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SEDIMENTOLOGY AND PETROLOGY OF A PRODELTAIC TURBIDITE SYSTEM - THE BRALLIER FORMATION (UPPER DEVONIAN), WESTERN VIRGINIA AND ADJACENT AREAS.

UNIVERSITY OF CINCINNATI, M.S., 1979

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SEDIMENTOLOGY AND PETROLOGY OF A PRODELTAIC TURBIDITE SYSTEM - THE BRALLIER FORMATION (UPPER DEVONIAN), WESTERN VIRGINIA AND ADJACENT AREAS

A thesis submitted to the
Department of Geology
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by

Paul D. Lundegard

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I hereby recommend that the thesis prepared under my supervision by Paul David Lundegard

entitled SEDIMENTOLOGY AND PETROLOGY OF A PRODELTAIC TURBIDITE SYSTEM - THE BRALLIER FORMATION (UPPER DEVONIAN), WESTERN VIRGINIA AND ADJACENT AREAS

be accepted as fulfilling this part of the requirements for the degree of Master of Science

Approved by:

CONTENTS

CONTENTS - cont'd

ABSTRACT

The Upper Devonian Brallier Formation of the central and southern Appalachian basin is a regressive sequence of siltstone turbidites interbedded with mudstones, claystones, and shales. It reaches 1000 meters in thickness and occurs between underlying basinal mudrocks and overlying deltaic sandstones and mudrocks. Facies and paleocurrent analyses indicate differences between the depositional system of the Brallier Formation and those of modern submarine fans and ancient Alpine flysch-type sequences. The Brallier system is of finer grain size and lower flow intensity. The entire stratigraphic sequence from basinal to topset sediments contains only the classic turbidites member of the resedimented coarse clastic family. In addition, the stratigraphic transition from turbidites to deltaic sediments is gradual and differs in its facies succession from the deposits of the proximal parts of modern submarine fans. Such features as massive and pebbly sandstones, conglomerates, debris flows, and massive slump structures are absent.

Paleocurrents indicate a homogeneous transverse dispersal pattern which is atypical of ancient turbidite systems and suggests that turbidity currents had multiple point sources. The petrography and paleocurrents of the Brallier Formation suggest an eastern source of sedimentary and low-grade metasedimentary rocks with moderate relief and rainfall.

The depositional system of the Brallier Formation is interpreted

as a series of small ephemeral turbidite lobes of low flow intensity which coalesced in time to produce a laterally extensive wedge. The lobes were fed by deltas rather than submarine canyons or upper fan channel systems.

This study shows that the present-day turbidite facies model, based mainly on modern submarine fans and ancient Alpine flysch-type sequences, does not adequately describe prodeltaic turbidite systems such as the Brallier Formation.

Key ideas: turbidites, sedimentology, paleocurrents, Upper Devonian of the Appalachian basin.

FIGURES

FIGURES - cont'd

FIGURES - cont'd

FIGURES - cont'd

Figure | Page

TABLES

PLATES

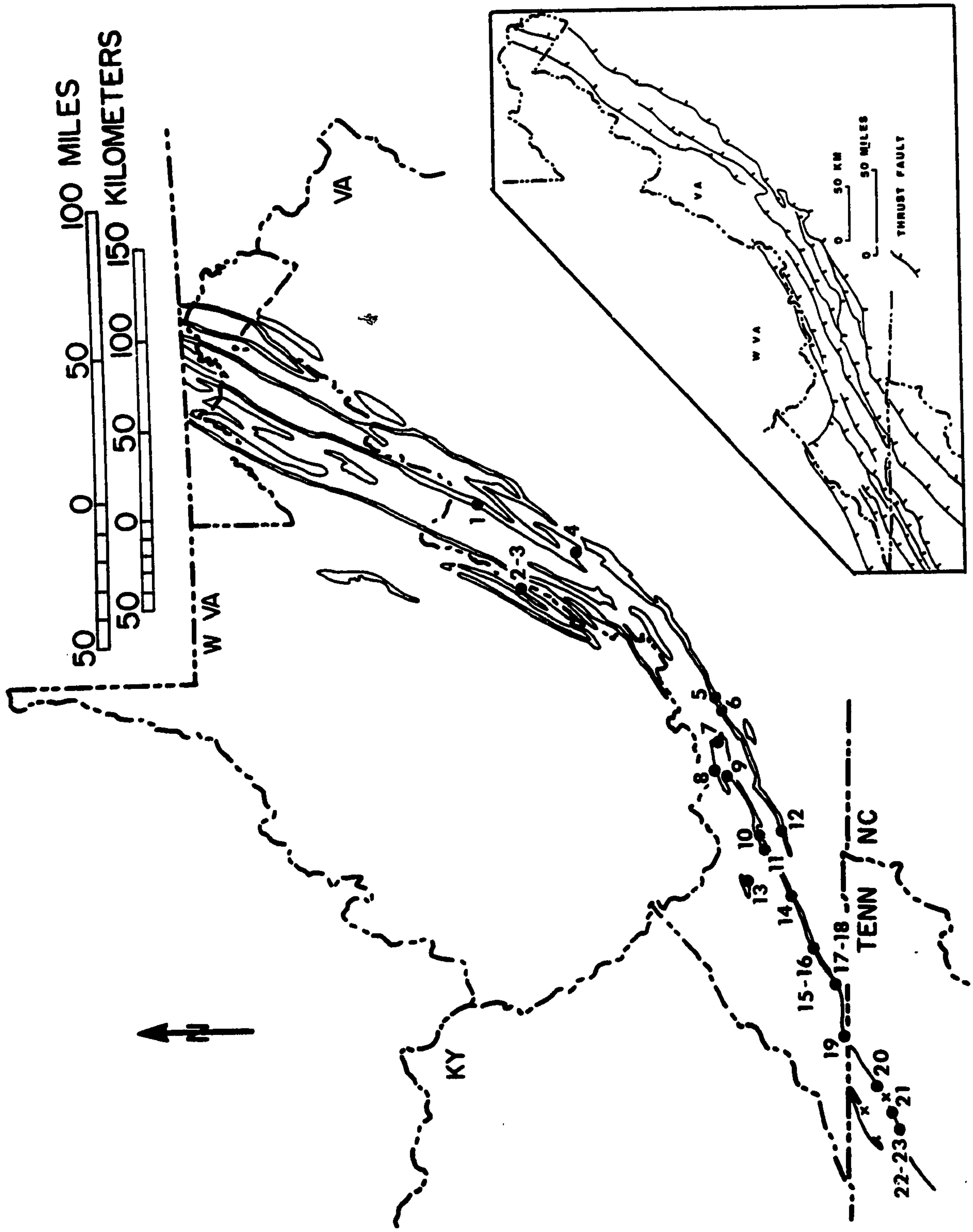
INTRODUCTION

The Brallier Formation, of Late Devonian age, is a regressive sequence of siltstone turbidites interbedded with mudstone, claystone, and shale. It reaches 1000 m in thickness and outcrops primarily in the Valley and Ridge Province from south-central Pennsylvania to southwestern Virginia (Fig. 1). There are minor exposures in the Allegheny Plateau Province of West Virginia.

The Valley and Ridge Province comprises the folded sedimentary part of the Appalachian mountain chain. Structural strike trends north-northeast and strata are exposed in a series of plunging anticlines and synclines. To the west of the Valley and Ridge are the relatively flat-lying rocks of the Allegheny Plateau and to the east are the highly deformed and metamorphosed rocks of the Blue Ridge. In the northern part of the study area folds are the dominant structure with thrust faults becoming more common to the south (Fig. 1). Bedding generally dips less than 45 degrees, but is locally overturned in the vicinity of thrust faults.

New York and Pennsylvania have long been the centers of research for Upper Devonian rocks in the Appalachians. Unfortunately, our understanding of equivalent rocks in the Virginias and Tennessee lags far behind. This study represents one-half of a regional sedimentologic and petrologic analysis of the Brallier Formation throughout its outcrop expression. While I have examined the Brallier in western

Fig. 1.- Map showing location of study area, outcrop of Brallier Formation, and measured sections. Inset shows major thrust faults. Location of two eastern Tennessee cores are shown by "x" marks; southeastern core is TDG-DOE-4; northwestern core is TDG-DOE-3.



50 0 50 100 MILES
50 0 50 100 150 KILOMETERS
W VA
VA
KY
TENN
NC
N
1
2-3
4
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22-23
THRUST FAULT

Virginia and adjacent areas in West Virginia and eastern Tennessee, Samuels (in progress) has studied it in the remainder of West Virginia, Maryland and south-central Pennsylvania. The combined results of these two studies, summarized by Lundegard, Samuels, and Pryor (1979, in press), represent the first comprehensive regional analysis of Upper Devonian turbidites in the central and southern Appalachians.

In addition to expanding our knowledge of an understudied rock sequence this research contributes to the broader topic of turbidite sedimentology. Most ancient turbidite sequences that have been studied to date are of the Alpine flysch type. Few examples of turbidites in deltaic settings, such as the Brallier turbidites, have been adequately described (see Kepferle, 1978; Link, 1975; Walker, 1978). Evidence is emerging, however, that present-day turbidite facies models, based mainly on our knowledge of modern submarine fans and Alpine flysch type sequences, are at least partially inapplicable to deltaic turbidite systems. This investigation documents some of the discrepancies and suggests modifications to the turbidite depositional model.

Previous Work

There have been few studies of the Brallier Formation since Butts (1918) named the unit in Bedford County, Pennsylvania. Walker (1967, 1971) and Frakes (1967) studied the Trimmers Rock Formation (a name now abandoned), which is partially equivalent to the Brallier Formation. Walker (1967) studied vertical variations in turbidite sedimentary structures at Woodmont and Oldtown, Maryland, and proximal-distal relationships in turbidites in Pennsylvania (1971). Frakes (1967) also interpreted the nature of the Late Devonian paleoslope in Pennsylvania based on his stratigraphic and sedimentologic study of the Trimmers Rock Formation.

There have been no modern sedimentologic studies of the Brallier Formation in either Virginia or West Virginia. Butts (1940) briefly described the Brallier in Virginia, as Woodward (1943) did in West Virginia in addition to compiling an isopach map. Dennison (1970) included the Brallier in a cross section of Devonian strata along the Allegheny Front in West Virginia and Maryland. Avary and Dennison (1978) mapped the Back Creek Siltstone, an informal member of the Brallier Formation, in parts of West Virginia and Virginia. In the Greendale syncline belt of east Tennessee, Dennison and Boucot (1974) identified strata of "Brallier lithology" in the Chattanooga Shale.

Acknowledgments

Professor Wayne A. Pryor suggested this study and provided advice and encouragement during its progress. I would also like to thank Professor Paul Edwin Potter and Associate Professor J. Barry Maynard for their helpful suggestions. I am indebted to Professor Arvid M. Johnson for his assistance in the preparation of the palinspastic paleocurrent map and to Assistant Professor David B. Nash for the devotion of his time and expertise in computer programming. Lily Kao ran the elemental analyses and Debbie Moorman typed several drafts of this thesis. I have benefited from numerous discussions with my fellow graduate students at the University of Cincinnati and gratefully acknowledge their interest in the study. Special acknowledgment is due Roy C. Kepferle of the U.S.G.S., and my friend and colleague Neil D. Samuels for their moral support and many hours spent in probing discussions. This study was supported by the Department of Energy contract ERDA No. EY-76-C-05-520J ORD 5201-4.

