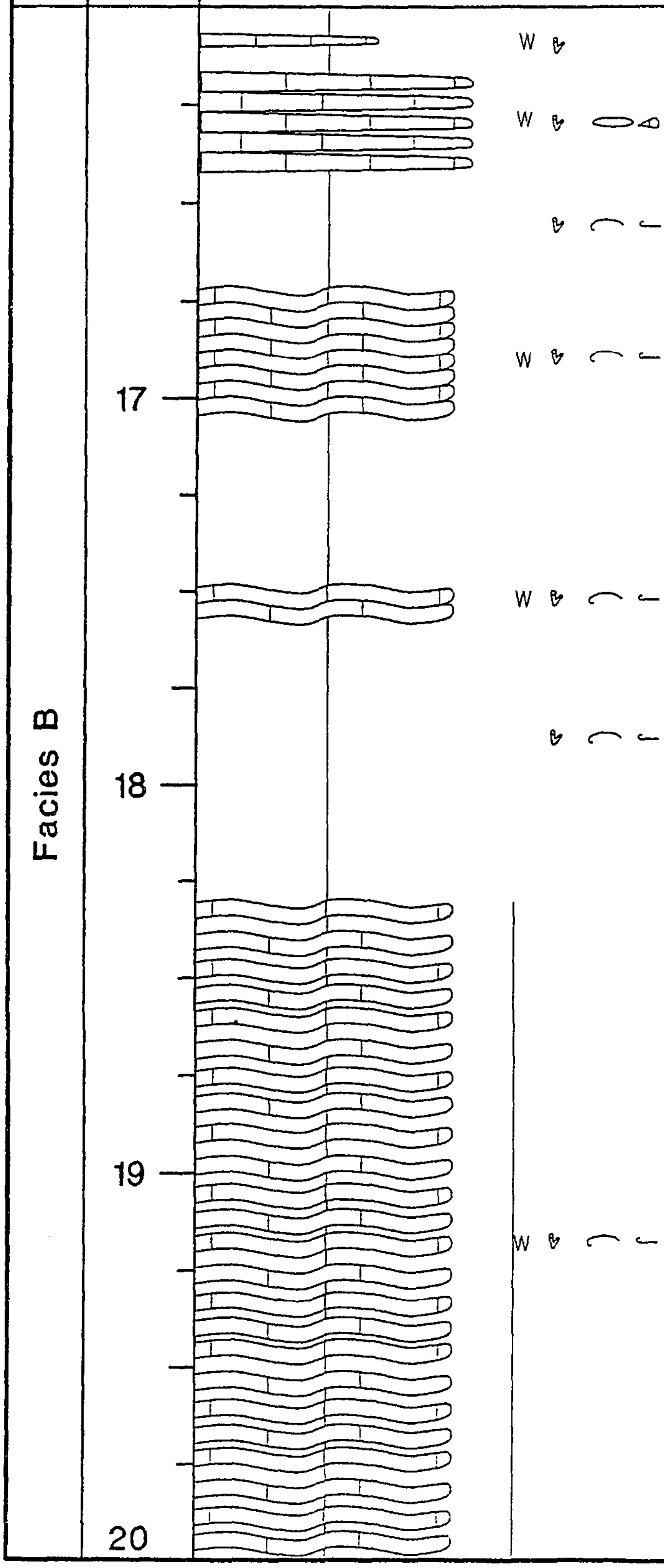
Geological Description

Facies	Meters	Litholog	Comments
Facies E	13		CLAY SHALE – Brownish gray (5YR4/1), extremely bioturbated, upper interval burrows are infilled with above dark greenish gray (5GY4/1) clay shales.
	14		CLAY SHALE – Dark greenish gray (5GY4/1), thin bedded, dolomitic, occasional conodonts.
	15		
	16	W	INTERBEDD WACKESTONES AND SHALES – See next page for description.

North Dayton Section

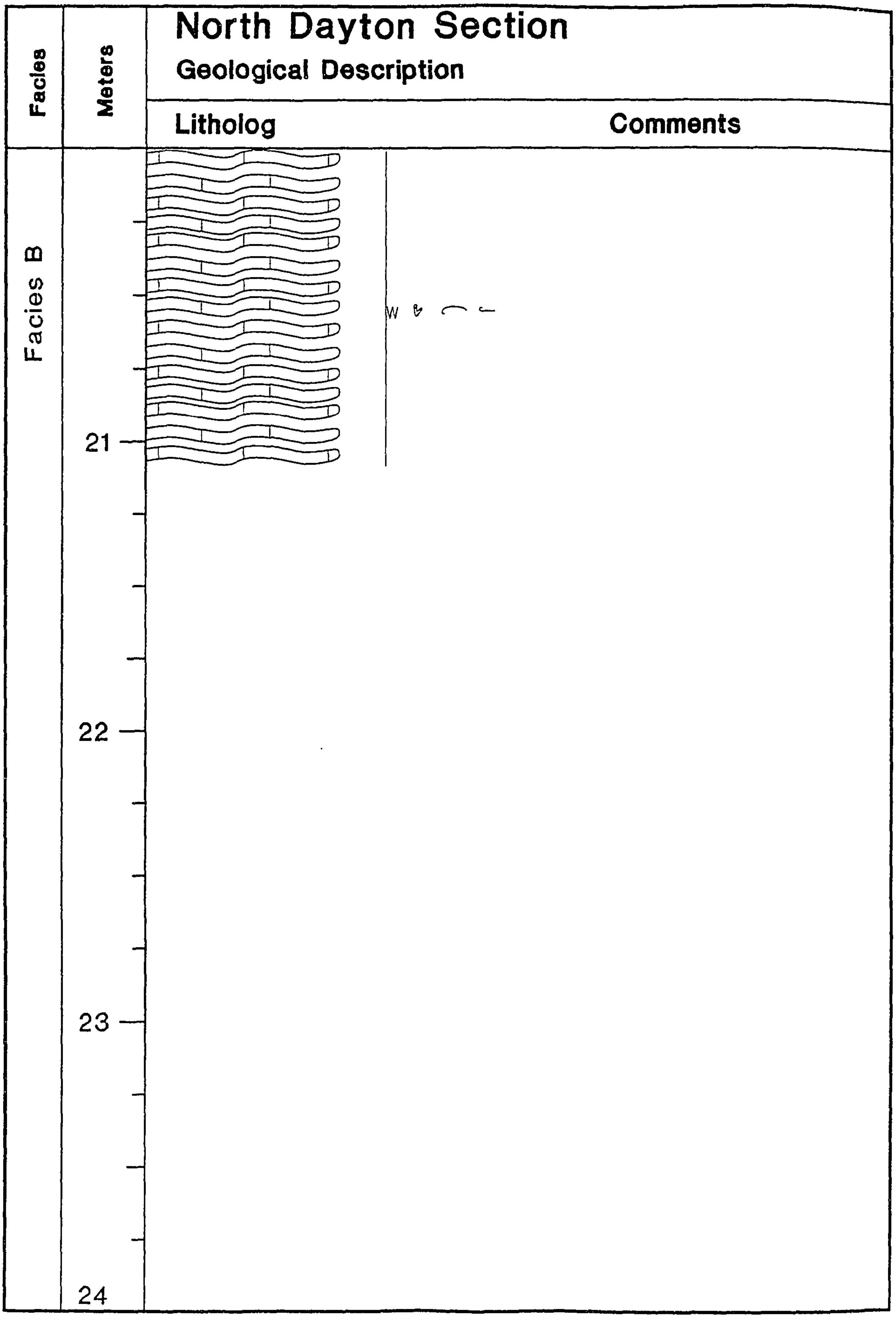
Geological Description

Facies | Meters | Litholog | Comments



INTERBEDDED WACKESTONES AND SHALES – Olive black (5Y2/1) to medium dark gray (N4), irregular bedding up to 5 cm, calcareuous, extremely fossiliferous in places including: _Platystrophia clarksvillensis_, _Batostomella gracilis_, _Rafinesquina alternata_, _Platystrophia sp._ _Grewingkia canadensis_ and _Lepidocyclus capax_.

INTERBEDDED WACKESTONES AND SHALES – Olive black (5Y2/1) to medium dark gray (N4), irregular 4 to 10 cm, with 5 to 10 cm shale beds, bryozoan rich shales, fossils include: _Protarea richmondensis_, _Isotelus sp._, bryozoan, _Rafinesquina alternata_, _Platystrophia sp._ and _Lepidocyclus capax_. The fossils are bored and commonly encrusted.


North Dayton Section
Geological Description
Facies
Meters
Litholog
Comments
Facies B
21
22
23
24

Appendix B

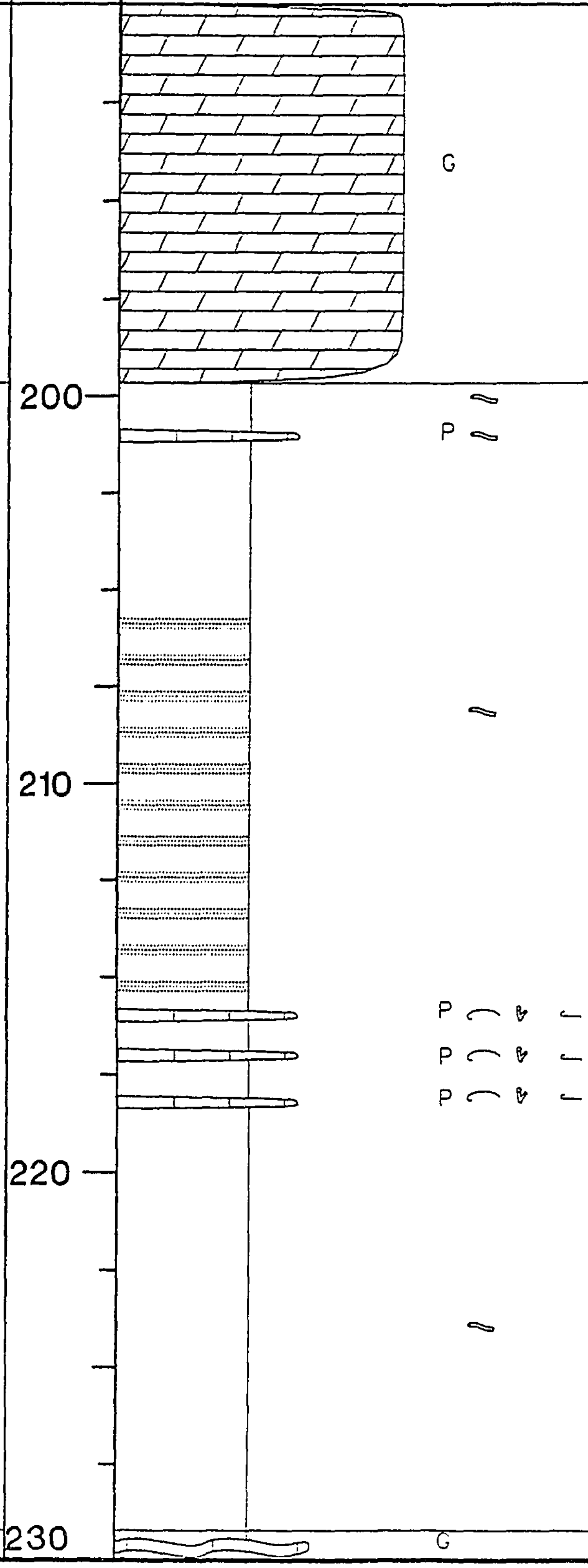
Core Descriptions

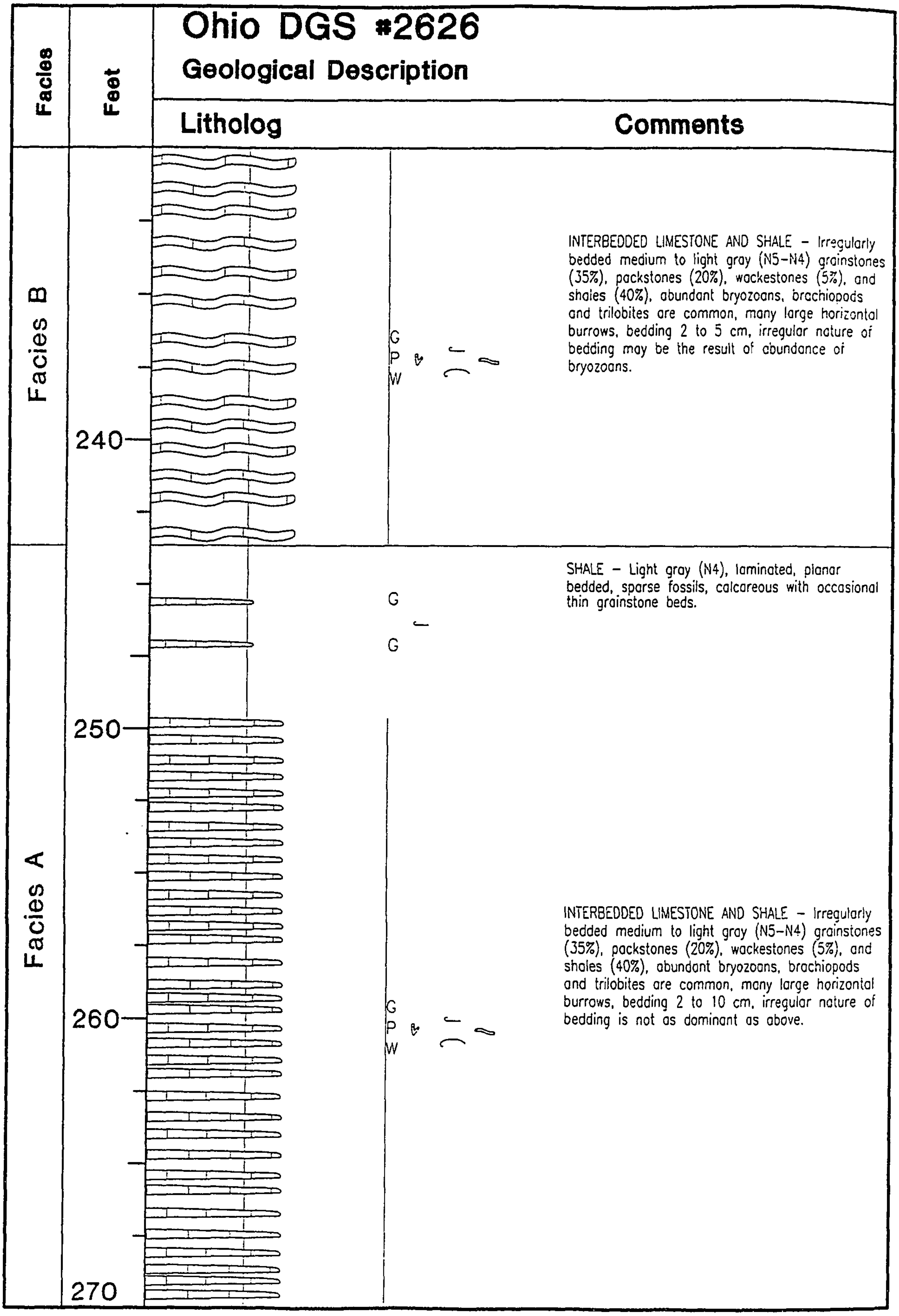
The key for the lithologic, paleontologic, and sedimentary symbols is located on pages A-1 and A-2 of Appendix A. Detailed descriptions of the Ohio Geological Survey Cores were completed, but are not submitted because the survey did not permit splitting of the cores during this study.

Ohio DGS #2626

Geological Description

Facies	Feet	Litholog	Comments
Silurian			GRAINSTONES – Light olive gray to medium gray (5Y6/1-N5), crinoid and brachiopod bioclasts, thin bedded to massive, trace of glauconite and pyrite with interbeds of greenish gray (5GY6/1) shale (20%), bioturbated.
Facies D	200 – 230		SHALE – Greenish gray (10GY5/2) with grayish red (5R4/2) banding from 206 to 215 feet, abundant ostracods, brachiopods and trilobites. horizontal burrows interbedded with medium gray (N5), fine grained packstones, 1 to 10 cm beds, horizontal burrows to 2 cm at top of beds, whole and fragmented brachiopods, bryozoans, and trilobites.

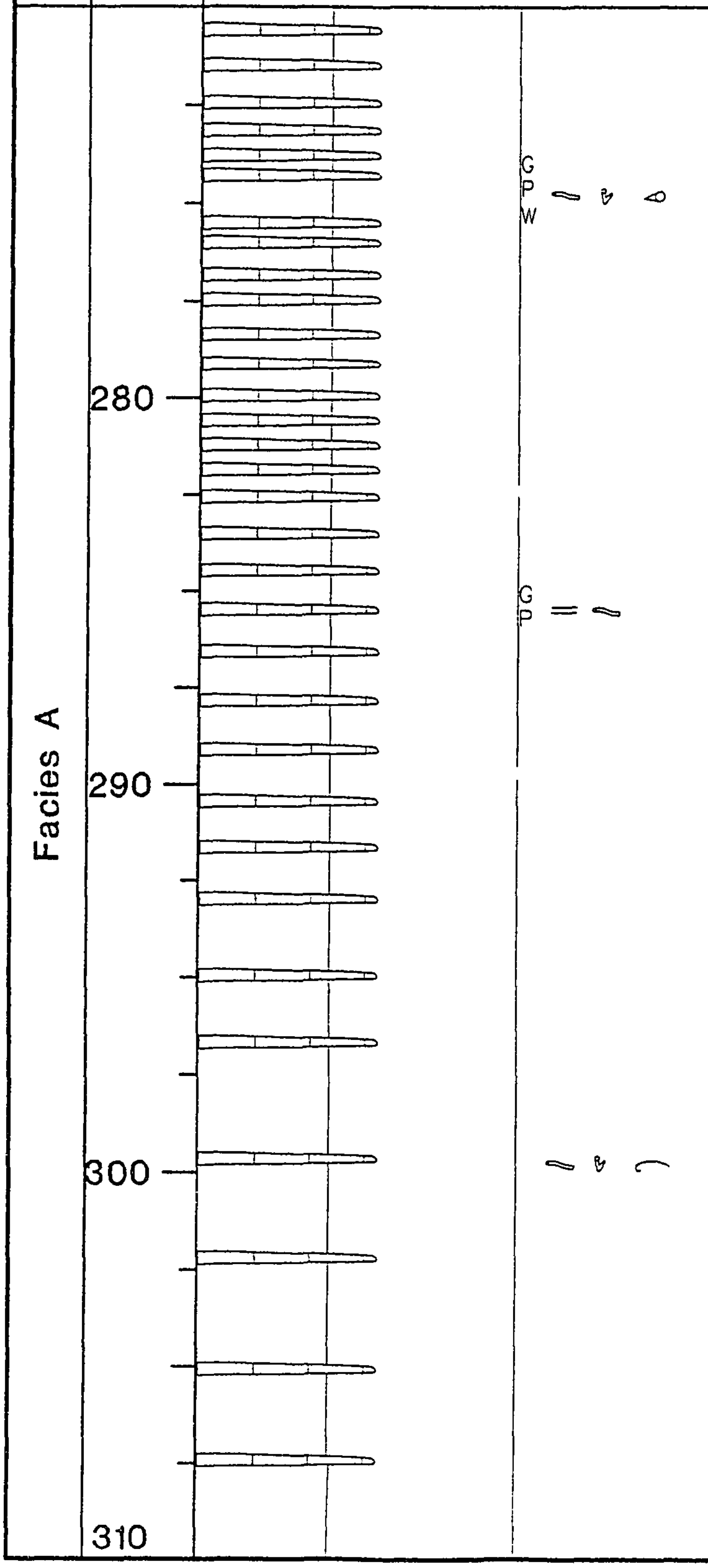



Ohio DGS #2626
Geological Description
Facies
Feet
Litholog
Comments
Facies B
240
G
P
W
INTERBEDDED LIMESTONE AND SHALE – Irregularly bedded medium to light gray (N5–N4) grainstones (35%), packstones (20%), wackestones (5%), and shales (40%), abundant bryozoans, brachiopods and trilobites are common, many large horizontal burrows, bedding 2 to 5 cm, irregular nature of bedding may be the result of abundance of bryozoans.
SHALE – Light gray (N4), laminated, planar bedded, sparse fossils, calcareous with occasional thin grainstone beds.
G
G
Facies A
250
260
270
G
P
W
INTERBEDDED LIMESTONE AND SHALE – Irregularly bedded medium to light gray (N5–N4) grainstones (35%), packstones (20%), wackestones (5%), and shales (40%), abundant bryozoans, brachiopods and trilobites are common, many large horizontal burrows, bedding 2 to 10 cm, irregular nature of bedding is not as dominant as above.

Ohio DGS #2626

Geological Description

Facies	Feet	Litholog	Comments



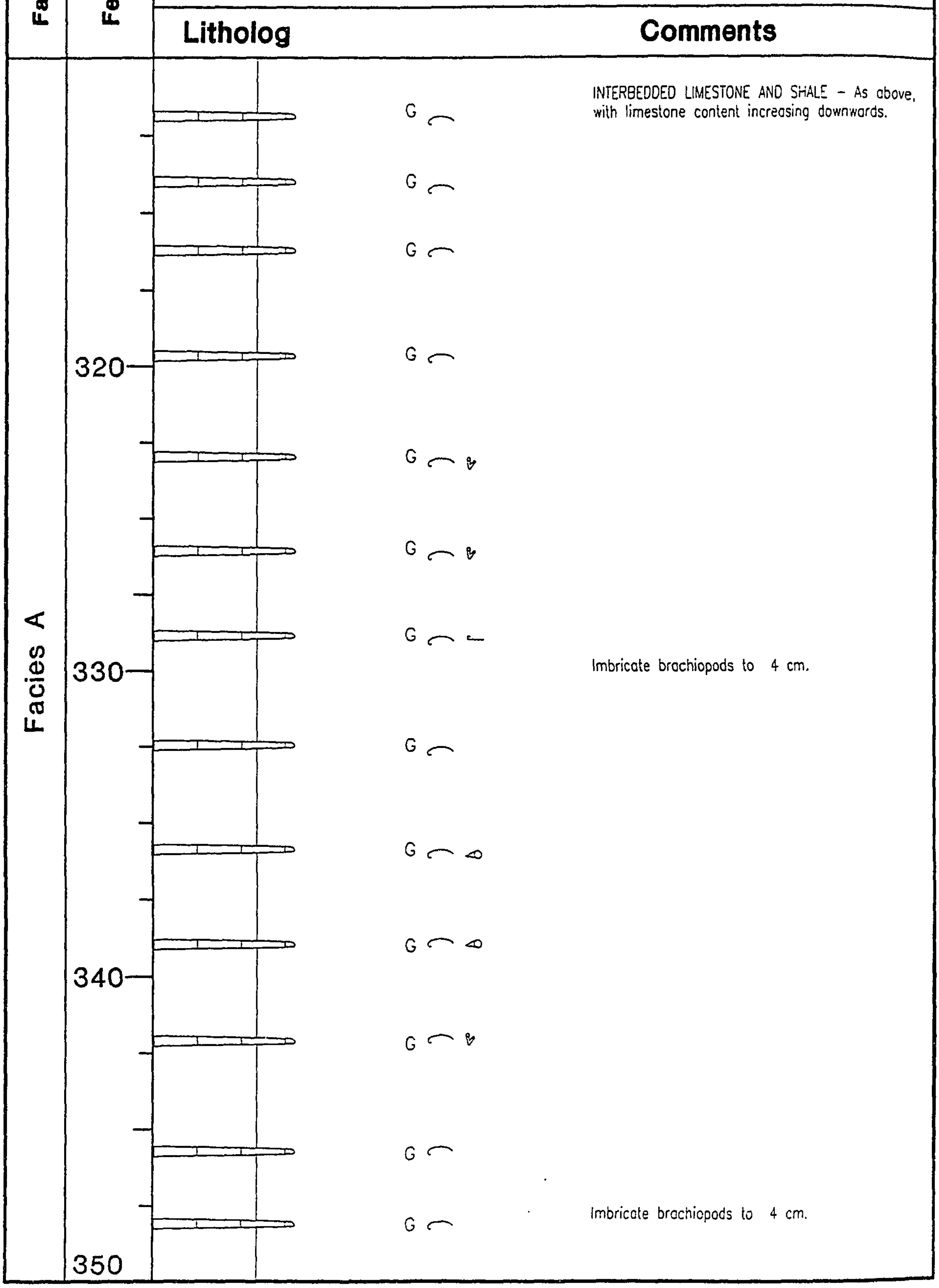
INTERBEDDED LIMESTONE AND SHALE – Olive gray (5Y4/1) to greenish gray (10GY5/2), 2 to 20 cm beds, interbedded with medium gray (5), irregular bedded to planar bedded, 1 to 9 cm grainstones, packstones, and wackestones, shale content increases downward.

INTERBEDDED SHALE AND LIMSTONE – Olive gray (5Y4/1), laminated shales, burrowed, interbedded with 1 to 7 cm grainstones (25%), planar to nodular bedded, medium gray (N6), mostly bioclastic.

INTERBEDDED SHALE AND LIMESTONE – As above but fewer limestones, almost all are grainstones, few horizontal burrows, planar bedded.

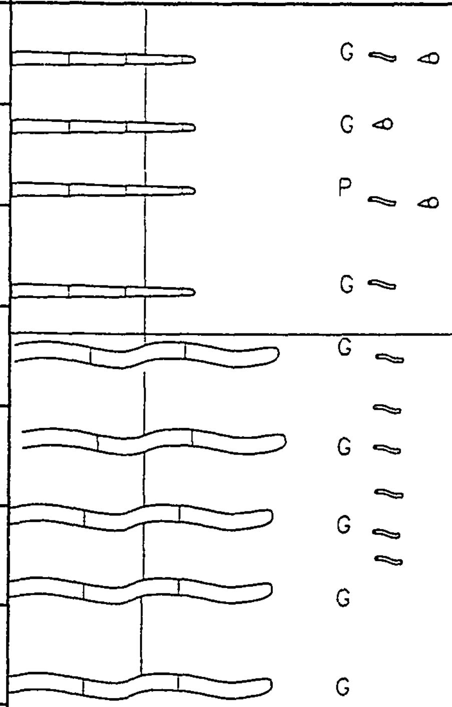
Ohio DGS #2626

Geological Description



Ohio DGS #2626

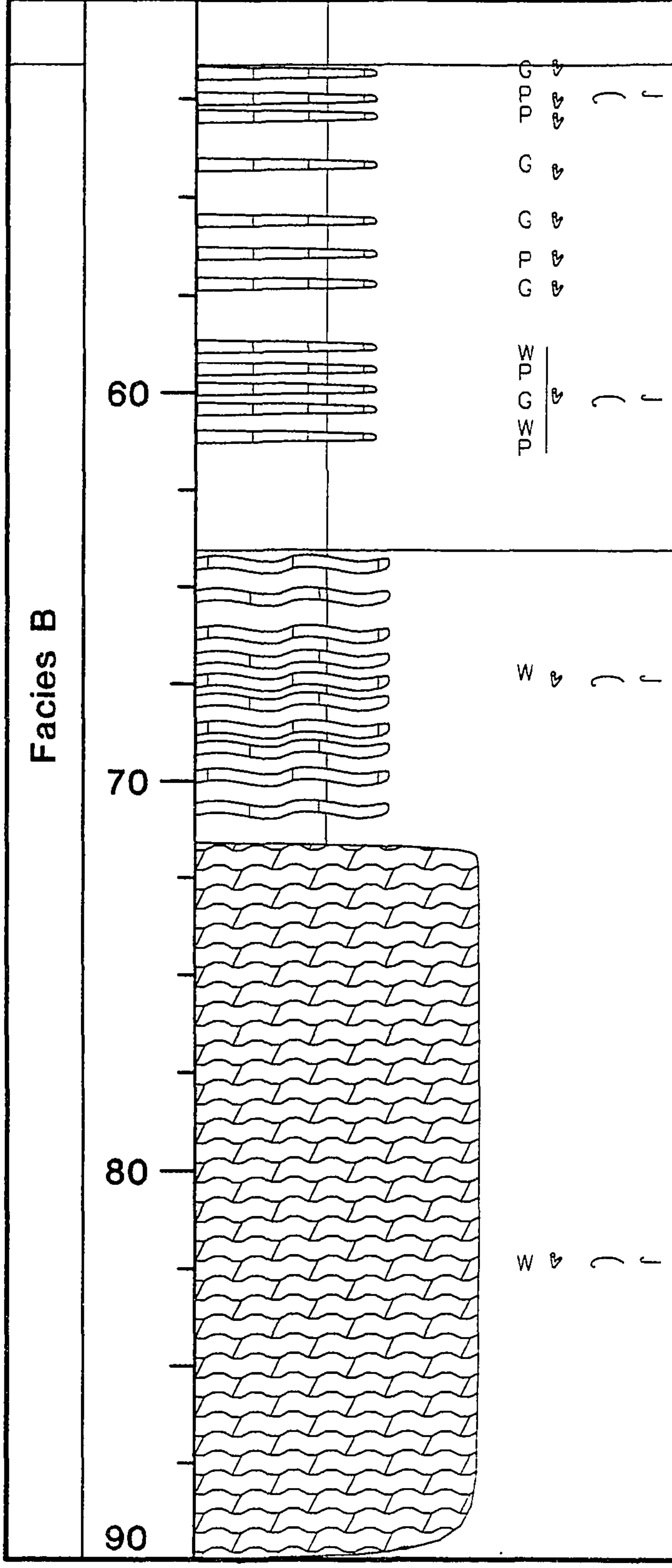
Geological Description

Facies	Feet	Litholog	Comments
Facies A			INTERBEDDED SHALE AND LIMESTONE - As above.
Arnheim Formation	360		INTERBEDDED LIMESTONE AND SHALE - Medium gray (N5) packstones and grainstones (60%), irregular bedded, burrow mottled, interbedded with greenish gray shale, intensely burrowed, possibly dolomitic.
	370		NOTE: This description is not intended to provide a bed by bed lithologic column for the core, rather a qualitative description of the geology. During the examination of this core, the author was not permited to perform any desctructive testing (including acids or stains) and the core was not split. The core was examined in greater detail, but until the core can be split and stained, additional description of this core will not be published by this author.
	380		
	390		

Ohio DGS #2627

Geological Description

Facies	Feet	Litholog	Comments



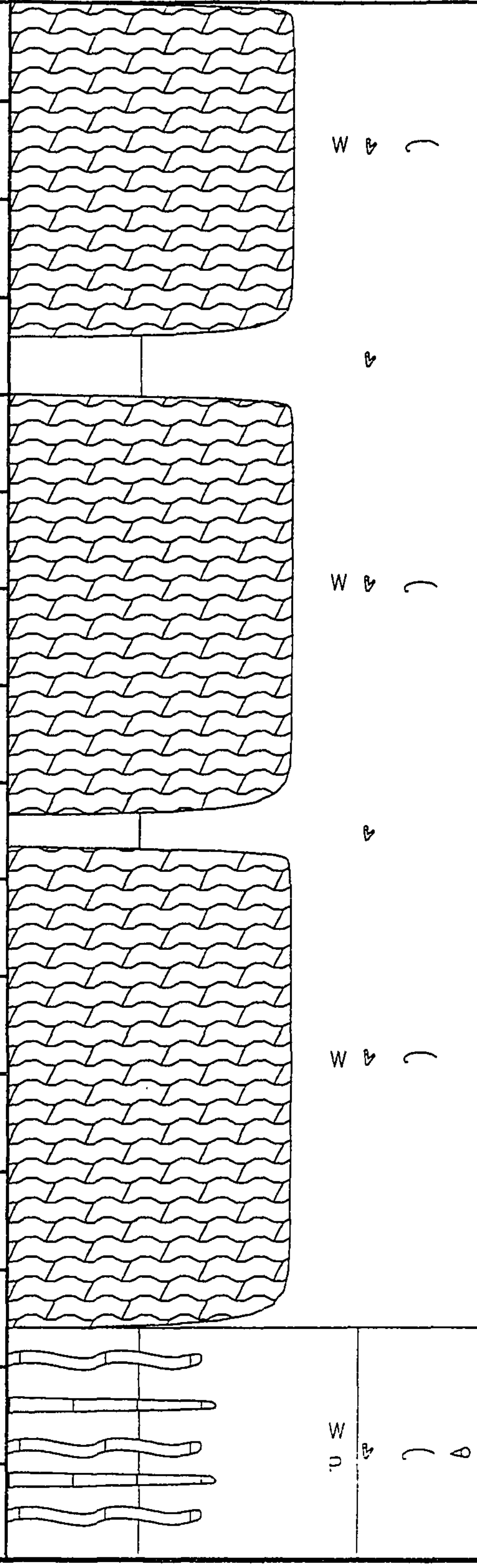
CLAY SHALE – As above with grainstone, packestone, and wackestone beds increasing downward, abundant bryozoans in the limestone beds and occasion fossiliferous shales. The base of the limestone beds are sharp with a gradational top. Many of the limestones are medium gray (N6).