STRATIGRAPHY

Most Upper Devonian stratigraphic units of the Appalachian Basin have their roots in New York and the work done there in the mid to late 19th century. The Brallier Formation is no exception. One can trace the lineage of the Brallier as far back as 1840 to James Hall's description of the "Portage group" in the Genesee River Valley of New York. Soon thereafter Hall's (1840) restricted concept of the "Portage group" was modified by Vanuxem (1842) to include a thicker sequence of rocks. The term "Portage group" (later "Portage shale") as defined by Vanuxem was used for some time and applied to rocks in Pennsylvania, West Virginia, and Virginia. More detailed mapping led to the recognition of many local stratigraphic units, however, the exact relationship of many of these units is difficult to decipher because earlier workers mixed litho-stratigraphic and biostratigraphic principles. Much of the present state of confusion involving Devonian stratigraphy is the legacy of these practices. Although Butts (1918) formally subdivided the Portage group in central Pennsylvania into the Brallier and Harrell shales, the term "Portage" group or series was used for some years thereafter in several states. Since Willard (1935) used "Brallier" for a member of the Fort Littleton formation of Pennsylvania, it has remained at member status in that state until recent years. Virginia and West Virginia, however, adopted the term as Butts (1918) originally defined it. The evolution of the terms "Portage" and

"Brallier" and their dissemination throughout the Appalachians is summarized in Table 1.

The Brallier Formation was named by Butts (1918) at Brallier Station on the Huntingdon and Broadtop Mountain Railroad, in Bedford County, Pennsylvania, for a sequence of siliceous shale with minor thin beds of fine-grained sandstone. Since then the name Brallier has been widely used in the central Appalachians. Throughout the study area in West Virginia and Virginia the Brallier is conformably underlain by either the Harrell or Millboro Shales (Fig. 2). Along the Allegheny Front in West Virginia the Brallier Formation is overlain by the Scherr Formation, the basal unit of the Greenland Gap Group established by Dennison (1970). To the southwest the Scherr Formation passes into the Brallier Formation by facies change in the vicinity of the West Virginia-Virginia border (Dennison, 1970). Where the Scherr Formation is absent, the Brallier is overlain by the "Chemung" Formation or, where both the Scherr and "Chemung" are absent in southwest Virginia, by the Price Formation of Mississippian age (Fig. 2). Dennison (1970) recommended that the name Chemung be used in quotations since it has been abandoned as a formal stratigraphic term in the area where it was first proposed. Sanders (1952, p. 93) used a tripartite subdivision of the Chattanooga Shale in east Tennessee and suggested that his Klepper School formation was equivalent to the Brallier and possibly the "Chemung" Formations of southwest Virginia. Sanders' results were never formally published and his terminology has not been adopted. I use the terminology of Oliver and

Fig. 2.- Stratigraphic nomenclature in the study area. Sources: eastern West Virginia - Dennison (1970); western Virginia - Milici and others (1963); eastern Tennessee - Oliver and others (1969).

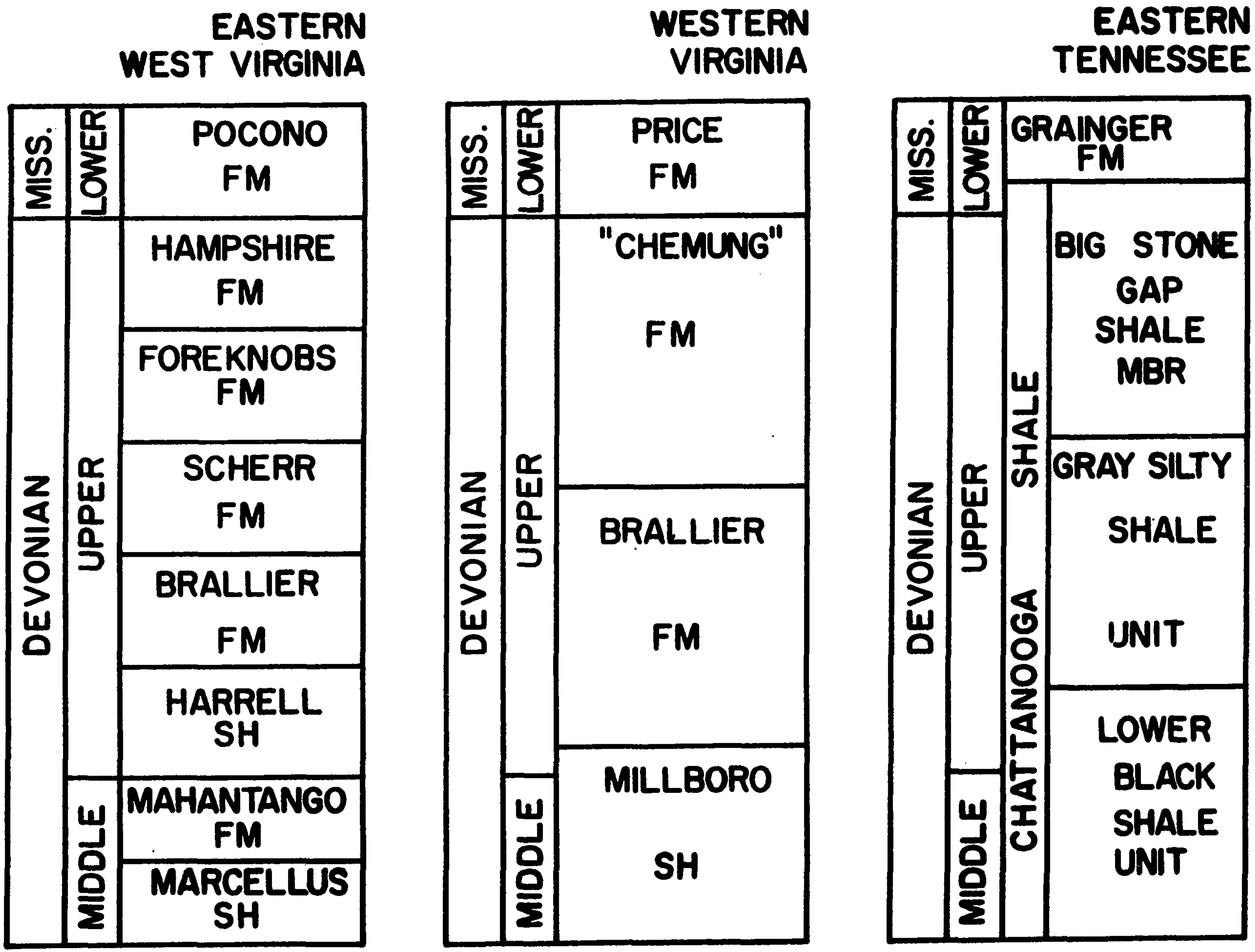

EASTERN WEST VIRGINIA
MISS.
LOWER
POCONO FM
DEVONIAN
UPPER
HAMPSHIRE FM
FOREKNOBS FM
SCHERR FM
BRALLIER FM
HARRELL SH
MIDDLE
MAHANTANGO FM
MARCELLUS SH
WESTERN VIRGINIA
MISS.
LOWER
PRICE FM
DEVONIAN
UPPER
"CHEMUNG" FM
BRALLIER FM
MIDDLE
MILLBORO SH
EASTERN TENNESSEE
MISS.
LOWER
GRAINGER FM
DEVONIAN
UPPER
MIDDLE
CHATTANOOGA SHALE
BIG STONE GAP SHALE MBR
GRAY SILTY SHALE UNIT
LOWER BLACK SHALE UNIT

TABLE 1

A Summary of the Evolution and Dissemination

of "Portage" and "Brallier"

Author and Date	Comments
Hall (1840)	Original reference to the "Portage or Upper Fucoidal Group", a sequence of sandstone with vertical fucoids and little shale interbeds in the Genesee River valley of New York.
Vanuxem (1842)	The Cashaqua shale, Gardeau Group, Portage group, and Sherburne flagstone and shale of earlier New York reports are collectively referred to as the "Portage group".
Rogers (1879)	Introduced the New York terms Catskill, Chemung, Portage, Genesee, and Hamilton to the Virginias.
Clarke (1885)	The term "Naples beds or shale" is used for the lower two units of Vanuxems (1842) Portage group, the Cashaqua shale and Gardeau group. It is defined by paleontological characteristics.
Darton (1892)	First used Hampshire formation, Jennings formation, and Romney shales in early U.S. Geological Survey mapping along the Allegheny Front in West Virginia and Maryland. The Jennings formation includes the Chemung and Portage of earlier workers.
O'Harra (1900)	Used Jennings formation for the Chemung, Portage and Genesee formations of earlier workers, in Allegheny County, Maryland.
Butts (1905)	"Nunda formation" is introduced in Pennsylvania for the shales above the Genesee shale, formerly called Portage.
Butts (1906)	Butts states that the U.S.G.S. restricts the term "Portage" to the Portage sandstone of the Genesee River section in New York (Hall's original usage). "Nunda", which was introducted in early New York reports, should be applied to rocks generally designated the Portage group or beds (Vanuxem's usage).

Table 1 (Cont.)

Prosser and Swartz (1913)	Authors give a succinct review of the terms "Portage" and "Naples" from Hall (1840) on. In Maryland the "Jennings formation", subdivided into four members is used for strata equivalent to the Genesee shale, Portage group and Chemung group. The four members are the Genesee black shale, Woodmont shale, Parkhead sandstone, and Chemung sandstone.
Butts (1918)	First usage of "Brallier shale". The Portage group is divided into two formations, the "Brallier shale" and the "Harrell shale", which includes at its base, the Burket black shale member. The Brallier shale is the same as the Woodmont shale member of the Jennings formation of Maryland (see Prosser and Swartz, 1913), except that the Woodmont extends down to the Burket black shale member, regarded by the Maryland Geological Survey as Genesee.
Stose (1923)	Employs a tripartite subdivision of the Chattanooga shale in southwestern Virginia. The New York names, Genesee shale and Portage shale, are assigned to the lower two lithologic subdivisions because of faunal affinities.
Reger (1924)	New York terms Chemung, Portage, and Genesee Series are applied to strata in Mineral and Grant Counties, West Virginia.
Swartz (1929)	The middle unit of the Chattanooga shale, referred to as the Portage shale by Stose (1923) is called the Chemung and Portage formations.
Woodward (1932)	Appears to be the first published usage of "Brallier shale" in Virginia. The term is used by Woodward in the Roanoke area at the suggestion of Butts. Prior to this, the terms used for the same rocks were Jennings formation, Kimerling shale, or Portage shale.
Willard (1935)	Stratigraphy of the Portage Group in Pennsylvania is discussed. It is divided into the Fort Littleton and Rush Formations. The five members of the Fort Littleton Formation are the Parkhead, Trimmers Rock, Lost Run, Brallier, and Harrell. The Brallier member may be equivalent to the beds with Naples fauna in the Woodmont shale member of the Jennings formation in Maryland.

Table 1 (Cont.)

Butts (1940)	Uses "Brallier shale" from central Pennsylvania to southern Virginia. In southwest Virginia "Brallier shale" is applied to the units of the Chattanooga shale which Stose (1923) referred to as Portage and Big Stone Gap shales.
Cooper, *et al*. (1952)	A correlation of Devonian formations of North America. Brallier is used in Pennsylvania, West Virginia, Virginia and Tennessee. It is everywhere part of the Senecan Series, predominantly in the Finger Lakes stage, and possibly Chemung stage in east Tennessee.
Woodward (1943)	Original reference to the Brallier shale in West Virginia. The Brallier shale as used here is equivalent to the Woodmont shale of Maryland and Brallier shale of Pennsylvania. Brallier shale isopach map presented on page 418.
Sanders (1952)	Chattanooga shale in east Tennessee is subdivided into three informal local mapping units. The middle unit, consisting of gray siltstone to sandstone, is referred to as the Klepper School formation and is possibly equivalent to the "Brallier shale" of Butts.
Frakes (1967)	"Trimmers Rock Member" of Fort Littleton Formation replaces "Chemung" of other authors. It overlies the Brallier Member of Willard (1935). Much of the lower Trimmers Rock is inseparable from the Brallier.
Dennison and Boucot (1974)	Over seven hundred feet of "Brallier lithology" are described in the Chattanooga Shale in Hawkins County, Tennessee. These beds comprise the Klepper School formation of Sanders (1952).

others (1969) for the subdivision of the Chattanooga Shale in eastern Tennessee. The unit of "Brallier lithology" described by Dennison and Boucot (1974) in the Greendale syncline comprises the middle gray silty shale unit of the Chattanooga Shale (Fig.2, Oliver and others, 1969) and is equivalent to Sanders' (1952, p. 93) Klepper School formation.

The Brallier Formation consists mainly of olive gray to medium dark gray mudstone, claystone, and shale with interbeds of even, distinct siltstone in variable amounts. Its contacts are both conformable and gradational. The basal contact of the Brallier is placed at the lowest distinct siltstone bed above the darker shales of the Harrell or Millboro Shales. In southwest Virginia where siltstone beds are rare I recommend that the basal contact be placed where the dominantly olive gray mudrocks of the Brallier Formation give way to the dominantly dark gray to black shales of the Millboro Shale. The contact of the Brallier and the overlying Scherr Formation is marked by the introduction of a small percentage of sandstone beds. Although the Scherr is slightly coarser grained it is otherwise similar to the Brallier Formation. The contact between the Brallier and "Chemung" Formations is also placed at an increase in grain size to very fine sand, accompanied by an increase in bed thickness. The "Chemung" Formation consists of interbedded sandstone, siltstone, and mudstone. The coarse grained beds are commonly fossiliferous and less even and persistent than those of the Brallier Formation. Low angle cross-bedding is a common feature as are thin coquina lenses at the base of beds. Some workers have used the lowest occurrence of *Spirifer disjunctus* or "Chemung fossils" to define the base of the "Chemung" (Willard, 1935), thus making the "Chemung" and indirectly the Brallier, biostratigraphic units. This practice is in violation of litho-stratigraphic principles and is not used here. In southwest Virginia where the "Chemung" Formation is absent the Brallier is directly over-lain by either the Cloyd Conglomerate member or the dark shales of the Big Stone Gap Shale member of the Price Formation (following the usage by Bartlett, 1974). In these areas the upper contact of the Brallier is easily recognized by the abrupt lithologic change.

In Virginia, the Harrell and Marcellus Shales are not distin-guished because the silty shale or shaly siltstone of the Mahantango Formation, which separates the two in West Virginia, is not recogniz-able (Fig. 2; Dennison, 1971). In addition, no non-marine redbed facies equivalent to the Hampshire Formation is present in rocks of Devonian age in western Virginia (Fig. 2). The Foreknobs Formation comprises the upper part of the Greenland Gap Group of Dennison (1970) and is similar in lithology and facies content to the "Chemung" Forma-tion in Virginia.

The gray silty shale unit of the Chattanooga Shale in eastern Tennessee (Fig. 2) consists of mudshale with abundant silt laminae, distinct beds of siltstone, and massive sandstone beds. Its lower contact is gradational and its upper contact fairly abrupt. The over-lying Big Stone Gap Shale Member and the thicker, underlying lower-black shale unit consist of non-silty fissile black shale.

Although its bounding units vary in both nature and nomenclature the Brallier Formation always occurs in a basin-slope-shelf facies tract (Fig. 3). As with most turbidite sequences, the Brallier is regressive in nature. In south-central Pennsylvania the Brallier Formation is entirely Finger Lakesian, whereas in southwest Virginia it ranges from upper Finger Lakesian to lower Cassadagan (Oliver and others, 1969). Furthermore, turbidites in the gray silty shale unit of the Chattanooga Shale in eastern Tennessee are entirely Cassadagan in age (Oliver and others, 1969). In general the Brallier Formation becomes younger from west to east (perpendicular to the shoreline, see Fig. 3) and because present structural strike is oblique to depositional strike it becomes younger along the outcrop belt to the southwest. This relationship between depositional and structural strike means that both lateral and onshore-offshore variations within the Brallier may occur along the outcrop belt.

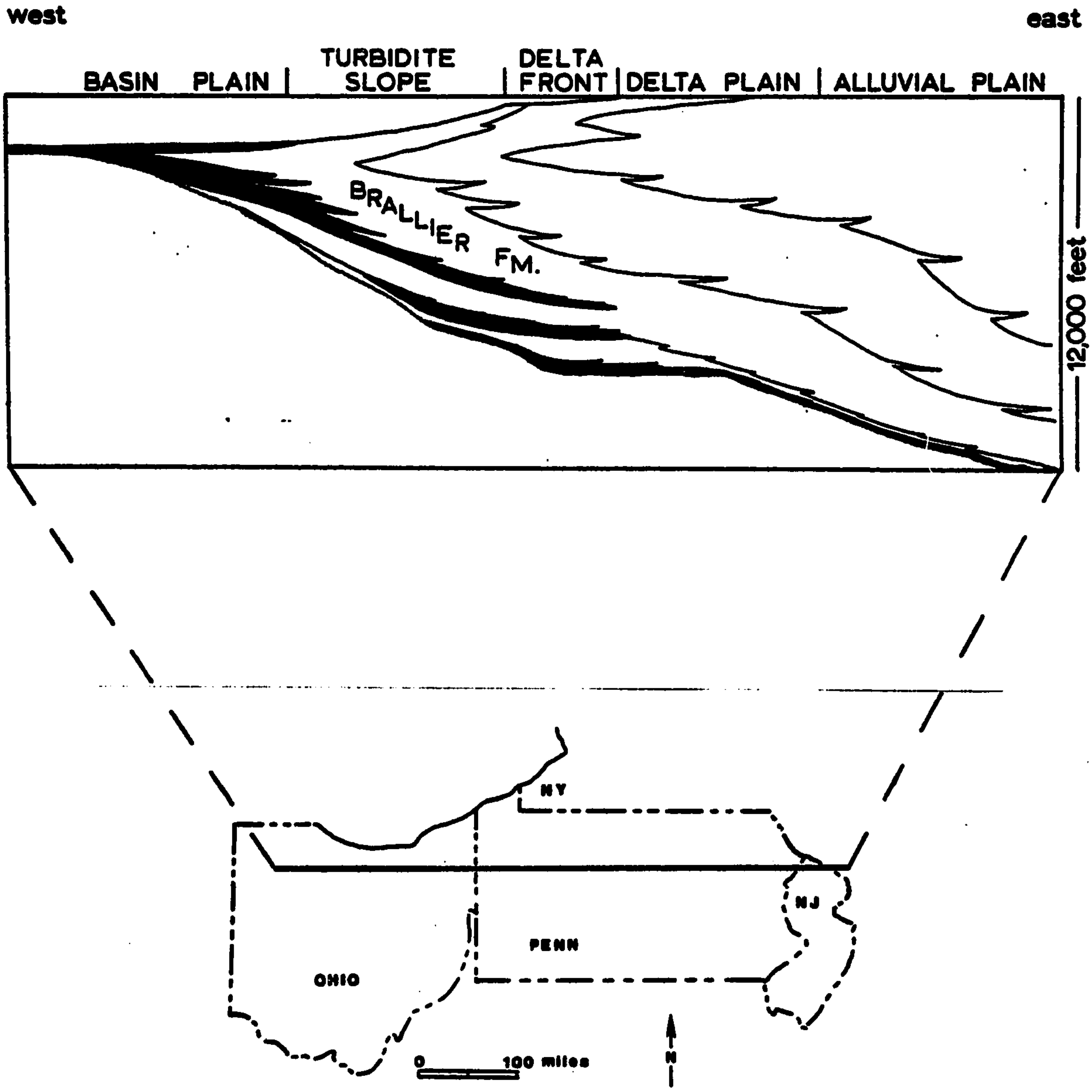


Fig. 3.- Schematic cross section of Upper Devonian rocks showing position of Brallier Formation in basin-slope-shelf facies tract. Black areas indicate black shale units. Data from diverse sources.

METHOD

This study is field oriented. Twenty-three stratigraphic sections totaling approximately 4000 m were measured and described through the Brallier Formation and adjacent units. Color determinations were made by comparison with the rock-color chart of Goddard and others (1963). In addition, foot by foot radioactivity profiles of approximately 1200 m of section were measured with a Geometrics GR-310 Gamma Ray Spectrometer. Outcrop gamma profiles proved to be of little value for correlation except in eastern Tennessee. Over 225 m of core from eastern Tennessee were also examined. These included parts of the TDG-DOE-3 and TDG-DOE-4 cores (Fig. 1). More than 700 directional measurements were made in the Brallier Formation and related rocks in Virginia, West Virginia, and Tennessee. Sections were measured over a span of 45 field days during the fall and winter of 1978, and the spring and summer of 1979. Directional measurements were made during June, July, and August of 1978.

Forty samples of siltstone and twenty-three samples of shale were collected for petrographic analysis. Microscopic mineralogic determinations were supplemented by bulk X-ray analyses and clay mineralogy of shales was investigated by X-ray powder diffraction using a General Electric XRD5 diffractometer. Forty-four shale samples were analyzed for organic carbon, nitrogen, and hydrogen with a Perkin-Elmer 240 Elemental Analyzer.

CLASSIFICATION OF MUDROCKS

It is necessary at the outset to make clear the implied meaning of lithologic terms used in the following pages. This is especially true because of the plethora of loosely applied names for the various members of the class of fine-grained sedimentary rocks.