Whole, flat lying brachiopods.

INTERBEDDED LIMESTONE AND SHALE – Medium gray wackestones (40–80%), irregularly bedded, bryozoan rich, many of this beds may be bryozoan colonies, extremely argillaceous, interbedded with olive gray (5Y3/2) shales, extremely fossiliferous (bryozoan rich), occasional burrows limestone content increases downward.

Ohio DGS #2627

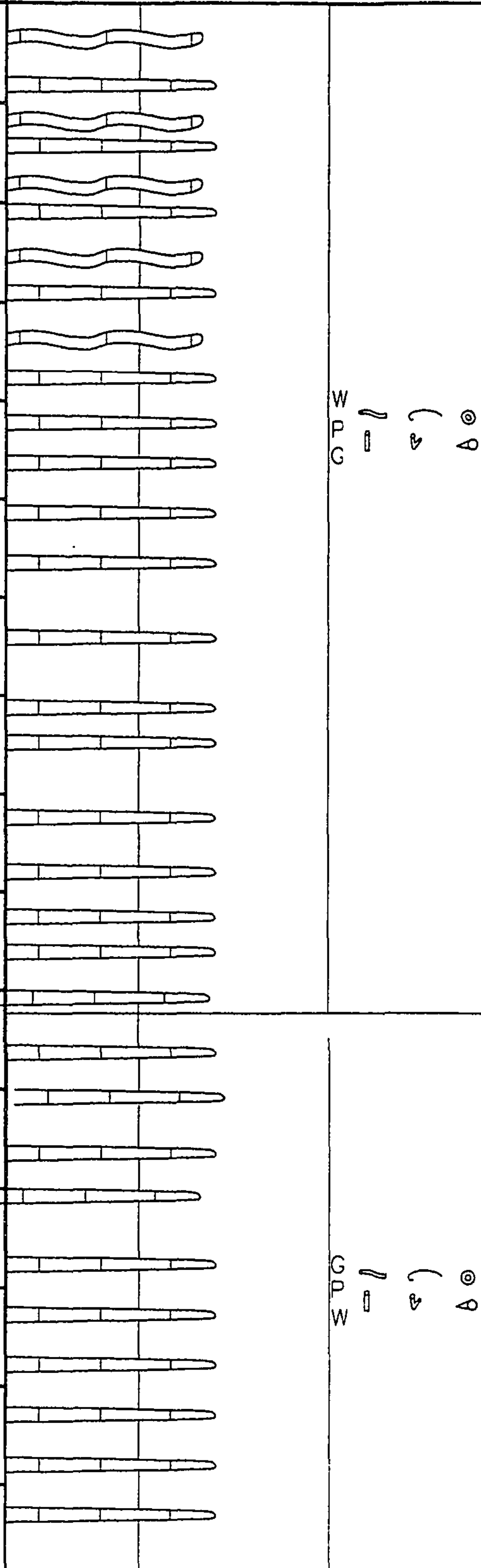
Geological Description

Facies	Feet	Litholog	Comments
Facies B	100, 110, 120		INTERBEDDED LIMESTONES AND SHALE – Irregularly bedded medium gray (N6) wackestones (45%) and packstones (15%), abundant bryozoan fragments and colonies, interbedded with olive gray (5Y3/2) shale, bryozoan rich, large, horizontally oriented brachiopods are common in both the limestones and shales. Shale rich zone Shale rich zone
	130		INTERBEDDED LIMESTONE AND SHALE – Medium gray (N6) wackestones (35%) and packstones (25%), planar to irregular bedded with occasional well sorted grainstones interbedded with olive gray shales, both limestones and shales have abundant bryozoan fragments with lesser abundaces of brachiopods, rugose corals and echinoderms.

Ohio DGS #2627

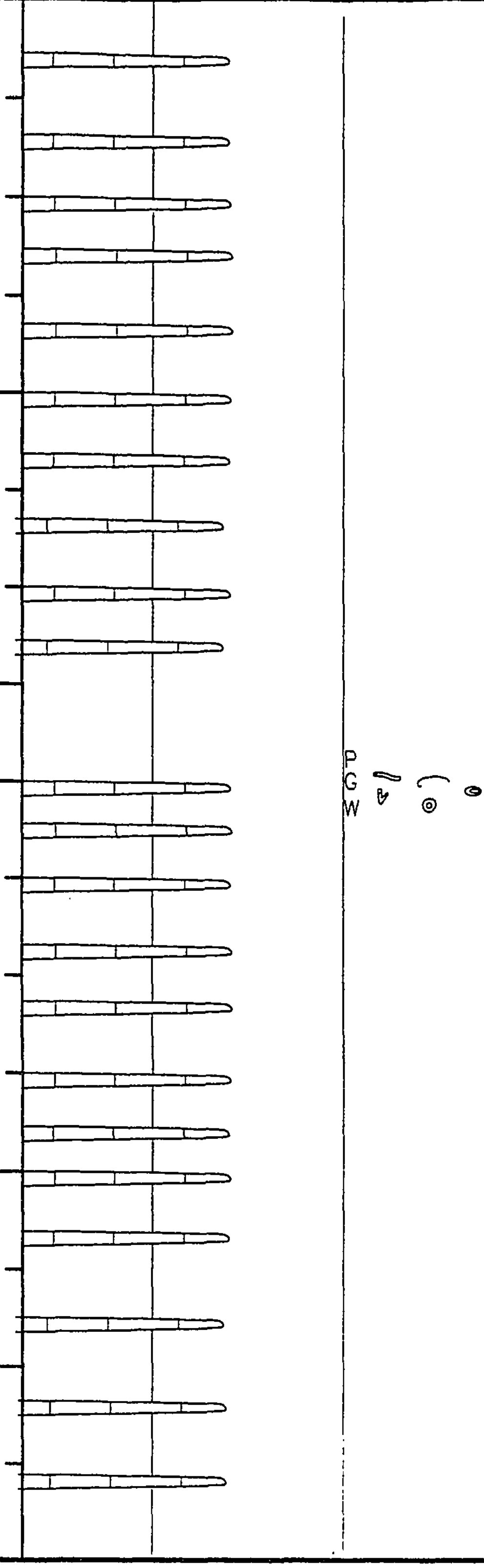
Geological Description

Facies	Feet	Litholog	Comments
Facies A2	140 150		INTERBEDDED LIMESTONE AND SHALE - As above, slight decrease in limestone content towards base and less irregular bedding towards base.
Facies A1	160 170		INTERBEDDED SHALE AND LIMESTONE - As above except that shale content is greater than limestone content and grainstones and packe-stones are the most abundant carbonate beds, extremely fossiliferous, but fossils smaller and often abraded or fragmented.



Ohio DGS #2627

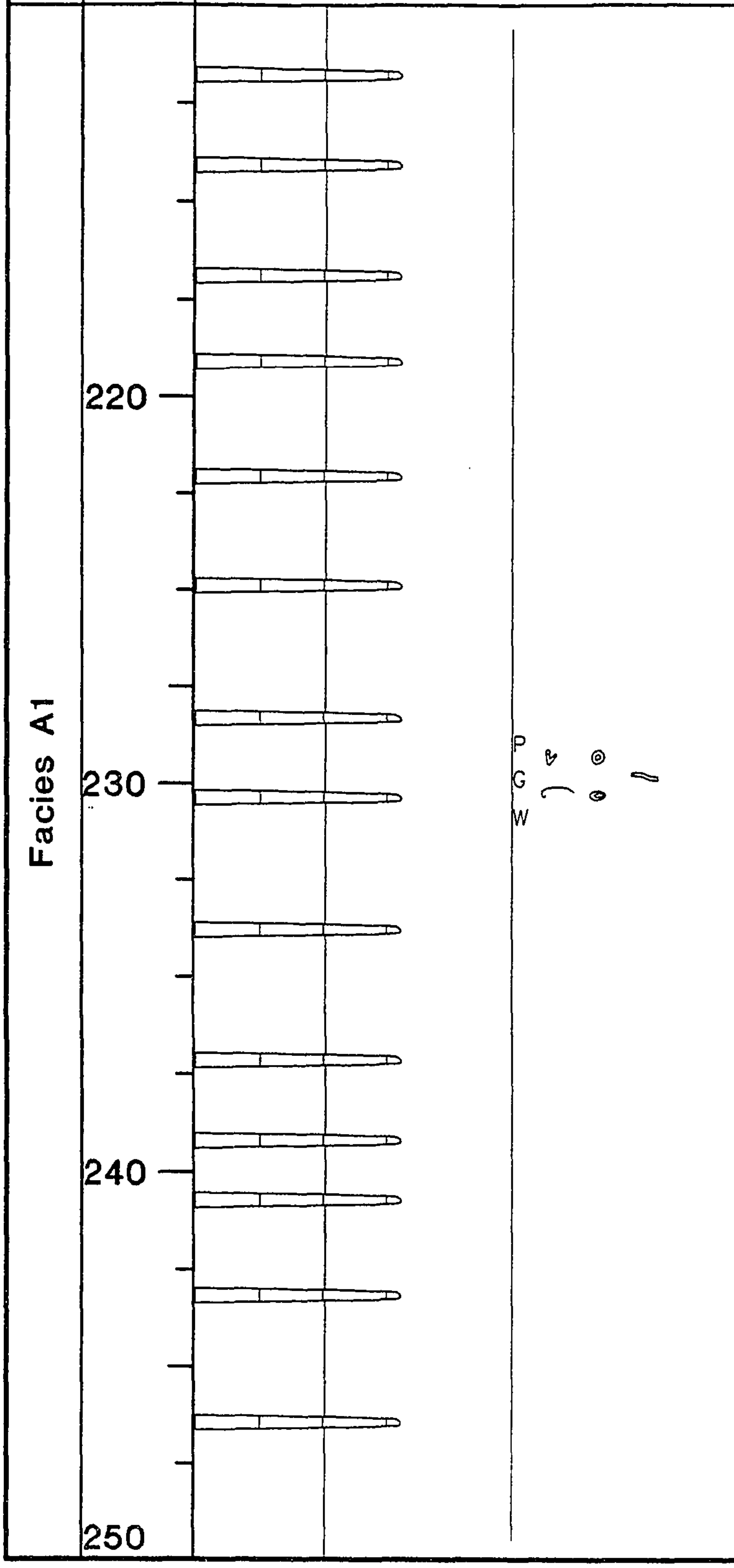
Geological Description

Facies	Feet	Litholog	Comments
Facies A1	180 190 200 210		INTERBEDDED SHALE AND LIMESTONE – As above but increased shale content, and bivalves are present in intervals, occasional amalgamated beds.

Ohio DGS #2627

Geological Description

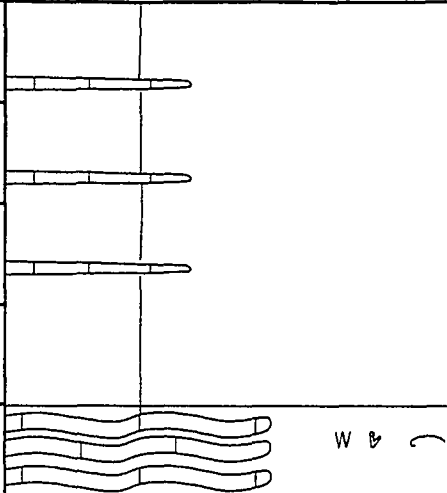
Facies | Feet | Litholog | Comments



INTERBEDDED LIMESTONE AND SHALE – As above, with occasional irregular beds, bedding varies from 1 to 6 cm, most carbonate beds are packstones, bryozoans are still abundant.

Ohio DGS #2627

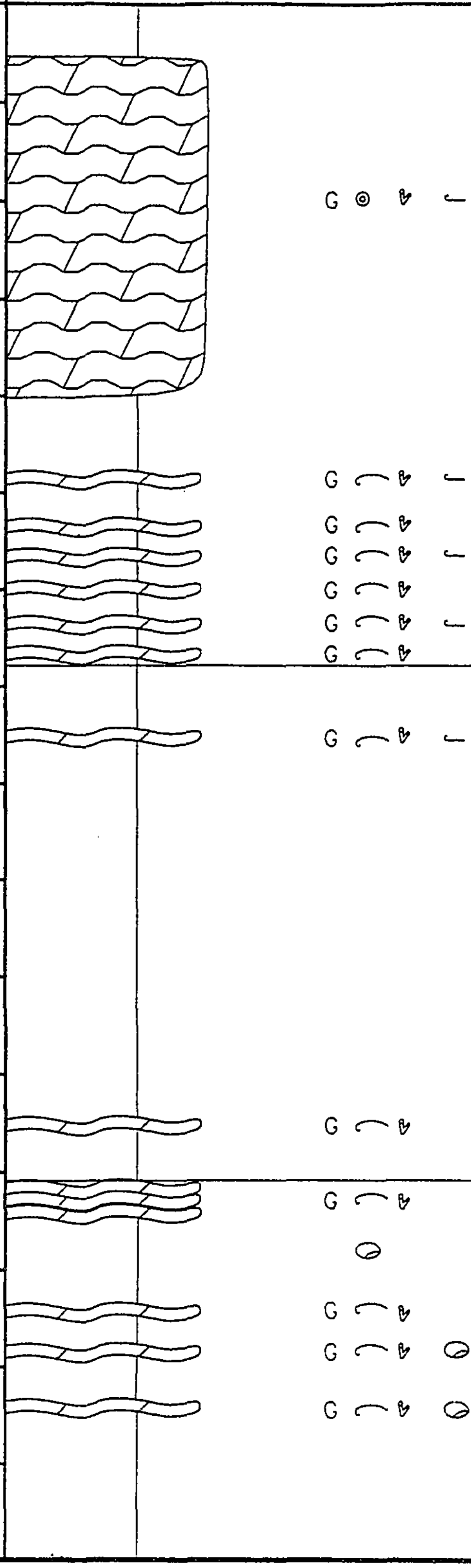
Geological Description

Facies	Feet	Litholog	Comments
Facies A1			As above.
Arnheim Formation	260	W	INTERBEDDED LIMESTONE AND SHALE – Medium gray (N5) to medium light gray (N6), irregularly bedded wackestones and shale, contact is placed where limestone content increases and bryozoan content increases, possible trace of phosphate.
	270		NOTE: This description is not intended to provide a detailed bed by bed analysis of the core, but rather a qualitive description. During the examination of the core, desctructive testing (including acids or stains) was not permitted.
	280		
	290		

Indiana SDH #57

Geological Description

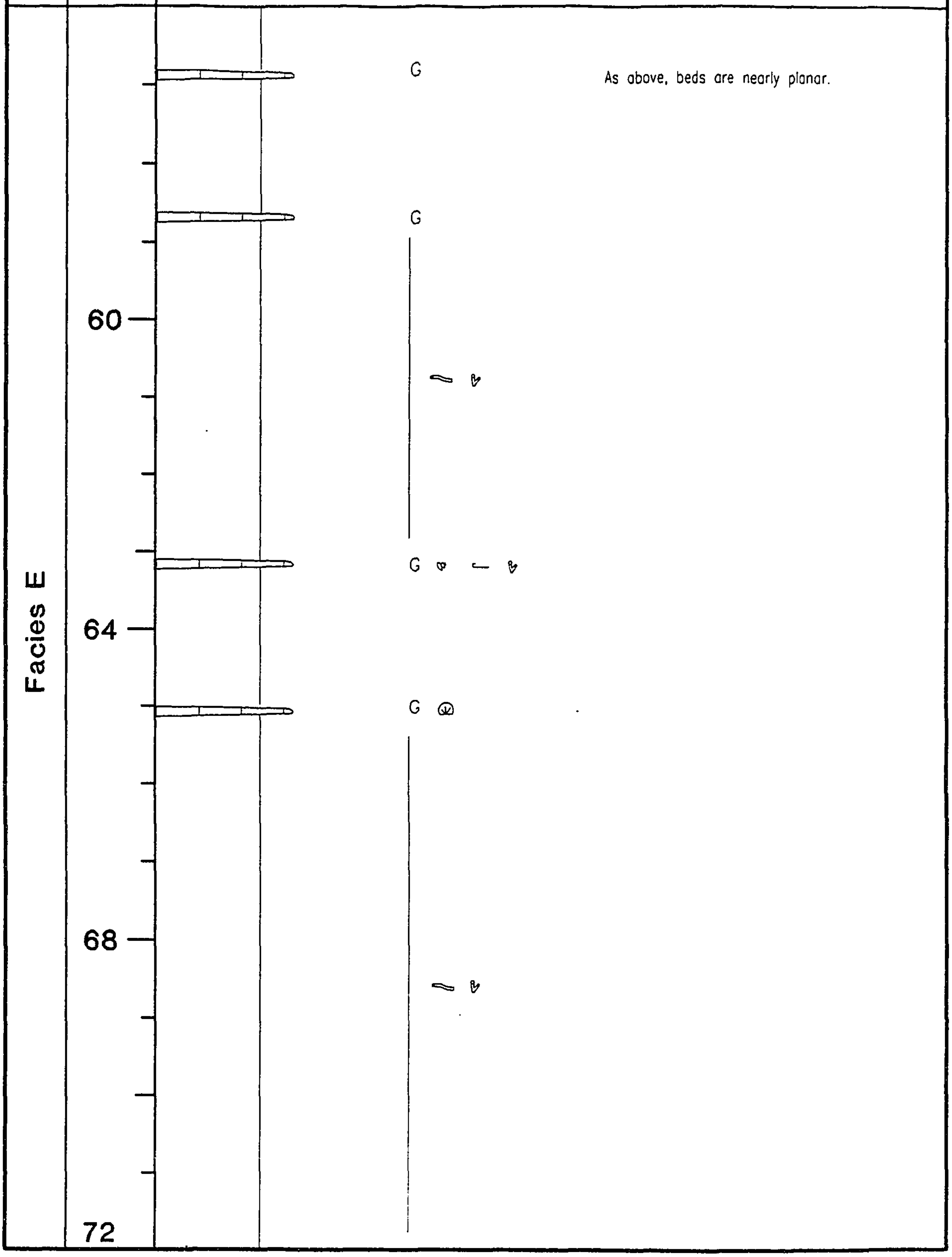
Facies	Feet	Litholog	Comments
Silurian	44		GRAINSTONES – Grayish orange (10YR7/4), medium grained, abundant crinoids throughout, reworked fossil debris at base.
			INTERBEDDED PACKSTONES, GRAINSTONES, AND SILTY SHALE – Yellowish gray (5Y7/2), abundant reworked fossil debris, pyrite common.
Facies D	48		SILTY CLAY SHALE – Grayish green (10GY5/2), occasional packstone / grainstone beds less than 1 cm thick, whole brachiopds are common.
Facies E	52, 56		INTERBEDDED GRAINSTONES AND SHALES – Yellowish gray (5Y7/2), irregularly bedded fossiliferous grainstones with occasional layers of bryozoans interbedded with silty clay shales, grayish olive green (5GY3/2), fossiliferous, calcareous, occasional bioturbated intervals.



Indiana SDH #57

Geological Description

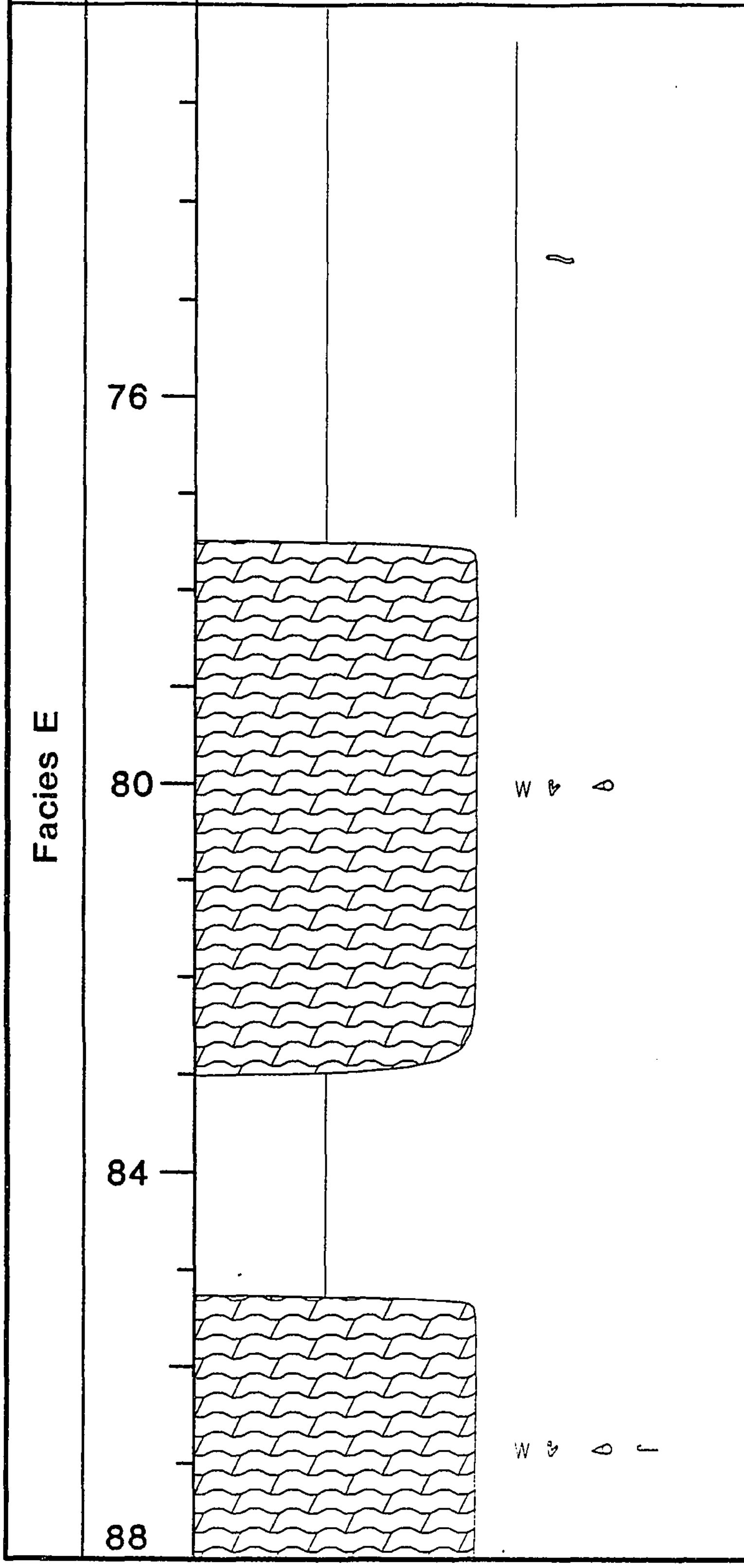
Facies	Feet	Litholog	Comments



Indiana SDH #57

Geological Description

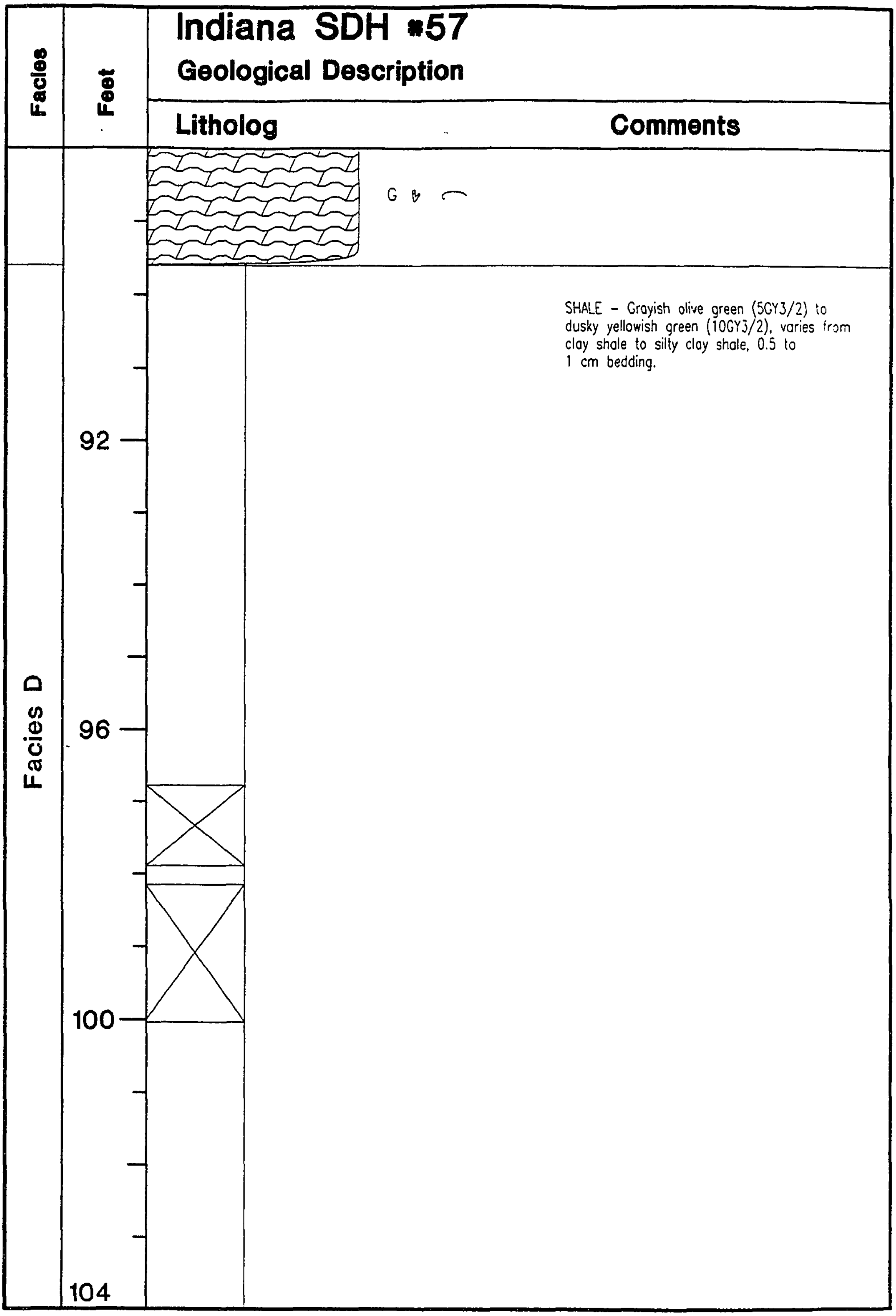
Facies	Feet	Litholog	Comments



As above

WACKESTONES – Grayish olive green (10G4/2), irregularly bedded, fossiliferous.

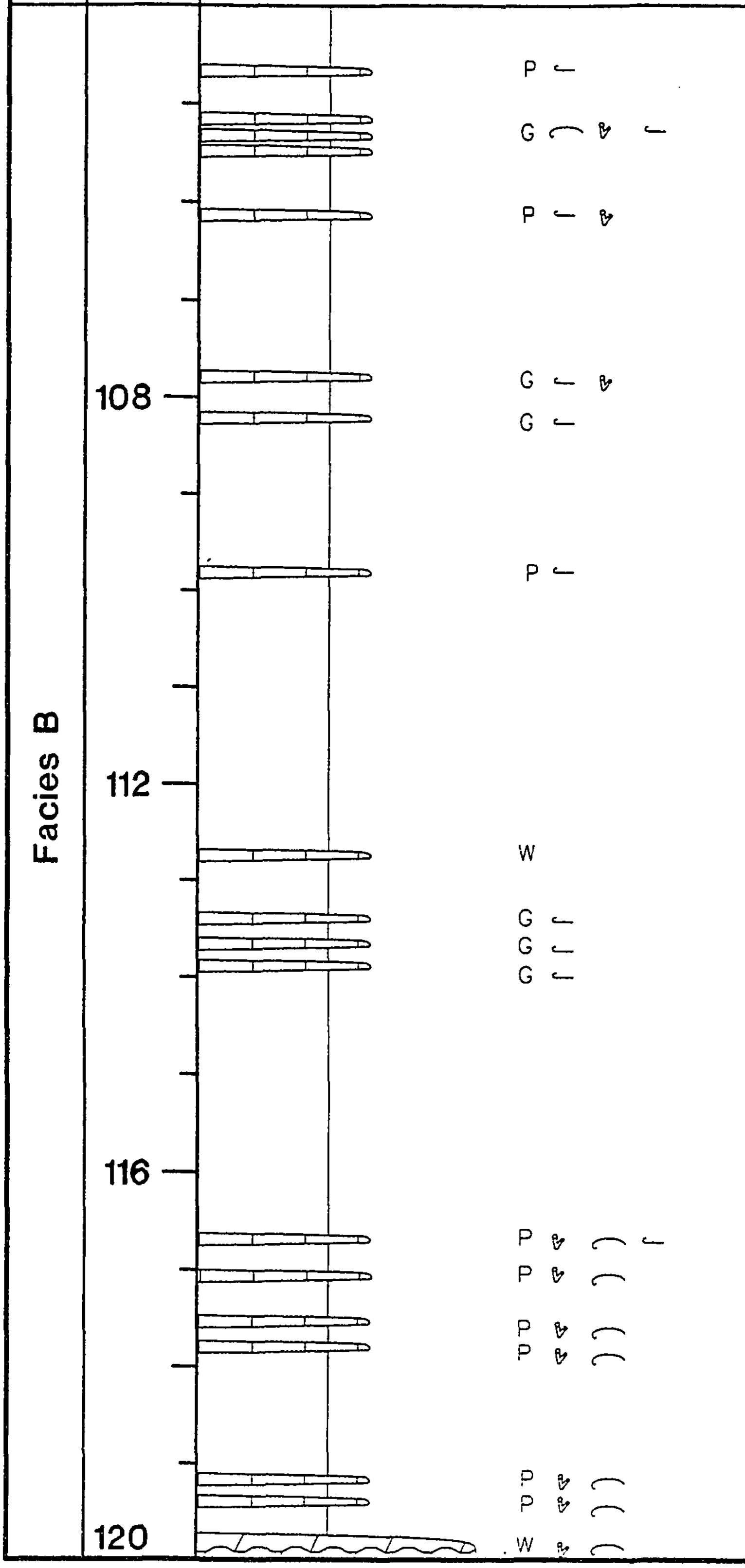
WACKESTONES – Grayish olive green, irregular bedding, shale rich, abundant fossils.