Traditional classifications of fine-grained sedimentary rocks fail to describe adequately or distinguish the various lithologies I encountered during the course of my field work. Currently there is no concise and widely accepted field classification of fine-grained sedimentary rocks, such as exists for limestones (Dunham, 1962). Because present terminology is imprecisely defined, confusion often results in discussing or describing these rocks. The word "shale" is a case in point. "Shale" is commonly used both as the class name for fine-grained sedimentary rocks and in a restricted sense for a member of this class that displays fissility and/or lamination (Table 2). It is, however, a frequently used word with which we are all familiar, and one which in many contexts is more convenient to use than other proposed terms. I therefore recommend, as Tourtelot (1960) has that "shale" be allowed its double meaning. But if "shale" is to have dual usage we must be explicit in our writing and conversation. We must specify in describing a rock unit as "interbedded sandstone and shale" whether "shale" is being used loosely or for a specific lithology. In some situations however, it is desirable to have an alterna-

TABLE 2 - CRITERIA USED TO DEFINE FINE-GRAINED SEDIMENTARY ROCKS

REFERENCE	GRAIN SIZE	SPLITTING		BEDDING
		Shale		
Pettijohn (1975, p. 261)	Clay and silt	Fissile	OR	Laminated
Folk (1968, p. 141)	>50% silt and/or clay	Fissile		N.S.
Ingram (1953, p. 870)	>50% silt and/or clay	Fissile		N.S.
Twenhofel (1937, p. 98)	>50% silt and/or clay	Fissile	OR	Laminated
		Mudstone		
Pettijohn (1975, p. 261)	Clay and/or silt	Non-fissile	AND/OR	Non-laminated
Folk (1968, p. 141	Subequal silt and clay in mud fraction	Non-fissile		N.S.
Ingram (1953, p. 870)	>50% silt and clay	Non-fissile		N.S.
Twenhofel (1937, p. 98)	Indefinite mixture of clay, silt, and sand	N.S.		N.S.
		Claystone		
Pettijohn (1975, p. 261	Clay	Non-fissile		N.S.
Folk (1968, p. 141)	>2/3 clay in mud fraction	Non-fissile		N.S.
Ingram (1953, p. 870)	>50% silt and clay; clay predominates	Non-fissile		N.S.
Twenhofel (1937, p. 97)	>50% clay	Non-fissile		N.S.
		Siltstone		
Pettijohn (1975, p. 261)	>50% silt	N.S.		N.S.
Folk (1968, p. 141)	>2/3 silt in mud fraction	Non-fissile		N.S.
Ingram (1953, p. 870)	>50% silt and clay; silt predominates	Non-fissile		N.S.
Twenhofel (1937, p. 98)	>50% silt	N.S.		N.S.

NOTE: N.S. = Not specified

tive name for the class of fine grained sedimentary rocks. In these situations I advocate the use of the term "mudrock", as proposed by Ingram (1953, p. 869) and Blatt and others (1972, p. 374). "Mudrock" should therefore be considered of equal stature with "sandstone" and "limestone". I will use "mudrock" in the above sense in the following discussion and in the rest of this thesis in order to avoid confusion between the general and specific meaning of "shale". Where "shale" is used, it is used for a specific rock type as defined below.

An effective field classification of mudrocks should be simple, equally applicable to outcrops, cores, and well cuttings, and based on features of genetic significance. The many classifications which use fissility as a criterion fail to meet the latter two requirements. Fissility, defined as the tendency of a rock to split along relatively smooth surfaces parallel to bedding (Pettijohn, 1975, p. 263) varies with the nature and duration of weathering processes. The transition in time of a fresh mudrock, to one with obvious fissility, may be depicted in space by a series of weathering zones. At the surface of an outcrop a rock may display well developed fissility, however, as one digs back into the outcrop, parting thickness increases gradually until, finally, fresh massive rock is reached. Lewan (1978, p. 748) noted this weathering series in different rock types in both humid and arid climates. Thus, using a classification based on fissility, identical rocks may be classified differently depending on their weathering histories. Core samples and well cuttings further illustrate this problem. They possess no natural partings, making them difficult, if not impossible, to classify in a scheme based on fissility. Furthermore, as a product of surficial weathering processes, fissility develops very late in a rock's history (if at all) and its relationship to primary depositional features is in many cases questionable. Mudrocks may tend to part along laminations but I have observed many instances where they do not. Thus, fissility is not a necessary product of lamination and the common practice of equating the two (Pettijohn, 1975, p. 261) is unwarranted.

From the above discussion, it is obvious that fissility should not be a factor in the classification of mudrocks. It is not equally applicable to all kinds of samples and it is of little genetic significance. Primary depositional features are strongly preferable criteria for establishing a classification of mudrocks or any rock type.

While sedimentary geologists are not yet aware of all the significant aspects of mudrocks, two fundamental attributes of primary origin are texture and lamination. I believe that a classification of mudrocks based on these two features best meets the requirements of a workable field classification as discussed above. The classification of mudrocks which I used in the field and use in this thesis is presented in Figure 4. "Shale" in its restricted sense, is subdivided into two textural groups and is applied only to laminated clayey rocks with 0 to 67 percent silt. This usage is in accordance with the term's original definition as discussed by Tourtelot (1960).

Lamination in mudrocks is defined by the parallel arrangement of layers less than 10 mm thick and may be of three types: textural,

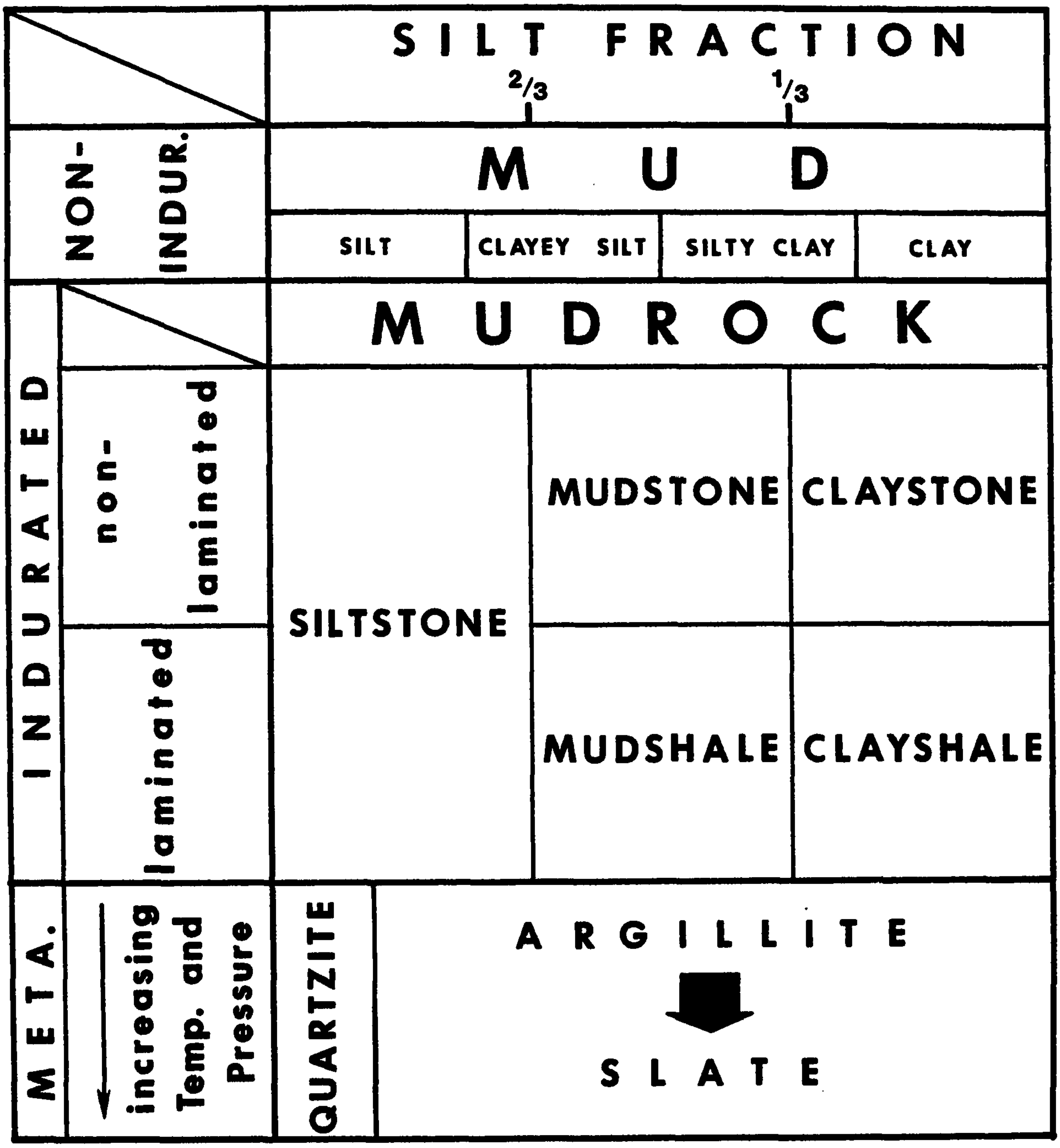


Fig. 4.- Field classification of mud and mudrock and their low-grade metamorphic equivalents. Classification is based on texture (grain size) and structure (lamination). In practice, no sharp boundaries exist between non-indurated, indurated, and low-grade metamorphic members.

compositional, or color (Fig. 5). Any combination of the three types may be present in a given sample. Textural lamination, the most common form, results from the parallel arrangement of platy mineral grains a few microns in size. This type of lamination does not lend itself to thickness measurements. Because it is a pervasive property, one can only determine its presence or absence, and perfection of development. Textural lamination is readily observed in the field with a hand lens, if not with the naked eye. Viewed in oblique light on a surface broken perpendicular to bedding, the tiny parallel ridges and valleys appear much like the pages of a book seen end-on (Fig. 6). Compositional variations produce a second type of lamination. In terrigeneous sediments layers of clay minerals commonly alternate with those of quartz silt, carbonate, or organic matter (Fig. 5). Color lamination consists simply of alternating layers of different color (Fig. 5). These alternations may involve underlying compositional differences, but in the field only the color differences may be apparent. One form of color lamination commonly seen in the Brallier Formation is a product of biologic activity. Referred to as biolamination, it consists of alternating light and dark gray layers (Fig. 7). The light colored layers are completely bioturbated and organic-poor, while the dark colored layers are unbioturbated and organic-rich. Biolamination probably results from intermittent bioturbation at the sediment-water interface during slow continuous sedimentation of clay, silt, and organic matter. Coleman (1976, p. 29) described a very similar bioturbation pattern in prodelta clays.