Indiana SDH #57
Geological Description
Facies
Feet
Litholog
Comments
G
SHALE - Grayish olive green (5GY3/2) to dusky yellowish green (10GY3/2), varies from clay shale to silty clay shale, 0.5 to 1 cm bedding.
Facies D
92
96
100
104

Indiana SDH #57

Geological Description

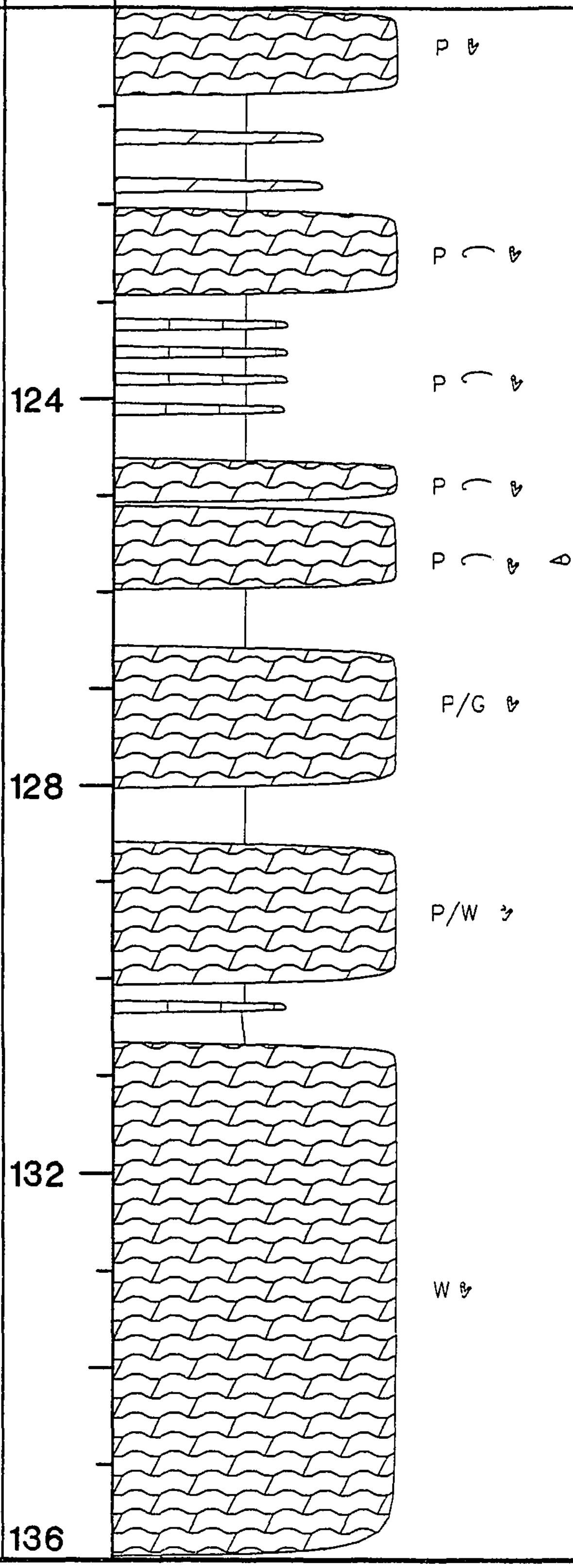
Facies	Feet	Lithology	Comments

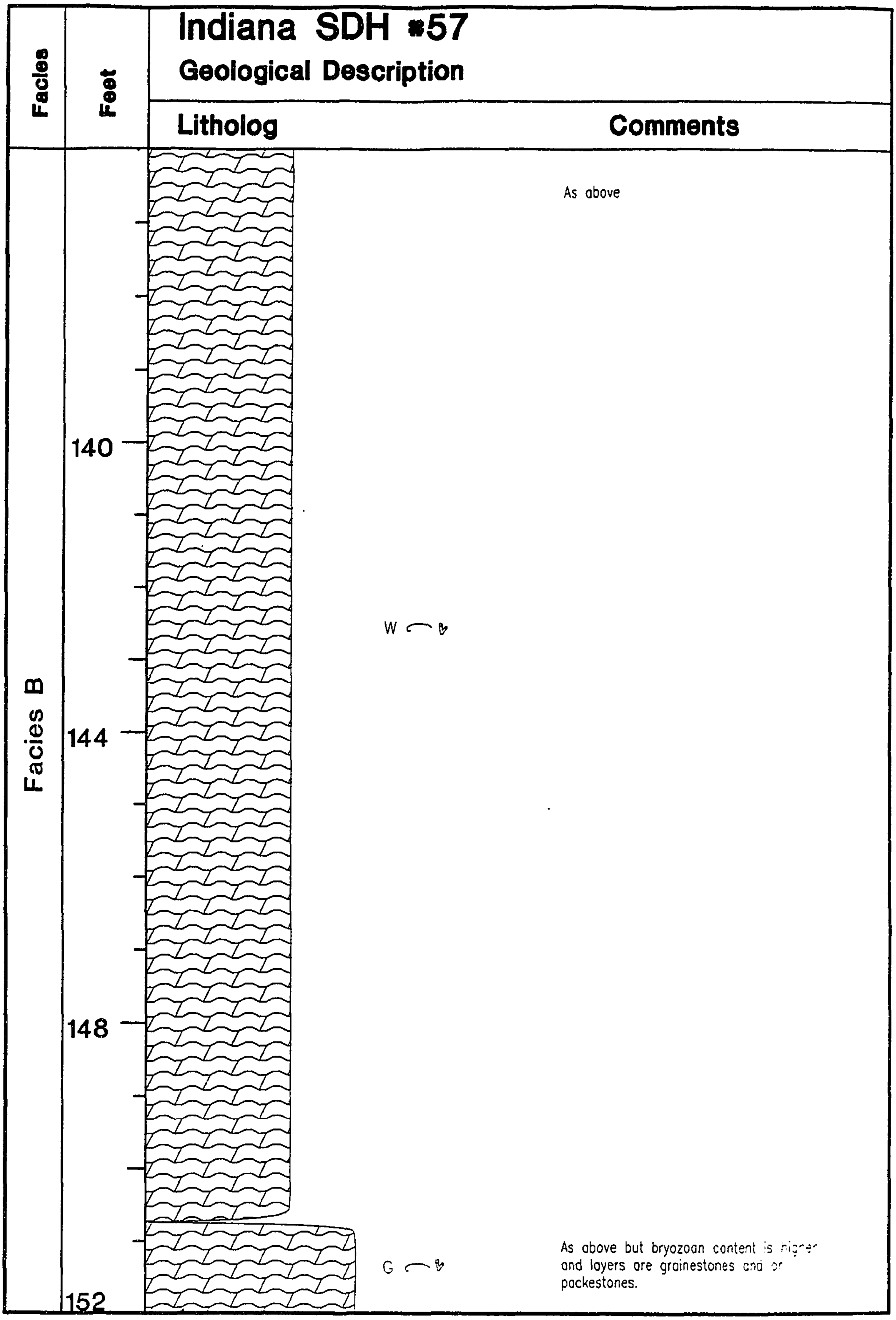


INTERBEDDED GRAINSTONES, PACKSTONES, WACKESTONES, AND SHALES - Grayish olive green (5GY3/2), limestones have abundant fossils that are well preserved, whole, flat lying brachiopods and trilobites are common. The shales are nonfossiliferous and have 0.5 to 1.5 cm partings.

Indiana SDH #57

Geological Description

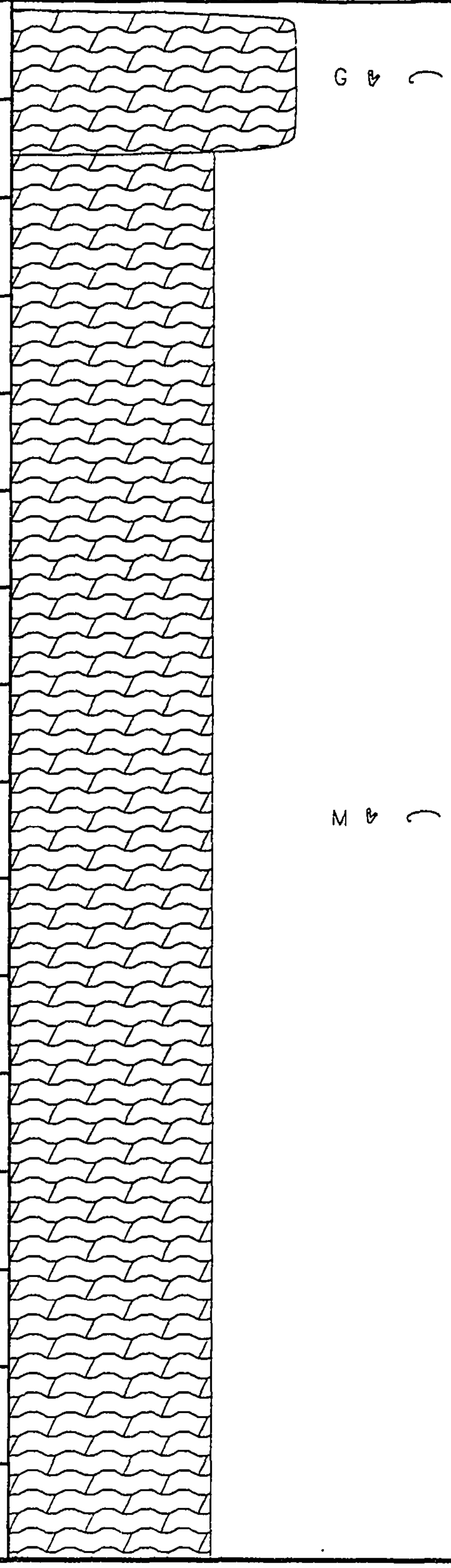
Facies	Feet	Litholog	Comments
Facies B			INTERBEDDED PACKSTONES, GRAINSTONES, WACKESTONES, AND SHALES – Medium dark gray limestones (N4), irregular bedded, abundant fossils that are fragmented, shale partings between beds, shale rich intervals are silty shales with abundant fossils. WACKESTONES – Medium dark gray, irregular bedded, abundant bryozoans, some intervals may be in place bryozoan thickets, the bryozoans are well preserved with silty shales between fronds.


Indiana SDH #57
Geological Description
Facies
Feet
Litholog
Comments
As above
140
W
Facies B
144
148
G
As above but bryozoan content is higher and layers are grainstones and or packestones.
152

Indiana SDH #57

Geological Description

Facies	Feet	Litholog	Comments



Facies B

Feet: 156, 160, 164, 168

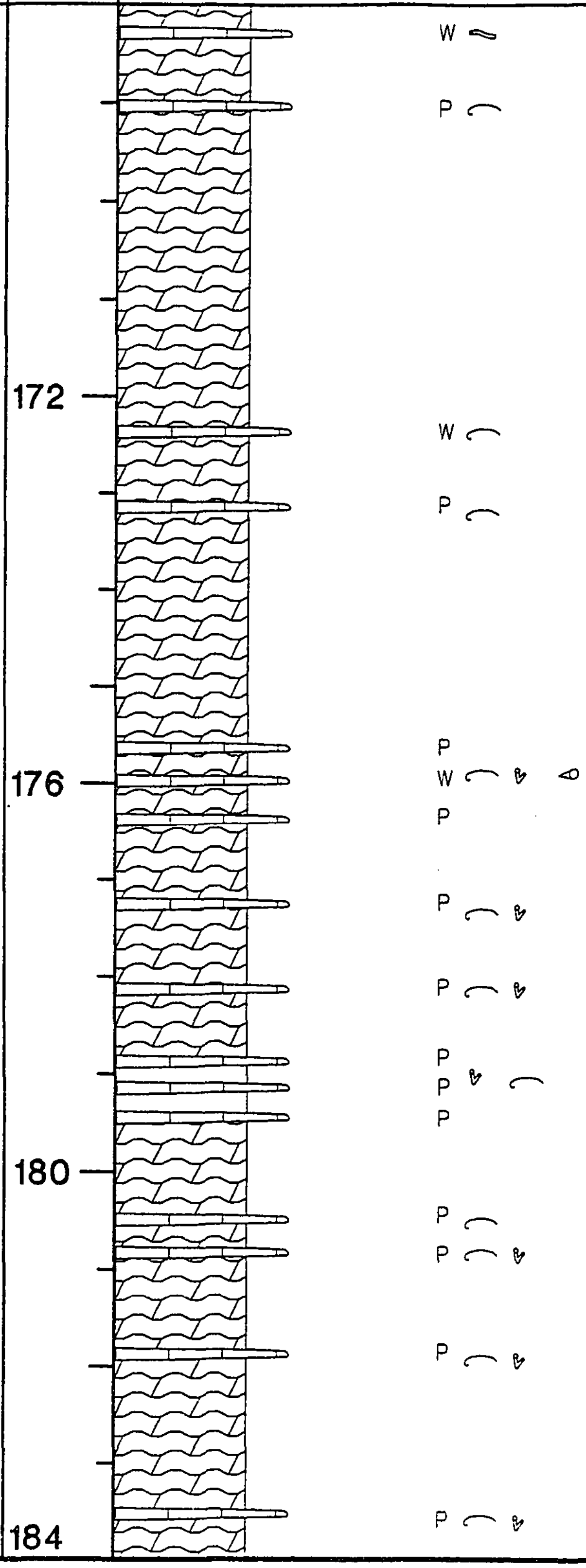
As above

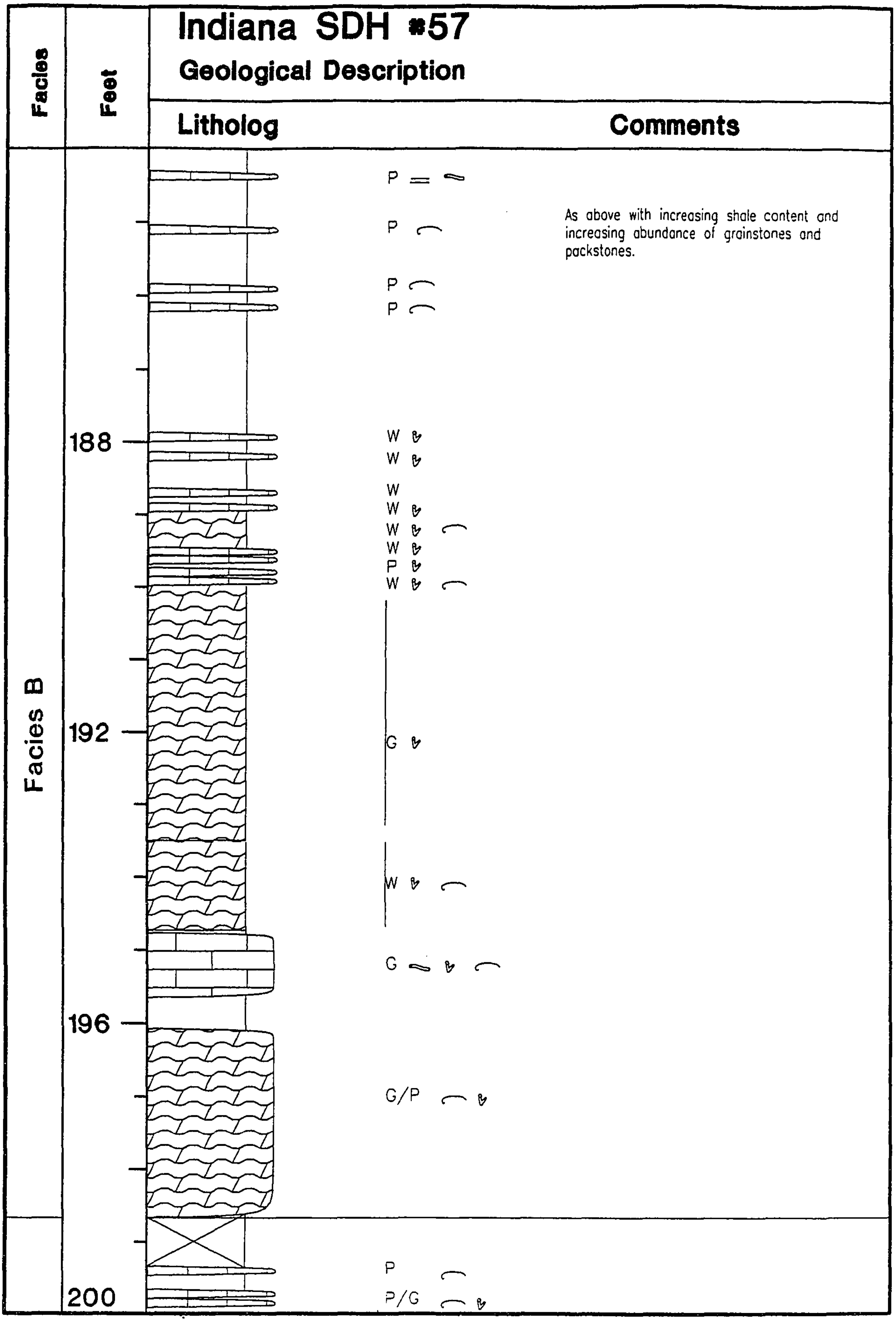
WACKESTONES – Dark greenish gray (5GY4/1), irregular 1 to 6 cm bedding, extremely argillaceous, abundant bryzoans and brachiopods that are commonly fragmented but occasionally whole.

Indiana SDH #57

Geological Description

Facies	Feet	Litholog	Comments
Facies B	172–184		WACKESTONES – As above with occasional interbeds of poorly laminated grainstones and packestones 1 to 4 cm thick.
			Some burrow mottling in wackestones.

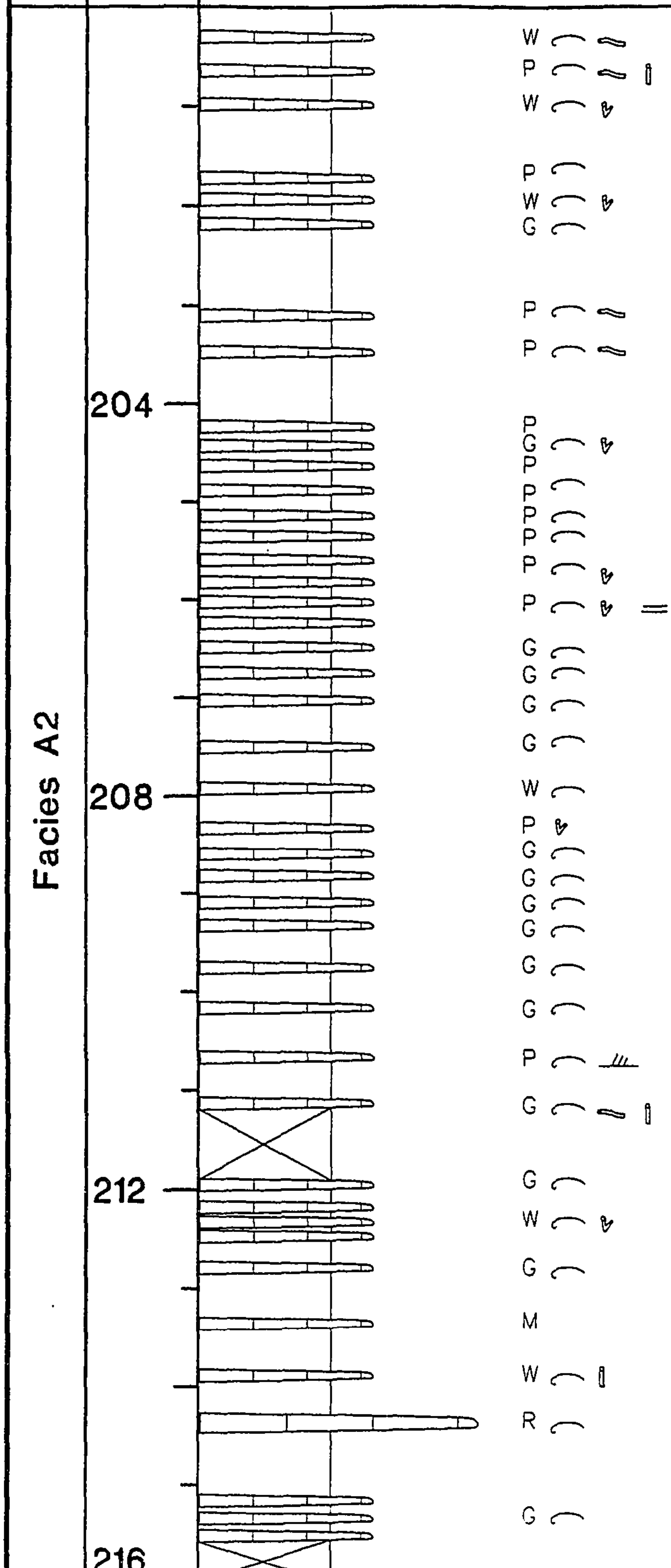



Indiana SDH #57
Geological Description
Facies
Feet
Lithólog
Comments
P
P
P
P
188
W
W
W
W
W
W
P
W
Facies B
192
G
W
G
196
G/P
P
200
P/G
As above with increasing shale content and increasing abundance of grainstones and packstones.

Indiana SDH #57

Geological Description

Facies	Feet	Litholog	Comments

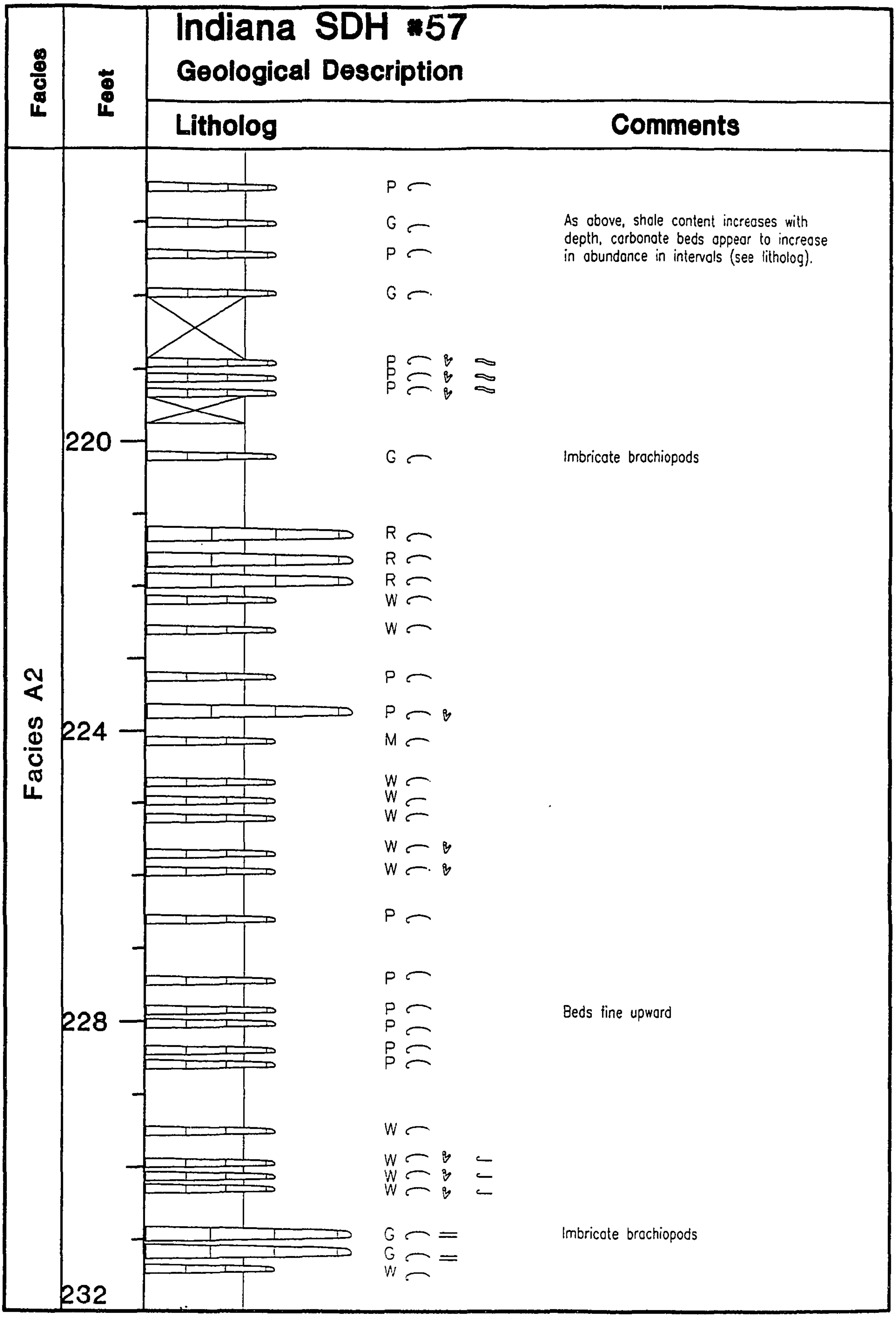


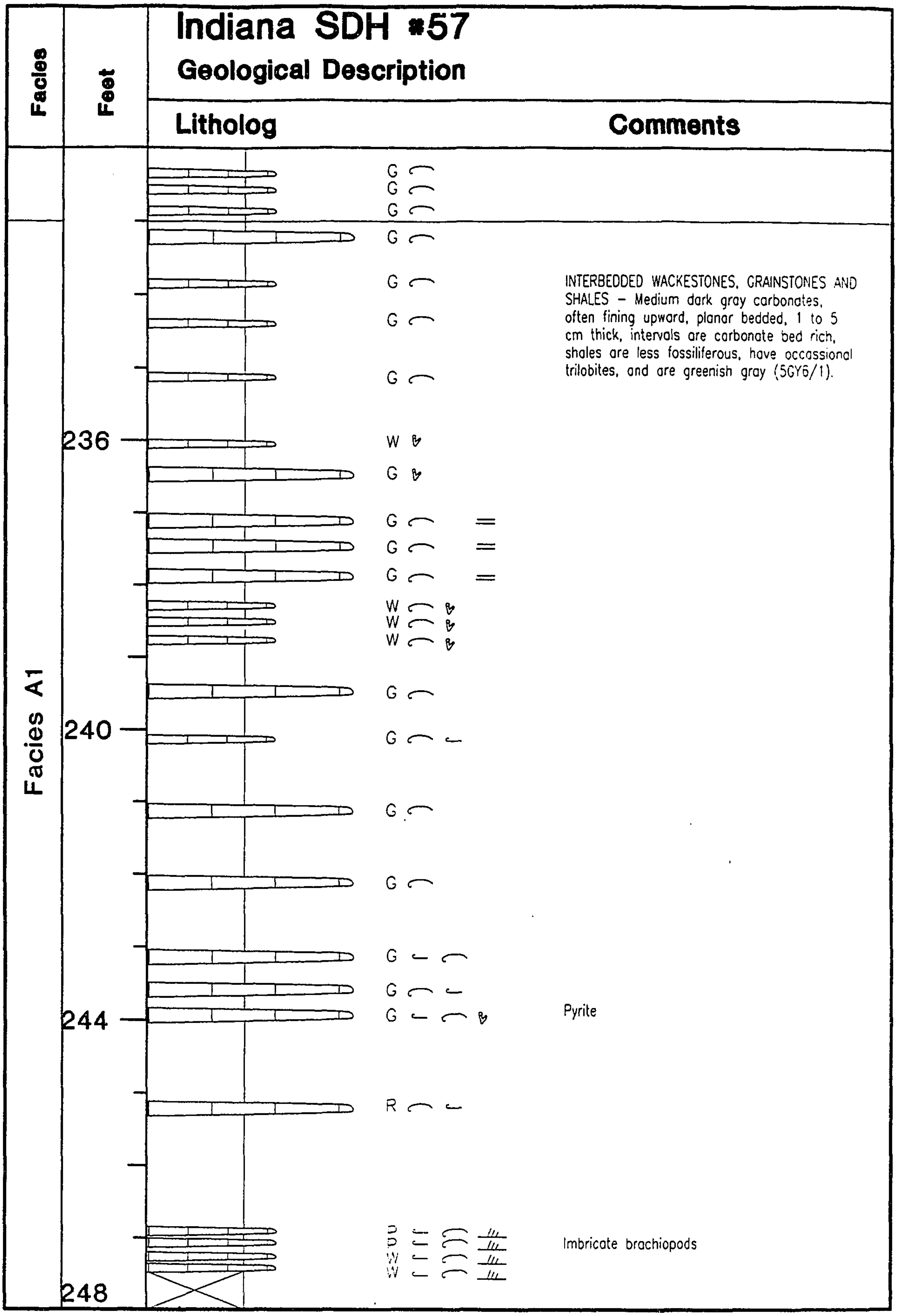
INTERBEDDED WACKESTONES, PACKSTONES, GRAINSTONES, AND SHALES - Medium dark gray (N4) to medium gray (N5), even bedded, laminated, occasional crossbedding, fossils in shale are generally whole, others fragmented, some carbonate beds are burrowed at top, contacts between carbonates and shales sharp but some may be gradational, carbonate beds fine upward.

Pyrite

Graded bedding

Whole brachiopods in shale.