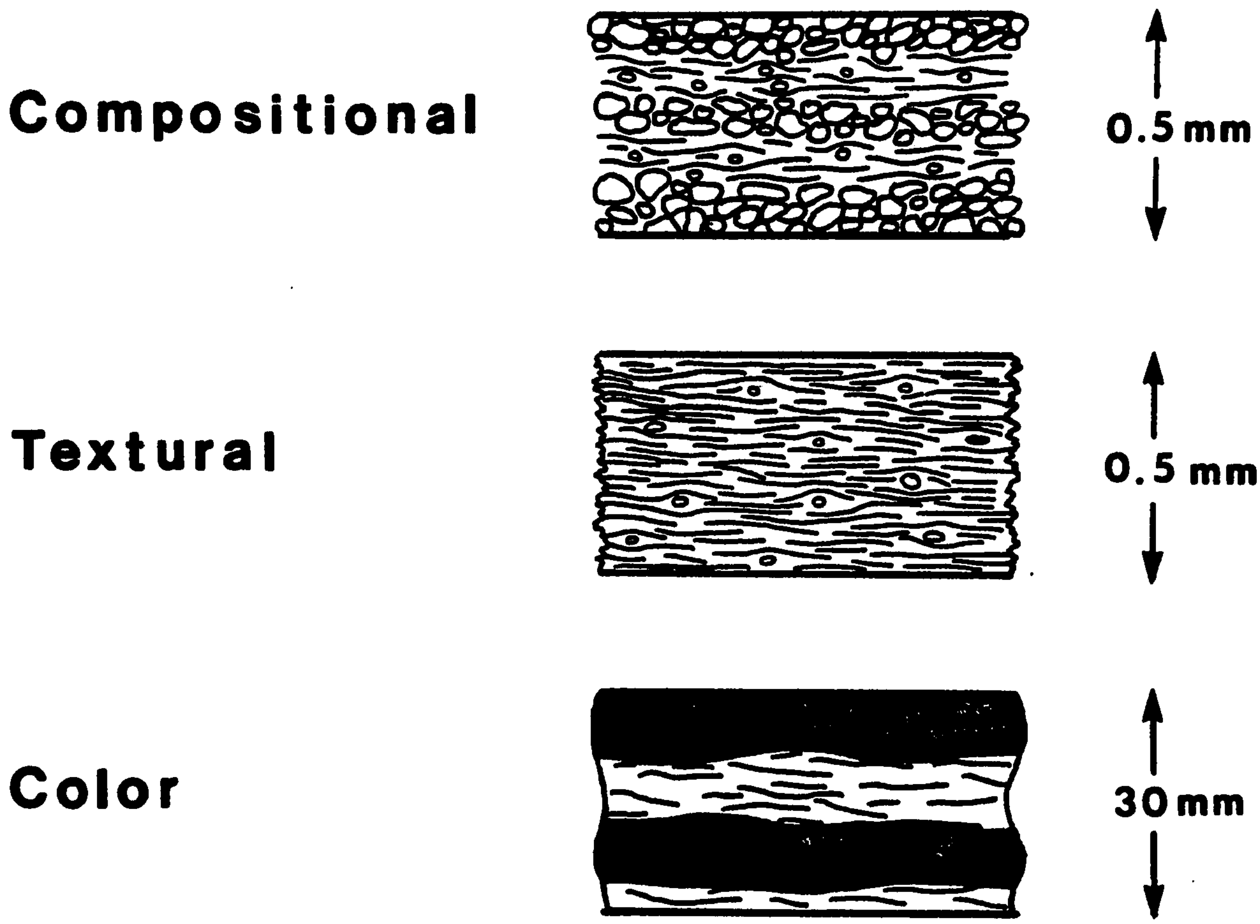


Fig. 5.- Types of lamination in shales. A given sample may show more than one type.

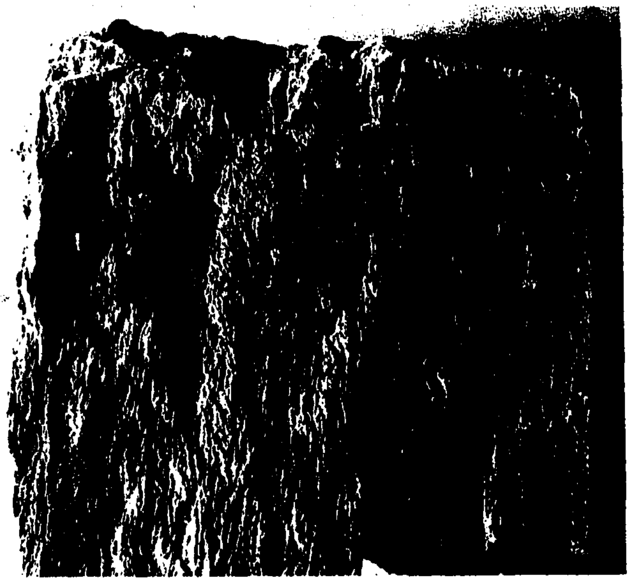


Fig. 6.- Textural lamination in Millboro Shale, Broadford section, unit 3 (Section 11, Appendix 3). The tiny ridges and valleys reflect the parallel arrangement of platy mineral grains. Sample is 3.5 cm wide.

Fig. 7.- Irregular biolaminae in upper Millboro Shale, Broadford section, unit 4 (Section 11, Appendix 3). Light gray layers are bioturbated and organic-poor. Dark gray layers are unbioturbated and organic-rich. Sample in 5 cm high.

The sedimentary structures of mudrocks are useful tools in environmental reconstruction. The preservation of laminae suggests that there was little burrowing of the sediment. This condition can be related to environmental stress which may have limited the population of infauna and its effect on the final aspect of the sediment. Lamination may also be absent because of rapid deposition, as from mudflows, or because of churning of sediment by waves or currents, as on tidal flats. The nature of laminae, specifically their thickness, geometry, continuity, contacts, and internal structure, is also useful in the interpretation of depositional processes. The terminology of Cole and Picard (1975) should be used to describe the geometry of laminae.

Some arbitrary boundary must be selected to distinguish laminated and non-laminated mudrocks. This is not so much a problem with textural lamination because although its perfection is variable, it is basically present or absent. However, in the case of compositional and color lamination one must ask how many laminae in an otherwise non-laminated rock are necessary for it to be considered a shale. I have found 10 percent laminae to be a convenient boundary. That is, if a mudrock contains less than two-thirds silt and greater than 10 percent laminae it is a shale. If however, laminae account for less than 10 percent of the rock, it is either a mudstone or claystone depending on its silt content. Ten percent silt laminae is generally conspicuous.

Siltstones, or mudrocks containing greater than two-thirds silt, are distinguished by textural criteria alone. This alleviates the problem of calling a distinct laminated turbidite bed of silt grade a "shale", as the presence of lamination would otherwise require. The use of appropriate name modifiers amply distinguishes laminated and non-laminated siltstones.

This classification is both simple and informative (Fig. 8). Only two questions need be answered in order to classify a given mudrock: how much silt does it contain, and is it laminated? The root names used describe both textural and structural features and as such convey more information than do those of other schemes. I feel this approach strikes a reasonable balance between the conveyance of genetically significant information and the amount of time and effort required to obtain it.

A discussion of the classification of muds and the low-grade metamorphic equivalents of mudrocks (Fig. 4) is not appropriate here.

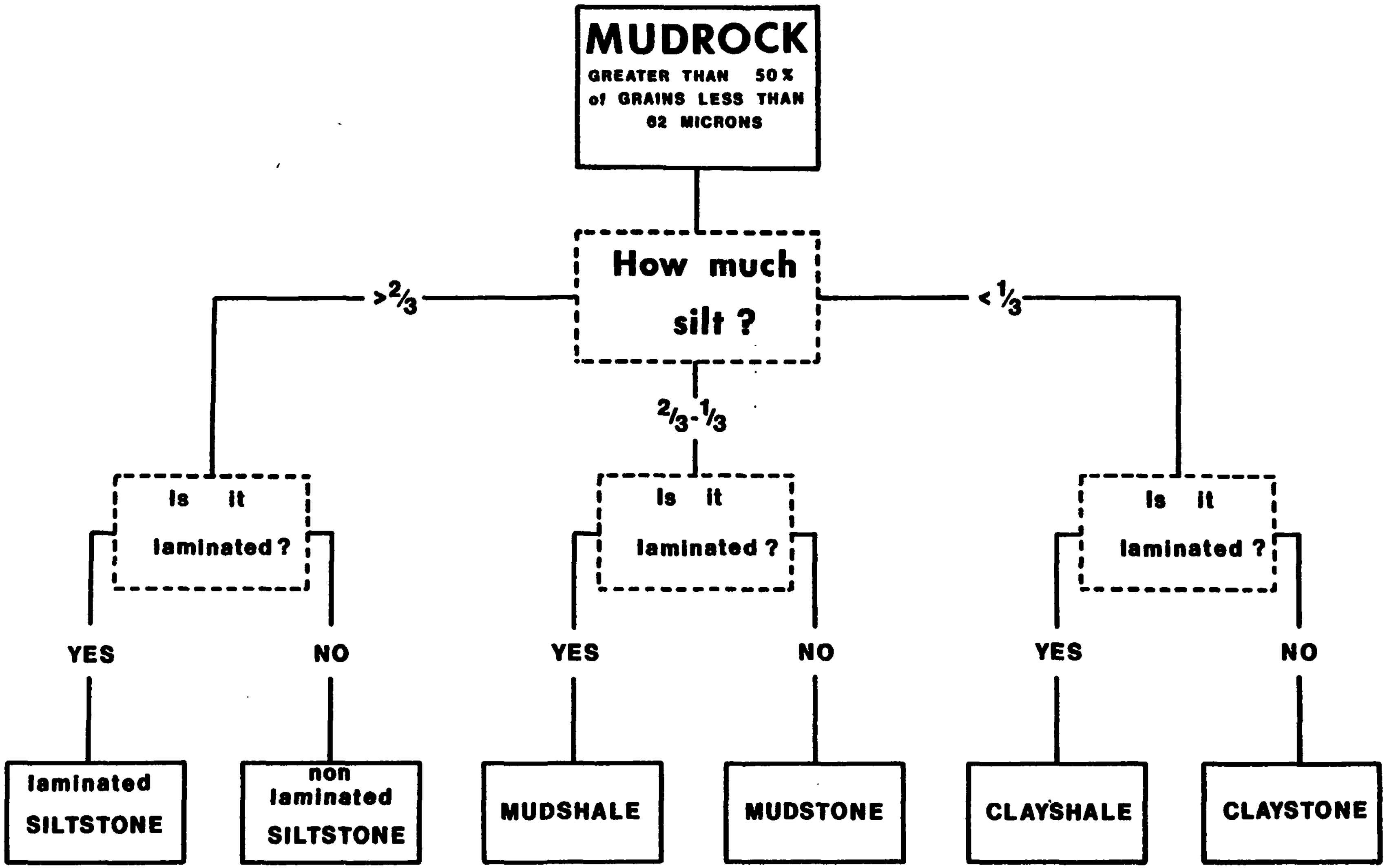


Fig. 8.- Flow diagram for the field classification of mudrocks. Only two simple questions need to be answered in order to classify any sample: how much silt does in contain, and, is it laminated? Both questions are easily answered for cores, well cuttings, and outcrop samples.

PETROLOGY

A total of 64 outcrop samples of the Brallier Formation and related rocks, including 41 siltstones and 23 mudstones, claystones, and shales were collected for thin section analysis. Subsamples were selected for clay mineral and bulk rock X-ray diffraction analysis as well as for the determination of organic carbon, nitrogen, and hydrogen content.

Thin Section Analysis

Thin sections were cut perpendicular to the bedding planes of the samples and 200 points were counted over thin-section areas of approximately 400 square mm. The results of these analyses are summarized in Tables 3 and 4. Individual analyses are compiled in Appendix 1.

Siltstones

In analyzing siltstones the following components were recognized: quartz, felspars, rock fragments, micas, matrix, cement, and heavy minerals. According to the classification scheme of McBride (1963), 85 percent of the siltstones are sublitharenites, 10 percent are quartzarenites, and 5 percent are litharenites (Fig. 9).