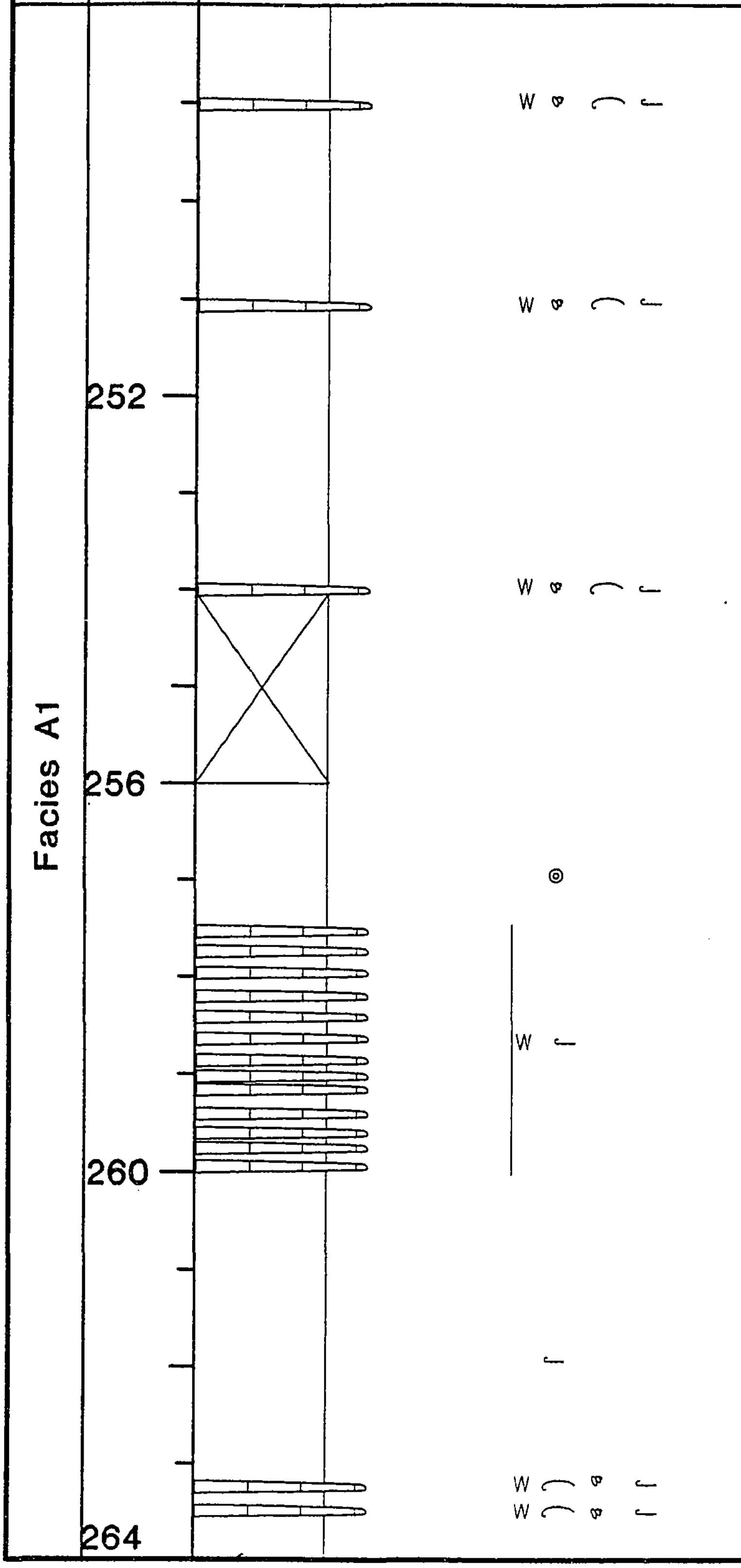

Indiana SDH #57
Geological Description
Facies
Feet
Litholog
Comments
Facies A2
220
224
228
232
P
G
P
G
P
P
P
G
R
R
R
W
W
P
P
M
W
W
W
W
W
P
P
P
P
P
P
W
W
W
W
G
G
W
As above, shale content increases with depth, carbonate beds appear to increase in abundance in intervals (see litholog).
Imbricate brachiopods
Beds fine upward
Imbricate brachiopods


Indiana SDH #57
Geological Description
Facies
Feet
Litholog
Comments
Facies A1
236
240
244
248
G
W
R
INTERBEDDED WACKESTONES, GRAINSTONES AND SHALES - Medium dark gray carbonates, often fining upward, planar bedded, 1 to 5 cm thick, intervals are carbonate bed rich, shales are less fossiliferous, have occassional trilobites, and are greenish gray (5GY6/1).
Pyrite
Imbricate brachiopods

Indiana SDH #57

Geological Description

Facies	Feet	Litholog	Comments



INTERBEDDED WACKESTONES AND SHALE – Grayish olive green (5GY3/2), planar bedded, graded bedded, well preserved fossils, abundant horizontal burrows in shale.

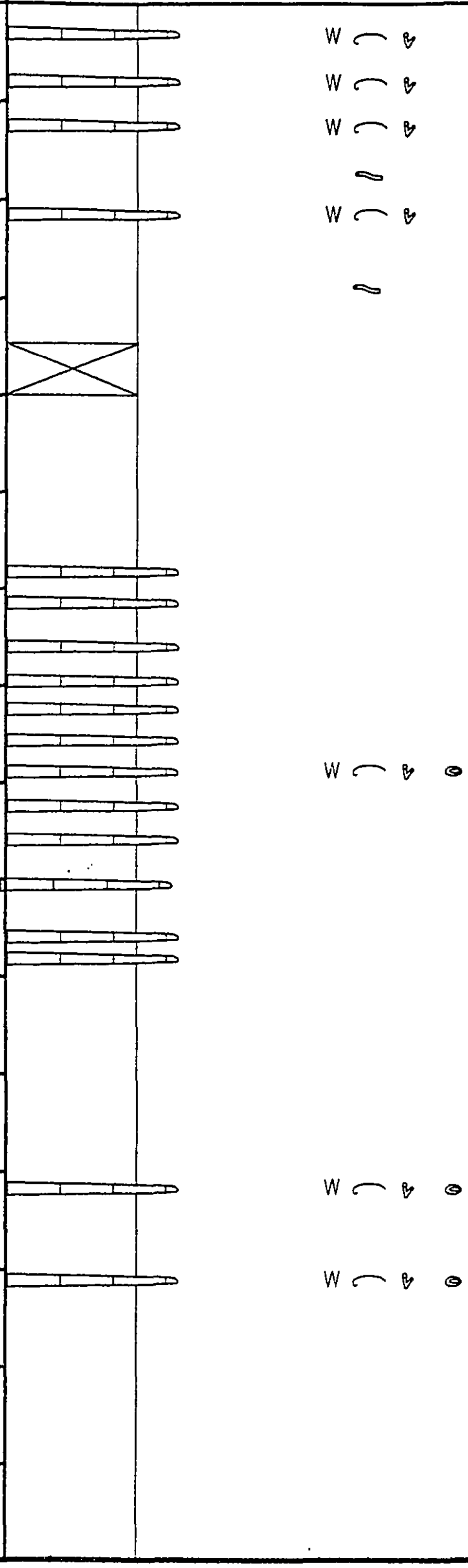
Abundant articulated crinoid stems, excellent preservation.

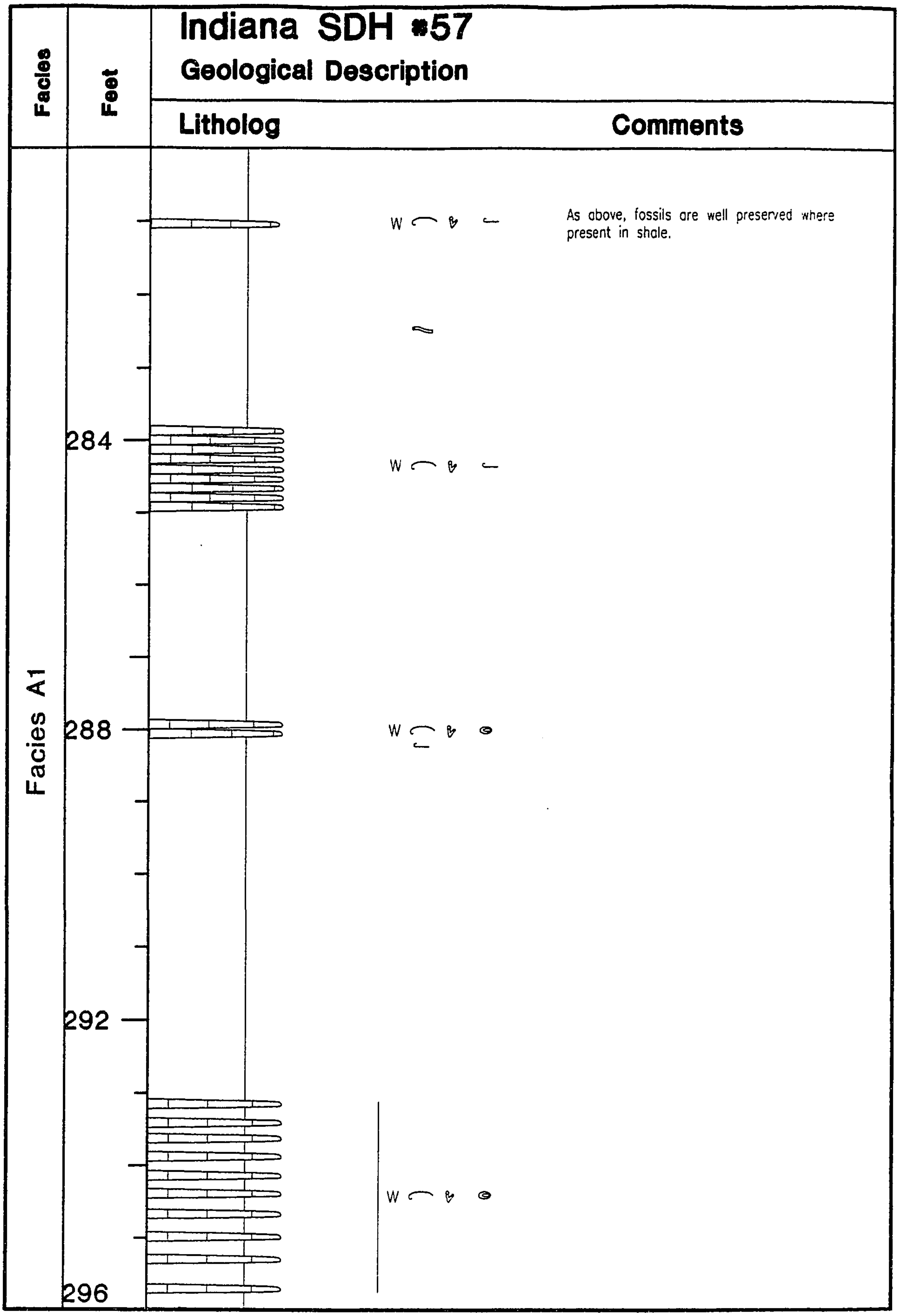
Trilobite spines

Indiana SDH #57

Geological Description

Facies	Feet	Litholog	Comments
Facies A1			As above, horizontal burows are common.
	268		
	272		
	276		Ambonychia
			Ambonychia
	280		

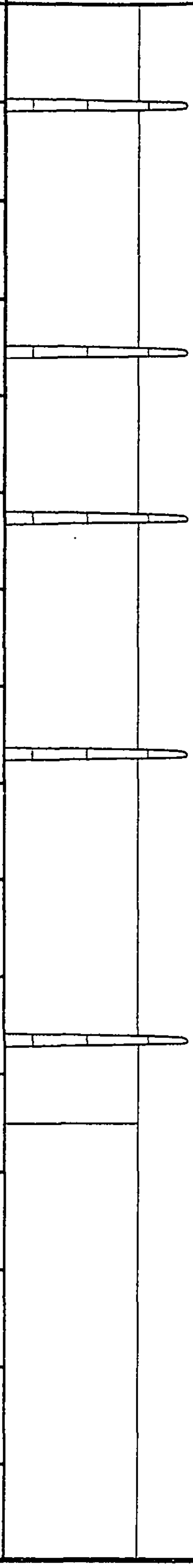



Indiana SDH #57
Geological Description
Facies
Feet
Litholog
Comments
As above, fossils are well preserved where present in shale.
W
W
W
W
284
288
292
296
Facies A1

Indiana SDH #57

Geological Description

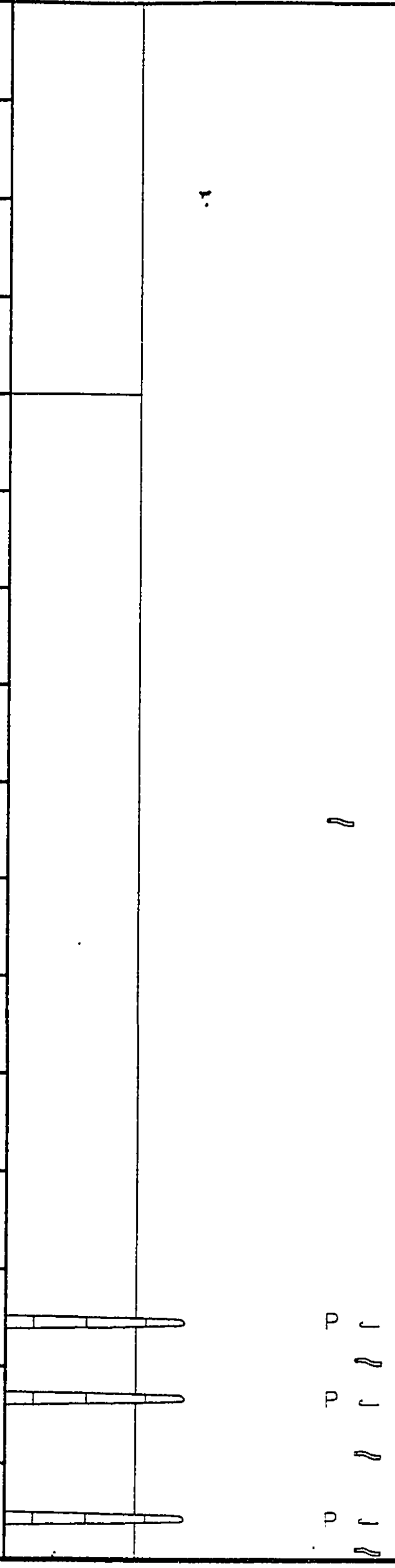
Facies	Feet	Litholog	Comments
Facies A1		W	As above, shale is extremely calcareous and carbonate beds are thinner, several zones of well indurated shale.
	300	W	
		W	
	304	W	
		W	
	308		SHALE - Dusky yellow (5GY5/2), extremely calcareous, thin stringers of wackestones or bryozoan rich shales are present.
	312		



Indiana SDH #57

Geological Description

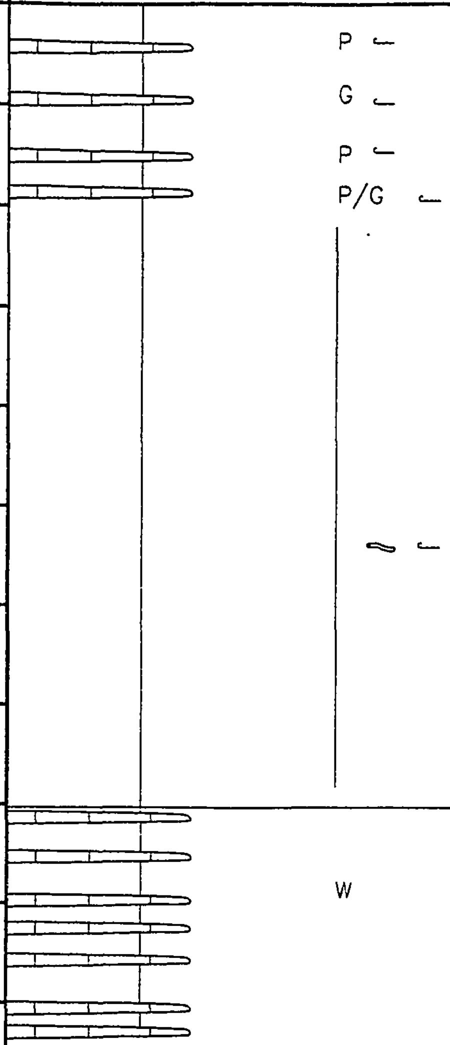
Facies	Feet	Litholog	Comments
Facies A1			As above, pale brown (5YR5/2) silt filled, horizontal burrows to 1.5 cm in diameter.
	316		SILTY SHALE – Dusky yellow green (5GY5/2), calcareous, several thin (less than 1 cm) intervals of packestone and grainstone beds, most are too thin to show on log, those thicker than 2 cm are shown, the shale is extremely bioturbated with a Chondrites like trace fossil, but traces appear more orthogonal.
	320		
	324		
	328		



Indiana SDH #57

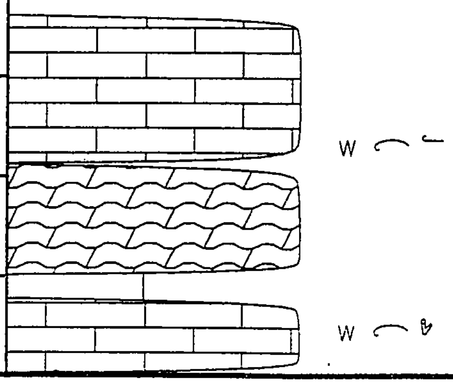
Geological Description

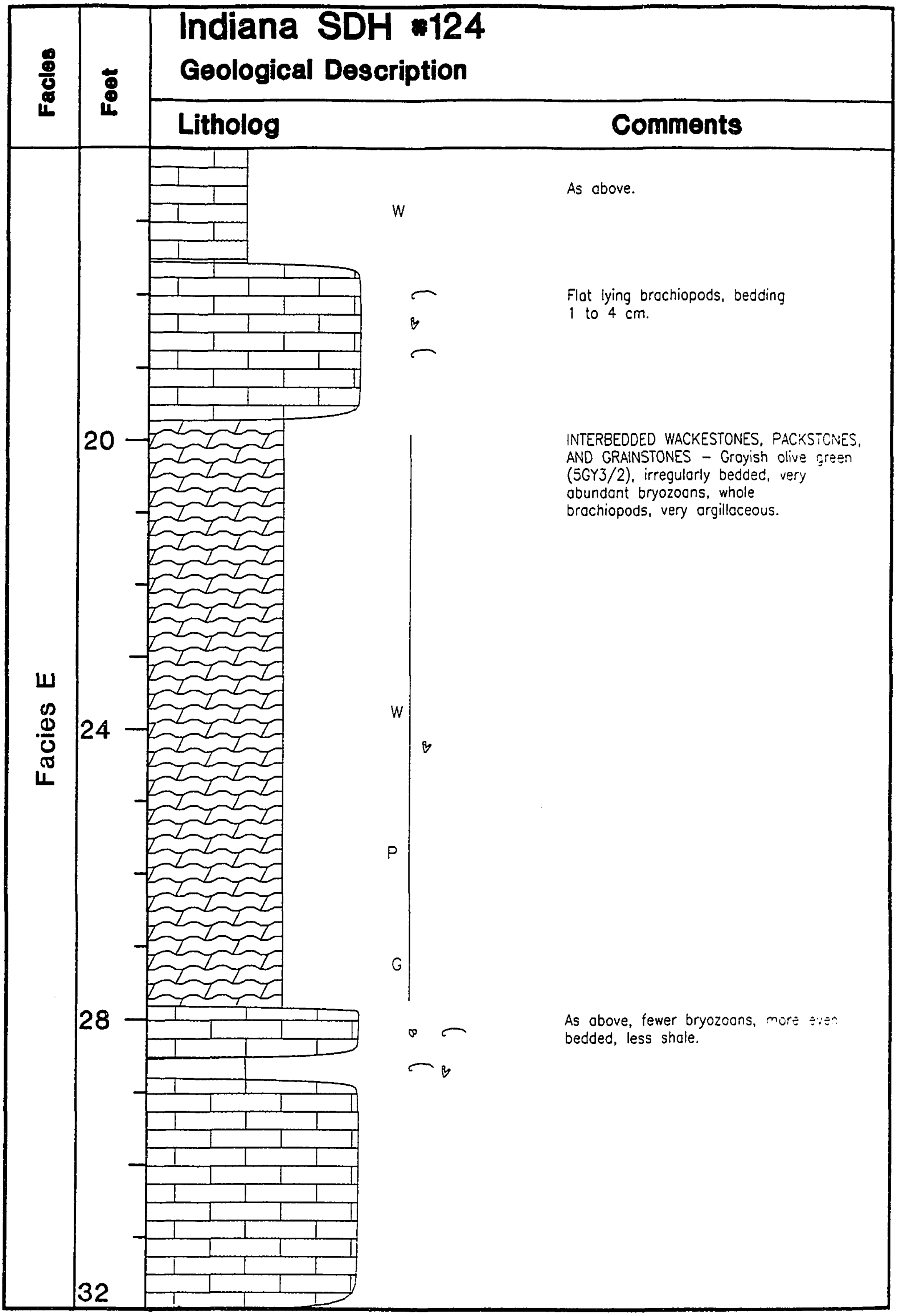
Facies	Feet	Litholog	Comments
Facies A1	332		As above, well preserved trilobites and 1 to 2 cm packstone and grainstone beds.
Arnheim Formation	336		INTERBEDDED WACKESTONES AND SHALES – Medium gray (N5) wackestones, with bryzoans and trilobites, interbedded with dusky yellow green (5GY5/2) shales, calcareous, bedding is becoming more irregular. contact picked at interval where carbonate content appears to increase.
	340		NOTE: Much of the core has been split into quarters, the continuity and bedding of these intervals is difficult to determine in some cases. Descriptions for much of Facies A may in errror by as much as 0.5 feet.
	344		



Indiana SDH #124

Geological Description

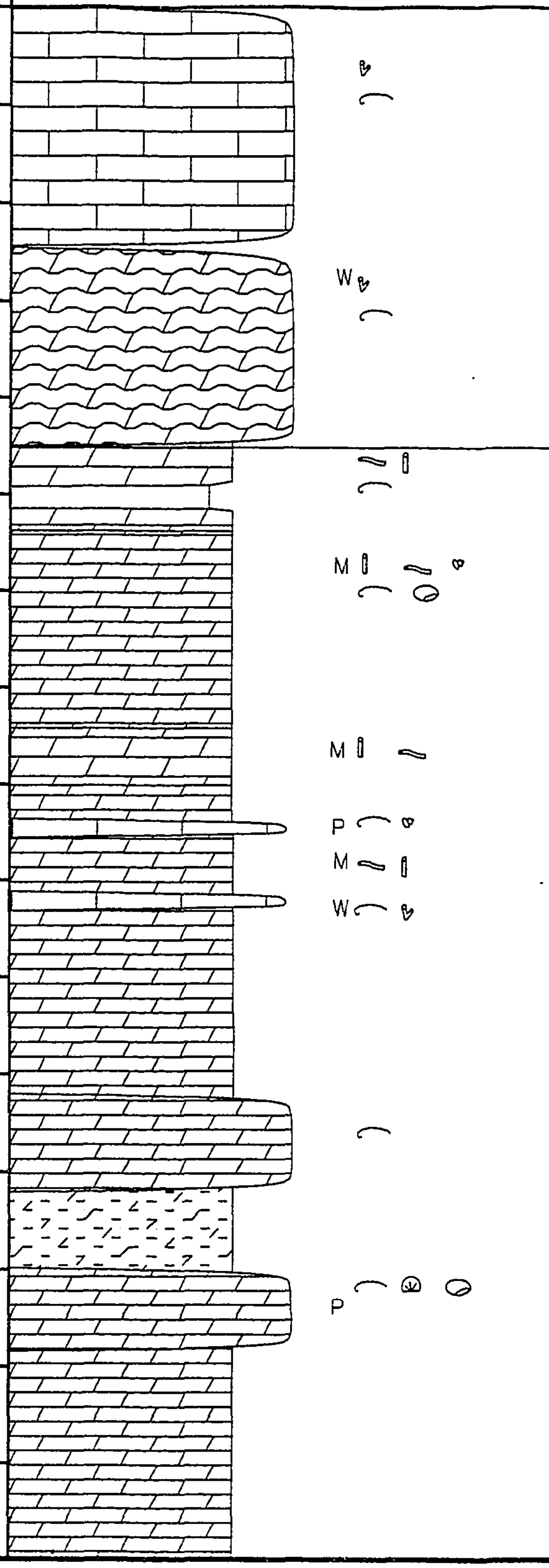
Facies	Feet	Litholog	Comments
	4		
	8		
	12		
Facies E			INTERBEDDED WACKESTONES, PACKSTONES, AND GRAINSTONES – Grayish olive green (5GY3/2), irregular to planar, 2 to 8 cm bedding, extremely fossiliferous, brachiopods, bryozoans, and trilobites are both whole and fragmented, occasional algal laminites.
	16		

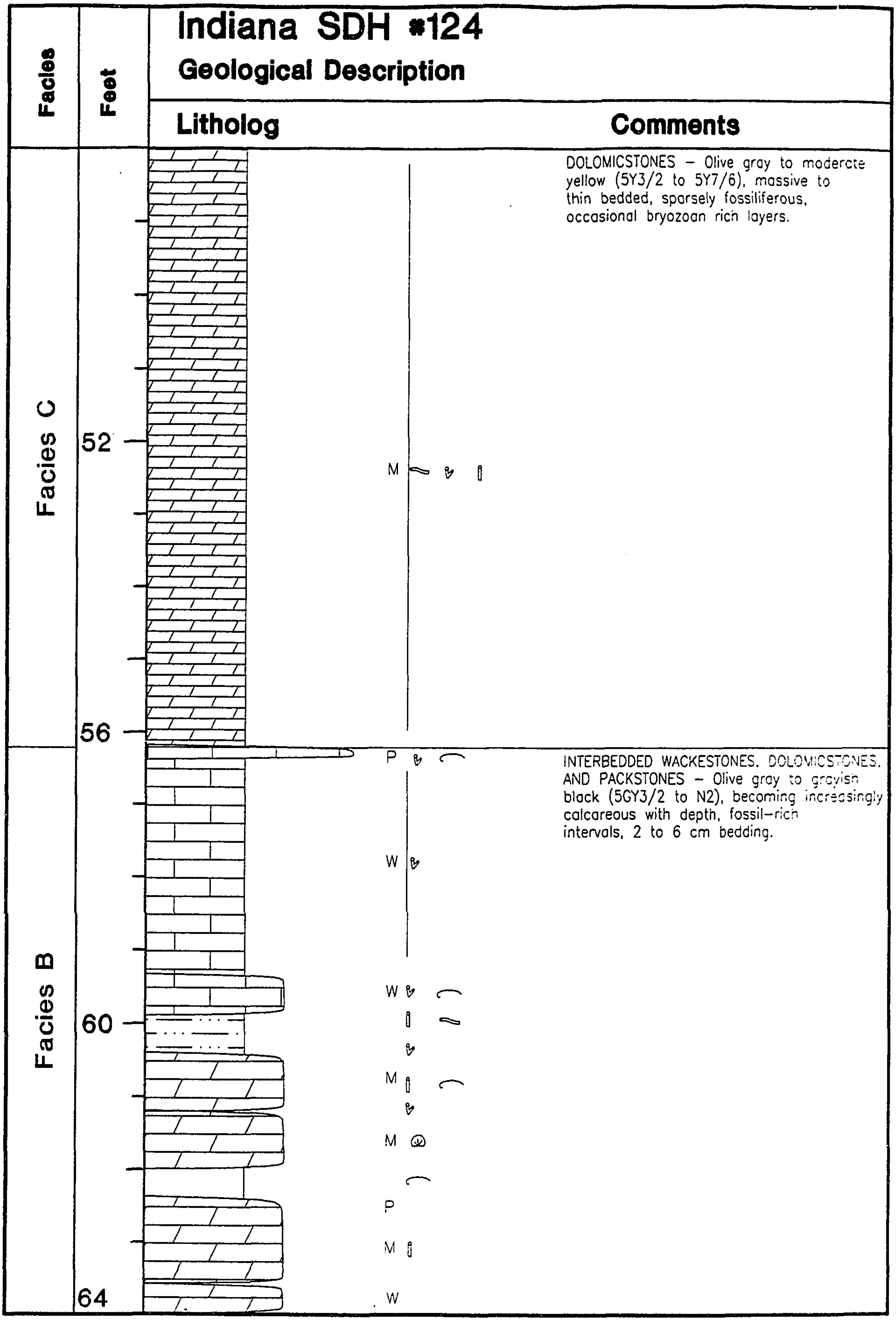

Indiana SDH #124
Geological Description
Facies
Feet
Litholog
Comments
Facies E
20
24
28
32
W
W
P
G
As above.
Flat lying brachiopods, bedding 1 to 4 cm.
INTERBEDDED WACKESTONES, PACKSTONES, AND GRAINSTONES – Grayish olive green (5GY3/2), irregularly bedded, very abundant bryozoans, whole brachiopods, very argillaceous.
As above, fewer bryozoans, more even bedded, less shale.

Indiana SDH #124

Geological Description

Facies	Feet	Litholog	Comments
Facies E	36		As above
Facies C	40 44 48		DOLOMICSTONES – Olive gray to light olive gray (5Y3/2 to 5Y5/2), thin to thick bedded, burrowed in places, occasional algal laminites, fossil rich zones are common but strata is generally not fossiliferous. Occluded trace fossils. Algal laminites Faint laminations, 2 to 4 cm bedding. Colonial corals which appear to be <u>Tetradium</u>.

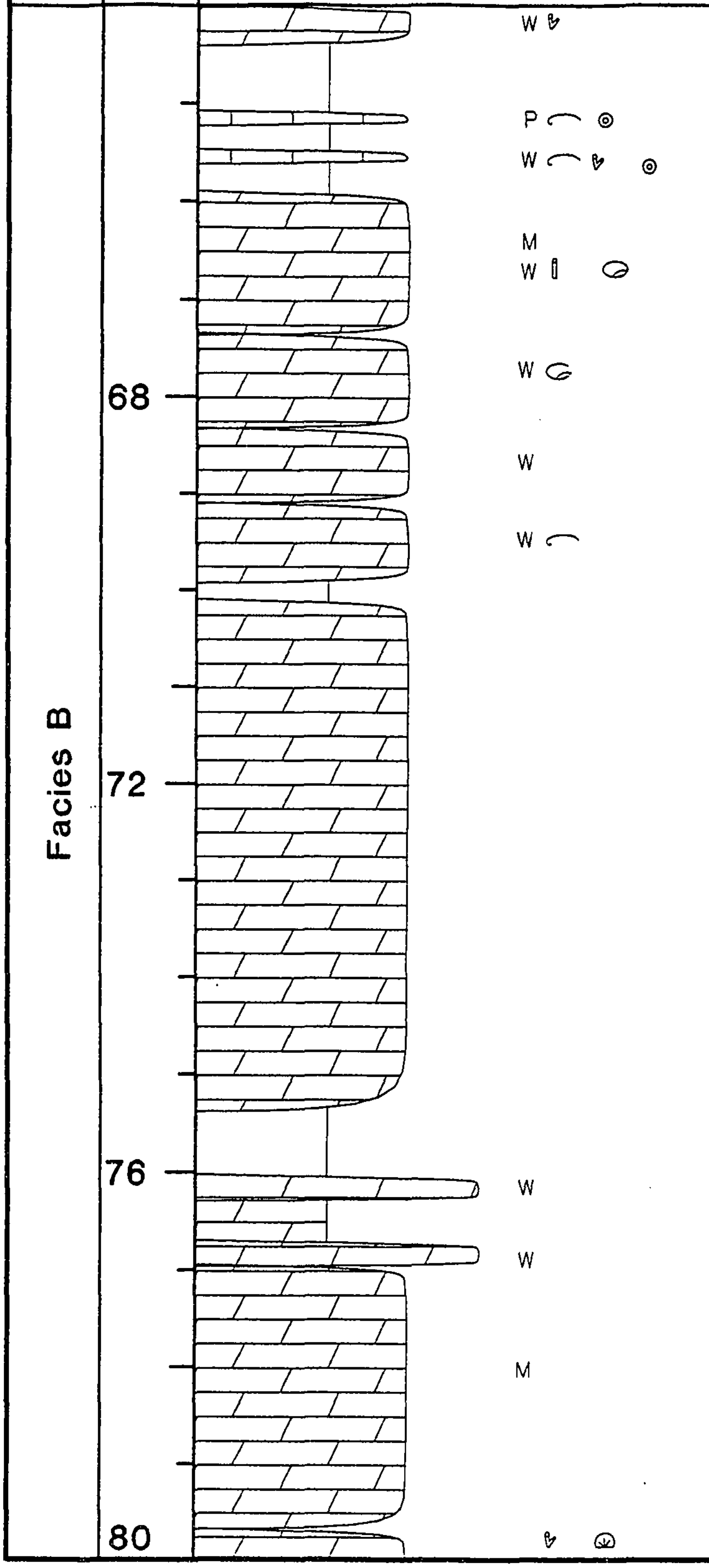



Indiana SDH #124
Geological Description
Facies
Feet
Litholog
Comments
Facies C
Facies B
52
56
60
64
M
P
W
W
M
M
P
M
W
DOLOMICSTONES – Olive gray to moderate yellow (5Y3/2 to 5Y7/6), massive to thin bedded, sparsely fossiliferous, occasional bryozoan rich layers.
INTERBEDDED WACKESTONES, DOLOMICSTONES, AND PACKSTONES – Olive gray to grayish black (5GY3/2 to N2), becoming increasingly calcareous with depth, fossil-rich intervals, 2 to 6 cm bedding.