Two varieties of quartz were recognized, monocrystalline and polycrystalline. Maximum grain size ranges from 109 to 229 microns and averages 153 microns which is in the fine sand range. Grains are typically angular to subangular and at least slightly undulose. Elongate grains or "chips" are very common (Fig. 10b), and generally show

TABLE 3

PETROGRAPHIC SUMMARY OF SILTSTONES

	QUARTZ		FELDSPAR			ROCK FRAGMENTS				MICA			MATRIX	CEMENT		OTHER
	MONOCRYSTALLINE	POLYCRYSTALLINE	PLAGIOCLASE	MICROCLINE	ORTHOCLASE	METAMORPHIC	QUARTZ POLYMINERALIC	CHERT	SEDIMENTARY	MUSCOVITE	CHLORITE	BIOTITE		CARBONATE	SILICA	
Virginia and West Virginia, n=35																
Mean	53.4	3.6	0.2	T	0.2	7.3	1.2	0.7	0.5	2.8	1.7	0.3	18.5	4.0	0.6	3.4
Std. Dev.	10.1	3.1	0.3	-	0.5	3.9	1.3	1.0	1.4	1.7	1.5	0.7	9.1	7.5	1.1	6.2
Eastern Tennessee, n=5																
Mean	71.8	4.9	0.7	0.1	0.7	2.6	1.2	0.3	-	2.2	T	0.1	8.1	-	0.4	4.5
Std. Dev.	11.2	2.0	0.8	0.2	1.0	2.3	0.9	0.5	-	2.3	-	0.2	4.5	-	0.7	2.1

TABLE 4

PETROGRAPHIC SUMMARY OF MUDSTONES, CLAYSTONES, AND SHALES

	QUARTZ		FELD-SPAR	ROCK FRAGMENTS			MICA			MATRIX	ORGANICS	OTHER	MAXIMUM GRAINSIZE (microns)	
	MONOCRYSTALLINE	POLYCRYSTALLINE		METAMORPHIC	QUARTZ-POLYMINERALIC	CHERT	MUSCOVITE	CHLORITE	BIOTITE				IN LAMINAE	DISSEMINATED
Olive Gray Mudrocks N = 8													(4)*	(9)*
Mean	10.8	-	T	0.1	0.1	-	2.6	1.4	0.1	82.0	0.7	2.2	40	36
Std. Dev.	5.6	-	-	0.2	0.4	-	1.8	1.4	0.2	9.6	0.8	2.5	11	9
Dark Gray to Black Shale N = 3													(6)	(8)
Mean	11.8	-	-	0.5	-	0.2	4.8	0.5	-	75.3	4.3	2.5	69	56
Std. Dev.	2.4	-	-	0.5	-	0.3	1.0	0.5	-	5.1	4.5	2.2	20	15
Bioturbated Claystone N = 7													(2)	(8)
Mean	16.7	0.3	-	0.1	0.1	0.2	4.0	0.1	-	71.1	5.7	2.9	63	47
Std. Dev.	8.6	0.6	-	0.2	0.4	0.4	1.2	0.2	-	12.6	9.5	1.9	24	13
Silt Laminated Shale N = 4													(8)	(8)
Mean	41.5	2.3	0.6	1.3	1.3	0.6	4.5	1.3	-	32.5	9.0	7.0	94	54
Std. Dev.	16.1	0.9	1.0	0.9	1.0	0.8	2.3	1.6	-	23.3	7.5	4.0	42	14

*Number of samples analyzed for grainsize.

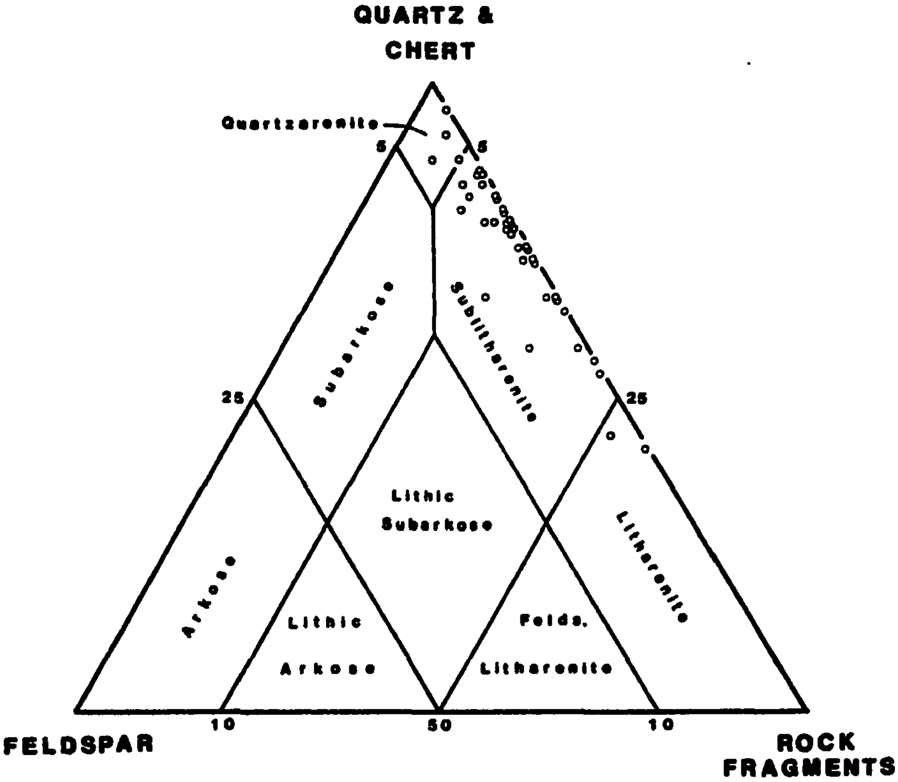


Fig. 9.- Triangular classification of Brallier Formation siltstones. Classification after McBride (1963). Notice that only the upper part of the triangle is used. N = 41.

Fig. 10.- A) Quartz-mica schist fragment in siltstone (Brallier Formation, sample ST1-1). Note elongate quartz grains and well developed foliation.

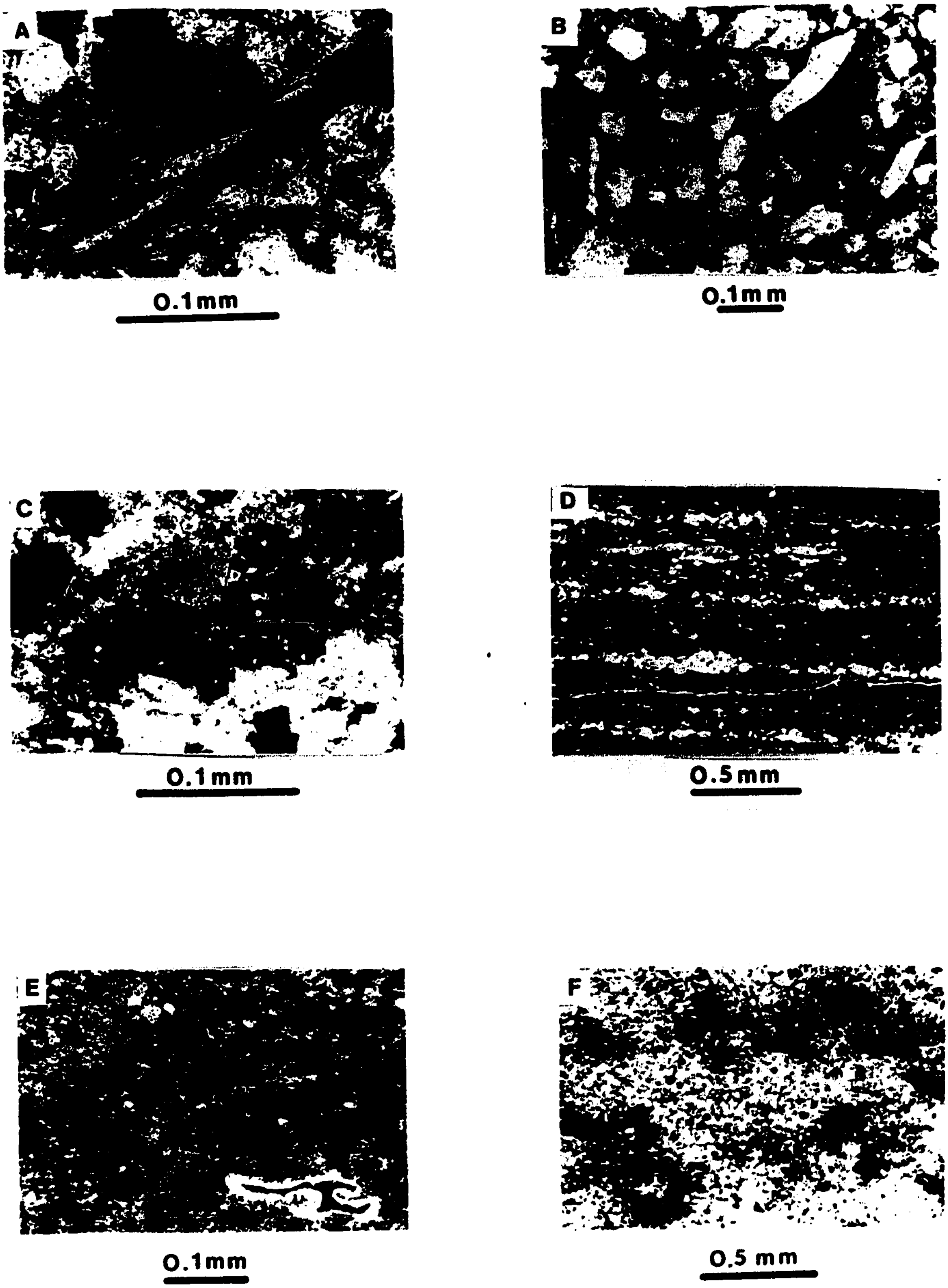
B) One of the few sandstones in the Brallier Formation (sample ST1-1). Note carbonate cement, elongate quartz grains, and tourmaline grain in middle-right.

C) Carbonate cement replacing chert grain (Brallier Formation, sample ST1-1). Note rhombohedral crystal faces at grain margin.

D) Discontinuous silt laminae in black mudshale (Brallier Formation, sample HG1-4). Matrix is clay and amorphous organic matter.

E) Nearly silt-free clayshale (Brallier Formation, sample HG2-3). Collapsed chertified spore in lower-right

F) Strongly bioturbated mudstone (Brallier Formation, sample HI1-7).