Indiana SDH #124

Geological Description

Facies	Feet	Litholog	Comments



As above

DOLOSILTSTONES – Olive gray (5Y3/2), 1 to 4 cm bedding, rare fossils and shale breaks.

SHALE – Dark gray (N3), 2 to 3 mm partings, heavily burrowed.

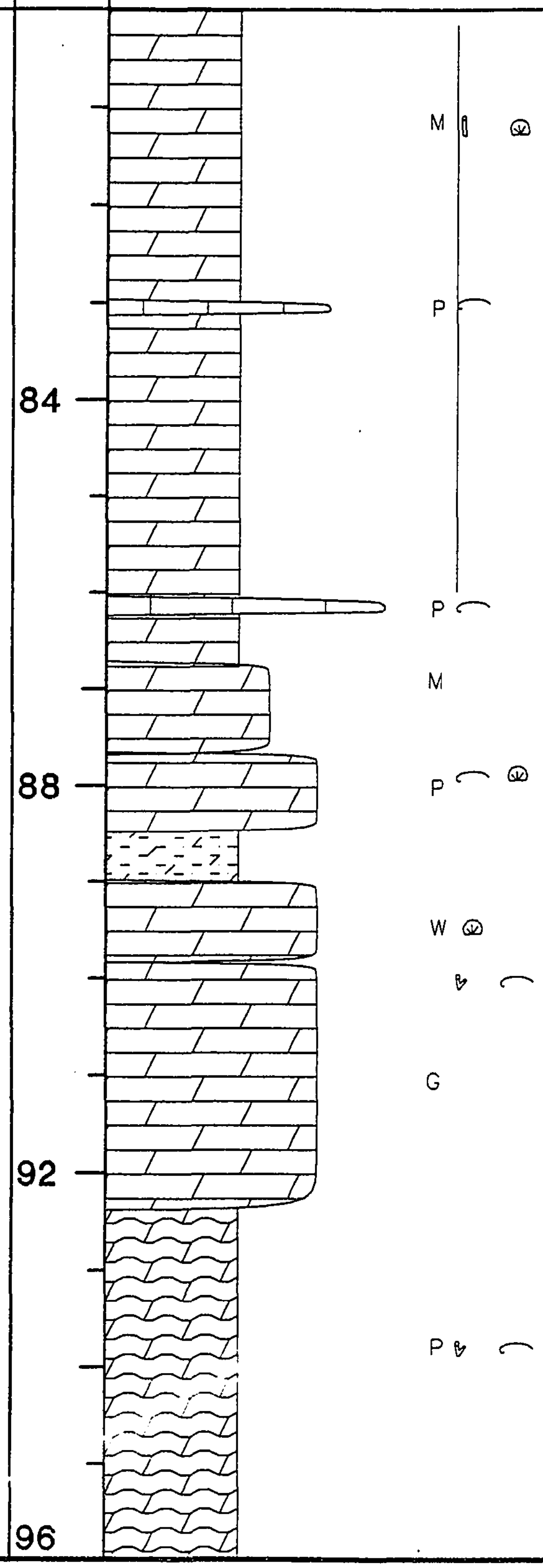
DOLOMICSTONE – as above, bioturbated.

Indiana SDH #124

Geological Description

Facies	Feet	Litholog	Comments

Facies B



Comments

As above

INTERBEDDED WACKESTONES, PACKSTONES, AND GRAINSTONES – Olive gray (5Y4/1), fossiliferous, including corals and brachiopods, irregular to planar bedded.

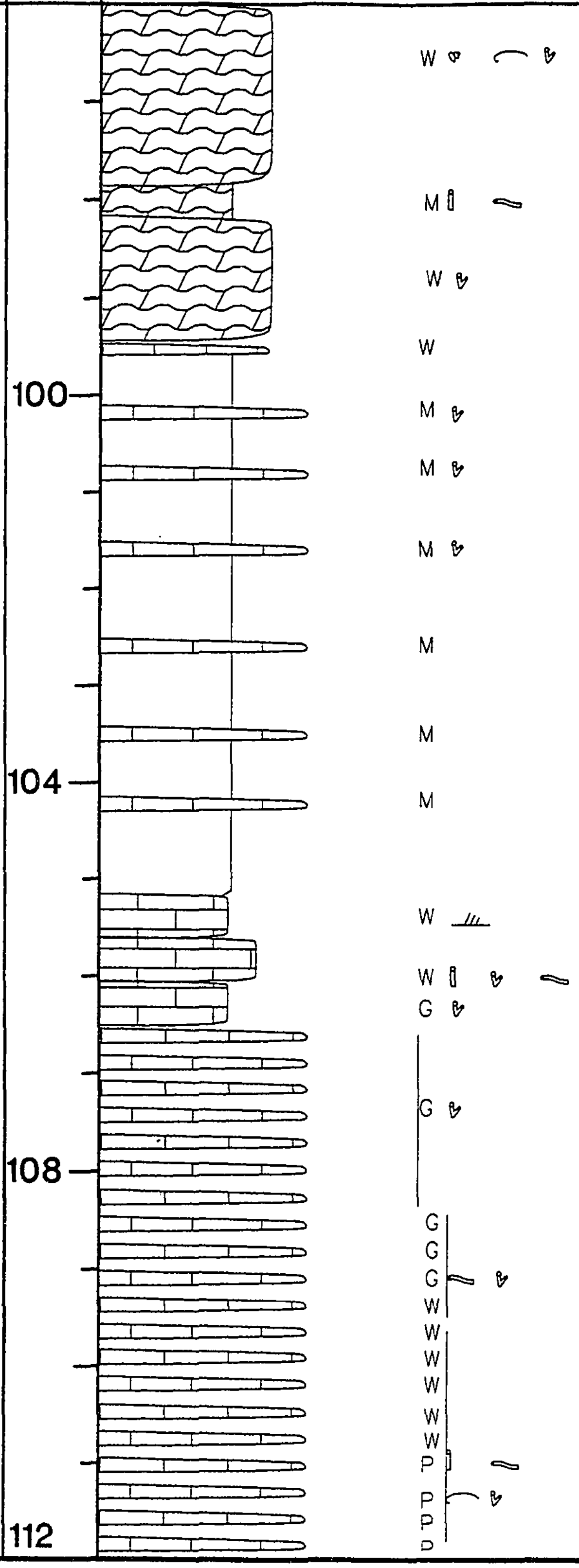
INTERBEDDED PACKSTONES AND SHALE – Olive gray (5GY3/2), irregularly bedded. packstones are poorly sorted, contain abundant bryzoan and brachiopod fragments, less than 40% shale.

Indiana SDH #124

Geological Description

Facies | Feet | Litholog | Comments

Facies B

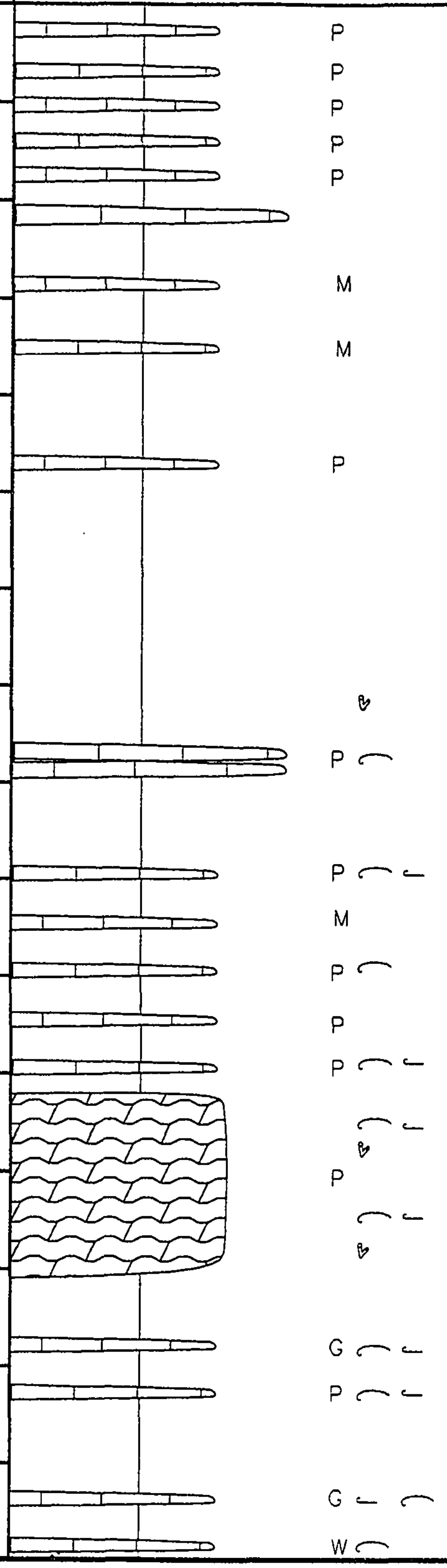


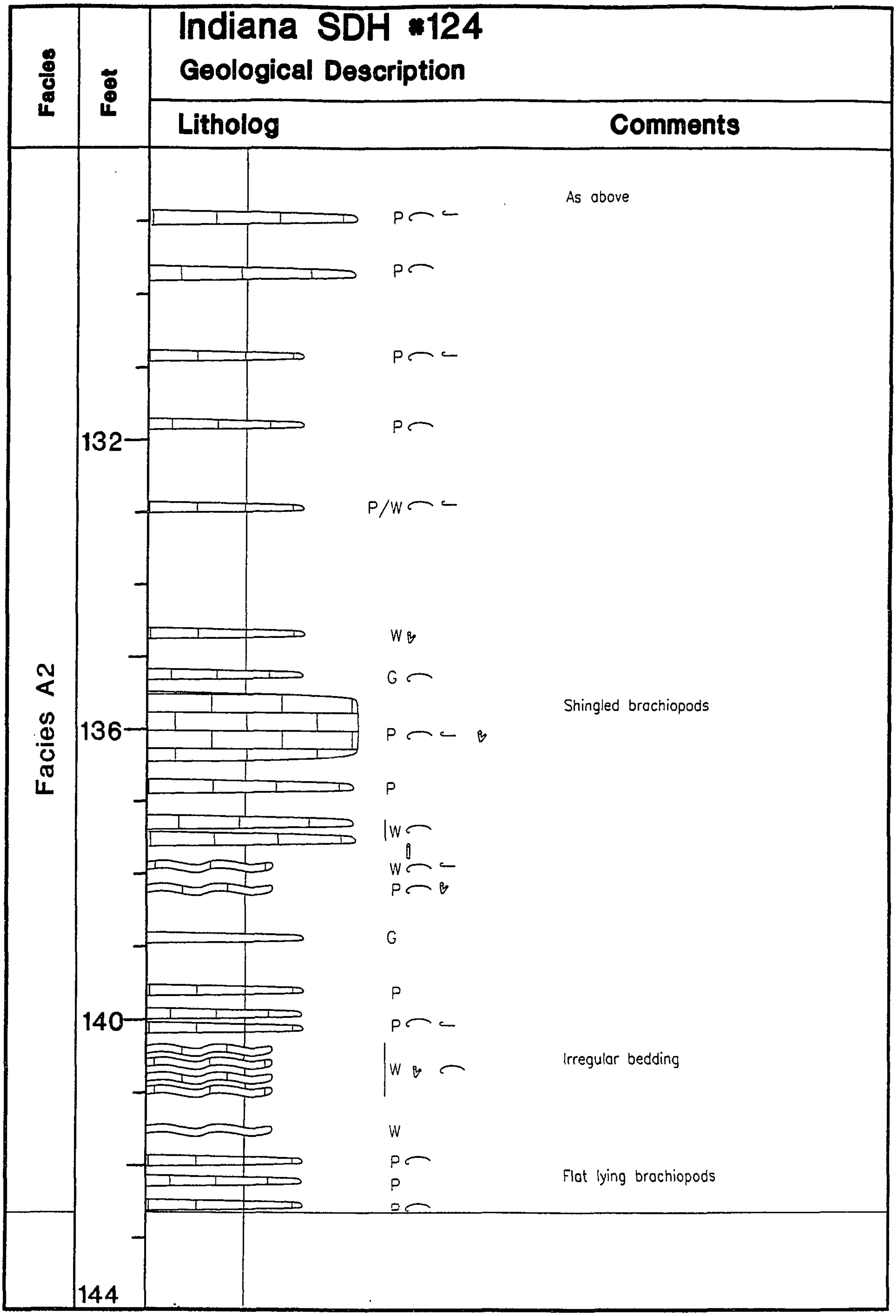
INTERBEDDED MICSTONES AND SHALES – Dark greenish gray (5GY4/1), rare bryozoan fragments, 1 to 5 cm bedding, finely laminated.

INTERBEDDED GRAINSTONES AND SHALES – Dark greenish gray (5GY4/1), very fine grained grainstones, bedding commonly less than 4 cm, fossils are abundant in carbonates, shales are silty.

Indiana SDH #124

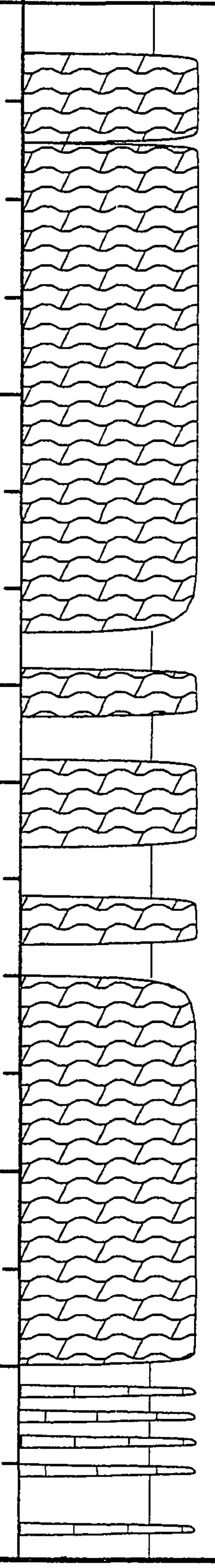
Geological Description

Facies	Feet	Litholog	Comments
Facies A2	116, 120, 124, 128		As above but coarser and bedding 3 to 8 cm. INTERBEDDED SHALES AND CARBONATES – Olive gray (5GY3/2), planar bedded, shales are burrowed, carbonates consist of 2 to 8 cm packstones with lesser abundances of grainstones, wackestones, and micstones, fossils are commonly fragmented and sorted but also can be whole. Whole


Indiana SDH #124
Geological Description
Facies
Feet
Litholog
Comments
As above
P
P
P
P
P/W
W
G
Shingled brachiopods
P
P
W
W
P
G
P
P
Irregular bedding
W
W
P
Flat lying brachiopods
P
132
136
140
144
Facies A2

Indiana SDH #124

Geological Description

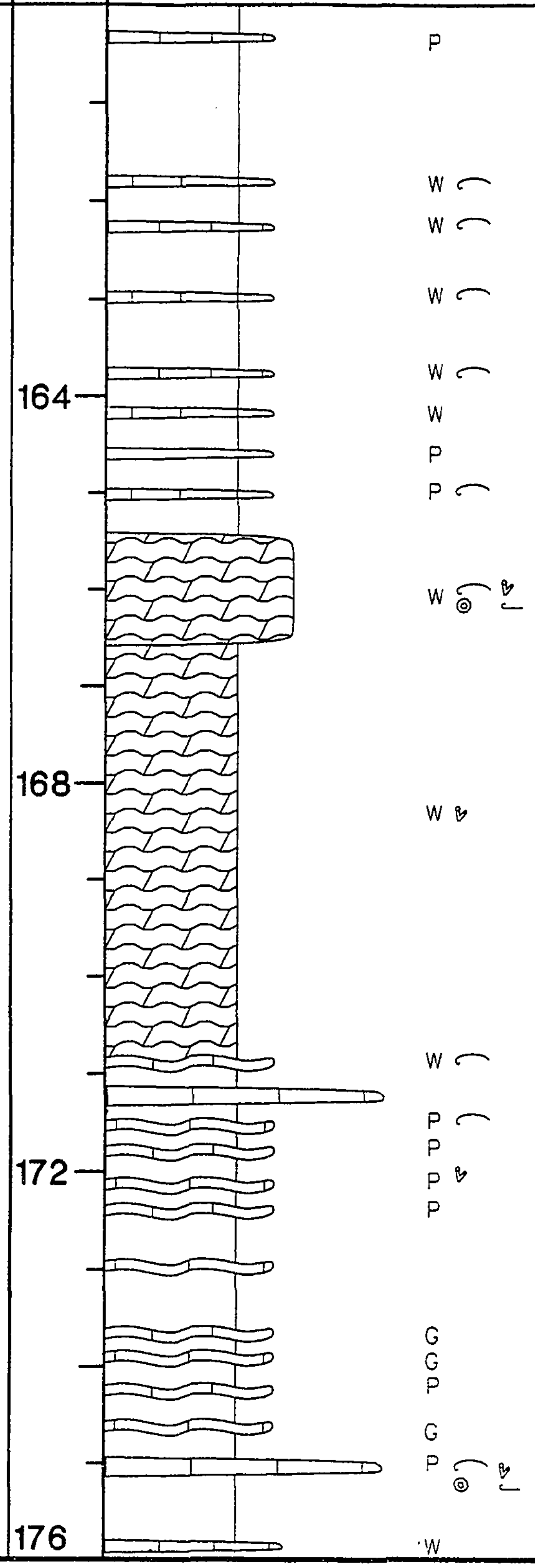
Facies	Feet	Litholog		Comments
Facies A1			W	WACKESTONES – Dark greenish gray (5GY4/1), rubbly bedded, burrowed, whole brachiopods and bryozoans, extremely argillaceous.
	148		W	
			W	
	152		W	
			W	
	156		W	
			P	INTERBEDDED WACKESTONES, PACKSTONES, AND GRAINSTONES – Dark greenish gray (5GY4/1), planar bedding, approximately 50% shale, poorly sorted, fossils fragmented.
			P/G	
			P/G	
	160		G	

Indiana SDH #124

Geological Description

Facies | Feet | Litholog | Comments

Facies A1



As above

WACKESTONES – Dark greenish gray (5Y4/1), thin bedded, dominantly shale, with abundant wackestones, abundant bryozoans.

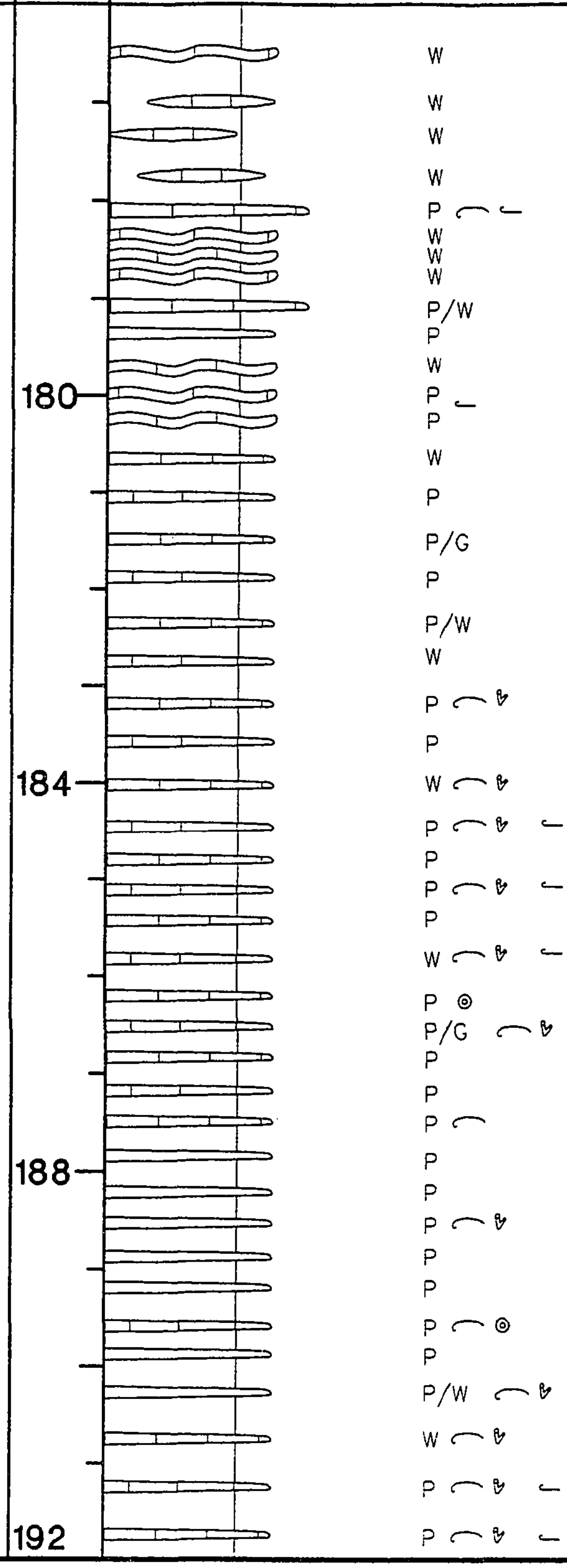
PACKSTONES AND GRAINSTONES – Olive gray (5Y4/1) to dark greenish gray (5GY4/1), well to moderately sorted grainstones that fine upward, packstones are poorly sorted, 2 to 5 cm bedding, approximately 60% shale, fossils are mostly fragmented but some whole whole fossils are present.

Indiana SDH #124

Geological Description

Facies | Feet | **Litholog** | **Comments**

Facies A1



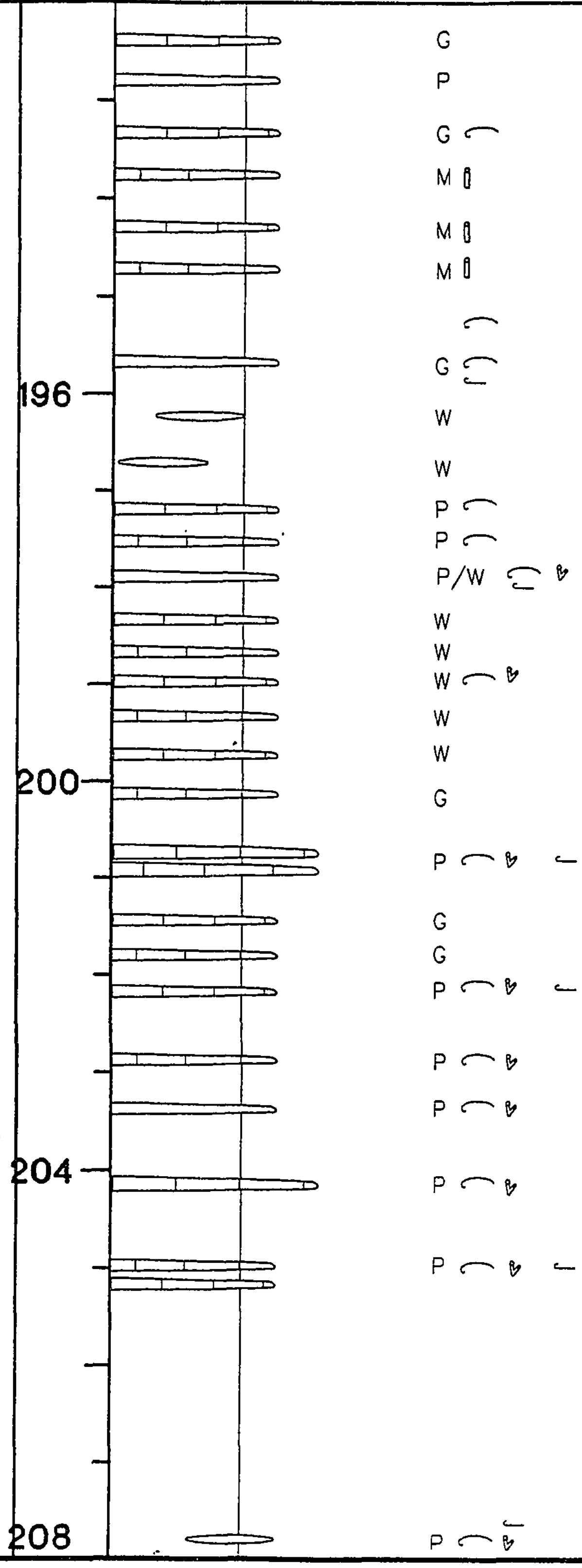
INTERBEDDED WACKESTONES, PACKSTONES, GRAINSTONES, AND SHALES - carbonates are medium gray (N5), planar bedded, very fossiliferous, fossils are smaller with well preserved trilobites, shales are dusky yellow green, occasionally laminated, oftern burrowed.

Shingled Rafinesquina

Indiana SDH #124

Geological Description

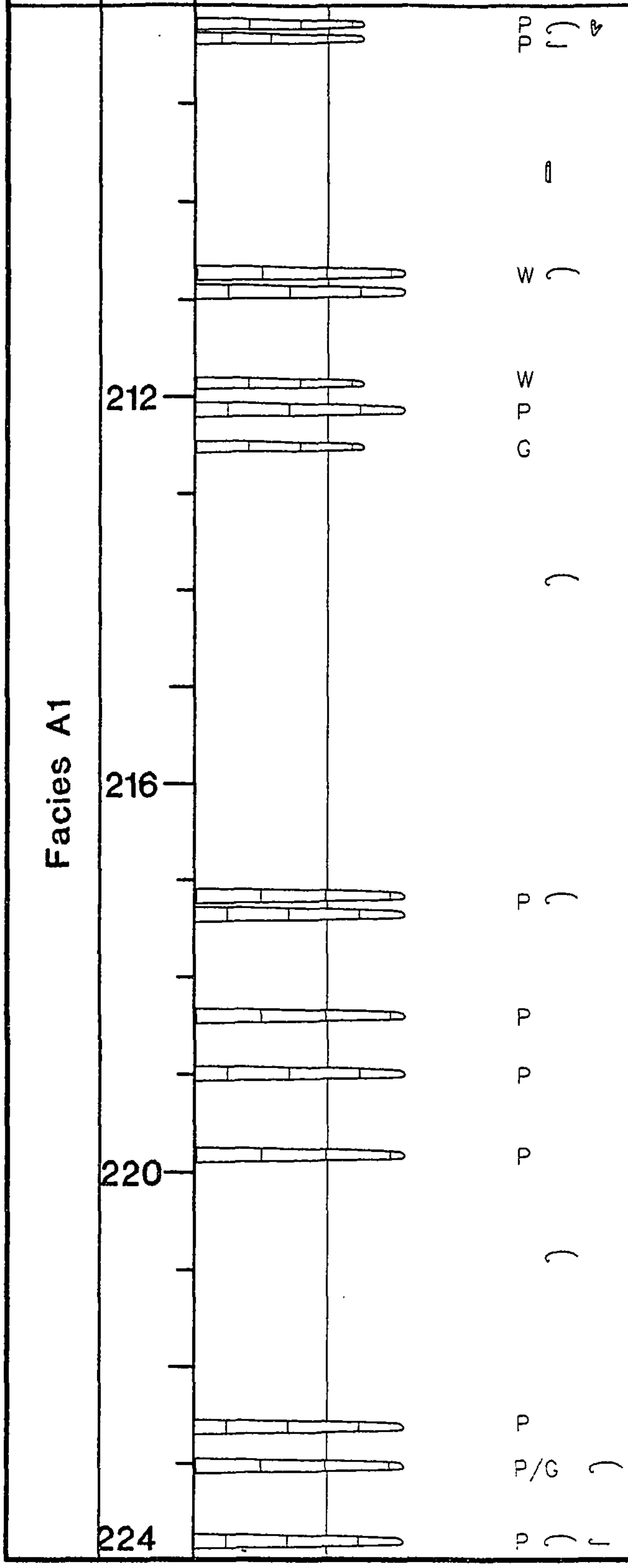
Facies	Feet	Litholog	Comments
Facies A1	196–208		As above, shales are extremely fossiliferous, orange trilobite fragments are present. Shale content increasing with depth.



Indiana SDH #124

Geological Description

Facies	Feet	Litholog	Comments

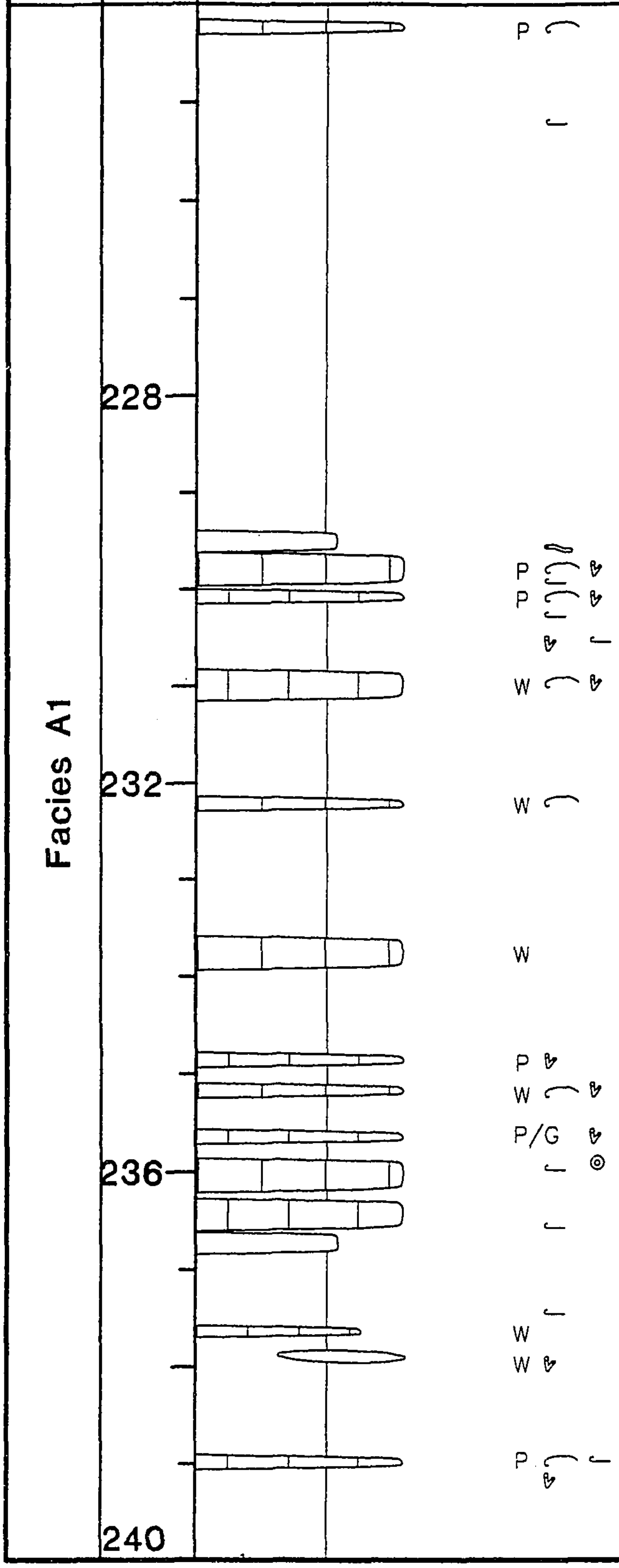


As above, shale is fossiliferous in intervals, most beds, fine upward, fossils are generally whole and well preserved.