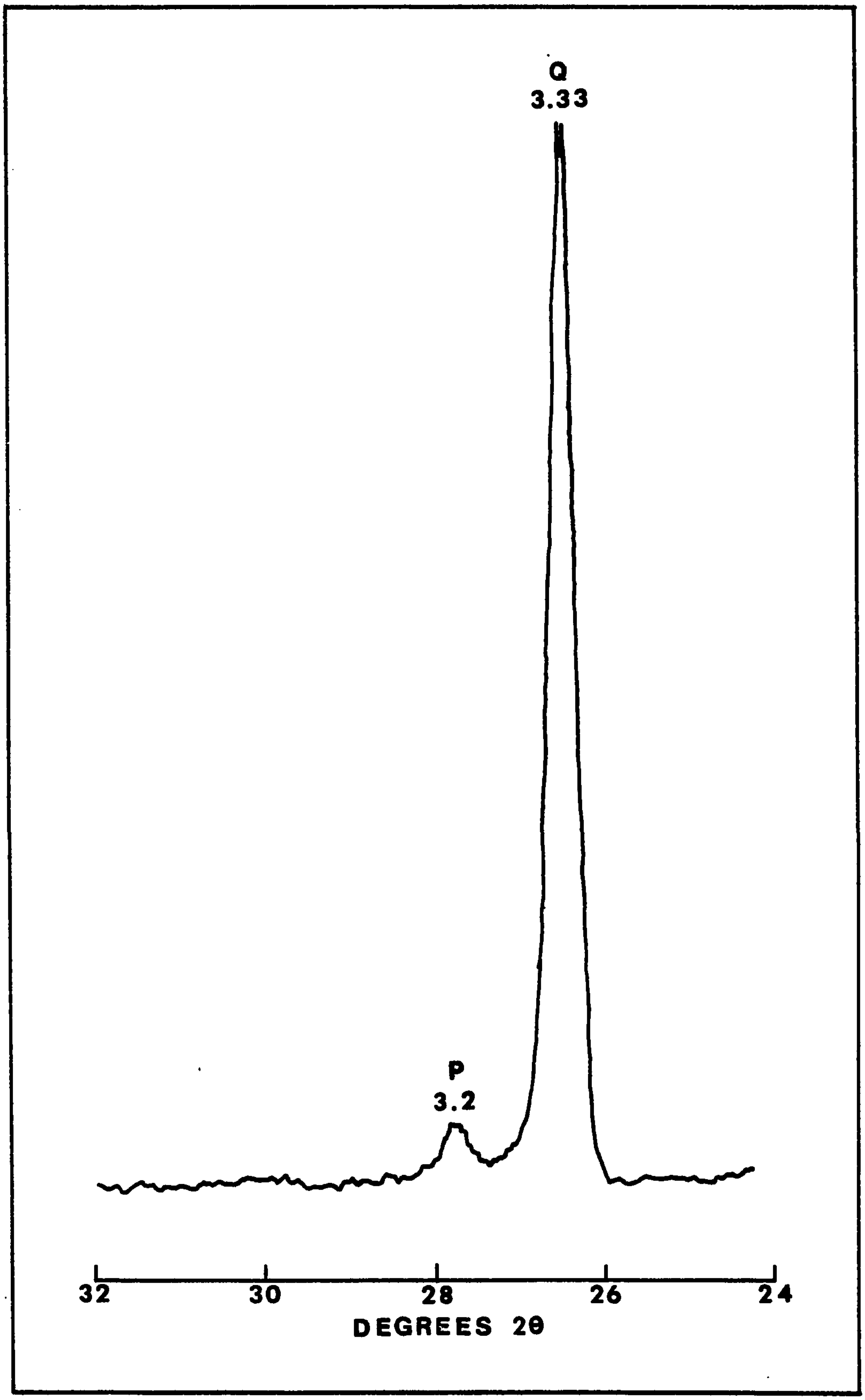

A
0.1mm
B
0.1mm
C
0.1mm
D
0.5mm
E
0.1mm
F
0.5 mm

a preferred orientation parallel to bedding. Floating grains are rare. Contacts between quartz grains or between quartz and feldspar grains are commonly long or concave-convex, giving the rock an annealed appearance. Although sutured contacts and quartz overgrowths are rarely observed the fabric suggests pressure solution and mobilization of silica.

Plagioclase, although rarely exceeding 0.5 percent, is the most common feldspar. Microcline and orthoclase, where present, occur only in trace amounts. Potassium feldspars exhibit slight sericitization whereas plagioclase is typically very fresh. Thin section identification of feldspars was supplemented by X-ray diffraction data. Both the plagioclase and K-feldspar peaks are small but the one for plagioclase is slightly larger (Fig. 11). Staining techniques proved to be of little help in feldspar identification because of the ubiquitous clay matrix which tended to absorb all the stain. The K-feldspar content of the siltstones is probably the least accurately determined petrographic variable.

Rock fragments are relatively abundant in the siltstones of the Brallier Formation and were subdivided into the following categories: metamorphic (74%), quartz-polymineralic (13%), chert (8%), siltstone (2%), mudrock (3%), and carbonate (1%). Metamorphic rock fragments are predominantly sericite-chlorite-quartz schists and phyllites with well developed foliation (Fig. 10a), and notably elonage quartz grains in some cases. Quartz-polymineralic rock fragments exhibit no foliation and consist of quartz and/or feldspar with lesser amounts of mica.

Fig. 11.- X-ray diffraction trace of typical Brallier Formation siltstone. The large peak at 26.6° is the 3.33 angstrom peak of quartz. Note the diminuative 3.20 angstrom plagioclase peak at 27.8° and the absence of a K-feldspar peak at 24.4°.


Q
3.33
P
3.2
32
30
28
26
24
DEGREES 2θ

They have crystalline rock textures but their exact origin is indeterminant. Because of the fine grain size of the samples, rock fragments are composed of but a few crystals. This makes distinguishing igneous and metamorphic rock fragments difficult, because the textural information is severly limited. Thus, it may not be possible to tell a quartzose igneous rock fragment from a quartzose metamorphic rock fragment. The quartz-polymineralic grains may be either metaquartzites or plutonic igneous rock fragments. Chert grains are relatively common and occur as a light colored, coarse-grained variety with individual microcrystals 2 to 4 μm (Fig. 10c). The mudrock fragments are similar in all respects to the mudrocks of the Brallier Formation, and I interpret them as locally derived rip-up clasts. Siltstone and carbonate rock fragments are both very rare constituents.

Detrital micas are very common in the siltstones and include muscovite (62%), chlorite (33%), and biotite (5%). Muscovite is present in all but one sample and occurs as fresh grains 50 to 200 μm in length. Chlorite, although present in most samples rarely exceeds 2 or 3 percent of the rock. Altered flakes of biotite are a rare constituent. The micas are commonly bent around rigid framework grains, indicating post depositional compaction. In general though, they are preferentially aligned parallel to bedding.

Matrix is composed chiefly of illitic and chloritic clay, is olive drab in white light and shows low-order yellow or orange birefringence in polarized light. In weathered samples however, it is partially altered to iron oxides and as a result is reddish or brownish. Matrix appears predominantly detrital in origin although some recrystallization is indicated. Tiny micas 5 to 10 µm in size have grown at the contacts between some quartz grains. These mica grains have slightly higher birefringence. Part of the matrix may also be derived from squashed argillaceous or micaceous rock fragments. In places phyllitic rock fragments merge imperceptibly with the matrix. Using Dickenson's (1970, p. 702) terminology, the "matrix" is predominantly protomatrix but is in part ortho- and pseudomatrix.

The amount of cement in the Brallier siltstones is highly variable, ranging from practically none to about 32 percent. The cementing minerals are predominantly carbonate but small amounts of microcrystalline quartz occur in many samples. Several samples show vertical fractures filled with coarsely crystalline quartz. Carbonate cement forms relatively large crystals and occasionally shows rhombic crystal faces. Commonly it penetrates the margins of chert and quartz grains (Fig. 10c).

The heavy mineral suite identified in thin section is very simple, consisting mainly of zircon and tourmaline. The grains vary from euhedral to well rounded and probably are recycled sedimentary particles. Brookite and rutile were observed in a few samples.

The petrographic features of the Brallier Formation siltstones and their paleocurrents (see following section) suggest an eastern source of sedimentary and low grade metasedimentary rocks. Similar rocks are exposed today, east of the Brallier outcrop belt in the Blue Ridge and Piedmont Provinces. The freshness of plagioclase feldspar grains and detrital chlorite suggests that chemical weathering was inhibited in the source area. The abundance of wood fragments indicates a moist climate and contradicts the contention of Woodrow and others (1973, Fig. 3) that the southern Appalachians were desert-like in Late Devonian time. A source with moderate relief and rainfall could explain all these features.

Little has been published on the petrology of Upper Devonian turbidites of the Appalachian basin with the exception of the recent study by Ethridge (1977), who examined 19 turbidite samples from the Sonyea Group of New York. My data indicate a significantly higher ratio of quartz to matrix. Ethridge's (1977, Table 1) average values for monocrystalline quartz and matrix are 24.5 and 63.7 percent, respectively. My values are 57 and 17 percent (Table 3). These differences seem quite large and perhaps reflect differences in operators and counting technique as much as anything. Identification of "matrix" is admittedly somewhat subjective. I point counted all my thin sections at high power, using a 25X or 40X objective and 12.5X ocular. The upper size limit of matrix was placed at 10 μm, but determining the size of interstitial clay was difficult. Where clay platelets are aligned parallel to one another they show mass extinction and thus their size tends to be overestimated. Ethridge does not report the magnification at which he did his counting or his definition of matrix, so this part of our data is difficult to compare. With respect to the nature and amounts of other constituents, however, our results are quite similar, especially in terms of the kinds and amounts of feldspar and rock fragments. Apparently the source areas of Upper Devonian turbidites in New York and Virginia were petrologically similar.

Mudstones, Claystones, and Shales

The same petrographic suite present in the siltstones is also present in the other mudrocks of the Brallier Formation, but the relative abundances are quite different (Table 4).

Clay minerals, predominantly illite and lesser chlorite are the most abundant constituents of all the Brallier mudrocks. Clay mineralogy was determined by X-ray diffraction. In thin section the clay is olive or grayish in white light and slightly pleochroic. In polarized light it shows low-order orange to yellow birefringence. Alteration to iron oxides gives the clay a reddish-brown coloration in weathered samples. The orientation of clay particles ranges from nearly random in burrows to strongly preferred in shales with megascopic textural lamination. Random to weak orientation is typical of the mudstones and claystones (Fig. 10f). Degree of orientation was qualitatively estimated by how closely the clay particles approached mass extinction as the microscope stage was rotated, and was described as either random, weak, moderate, strong, or very strong. Round aggregates of pyrite crystals 5 to 50 μm in diameter are commonly dispersed through the clay.

Quartz silt, the second most abundant constituent of the mudrocks, is present in variable amounts in all samples. The grains are predominantly angular and monocrystalline. Most samples contain a few grains of fresh plagioclase but other feldspars are rare. In some samples silt grains of quartz and feldspar occur in two modes: disseminated in the clay and concentrated in thin laminae (Fig. 10d). The disseminated silt particles are generally finer grained than those in laminae (Table 4). Maximum grain size averages 51 μm for disseminated silt and 75 μm for silt in laminae. Grain contacts are long or concave-convex in the silt laminae and thus have the "annealed" appearance typical of many of the siltstones. The nature and origin of these silt laminae are discussed in detail in a later section. As a whole, maximum grain size in the mudstones, claystones, and shales, ranges from 40 to 90 μm, averaging 65 μm or less than half the maximum grain size of the siltstones.

Muscovite is equally abundant in the mudstones, claystones, and shales as it is in the siltstones, although it is finer grained. The flakes are predominantly 20 to 50 μm long. Chlorite is present in trace amounts in most samples but biotite is a rare constituent.

Rock fragments are less common in the mudrocks than in the siltstones. Those observed, foliated metamorphic, quartz-polymineralic, and chert are the same as in the siltstones. The scarcity of rock fragments probably reflects the finer grain size of the mudrocks rather than differences in provenance.

Organic matter occurs in three forms: disseminated brown amorphous material, discrete dark brown streaks, and as spores. Pyrite commonly replaces the first two types. The dark brown streaks of organic matter are typically 50 to 120 μm long and 5 to 15 μm thick. Spores, the least common type of organic matter, are generally flattened parallel to bedding and chertified (Fig. 10e). They range from about 60 to 200 μm in length.

In two mudrock samples probable layers of volcanic ash were observed. The layers are 0.3 to 0.6 mm thick and consist almost entirely of coarse flakes of muscovite lying parallel to bedding. The muscovite flakes are typically 150 to 310 μm long. Quartz is absent in these layers.

Elemental Analysis

Forty-four samples of mudstone, claystone, and shale were analyzed for organic carbon, nitrogen, and hydrogen with a Perkin-Elmer 240 Elemental Analyzer. Carbonate carbon was removed by acid dissolution and the percent C, N, and H in the remaining insoluble residue was calculated from

$$\% \, x = \frac{\text{weight of sample}}{Kx \, (mv)}$$

where Kx is a calibration factor determined for a standard sample of known composition, and (mv) is the instrument reading in millivolts, corrected to the net output. The percent C, N, and H in the insoluble residue were then corrected to their whole rock values. These values are accurate to $\pm$ 0.01 percent. In general, the upper Millboro Shale has higher organic carbon content than do the mudrocks of the Brallier Formation although the few dark colored shales in the Brallier are as organic rich as those in the Millboro (Table 5). I interpret this to indicate that the base-of-slope where the Brallier turbidites were deposited marked the transition from dominantly anerobic to dysaerobic conditions. Associated with this change in organic carbon content is a change in the color of the mudrocks from dark gray to black shales of the Millboro Shale to olive gray mudstones, claystones, and shales of the Brallier Formation.