Indiana SDH #124

Geological Description

Facies	Feet	Litholog	Comments

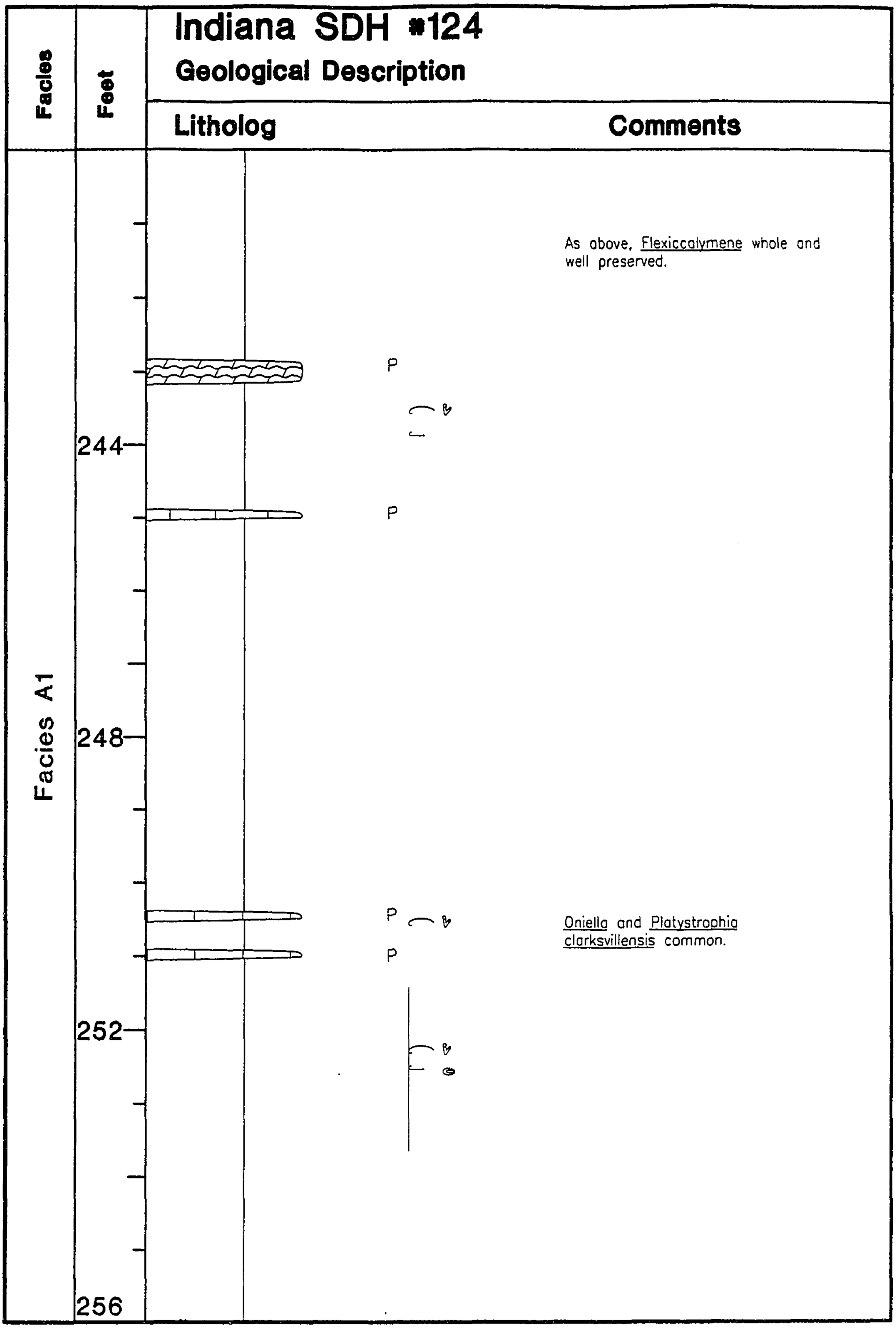


As above

INTERBEDDED SHALES AND WACKESTONES – light olive gray (5Y6/1), shale intervals are 3 to 10 cm with conodonts, Isotelus, and possible graptolites. wackestones are planar bedded, 1 to 2 cm thick, fine upward, and contain abundant fossils, fossils in shale are extremely well preserved.

Indiana SDH #124

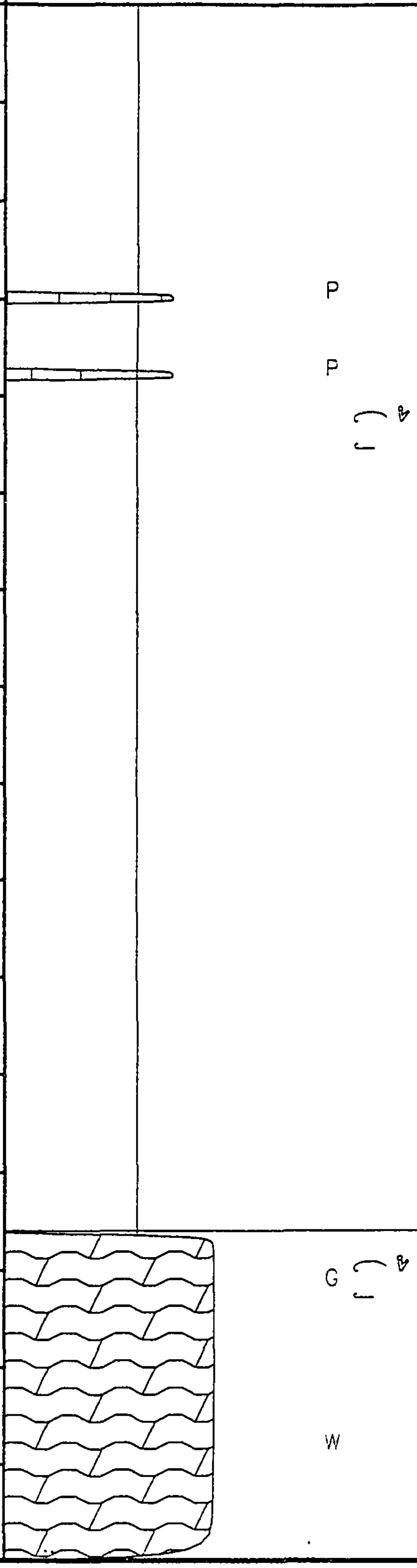
Geological Description



Indiana SDH #124

Geological Description

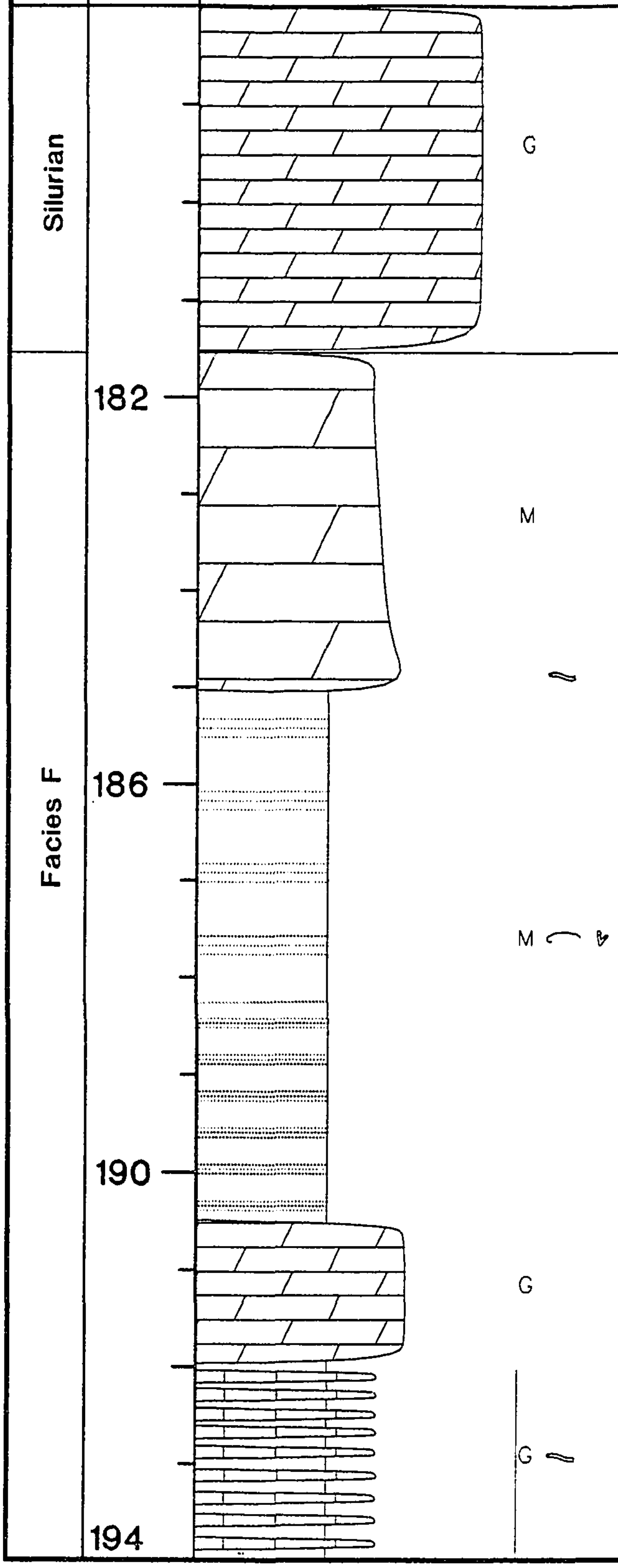
Facies	Feet	Litholog	Comments
Facies A1		P	
		P	
	260		Phosphate enriched.
			SHALE – Dark greenish gray (5GY4/1) with pale brown (5YR5/2) silt-filled burrows, extremely bioturbated in intervals.
	264		
			Burrowed
	268		
Arnheim		G	GRAINSTONE TO WACKESTONE – Brownish gray (5YR4/1) with grayish orange pink very fine grained fossil hash layers, argillaceous, increase in carbonate content towards top.
		W	
	272		



Indiana SDH #236

Geological Description

Facies	Feet	Litholog	Comments



GRAINSTONES – Pale yellowish brown 10YR6/2), recrystallized, abundant crinoid columnals averaging 250 to 350 microns, occasional shale partings, occasional glauconite and pyrite.

DOLOSTONE – Grayish olive green (5GY3/2) bedding 2 to 25 cm, unfossiliferous, bioturbated at base.

DOLOMICSTONE AND DOLOSTONE – Olive gray dolomicstone (5Y3/2) with yellowish gray dolostone banding (5Y7/2) 1 to 5 cm thick, occasional fossils.

SHALE – Olive gray (5Y3/2) laminated with yellowish gray (5Y7/2), probable algal laminites, up to 10 laminate per cm.

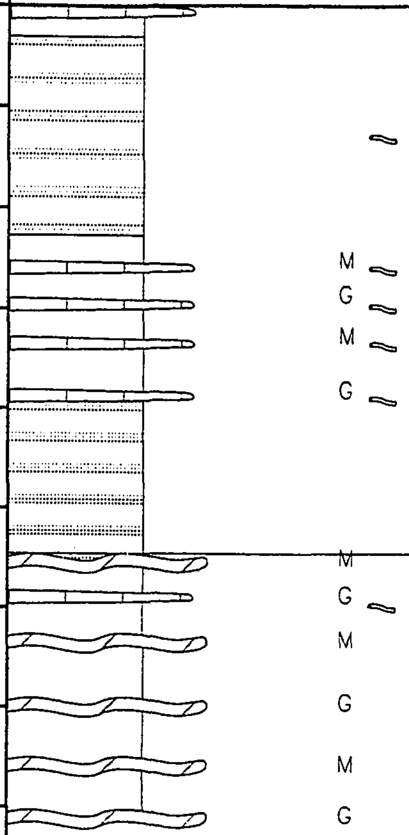
DOLOGRAINSTONES – Olive gray (5Y3/2), 3 to 5 cm bedding, unfossiliferous.

GRAINSTONES – Medium gray (N5), coarsen upwards, 250 microns at base up to 750 microns at top, 6 to 10 cm beds with shale partings, pyrite at contact with above unit.

Indiana SDH #236

Geological Description

Facies	Feet	Litholog	Comments



Facies F

DOLOSILTSTONES – Olive gray (5Y3/2), as above with prominent yellowish gray (5Y7/2) bands.

GRAINSTONES – Medium gray (N5), coarsen upward, as above.

198

ALGAL LAMINITES – as above.

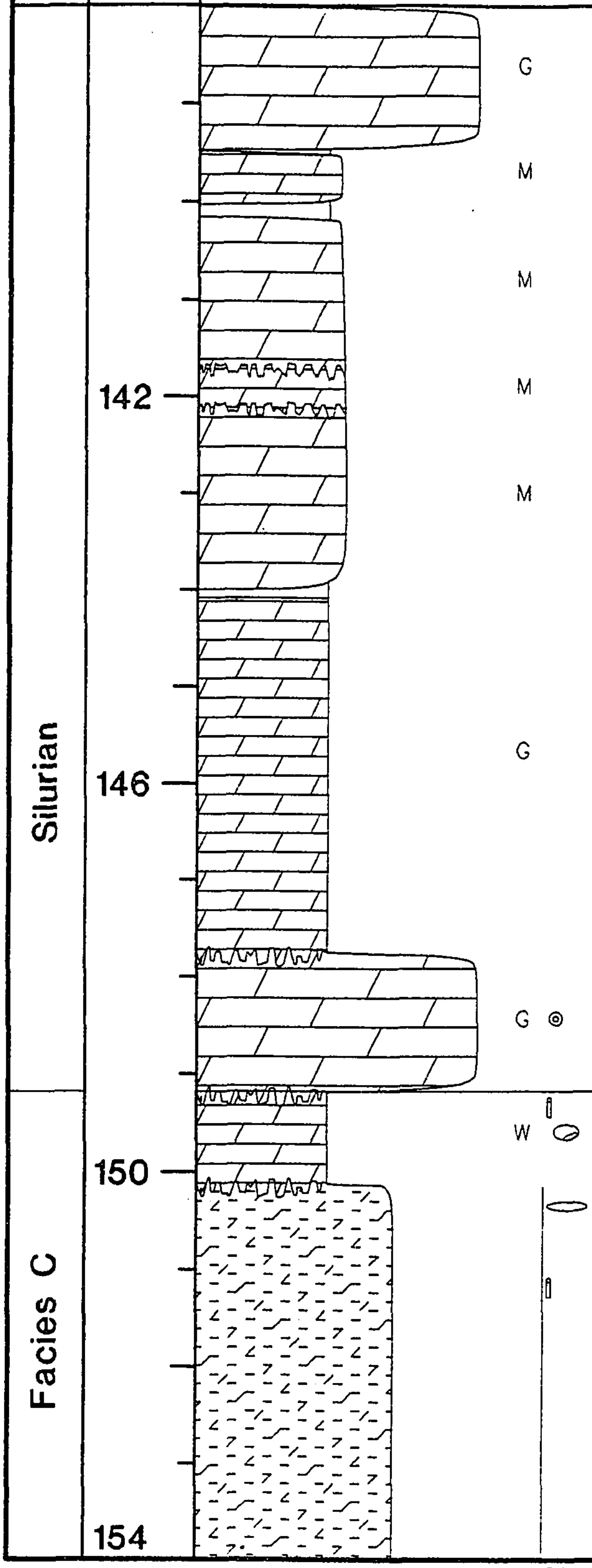
Facies E

INTERBEDDED SHALES AND WACKESTONES – Dark greenish gray (5GY4/1) clay shales 4 to 15 cm thick interbedded with olive gray (5Y3/2) skeletal wackestones, 3 to 8 cm, nodular bedded.

202

Indiana SDH #332

Geological Description



Comments

DOLOMICSTONES TO DOLOGRAINSTONES – Dark yellowish brown (10YR4/2) to olive gray (5Y3/2), styolites, bioclastic ghosts are present in grainstones.

CLAY SHALE – Olive gray (5Y3/2) with grayish red (5R4/2) banding, sharp contacts with above and below.

DOLOMICSTONES – Dark yellowish brown (10YR4/2) to olive gray (5Y3/2), bedding 2 to 4 cms, styolites, recrystallized, grains not evident.

Very light gray (N8) phosphate layer with mica.

Dusky yellowish green (10GY3/2) shale seam.

Very light gray (N8) phosphate layer with mica.

DOLOMICSTONES – Dark yellowish brown (10YR4/2) to olive gray (5Y3/2), bedding 1 to 4 cms, styolites, recrystallized, abundant glauconite.

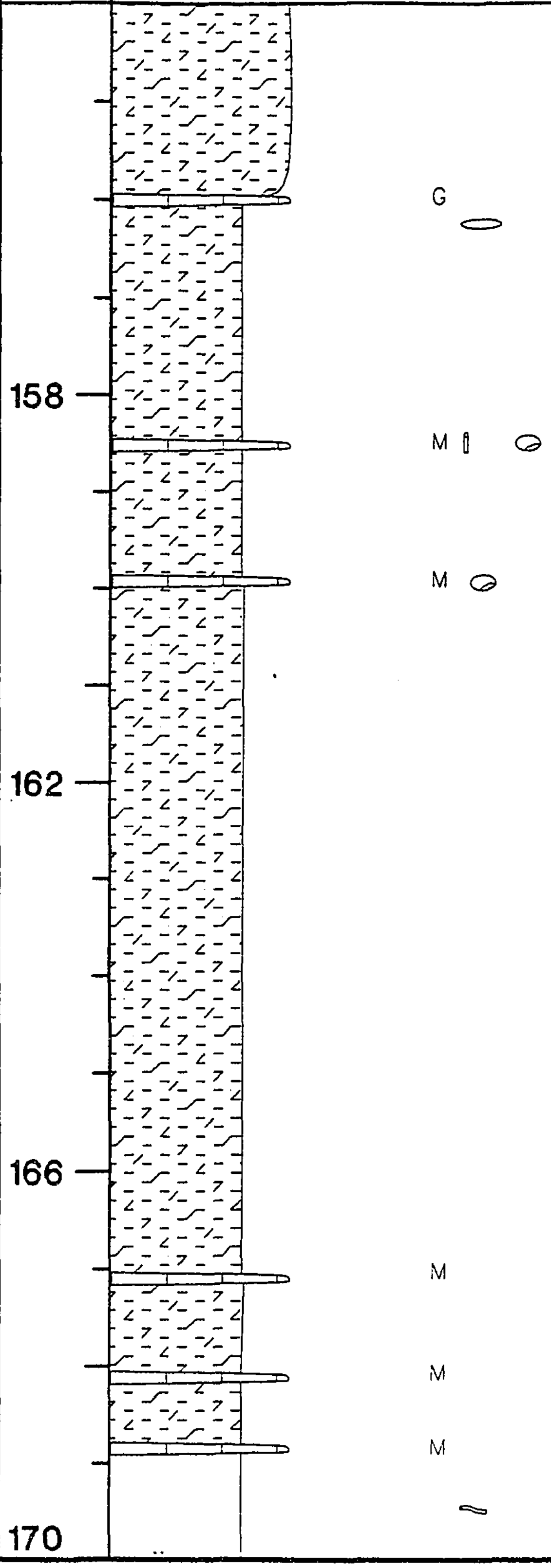
DOLOGRAINSTONES – Dark gray (N3), calcite filled vugs, bedding 2 to 8 cm, styolites.

WACKESTONES – Light olive gray (5Y6/1), abundant ostracods, calcite filled, occluded vertical burrows.

DOLOSILTSTONES – Greenish gray (5GY6/1) triangular shaped, vertically oriented structures filled with spar and glauconite, occluded spar-filled burrows, intraformational conglomerate at top, 4 to 16 cm bedding.

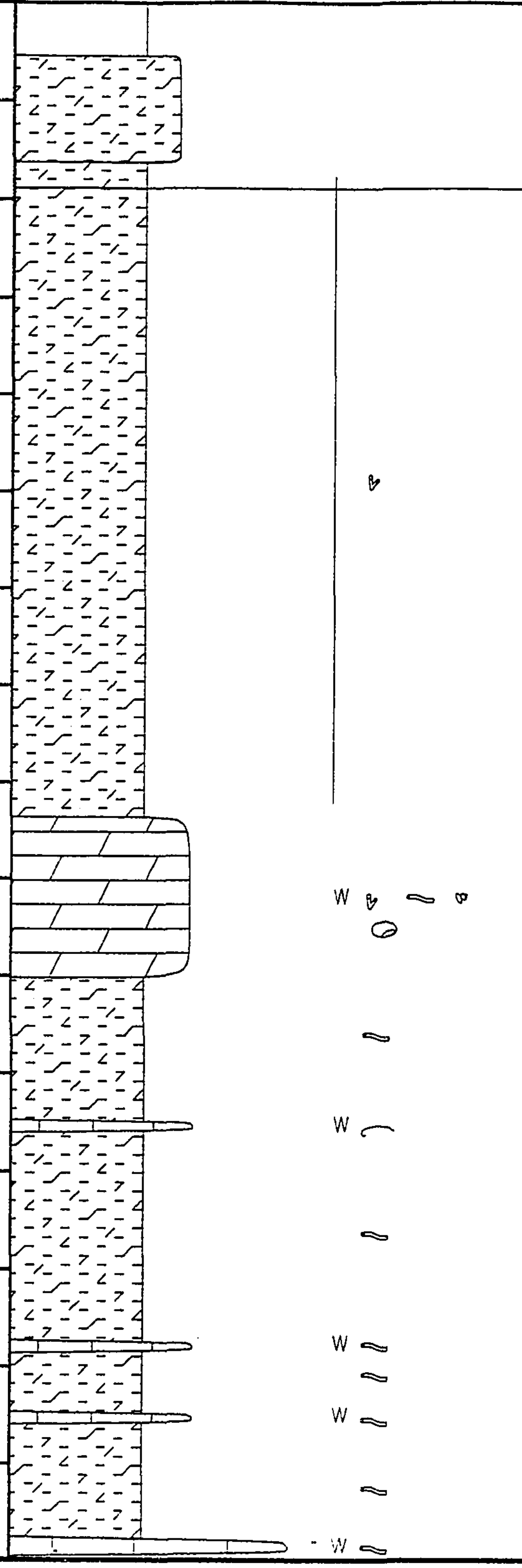
Indiana SDH #332

Geological Description

Facies	Feet	Litholog	Comments
Facies C	158–170		As above INTERBEDDED DOLOSILTSTONES AND DOLOMICSTONES AND DOLOGRAINSTONES – Greenish gray (5GY6/1) dolosiltstones, burrowed, with a light olive gray (5Y6/1) intraformational congolomerate at top; interbedded with light olive gray (5Y6/1) dolomicstones, 4 to 10 cm thick, with ostracods, styolitic contacts between some beds. Glauconite SHALE – Dark gray (N3), fissile, burrowed at top, burrows infilled with above dolosiltstone, fissile, 1 to 3 cm beds.

Indiana SDH #332

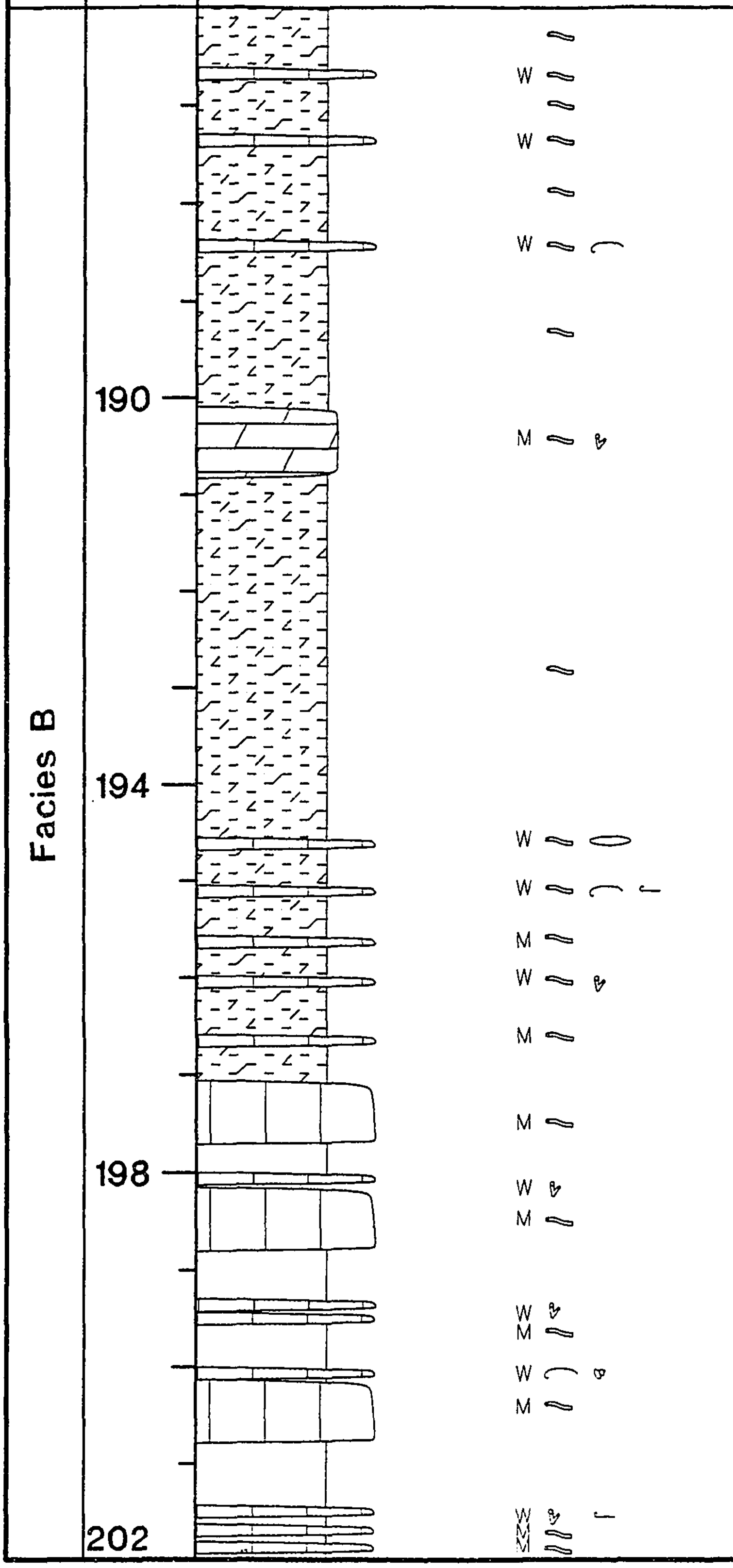
Geological Description

Facies	Feet	Litholog	Comments
			DOLOSILTSTONES – Olive gray (5Y4/1), homogeneous, sharp contacts above and below.
Facies B	174, 178, 182, 186		DOLOSILTSTONES – Dark gray (N3), with occasional coarser intervals, and 3 to 7 cm beds of whole bryozoans at 3 to 15 cm intervals. DOLOWACKESTONE – Light olive gray (5Y6/1), poorly bedded, burrowed, very fossiliferous, sharp contacts with above and below. DOLOSILTSTONES – Olive gray (5Y4/1) intense burrowing, sharp contacts with above and below. SILTSTONES – Light olive gray (5Y5/2), argillaceous, burrowed, with occasional interbeds of wackstones, some beds fine upward.

Indiana SDH #332

Geological Description

Facies	Feet	Litholog	Comments

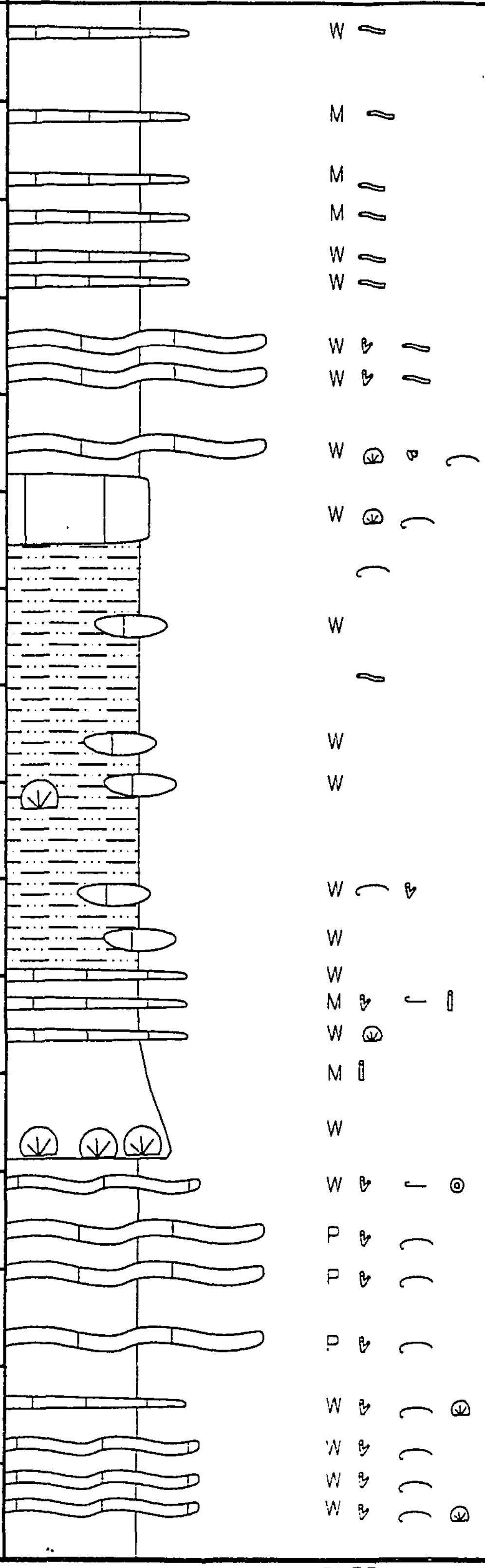


As above

INTERBEDDED WACKESTONES, MICSTONES, AND SHALES – Olive gray (5Y4/1), sparsely fossiliferous micstones, burrowed, fossiliferous wackestones, and bioturbated shale with occasional dolosiltstones at top.

Indiana SDH #332

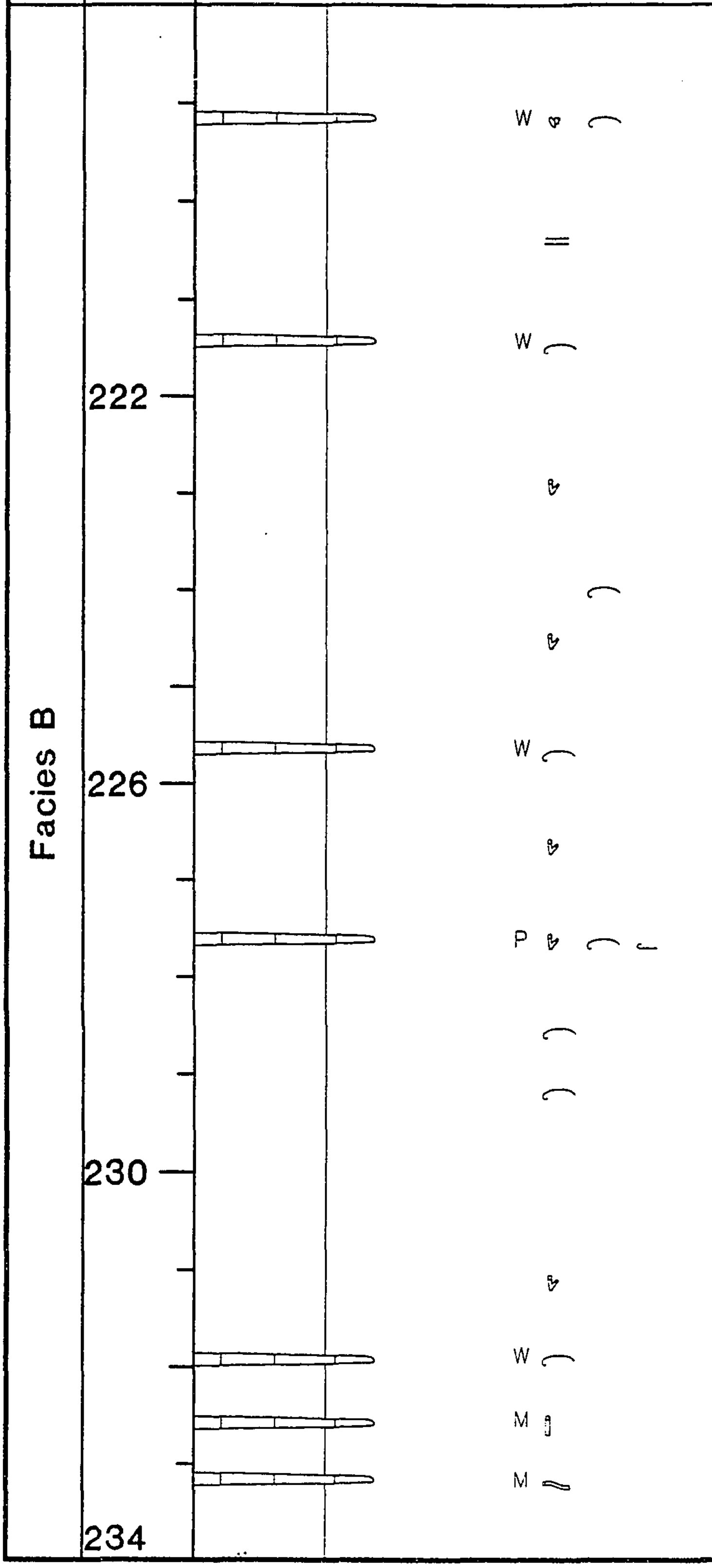
Geological Description

Facies	Feet	Litholog	Comments
Facies B	206, 210, 214, 218		As above As above except that bedding is becoming more irregular. CALCISILTITE – Dark gray (N3) mottled with medium dark gray (N4), sharp contacts, laminated, burrowed. INTERBEDDED LIMESTONE AND SHALE – Alternating beds of packstones and wackestones with calcareous shale, whole, flat lying (concave upwards) brachiopods, very fossiliferous.

Indiana SDH #332

Geological Description

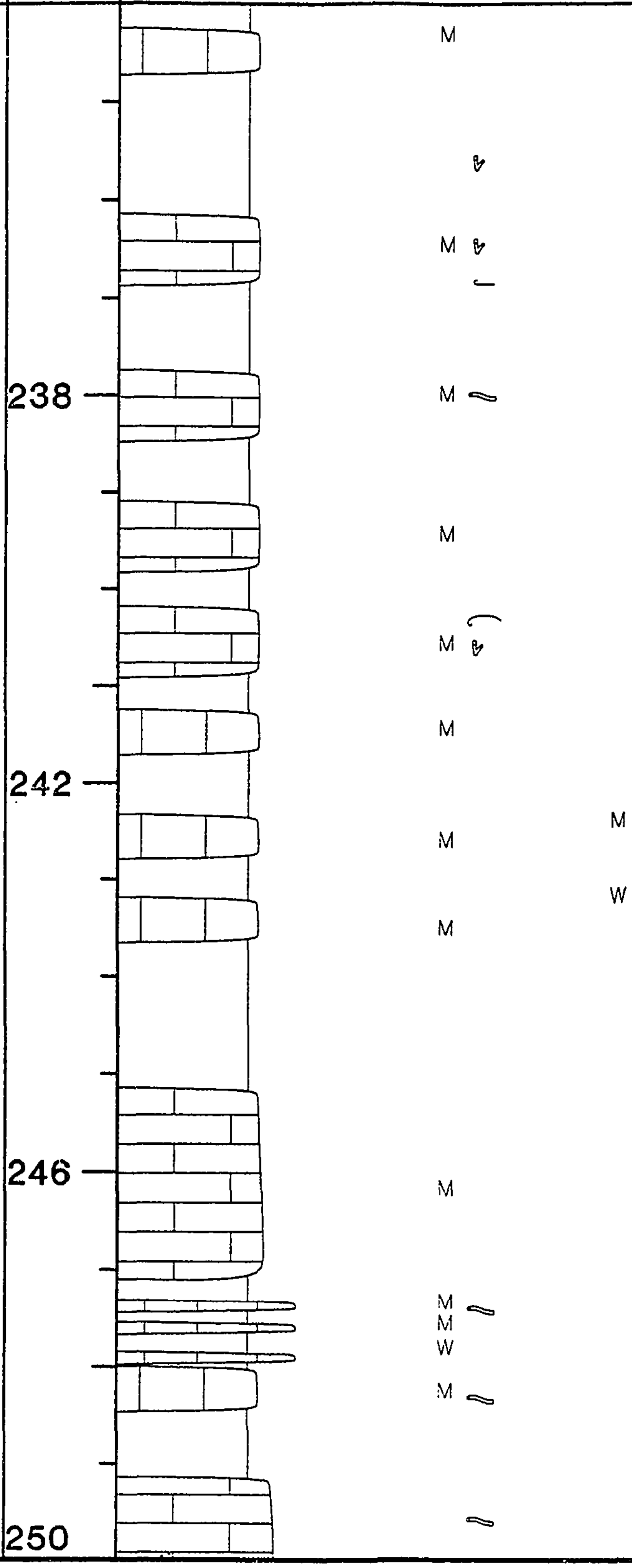
Facies	Feet	Litholog	Comments



INTERBEDDED LIMESTONE AND SILTY SHALE – Olive gray (5Y3/2) silty shales, extremely fossiliferous in places, calcareous, well indurated, poorly bedded, laminations are present at 220 feet, interbedded with olive gray (5Y3/2) wackestones, packstones, and micstones, poorly bedded, fossilerous, some f

Indiana SDH #332

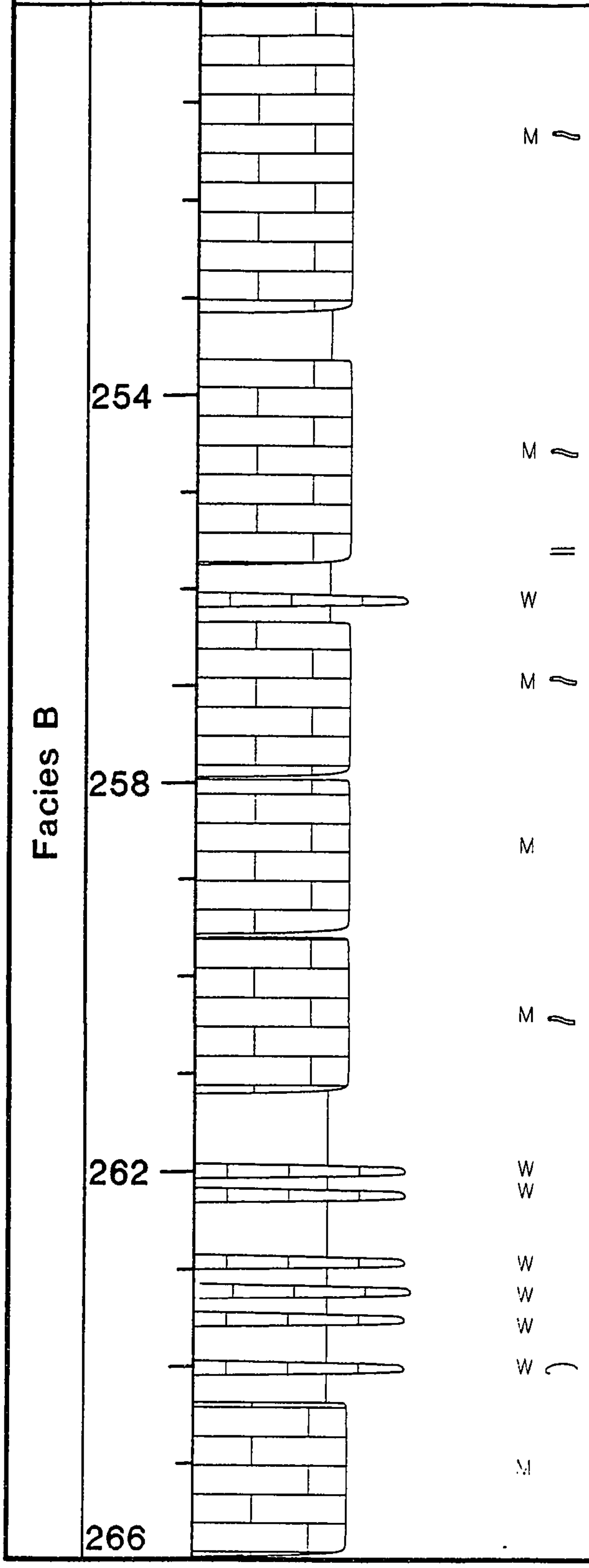
Geological Description

Facies	Feet	Litholog	Comments
Facies B	238–250		As above but less silt, and more carbonate beds, sharp contacts between shales and carbonate beds. Intensely burrowed, possible hardground.

Indiana SDH #332

Geological Description

Facies	Feet	Litholog	Comments

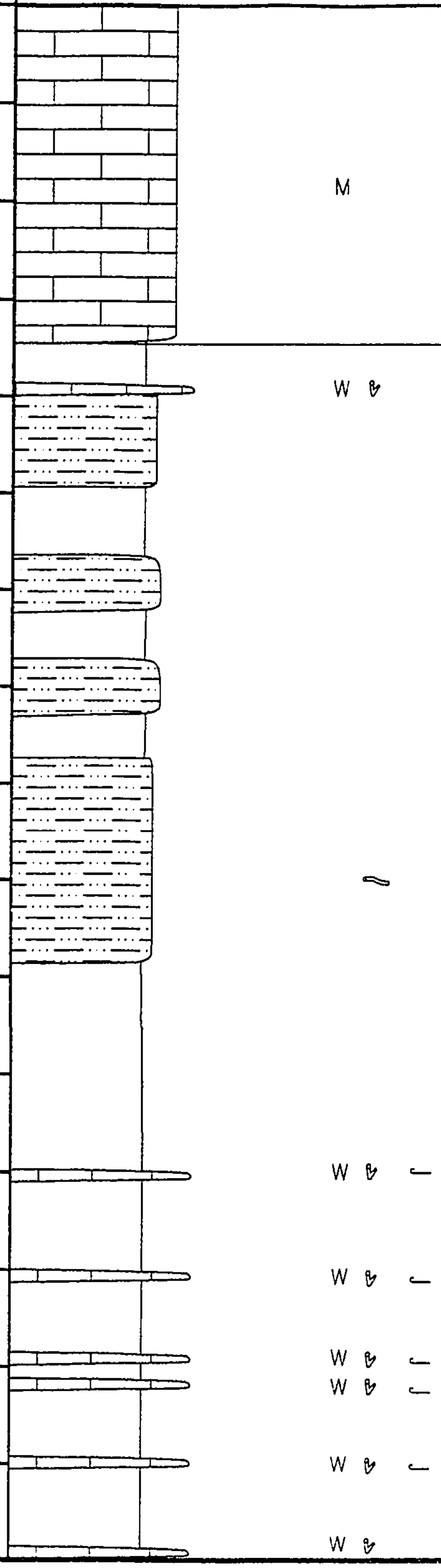


INTERBEDDED MICSTONES AND WACKESTONES – Medium dark gray (N4) to light olive gray (5GY6/1), 3 to 10 cm bedding, extremely bioturbated, with occasional interbeds of dusky red (5R3/4) shale.

Graptolites

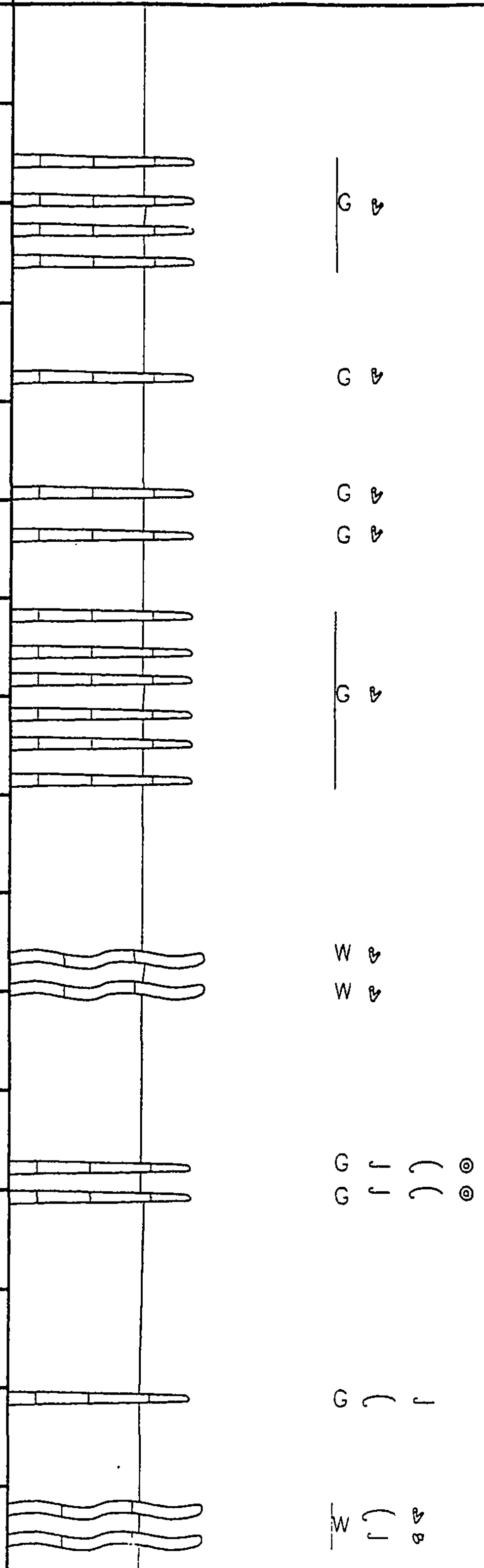
Indiana SDH #332

Geological Description

Facies	Feet	Litholog	Comments
Facies B			As above
Facies A	270, 274, 278, 282		CALCISILTITE – Grayish olive green (5GY3/2) laminated, bioturbated with intervals of grayish olive green (5GY3/2) shale. SHALE – Grayish olive green (5GY3/2), wavy laminated, very well indurated, calcareous, abundant conodonts, with thin (1 to 8 cm) grainstone and wackestone beds that are cross-bedded, a 2 mm thick, dusky red siltstone layer is present at 281.5 feet.

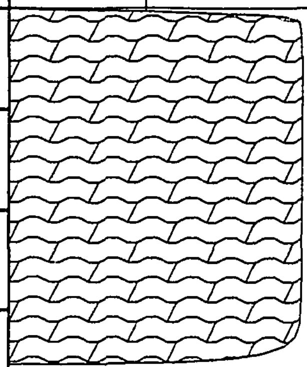
Indiana SDH #332

Geological Description

Facies	Feet	Litholog	Comments
Facies A	286 290 294 298		As above with increasing bioturbation towards the base. Abundant Chondrites

Indiana SDH #332

Geological Description

Facies	Feet	Litholog	Comments
Arnheim Formation	302	 W	WACKESTONES – Medium gray (N5), irregularly bedded, abundant bryzoans, several thin (less than 2 cm) layers of medium to fine grained, grayish orange pink, crinoid rich, fossil hash. Beds in this interval tend to coarsen upward and have coarse fossil hash at top.
	306		
	310		
	314		

Appendix C

Geophysical Log Database

APPENDIX C

LIST OF WELL NAMES AND LOCATIONS
GEOPHYSICAL LOG DATA BASE

Permit Number	Company Name	Well Name	County	State	Township	Range	Section	Footage	Data	Date Logged	Reference Elevation	Latitude	Longitude
37131	Harold B. Brett	Megammon #9-B	Blackford	IN	24N	11E	20	330NL,330WL NW,NE,SE	G,FD	12/21/77	894	40.54220	-85.30090
27387	Indiana Gas & Water	Ross #1	Clark	IN	1S	7E	93	300NEL,460NWL	G,N,Core	10/16/64	483	38.42079	-85.69550
30859	Indiana Gas & Water	Garvey #4	Clark	IN	1S	7E	92	330W, 330E	G,N	12/13/66	547	38.41365	-85.70950
33486	Indiana Gas Co.	Frued, Homer #3	Clark	IN	1S	7E	92	1670NEL, 326NWL	G,N	08/01/75	529	38.41145	-85.71370
24526	Continental Oil	Perrel #1	Clinton	IN	22N	1E	36	330SL, 150WL, SW,SW,NW	G,N	06/05/61	905	40.30008	-86.36900
124	Indiana Geological Survey	SDH 124	Decatur	IN	10N	11E	8	630SL,530EL, SE,SW,SW	SP,R,Core	10/06/64	942	39.32533	-85.33240
29547	Gulf Oil	Osborn #1	Decatur	IN	12N	11E	33	330NL, 330EL, NE,NE,NW	S	09/23/65	1061	39.45267	-85.27270
35122	Shawnee Oil & Gas	Morgan Miers #2	Decatur	IN	10N	8E	15	92SL, 255WL, SW,NE,SE	G,NP	01/19/75	836	39.30973	-85.61680
37046	D. B. Baxter	Richardson #1	Decatur	IN	9N	8E	34	397SL, 330WL, SW	G,FD	10/05/77	791	39.17630	-85.63030
236	Indiana Geological Survey		Deleware	IN	22N	10E	23	175 FSL, 20 FWL, SW,NE,SW	Core	12/11/72	873	0.00000	0.00000
15754	Moore & Baggett	Martin #1	Deleware	IN	20N	11E	9	177SL,490WL SW,SE,SW	G,N	11/18/54	983	40.19367	-85.28590
38416	Trenton Energy Co.	Broyles #1	Deleware	IN	22N	8E	36	330SL,395WL, NE,SW	G,N	10/28/80	885	40.31340	-85.57120
40797	K & M Drilling	Shreve #1	Deleware	IN	21N	11E	30	1874SL,480WL SW	G,FD	10/13/81	958	40.23773	-85.32890
29516	R. G. Lowry	Vinnedge #1	Grant	IN	24N	6E	15	297NL,363WL,NW,SW,NW	G,N	09/02/65	851	40.53339	-85.83910
31869	Patrick Petroleum	Kirkpatrick #1a	Grant	IN	25N	9E	22	330NL, 330EL, NE,SW,SW	G,N	01/29/68	843	40.59852	-85.50060
41288	Mapco Prduction	Haisley #1	Grant	IN	23N	7E	14	1650SL, 1650EL, SE	G,FD	02/08/82	864	40.44101	-85.68460
41467	Mapco Production	Johnson #1	Grant	IN	25N	8E	28	470NL,330EL,NE,SE,NW	G,SP,IN	01/15/82	851	40.59246	-85.62920
34467	Charles Carraway	Olson #1	Hancock	IN	17N	5E	25	700SL,1315EL, SE,NE	G,FD	11/20/73	870	39.89275	-85.91390
40747	Subadon Energy	Jacobi #1 A	Hancock	IN	17N	6E	30	502NL,275EL,NE,SE,NW	G,N	07/28/81	870	39.89485	-85.89110
2104	Ohio Valley Transmission	Holliday #1	Harrison	IN	6S	4E	4	1150SL, 870WL, SW,SE	G,N	03/16/60	678	38.01271	-86.07310
20747	Citizens By-Product Coal	Bishop #1	Hendricks	IN	14N	1E	12	330NL,330EL, NE,NE,NE	G	03/26/59	767	39.67432	-86.36250
30314	E. F. Moran	Nugen #1	Henry	IN	16N25	10E	25	325NL,1472WL NW	G,S	07/05/66	1086	39.78811	-85.36700
30510	Horizon Oil	Draper #1H	Henry	IN	17N	10E	30	620NL,504EL NE,NE,SE	G,N	09/14/66	1033	39.89801	-85.44350
32709	Moses and Stewart	Shrack #2A	Jay	IN	22N	12E	27	330NL,330WL, NW,NW,NW	G,N	02/02/70	945	40.33522	-85.18590
34102	Mitchell INC.	Mitchell 9D-9 Miller	Jay	IN	24N	12E	9	1760SL,330EL, SE,NE,SE	G,S	02/14/73	908	40.54602	-85.16650
34103	Mitchell	Mitchell #7D-11 Snyder	Jay	IN	24N	13E	11	330SL,330EL, SE,SW,NE	G,N	02/24/73	855	40.55015	-85.01670
39099	Hamilton Enterprises	Nuckols #1	Jay	IN	22N	14E	26	330SL,330WL SW,SW,SW	G,N	01/19/80	1068	40.32492	-84.93800
39102	Kirby Exploration	May #1-26	Jay	IN	23N	15E	26	330SL,300WL SW,NW,SW	G,FD	06/11/80	938	40.41605	-84.82430
38016	Citizens Gas & Coke	H. F. Lautenbach #1	Johnson	IN	12N	5E	3	1440NL, 660EL, NE	N,LD	10/07/78	715	39.51915	-85.95400
18506	Madison-Monroe Oil	Allen #1	Madison	IN	21N	8E	3	900NL,725EL NE,NW	G,N	05/17/58	881	40.30299	-85.60850

APPENDIX C

LIST OF WELL NAMES AND LOCATIONS
GEOPHYSICAL LOG DATA BASE

Permit Number	Company Name	Well Name	County	State	Township	Range	Section	Footage	Data	Date Logged	Reference Elevation	Latitude	Longitude
34752	Indiana Gas Co.	Ward #3 T-5	Monroe	IN	9N	1E	5	672SL,757WL, SW,SW	G,N	10/15/74	875	39.23866	-86.44290
37399	Texaco Inc.	Conder #1	Monroe	IN	8N	2W	35	330SL,330WL, SW,SW,SW	G,FD	01/06/78	820	39.08007	-86.60930
17921	Hiawatha Oil and Gas	Payton #1	Morgan	IN	11N	1W	15	630NL,580WL, NW,NW	G,N	11/09/56	582	39.39607	-86.52000
20860	Citizens Gas and Coke	Marionos #1	Morgan	IN	13N	2E	10	330NL,330EL, NE,SW,SW	G	04/26/59	763	39.57686	-86.30140
43558	Citizens Resource Dev.	E. Galey #1	Perry	IN	4S	1N	5	660SL, 660WL, SW,SE	BD,CN	08/25/83	767	38.19286	-86.54120
45250	C. J. Warren Oil Co.	E. Paulin #1	Perry	IN	3S	3W	23	390SL, 330WL, SW,NW	G,SON	09/22/84	463	38.24322	-86.70570
21420	Continental Oil Co.	R. Johnton #1	Randolf	IN	18N	14E	15	2475SL, 1320EL, SE	G,N	09/06/59	1154	40.01168	-84.94390
29474	Central Indiana Gas Co.	Haynes #20T48	Randolf	IN	19N	13E	20	73NL, 56WL, NW,NW,SW	G,N	08/09/65	1154	40.08453	-85.11040
30422	B. B. Zavoico	F. Tibbets #1	Randolf	IN	20N	15E	19	330SL, 330EL, NE,NE,SE	G,N	03/10/67	1117	40.14279	-84.88350
31352	B. B. Zavoico	L. E. Welch #1	Randolf	IN	19N	15E	5	330NL, 330WL, NW,NW,SW	G,N	10/27/67	1170	40.12768	-84.88190
30282	E. F. Moran Inc.	R. B. Anderson #1	Rush	IN	13N	10E	7	149SL, 1403WL, SW	G,SON	06/18/66	964	39.58738	-85.44820
30294	E. F. Moran Inc.	W. G. Waggoner #1	Rush	IN	14N	10E	10	1120SL, 340WL, SW,SW	G,SON	06/26/66	973	39.67116	-85.40320
35789	Eagle Gas & Oil	H. Everhart #1	Shelby	IN	13N	7E	4	1084NL, 677WL, NW	G,BD	06/17/76	790	39.60828	-85.76080
36640	General Electric	R.& H. Yarling #1	Shelby	IN	13N	7E	26	423NL, 320WL, NW,NW,NE	G,LD	05/05/77	820	39.46664	-85.71110
36671	General Electric	General Electric #1	Shelby	IN	12N	7E	4	200SL, 191EL, NW,SE,SE	G,BD	04/25/77	789	39.51989	-85.74640
36744	General Electric	R. and C. Stiles #1	Shelby	IN	12N	7E	3	450SL, 330WL, SW,SW,SE	G,N	05/18/77	787	39.51276	-85.73180
27418	Sun Oil Co.	Wells Estate #1	Tippton	IN	23N	3E	36	330SL, 330WL,SW,NE,SW	G,N	09/11/63	885	40.39359	-86.10430
57	Indiana Geologic Survey	SDH 57	Wayne	IN	14N	1W	12	50SL, 490WL, SW,SW,NW	SP,R,Core		1028	39.71951	-84.82930
42617	Farrar Oil Co.	Muse, Harris, Briar, Etal	Wayne	IN	16N	12E	20	660NL, 330EL, NE,SE	LD,N	10/27/82	1021	39.82633	-85.20320
332	Indiana Geological Survey	SDH-336	Wells	IN	25N	10E	12	160FNL, 50FWL	G,N,CD	05/21/85	853	40.63877	-85.35290
72625	Froman	Froman #1	Bullit	KY	10	S	45	180NL,3100WL	G,CD	10/22/86	660	38.06617	-85.75590
398	United Fuel Gas	Stamper 8807T	Carter	KY	3	V	77	2450NL,1525WL	G,N	08/09/59	857	38.32660	-83.12800
16235	Cabot	Stapleton #1	Carter	KY	12	V	77	2450NL, 1525WL	G,N	04/22/66	956	38.29327	-83.11130
25730	Inland Gas Co.	McDavid	Carter	KY	22	U	79	2580SL, 900WL	G,N	06/23/72	808	38.17375	-82.94680
26995	Inland Gas	Duncan #547	Carter	KY	25	W	77	400SL, 2150EL	G,FD	07/15/73	985	38.33443	-83.15740
271	United Fuel Gas	Litton #8802T	Elliot	KY	22	T	76	1900NL, 950WL	G,N	06/03/60	968	38.09478	-83.19670
1555	United Fuel Gas	Pennington #9021T	Elliot	KY	21	T	76	750NL,1750EL	GG	04/18/61	921	38.09794	-83.17270
25781	Monitor Petroleum	Kaufman #1	Elliot	KY	7	T	79	1415SL,1640WL	G,FD	06/07/72	710	38.13721	-82.97760
29843	Ashland Oil	Gillum #1	Elliot	KY	15	T	78	2000SL,1350WL	G,FD	07/30/75	816	38.12215	-83.07860
67748	Ashland Exploration	Kazee #1	Elliot	KY	8	T	79	1935NL,1735EL	G,LD	05/05/85	727	38.14468	-82.95600
20187	Mid-Terra	Huber #1	Greenup	KY	25	Z	78	250SL, 100WL	G,FD	12/21/67	1100	38.58402	-83.08290
21256	Commonwealth Gas	Newell #1	Greenup	KY	7	Z	78	3850NL, 420EL	G,FD	08/22/68	1054	38.63942	-83.05140
22214	Monitor Petroleum	Newell #1A	Greenup	KY	7	Z	78	1750SL, 140EL	G,FD	04/19/69	1031	38.63813	-83.05040
30578	Ashland Oil	Gilliam #1	Greenup	KY	16	Z	78	775SL, 125EL	G,FD	02/08/76	1081	38.60212	-83.06710
24576	Dupont	#1-WDW	Jefferson	KY	10	U	44	922SL,2763WL	G,N,POR	04/02/71	462	38.21919	-85.84030
2579	United Fuel Gas Co.	Shepard #9060-T	Lewis	KY	19	W	75	1050NL,1700EL	G,Lat	04/28/61	915	38.36378	-83.27250
20314	Midterra Assoc.	Curtis #1	Lewis	KY	7	X	74	200NL, 100WL	G,FD	01/19/68	734	38.48278	-83.39960
21132	Ashland Oil & Refining	Wolfe #1	Lewis	KY	13	Y	77	1000 SL, 820 WL	G,N	08/03/68	1113	38.53607	-83.13040
31428	Har-Ken Oil	Mead #1	Lewis	KY	20	Z	77	750SL, 470WL	G,BD	10/26/76	662	38.60205	-83.09830
10526	Duchscherer	Pack #1	Meade	KY	13	R	41	2800NL,1800WL	G,N	11/30/61	637	37.95897	-86.12700

APPENDIX C

LIST OF WELL NAMES AND LOCATIONS
GEOPHYSICAL LOG DATA BASE

Permit Number	Company Name	Well Name	County	State	Township	Range	Section	Footage	Data	Date Logged	Reference Elevation	Latitude	Longitude
18101	United Fuel Gas	Brown 9380T	Menifee	KY	21	S	72	2600NL,1050WL	G,FD	06/07/67	989	38.00952	-83.51300
24194	Monitor Petroleum	Ison #1	Morgan	KY	3	R	78	1515SL,1920EL	G,FD	12/05/70	821	37.98749	-83.03990
26795	Dehart Oil	Vance #1	Morgan	KY	20	R	74	1050SL,1400EL	G,FD	07/04/73	938	37.93621	-83.33810
27544	Monitor Petroleum	Blanton #1	Morgan	KY	23	R	73	2010SL,2210WL	G,FD	02/12/74	996	37.92218	-83.45900
51605	Ashland Exploration	Brown #1	Morgan	KY	8	R	78	880SL,1890WL	G,LD	10/05/82	835	37.96908	-83.04340
14647	Penzoil	Jones #1	Rowan	KY	4	T	75	450NL,3600WL	G,FD	10/07/65	1199	38.16543	-83.30410
18028	Penzoil	Fannie May #1	Rowan	KY	25	U	75	1750SL,1590WL	G,FD	11/10/66	905	38.17147	-83.32780
22478	Henderson	Baily #1	Rowan	KY	19	U	72	910NL,1315WL	G,FD	06/30/69	737	38.19750	-83.52870
25356	Kentucky Central	Perkins #1	Rowan	KY	21	T	74	875NL,750WL	G,FD	02/07/72	1240	38.09759	-83.34730
34457	Louisville Gas & Electric	Myrtle Heaton #1	Trimble	KY	Z	50	16	2355 FNL, 2150 FWL	G,N	05/03/79	795	38.37000	85.24400
14190	Kin-Ark Oil	Chambers #1	Wolfe	KY	23	P	73	2520EL,1450SL	G,N	06/20/65	998	37.75398	-83.45870
17590	Holly Creek	White #2	Wolfe	KY	20	O	73	2220SL,275WL	G,FD	08/29/66	948	37.68943	-83.43230
30520	Exxon USA	Banks #1	Wolfe	KY	13	O	74	3100SL,350EL	G,Lat	05/22/76	1057	37.70851	-83.36780
4	Cabot	Bailey #1 - S14-1A	Adams	OH	Jefferson			26504NL, 18712EL of TWP	G,N	11/22/64	714	38.78140	-83.33410
5	Comonwealth Gas Co.	G. & E. Covert #1	Adams	OH	Jefferson			10400NL, 16850L	G,N	10/13/65	625	38.82598	-83.29260
71	West Ohio Gas	Hoelscher #1-1	Auglaize	OH	St Marys		22	500SL,600WL,NW	G,FD	12/03/70	896	40.50378	-84.39440
2981	ODNR	Butler County Strattest	Butler	OH	4	4	19	Riley Twp.	G,N	06/09/89	1012	39.44567	-84.81370
3	Kelly Oil Co.	Samuel Yocum #1	Champaign	OH	Union			VMSL5596	G,N	04/06/64	1227	40.11666	-83.65000
10	Southern Independent	Schultz #1	Champaign	OH	Concord		22	660SL, 660WL, SE	G,N	02/11/66	1133	40.17225	-83.85800
11	Southern Independent	Mc Candless #1	Champaign	OH	Salem			660SL, 490WL, NW,25N	G,N	02/25/66	1072	40.21392	-83.76420
12	Southern Independent	Detweiler #1	Champaign	OH	Salem		25	660NL,1980WL, SW	G,N	04/22/66	1069	40.22093	-83.63090
13	Teeters Brothers Drilling	Vaughn #1	Champaign	OH	Johnson		9	250SL,900WL, SW	G,BD	08/30/67	1126	40.16739	-83.94480
14	Tartan Oil Co.	Mc Candless #2	Champaign	OH	Salem		31	660SL,565EL, NE	G,N	02/16/68	1076	40.21407	-83.76790
16	Teeters Brothers Drilling	Perry #1	Champaign	OH	Union			3190SL,1845WL, VMS 2195	G,N	11/13/68	1239	40.08796	-83.62630
17	Teeter Brothers	Cyrus Circle #1	Champaign	OH	Jackson		12	550SL, 646 WL, NW	G	05/01/69	1162	40.04755	-83.82980
1	Kewanee Oil	Luttrel #1	Clinton	OH	Wayne			330SE,330NE,VMS1027,Luttrel	G,N	08/25/58	1112	39.41225	-83.60050
10	Stocker & Stiler, Inc.	Coy #1	Clinton	OH	Wilson			616 NWL, 1280 NEL, VMS 743	G,N	01/17/83	1098	39.52571	-83.66800
64	An-Car Oil Co. Inc.	James A. Martin #1	Darke	OH	Washington		14	0FNL, 350FWL, SW	G,N	10/26/72	1077	40.14262	-84.73110
65	Premier Oil, Ltd.	Breymier #1	Darke	OH	Jackson		5	710SL, 667WL, NE	G,CN	09/14/73	1038	40.26201	-84.79240
13	Sun Oil Co.	Appelman #1	Delaware	OH	Oxford			802Nl, 1654WL, Lot 15, Q1	G,N	02/25/63	985	40.40135	-82.95880
19	Pan American Petroleum	Reppart #1	Delaware	OH	Trenton		8	1600NL, 520WL, NE, 1Q	G,N	12/17/63	1081	40.25833	-82.79870
22	Southern Triangle Oil	Jones #1	Delaware	OH	Radnor			24900NL, 9800EL/TWP lot 1	G,N	01/15/64	945	40.36965	-83.15520
29	T. A. Ferral	Daily #1	Delaware	OH	Kingston				G,N	02/29/64	992	40.30472	-82.88930
44	Earl Shehorn	Potts #1	Delaware	OH	Thompson			347Wl, 80080NL/TWP VMS6293	G,N	05/26/64	907	40.42206	-83.24810
80	Pettit & Hurtt Drilling	ChildrensHome Unit A #1	Delaware	OH	Deloware		4	580NL, 2600WL, of Lot 3	G,N	06/12/64	922	40.31599	-83.06830
102	Delaco Petroleum Inc.	Chrismer & Davenport #1	Delaware	OH	Berlin	18	8	1650NL, 5640EL, 4Qtr.	G,N	04/27/64	904	40.22840	-82.97800
103	Santo Fe Drilling	Daugherty #1	Delaware	OH	Oxford			240SL,586EL,SE,Lot 6	G,N	07/02/64	984	40.39512	-82.93830
104	Algonquin Petroleum	Innis #1	Delaware	OH	Brown			1190WL, 1036NL, Lot 10, 4Q	G,N	07/07/64	945	40.30608	-82.96590
118	Westbury Petroleum	Coy #1	Delaware	OH	Liberty		3	298SL, 1427WL, Lot 1, Q3	G,S	07/11/64	943	40.24828	-83.08690
123	Clifton Lewis	Evarts #1	Delaware	OH	Genoa	17E		482SL, 2445WL, Lot 6 3N 1Q	G,N	08/18/64	960	40.19981	-82.86200

APPENDIX C

LIST OF WELL NAMES AND LOCATIONS
GEOPHYSICAL LOG DATA BASE

Permit Number	Company Name	Well Name	County	State	Township	Range	Section	Footage	Data	Date Logged	Reference Elevation	Latitude	Longitude
136	Algonquin Petroleum	Link #1	Delaware	OH	Brown			1190WL,486NL, 4Q, Lot 10	G,N	08/14/64	935	40.34332	-82.95390
174	Jim Gibson	Lathrop #1	Delaware	OH	Porter				G,N	09/27/64	1181	40.33841	-82.75930
188	KinArk Oil	Shultz #1	Delaware	OH	Berkshire			695SL, 3589WL, Lot 4, 1Q	G,N	10/14/64	966	40.26714	-82.87900
206	Algonquin Petroleum	Slemmons - Marshall #1	Delaware	OH	Berlin			1270NL, 4710FL, Lot 6, 4Q	G,N	11/19/64	863	40.23551	-82.97090
231	KinArk Oil	Jaycox #1	Delaware	OH	Orange				G,N	01/10/65	925	40.19032	-82.94590
250	L. B. Jackson	Beatty #1	Delaware	OH	Harlem			820EL, 1332NL, Lot 5, 1Q	G,N	05/27/65	1096	40.16824	-82.78500
2	Kewanee Oil Co.	Esther #1	Fayette	OH	Concord			330SE 153, 330SW Miami Trace	G,N	08/24/57	1017	39.45437	-83.51280
4	Kewanee Oil Co.	Barnes #1	Fayette	OH	Jasper				G,N	11/25/58	1043	39.58970	-83.57800
9	Oxford Oil Co.	B. E. Hanalworth	Fayette	OH	Madison			963NL, 2423SL, Lot 10414	G,FD	07/21/79	907	39.67960	-83.28840
10	Oxford Oil Co.	Braun #1	Fayette	OH	Wayne				G,N	08/02/79	980	39.42571	-83.35490
14	Marble Cliff Quarries	Marble Cliff Quarries #1	Franklin	OH	Franklin				G,N	01/30/65	697	39.98856	-83.08240
15	Madson Ohio Oil	Long & Schirm #1	Franklin	OH	Madison		12	1096NL,45EL,NW of 12-S	G,S	12/02/65	793	39.80684	-82.83290
3	Jonsu Oil Co.	Pitstick #1	Greene	OH	Bath		2	160NL, 1360EL	G,FD	12/11/82	1034	39.81415	-83.94710
3	Ohio Valley Oil & Gas	Peabodys #1	Highland	OH	Paint		2		G,N	07/01/63	880	39.25237	-83.34680
4	Amerada Petroleum	W. Wright #1	Highland	OH	Penn			2150NL, 2480EL, Lot 2326	G,N	12/07/64	1139	39.27181	-83.58490
2626	Ohio Geological Survey	ODS 2626	Highland	OH	Concord				G,N	10/01/87	1110	39.04977	-83.61760
2682	Ohio Geological Survey	CA-54	Highland	OH	Fairfield			VMS 1082	None	12/21/70	1056	39.37831	83.57421
48	Pruitt Tool & Sup.	A. D. Vault #1	Logan	OH	Zane			12700NL, 10775EL	G,N	10/13/64	1168	40.24999	-83.56660
90	Oxford Oil Co.	Evans #1	Logan	OH	Miami		28	1805SL, 1009EL	G,N	11/20/78	1090	40.26666	-83.96660
3	Amerada Petroleum	Hume #1	Madison	OH	Fairfield			11660NL, 5160WL, VMS 9717	G,S	11/02/65	995	39.86895	-83.32080
4	Amerada Petroleum	Englo #1	Madison	OH	Jefferson			4300SL, 3750WL, VMS 7628	G,S	11/11/65	995	39.91231	-83.32340
103	M. C. Milam	Van Horn #1	Mercer	OH	Union				G	08/06/59	0	40.71791	-84.46110
132	K. W. Hopkins	Thomas #1	Mercer	OH	Union		34	4S,3E, 330SL, 330WL, NW	G,N	09/02/65	823	40.64891	-84.51220
141	Harner Union Oil	Yewey #2	Mercer	OH	Center		4	747NL, 765EL, SE	G,BD	08/21/70	838	40.63124	-84.51600
150	West Ohio Gas	Selhorst #1	Mercer	OH	Butler		1	475SL, 250WL, SW	G,Por	10/27/71	921	40.45097	-84.58880
1	Sun Oil Co.	Levering #1	Miami	OH	Washington		3	T8,R5 NE,SW,NW	G,N	09/04/55	985	40.17972	-84.31510
3	National Assoc. Petroleum	Walker #1	Miami	OH	Lost Creek		13	T2,R11, 990EL, 330SL	G,N	10/30/58	1035	40.03261	-84.08200
11	F. M. Mc Hale	Roemisch #1	Miami	OH	Brown		2	992SL, 330EL, NW	G,N	09/13/66	1138	40.16528	-84.03530
?	Belden & Blake Oil	R. S. Jenkins #2	Montgomery	OH	Butler		11	NW,SE,SE	G,N	11/01/59	930	39.89421	-84.28410
2	Belden & Blake Oil	R. S. Jenkins #1	Montgomery	OH	Butler		11	1600SL, 2000WL, SW	G,N	06/14/61	930	39.89615	-84.28270
5	Belden & Blake	Hayes #1	Montgomery	OH			11	2225NL,2425WL,NW	G,N	08/16/62	919	39.89956	-84.28420
5	Mc Mahon & Bullington	Croman #2	Pickaway	OH	Jackson			15680SL, 440WL, MSL 7947	G,N	03/07/64	803	39.64999	-83.11660
6	Midwest Oil & Gas	Miller #1	Pickaway	OH	Pickaway			330 N/S, 330 W/E, NE, 7W	G,N	10/02/64	693	39.53103	-82.96230
8	P. L. Clarkson	Mary Synder #1	Pickaway	OH	Deercreek				G,N	08/02/64	758	39.57640	-83.09790
10	Hammerstone Oil	Graham #1	Pickaway	OH	Scioto			4180WL, 660SL, VMS 6115	G,FD	11/25/64	794	39.79881	-83.05840
17	Phillips Petroleum Co.	Heffner A #1	Pickaway	OH	Walnut		33	2300NL, 1400EL	G,N	09/24/66	830	39.66098	-82.89990
18	Ephraim Petroleum	Brown #1	Pickaway	OH	Madison		15	859NL, 2069WL, SW	G,N	05/19/70	753	39.78782	-82.87450
20	Minute Man Exploration	Higgy #1	Pickaway	OH	Muhlenberg			1683NL, 2228WL, VMS 1347	G,N	08/02/79	799	39.79881	-83.05840
28	Shure Oil Co.	B. W. Williams #1	Pike	OH	Sunfish			13800SL, 1500EL	G,N	10/01/63	634	39.03868	-83.14460

APPENDIX C

LIST OF WELL NAMES AND LOCATIONS
GEOPHYSICAL LOG DATA BASE

Permit Number	Company Name	Well Name	County	State	Township	Range	Section	Footage	Data	Date Logged	Reference Elevation	Latitude	Longitude
29	Well Supervision Inc.	E. Conly #1	Pike	OH	Pebble			VMS A. LATHAM 4840N,L 8708WL	G,N	08/09/64	941	39.16666	-83.13330
33	Katex	Easterday #1	Pike	OH	Peepee		1	660NEL,1340SE,VMS8942	G,N	06/11/65	762	39.15046	-83.00030
8	Well Supervision	Immel #1	Ross	OH	Green		18	660SL, 660EL, SE	G,N	08/14/64	695	39.41404	-82.92610
9	Crest Oil Co.	Clark #1	Ross	OH	Concord			3200SL, 8200WL	G,N,L	12/30/64	1033	39.43187	-83.30260
12	Amerada	A. Boreson #1	Ross	OH	Deerfield			100SL, 8950WL, USM599	G,N	12/19/64	832	39.49560	-83.25240
13	Hammerston Oil	Carper #1	Ross	OH	Harrison		30	660S/N, 660W/E, NW,NE, NW	G,FD	02/10/65	678	39.32739	-82.85830
14	Hammerstone Oil Co.	Cryder #1	Ross	OH	Liberty		9	660SL, 660WL, SW, SW	G,N	01/22/65	640	39.27189	-82.83310
18	Hammerstone Oil Co.	Scott #1	Ross	OH	Springfield		1	230NL, 1850EL, NE	G,N	03/07/65	818	39.38695	-82.86620
21	Oxford Oil Co.	R. M. Irvine #1	Ross	OH	Buckskin			5800, 13500, UMS3074	G,FD	08/12/79	985	39.38634	-83.31120
212	Engineers	USS Chemical #1	Scioto	OH	Green			7360SL,5550WL	G,Por	07/05/68	546	38.59214	-82.82150
257	Adobe Oil & Gas Co.	Smith #1	Scioto	OH	Rarden			3675NL,835WL VMS15902 Lot103	G,FD	10/15/79	1213	38.98787	-83.24260
12	Sun Oil Co.	D. Nelson #1	Shelby	OH	Perry			850NL, 21WL, of 21, SW14	G,N	12/14/55	1040	40.26666	-84.06660
41	L. H. Wright Inc.	Dunson #1	Shelby	OH	Clinton		22	634SL, 300WL, SW	G,N	08/22/75	993	40.30330	-84.20690
118	Energy Development Corp	Micheal #1	Shelby	OH	Turtle Creek		8	1671SL,860WL, SE	LD,N	10/10/88	1020	40.33521	-84.23450
119	Energy Development	Hall #1	Shelby	OH	Turtle Creek		9	938SL,1145EL, NW	LD,N	02/19/88	1020	40.34061	-84.22200
123	Energy Development	Wehrman #1	Shelby	OH	Turtle Creek		5	831SL,766WL	LD,N,G	10/03/88	1000	40.34685	-84.25050
3	John Adams	Synder #1	Union	OH	Allen			VMS 3151	G,N	04/20/62	1093	40.26998	-83.49900
4	John Adams	Synder #1	Union	OH	Darby			3000EL, 300SL, Lot 15310	G,N	05/22/62	1040	40.18230	-83.34340
5	John Adams	Carreker #1	Union	OH	Liberty			1400EL, 3300NL, VMS 12400	G,N	06/27/62	1078	40.29999	-83.50000
11	Lauk Drilling	Howard #1	Union	OH	Union			101000WL, 81000NL of TWP	G,N	08/24/65	998	40.17916	-83.46220
20	Miller-Pieroni Assoc.	Potts #1	Union	OH	York			1225NL, 2150EL, VMS 3470	G,N	07/31/64	1011	40.38000	-83.40410
23	Texas Coastal Oil	Bouic #1	Union	OH	Millcreek			4425WL, 1525NL, VMS 2995	G,N	07/13/64	935	40.23970	-83.25800
25	Branoco of Ohio	Beeson #1	Union	OH	Taylor				G,N	08/16/64	1025	40.29014	-83.38490
74	Funk Exploration Inc.	Yoder #1	Union	OH	Dover			1283NL,1003EL, VMS3956	G,SON	08/16/84	971	40.22478	-83.27590
2627	ODNR	Warren Co. Core	Warren	OH	N.A.				G,N	04/26/89	1005	39.56537	-84.11560

Key:

G = Gamma ray log,
FD = Formation density log,
N = Neutron log,
Core = Core was available.
SP = Spontaneous potential log,
R = Resistivity log,
IN = Dual induction log,

LD = Lithodensity log,
BD = Bulk density log,
CN = Compensated neutron log,
SON = Sonic log,
CD = Compensated density log,
POR = Porosity log,
Lat = Lateral log,

Appendix D

Stratigraphic Picks

APPENDIX D

STRATIGRAPHIC PICKS
GEOPHYSICAL LOG DATA BASE

Permit Number	County	State	Facies A1 Top	Facies A1 Base	Facies A2 Top	Facies A2 Base	Facies B Top	Facies B Base	Facies C Top	Facies C Base	Lower Facies D Top	Lower Facies D Base	Facies E Top	Facies E Base	Upper Facies D Top	Upper Facies D Base	Facies F Top
37131	Blackford	IN	499	600	456	499	378	456			372	378	322	372			262
27387	Clark	IN	269	299	UD		172	269	149	172							
30859	Clark	IN	321	344	UD		222	321	198	222							
33486	Clark	IN	332	360	UD		228	332	203	228							
24526	Clinton	IN	689	809	652	689	629	652					601	629			
124	Decatur	IN	143	267	114	143	56	114	36	56			1	036			
29547	Decatur	IN	284	409	252	284	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
35122	Decatur	IN	247	361	217	247	144	217	128	144	120	128	102	120			
37046	Decatur	IN	251	364	219	251	157	219	137	157	126	137	117	126			
236	Deleware	IN	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL	185	NB
15754	Deleware	IN	376	482	313	376	232	313			226	232	182	226			
38416	Deleware	IN	430	530	387	430	298	387			294	298	252	294			
40797	Deleware	IN	392	495	331	392	238	331			232	238	196	232			
29516	Grant	IN	525	640	494	525	422	494			409	422	355	409			
31869	Grant	IN	481	590	440	481	367	440			360	367	298	360	293	298	
41288	Grant	IN	450	557	412	450	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL
41467	Grant	IN	486	591	446	474	368	446	NL	NL	357	368	NL	NL	NL	NL	NL
34467	Hancock	IN	500	579	464	500	416	464			399	414					
40747	Hancock	IN	516	597	482	516	429	482			415	429	402	415	398	402	
2104	Harrison	IN	1042	1058	UD		947	1042									
20747	Hendricks	IN	794	900	761	794	738	761			730	738					
30314	Henry	IN	476	592	443	476	375	443			359	375	337	359	335	337	
30510	Henry	IN	370	476	327	370	253	327			231	253	210	231	206	210	
32709	Jay	IN	386	502	338	386	266	338			259	266	180	259	176	180	158
34102	Jay	IN	499	600	451	499	361	451			358	361	295	358	291	295	262
34103	Jay	IN	441	555	395	441	317	395			293	317	NL	NL	NL	NL	NL
39099	Jay	IN	534	642	483	534	392	483			367	392	306	367	302	306	
39102	Jay	IN	464	563	413	464	325	413			301	325	232	301	221	232	
38016	Johnson	IN	408	514	376	408	354	376					322	354			
18506	Madison	IN	432	531	389	432	304	389			295	304	268	295			

APPENDIX D

STRATIGRAPHIC PICKS
GEOPHYSICAL LOG DATA BASE

Permit Number	County	State	Facies A1 Top	Facies A1 Base	Facies A2 Top	Facies A2 Base	Facies B Top	Facies B Base	Facies C Top	Facies C Base	Lower Facies D Top	Lower Facies D Base	Facies E Top	Facies E Base	Upper Facies D Top	Upper Facies D Base	Facies F Top
34752	Monroe	IN	1353	1455	1315	1353	1292	1315									
37399	Monroe	IN	1714	1801	1683	1714	1631	1683									
17921	Morgan	IN	1056	1156	1023	1056	992	1023									
20860	Morgan	IN	829	919	795	829	766	795			753	766					
43558	Perry	IN	2349	2375	UD		2253	2349									
45250	Perry	IN	2461	2544	UD		2372	2461									
21420	Randolf	IN	424	532	366	424	282	366			260	282	215	260	198	215	
29474	Randolf	IN	442	558	384	442	307	384			282	307	246	282	242	246	
30422	Randolf	IN	473	574	420	473	327	420			310	327	251	310	240	251	
31352	Randolf	IN	506	616	451	506	364	451			343	364	290	343	280	290	
30282	Rush	IN	235	346	201	235	153	201	127	153	122	127	92	127			
30294	Rush	IN	240	363	203	240	152	203	128	151	118	128	82	118			
35789	Shelby	IN	320	424	289	320	256	289			250	256	219	250			
36640	Shelby	IN	322	424	278	322	246	278			239	246	219	239			
36671	Shelby	IN	308	405	265	308	232	265			225	232	NL	NL	NL	NL	NL
36744	Shelby	IN	295	386	251	295	212	251			205	212	NL	NL	NL	NL	NL
27418	Tippton	IN	567	698	540	567	485	540			479	485	428	479			
57	Wayne	IN	233	336	199	233	104	199			89	104	52	90	47	52	
42617	Wayne	IN	235	338	187	235	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL
332	Wells	IN	495	596	451	495	378	451			375	378	297	375			270
72625	Bullit	KY	740	746	UD	UD	636	740	601	636							
398	Carter	KY	1763	1857	UD	UD					1728	1763					
16235	Carter	KY	1885	1982	UD	UD					1857	1885					
25730	Carter	KY	2965	2994	UD	UD	2896	2965			2855	2896					
26995	Carter	KY	1746	1850	UD	UD					1719	1746					
271	Elliot	KY					1812	1888			1768	1812					
1555	Elliot	KY					1849	1892			1801	1849					
25781	Elliot	KY					2675	2739			2628	2675					
29843	Elliot	KY					1984	2049			1950	1984					
67748	Elliot	KY	2728	2746	UD	UD	2655	2728			2624	2655					
20187	Greenup	KY	1902	1996	UD	UD					1856	1902					
21256	Greenup	KY	1892	1978	UD	UD					1845	1892					
22214	Greenup	KY	1859	1952	UD	UD					1816	1859					
30578	Greenup	KY	1926	2015	UD	UD					1879	1926					
24576	Jefferson	KY	492	495	UD	UD	400	492	369	400							
2579	Lewis	KY	1299	1386	UD	UD					1239	1299					
20314	Lewis	KY	543	638	UD	UD					506	543					
21132	Lewis	KY	1761	1862	UD	UD					1725	1761					
31428	Lewis	KY	1402	1495	UD	UD					1357	1402					
10526	Meade	KY	1088	1106	UD	UD	988	1088									

APPENDIX D

STRATIGRAPHIC PICKS
GEOPHYSICAL LOG DATA BASE

Permit Number	County	State	Facies A1 Top	Facies A1 Base	Facies A2 Top	Facies A2 Base	Facies B Top	Facies B Base	Facies C Top	Facies C Base	Lower Facies D Top	Lower Facies D Base	Facies E Top	Facies E Base	Upper Facies D Top	Upper Facies D Base	Facies F Top
18101	Menifee	KY					1169	1224			1115	1169					
24194	Morgan	KY					2391	2461			2336	2391					
26795	Morgan	KY					1809	1872			1765	1809					
27544	Morgan	KY					1503	1567			1458	1503					
51605	Morgan	KY					2456	2521			2390	2456					
14647	Rowan	KY					1599	1659			1536	1599					
18028	Rowan	KY					1224	1284			1165	1224					
22478	Rowan	KY					464	518			414	464					
25356	Rowan	KY					1598	1672			1552	1598					
34457	Trimble	KY	113	176	93	113	64	93	54	64							
14190	Wolfe	KY					1931	1995			1895	1931					
17590	Wolfe	KY					2038	2105			2002	2038					
30520	Wolfe	KY					2406	2473			2361	2406					
4	Adams	OH	510	608	UD	UD					471	510					
5	Adams	OH	536	619	UD	UD					504	536					
71	Auglaize	OH	491	592	428	491	312	428			302	312	280	302	248	280	
2981	Butler	OH	103	216	68	103	NT	68			NT	NT	NT	NT	NT	NT	
3	Champaign	OH	682	791	636	682	566	636			526	566					
10	Champaign	OH	514	621	472	514	383	472			347	383					
11	Champaign	OH	490	583	440	490	354	440			312	354					
12	Champaign	OH	484	581	430	484	358	430			309	358					
13	Champaign	OH	547	647	494	547	405	494			355	405					
14	Champaign	OH	489	593	441	489	353	441			315	353					
16	Champaign	OH	684	795	638	684	573	638			530	573					
17	Champaign	OH	475	587	431	475	347	431			297	347					
1	Clinton	OH	434	485	369	434	337	369			292	337					
10	Clinton	OH	293	398	247	293	202	247			149	202					
64	Darke	OH	465	571	426	465	320	426			299	320	236	299	232	236	
65	Darke	OH	495	619	445	495	354	445			334	354	254	334	250	254	
13	Delaware	OH	1255	1389	UD	UD					1160	1255					
19	Delaware	OH	1727	1864	UD	UD					1648	1727					
22	Delaware	OH	782	860	UD	UD					648	782					
29	Delaware	OH	1419	1549	UD	UD					1324	1419					
44	Delaware	OH	637	699	UD	UD					520	637					
80	Delaware	OH	999	1084	UD	UD					857	999					
102	Delaware	OH	1199	1324	UD	UD					1112	1199					
103	Delaware	OH	1248	1396	UD	UD					1165	1248					
104	Delaware	OH	1212	1348	UD	UD					1135	1212					
118	Delaware	OH	992	1079	UD	UD					863	992					
123	Delaware	OH	1466	1589	UD	UD					1372	1466					

APPENDIX D

STRATIGRAPHIC PICKS
GEOPHYSICAL LOG DATA BASE

Permit Number	County	State	Facies A1 Top	Facies A1 Base	Facies A2 Top	Facies A2 Base	Facies B Top	Facies B Base	Facies C Top	Facies C Base	Lower Facies D Top	Lower Facies D Base	Facies E Top	Facies E Base	Upper Facies D Top	Upper Facies D Base	Facies F Top
136	Delaware	OH	1185	1342	UD	UD					1112	1185					
174	Delaware	OH	1874	2018	UD	UD					1807	1874					
188	Delaware	OH	1433	1562	UD	UD					1347	1433					
206	Delaware	OH	1142	1264	UD	UD					1049	1142					
231	Delaware	OH	1256	1379	UD	UD					1157	1256					
250	Delaware	OH	1777	1905	UD	UD					1694	1777					
2	Fayette	OH	404	463	343	404	313	343			271	313					
4	Fayette	OH	381	443	311	381	286	311			235	286					
9	Fayette	OH	669	723	600	668	584	600			533	584					
10	Fayette	OH	677	730	612	677	594	612			543	594					
14	Franklin	OH	805	923	UD	UD					705	805					
15	Franklin	OH	1402	1519	UD	UD					1311	1402					
3	Greene	OH	252	354	210	252	137	210			86	137					
3	Highland	OH	377	480	UD	UD					338	377					
4	Highland	OH	439	487	377	439	348	377			296	348					
2626	Highland	OH	299	358	243	299	229	243			198	229					
2682	Highland	OH	NL	441	327	379	296	327			247	296					
48	Logan	OH	652	754	607	652	570	607			503	570					
90	Logan	OH	567	671	517	567	427	517			393	427					
3	Madison	OH	708	809	668	708					594	668					
4	Madison	OH	695	791	652	695					583	652					
103	Mercer	OH	596	690	559	596	481	559			472	481	451	472	442	451	
132	Mercer	OH	530	622	481	530	405	481			378	405	351	378	340	351	
141	Mercer	OH	518	613	466	518	373	466			348	373	336	348	326	336	
150	Mercer	OH	505	597	457	505	377	457			351	377	284	351	269	284	
1	Miami	OH	379	461	330	379	242	330			215	242	166	215	153	166	
3	Miami	OH	380	477	329	380	265	329			220	265					
11	Miami	OH	550	652	502	550	416	502			381	416					
-1	Montgomery	OH	230	350	202	230	116	202	NL		NL		NL		NL		
2	Montgomery	OH	151	272	131	151	38	131	NL		NL		NL		NL		
5	Montgomery	OH	223	345	197	223	111	197	NL		NL		NL		NL		
5	Pickaway	OH	778	896	UD	UD					722	778					
6	Pickaway	OH	1139	1249	UD	UD					1071	1139					
8	Pickaway	OH	826	913	UD	UD					752	826					
10	Pickaway	OH	874	992	UD	UD					821	874					
17	Pickaway	OH	1308	1420	UD	UD					1224	1308					
18	Pickaway	OH	1288	1400	UD	UD					1198	1288					
20	Pickaway	OH	742	852	UD	UD					688	742					
28	Pike	OH	875	959	UD	UD					812	875					

APPENDIX D

STRATIGRAPHIC PICKS
GEOPHYSICAL LOG DATA BASE

Permit Number	County	State	Facies A1 Top	Facies A1 Base	Facies A2 Top	Facies A2 Base	Facies B Top	Facies B Base	Facies C Top	Facies C Base	Lower Facies D Top	Lower Facies D Base	Facies E Top	Facies E Base	Upper Facies D Top	Upper Facies D Base	Facies F Top
29	Pike	OH	1162	1248	UD	UD					1102	1162					
33	Pike	OH	1308	1396	UD	UD					1240	1308					
8	Ross	OH	1188	1290	UD	UD					1118	1188					
9	Ross	OH	757	841	UD	UD	754	757			706	754					
12	Ross	OH	610	689	UD	UD					559	610					
13	Ross	OH	1518	1618	UD	UD					1458	1518					
14	Ross	OH	1588	1690	UD	UD					1517	1588					
18	Ross	OH	1592	1697	UD	UD					1528	1592					
21	Ross	OH	698	790	UD	UD					647	698					
212	Scioto	OH	2283	2377	UD	UD					2234	2283					
257	Scioto	OH	1211	1296	UD	UD					1150	1211					
12	Shelby	OH	495	599	443	495	365	443			346	365	327	346	303	327	
41	Shelby	OH	455	560	422	455	345	422			330	345	304	330	272	304	
118	Shelby	OH	502	604	460	502	379	460			374	379	349	374	315	349	
119	Shelby	OH	492	594	450	492	370	450			361	370	349	361	311	349	
123	Shelby	OH	490	593	449	490	371	449			361	371	338	361	307	338	
3	Union	OH	571	707	UD	UD	533	571			478	533					
4	Union	OH	711	790	UD	UD					570	711					
5	Union	OH	546	690	UD	UD	511	546			462	511					
11	Union	OH	532	643	UD	UD					410	532					
20	Union	OH	561	640	UD	UD					409	561					
23	Union	OH	802	901	UD	UD					692	802					
25	Union	OH	641	769	UD	UD					497	641					
74	Union	OH	685	796	UD	UD					572	685					
2627	Warren	OH	156	260	124	156	51	124			NT	51					

Key:

UD	= Facies A is undifferntiated (see text).
NT	= Top of section is not present.
NL	= Interval not logged.
NB	= Base of section not present.
Blank	= Facies was not identified at location.