Lithologically distinct mudrock groups of the Brallier Formation are for the most part distinct in their C, N, and H contents (Fig. 12).

TABLE 5

Part A

ORGANIC CARBON, NITROGEN, AND HYDROGEN ANALYSES

STRAT. UNIT	SAMPLE NUMBER	PERCENT C	WHOLE N	ROCK H
BRALLIER FORMATION	BS1-54.8	0.27	0.06	0.46
	BS1-59.6	0.18	0.07	0.50
	BS1-70.3	0.19	0.04	0.37
	BS1-85	0.09	0.00	0.45
	BS2-100	1.13	0.11	0.45
	BS4-32	1.10	0.03	0.48
	GC1-1	0.15	0.08	0.40
	HG1-4	2.59	0.47	0.55
	HI1-1	0.37	0.10	0.51
	MC1-1	0.20	0.14	0.55
	MC1-13	0.12	0.09	0.44
	MH2-5	0.05	0.17	0.41
	McD-182	0.24	0.06	0.47
	R16-BLK	1.05	0.11	0.57
	ST1-36	0.10	0.12	0.50
	ST1-37	0.23	0.05	0.46
	ST1-38	0.00	0.07	0.29
	ST1-42	0.14	0.06	0.61
	ST1-43	0.05	0.13	0.56
	ST1-45	0.05	0.11	0.52
	ST1-46	0.05	0.06	0.56
	ST1-53	0.85	0.10	0.59
	ST1-54	0.86	0.11	0.45
	ST1-60	0.14	0.03	0.36
	ST1-67	0.11	0.04	0.43
	ST1-73	0.08	0.04	0.44
	ST1-75	0.31	0.10	0.58
	ST1-77	0.49	0.17	0.47
	ST1-78	0.32	0.04	0.47
	ST2-149	0.19	0.17	0.50
	ST3-817	0.20	0.06	0.50
	ST3-888	0.21	0.03	0.48
	ST3-893	0.68	0.15	0.31
MILLBORO SHALE	BS1-4.5	2.13	0.09	0.42
	BS1-34.6	0.18	0.07	0.41
	BS1-43.7	0.37	0.11	0.51
	BS1-48.7	0.24	0.07	0.41
	BR1-2	1.58	0.14	0.52
	BR1-3	0.91	0.16	0.49
	ST1-31	0.20	0.09	0.53
	ST1-32	0.19	0.09	0.41
*	PH1-1	0.54	0.07	0.32
	TO-6	0.09	0.04	0.47
**	R16-BSG	1.10	0.13	0.48

* Chattanooga Shale

** Price Formation, Big Stone Gap Shale Member of Bartlett (1974).

TABLE 5

Part B

LOCATIONS OF SAMPLES

SAMPLE	LOCATION
BS1-54.8	Bastian Section; 0.3 ft above base of unit 2.
BS1-59.6	Bastian Section; 5.1 ft above base of unit 2.
BS1-70.3	Bastian Section; 7.4 ft above base of unit 2.
BS1-85	Bastian Section; 5.0 ft above base of unit 3.
BS2-100	Bastian Section; 100 ft above base of unit 5.
BS4-32	Bastian Section; 6.5 ft below top of unit 18.
GC1-1	Nottingham Section; 110 ft above base of unit 1.
HG1-4	Hayters Gap Section; 2.5 ft above base of unit 20.
HI1-1	Hilton Section; 11.4 ft above base of unit 1.
MC1-1	Gauley Ridge Section; 23 ft above base of unit 5.
MC1-13	Gauley Ridge Section; 23 ft above base of unit 5.
MH2-5	Minnehaha Springs Section; 10 ft below top of unit 7.
McD-182	McDowell Section; middle of unit 30.
R16-BLK	Virginia Route 16 Section; unit 32.
ST1-36	Cloyds Mountain Section; top of unit 3.
ST1-37	Cloyds Mountain Section; 1.6 ft below top of unit 4.
ST1-38	Cloyds Mountain Section; base of unit 5.
ST1-42	Cloyds Mountain Section; 2.8 ft above base of unit 6.
ST1-43	Cloyds Mountain Section; 8.1 ft above base of unit 6.
ST1-45	Cloyds Mountain Section; 9.2 ft above base of unit 6.
ST1-46	Cloyds Mountain Section; 10.3 ft above base of unit 6.
ST1-53	Cloyds Mountain Section; 8.5 ft above base of unit 7.
ST1-54	Cloyds Mountain Section; top of unit 7.
ST1-60	Cloyds Mountain Section; 8.5 ft above base of unit 12.
ST1-67	Cloyds Mountain Section; 79.9 ft above base of unit 16.
ST1-73	Cloyds Mountain Section; 12.1 ft below top of unit 16.
ST1-75	Cloyds Mountain Section; 12.9 ft above base of unit 18.
ST1-77	Cloyds Mountain Section; 13.2 ft above base of unit 24.
ST1-78	Cloyds Mountain Section; 11.5 ft above base of unit 27.
ST2-149	Cloyds Mountain Section; 20 ft above base of unit 38.
ST3-817	Cloyds Mountain Section; 8 ft above base of unit 53.
ST3-888	Cloyds Mountain Section; 1 ft below top of unit 60.
ST3-893	Cloyds Mountain Section; 4 ft above base of unit 61.
BS1-4.5	Bastian Section; 4.5 ft above base of unit 1.
BS1-34.6	Bastian Section; 34.6 ft above base of unit 1.
BS1-43.7	Bastian Section; 43.7 ft above base of unit 1.
BS1-48.7	Bastian Section; 48.7 ft above base of unit 1.
BR1-2	Broadford Section; 15 ft above base of unit 3.
BR1-3	Broadford Section; 38 ft above base of unit 3.
ST1-31	Cloyds Mountain Section; 7.5 ft above base of unit 1.
ST1-32	Cloyds Mountain Section; 17.5 ft above base of unit 1.
PH1-1	Little War Gap Section; 26 ft above base of unit 7.
TO-6	U.S. Highway 25-E Section; 4 ft above base of unit 10.
R16-BSG	Virginia Route 16 Section; 175 ft above top of unit 60.

There is little variation in the percent nitrogen, regardless of lithology. Hydrogen in these samples occurs mostly in water in clays, so the C/H ratio is a measure of the organics/clay ratio. Dark gray to black shales occupy a distinct field in Figure 12 characterized by high organic carbon contents. Bioturbated yellowish gray claystones and olive gray mudrocks, however, are inseparable. Both are characterized by low organic carbon contents. Medium gray shales are of intermediate organic carbon content and plot between the other two fields. The dark color of the black shales is a reflection of their high organic content and the medium gray shales simply contain less organic matter. The bioturbated yellowish gray claystones and olive gray mudrocks have different facies relationships as discussed in a later section. Therefore, the fact that they plot in the same field in Figure 12 suggests that organic carbon content of muds is not controlled solely by depositional environment.

Few of the samples in Table 5 are sufficiently organic rich as to be considered good source rocks for oil or gas, however, farther west in the subsurface, turbidite siltstone bundles are interstratified with shales having high organic contents (Cheema, 1977). These occurrences make attractive source bed-reservoir packages.

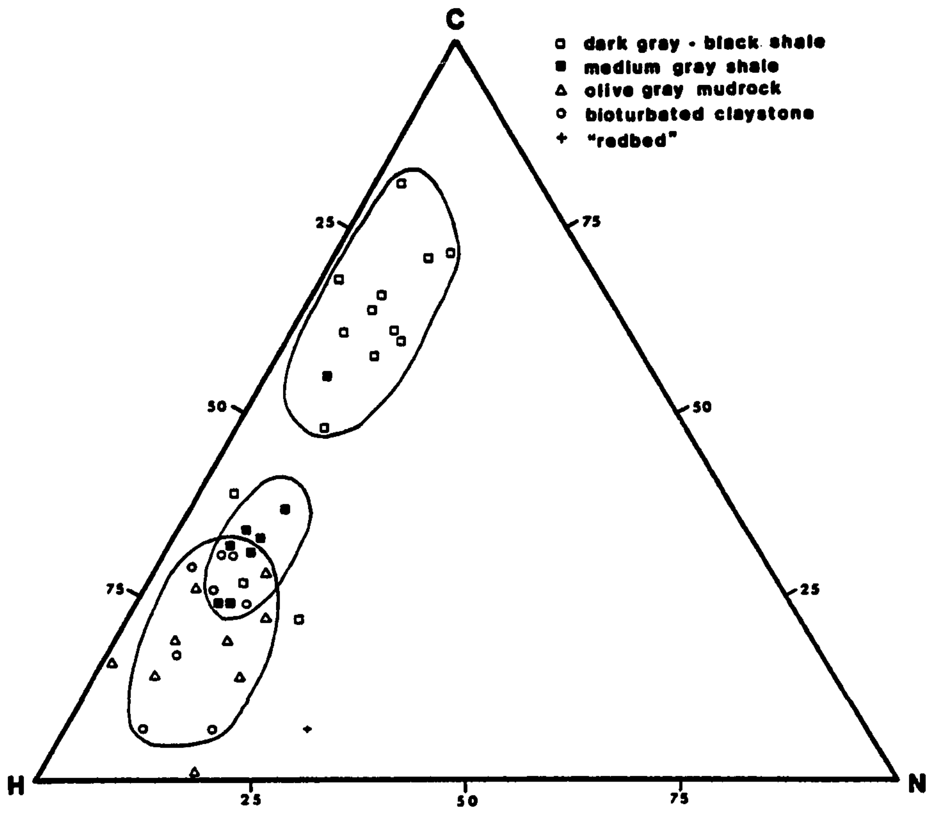


Fig. 12.- Triangular plot of elemental analysis data. The percentage of organic carbon, nitrogen, and hydrogen is recalculated to 100 percent.

PALEOCURRENTS

Approximately 700 directional structures were measured in the Brallier Formation and related rocks in Virginia, West Virginia, and east Tennessee. Of these, 560, or 80 percent are substratal markings, including flute and groove molds, prod and bounce marks, and ridge and furrow structure. The remainder are mostly ripple marks but include elongate wood fragments, parting lineations, and cross bedding. These data are distributed over eighty-five 7-1/2-minute quadrangles at an average density of eight observations per quadrangle. Approximately 90 percent of the data are from the Brallier Formation, the rest are from the "Chemung" Formation, Scherr Formation, and Chattanooga Shale (east Tennessee data). Many more observations of sole mark orientations were made than other directional structures because they are more precise indicators of turbidite flow patterns (Potter and Pettijohn, 1977, p. 172) and are easier to measure. The distribution of paleocurrent data is summarized in Figure 13 and Table 6.

In the field, many of the directional structures measured no longer retain their original orientation because the strata are tilted. It is necessary, therefore, to correct their present attitude for tectonic deformation and to "restore" them to their original position prior to any analysis. Directional structures in severely deformed strata were not measured. The correction for tectonic tilt was generally made in the field as recommended by Dott (1974). The correc-

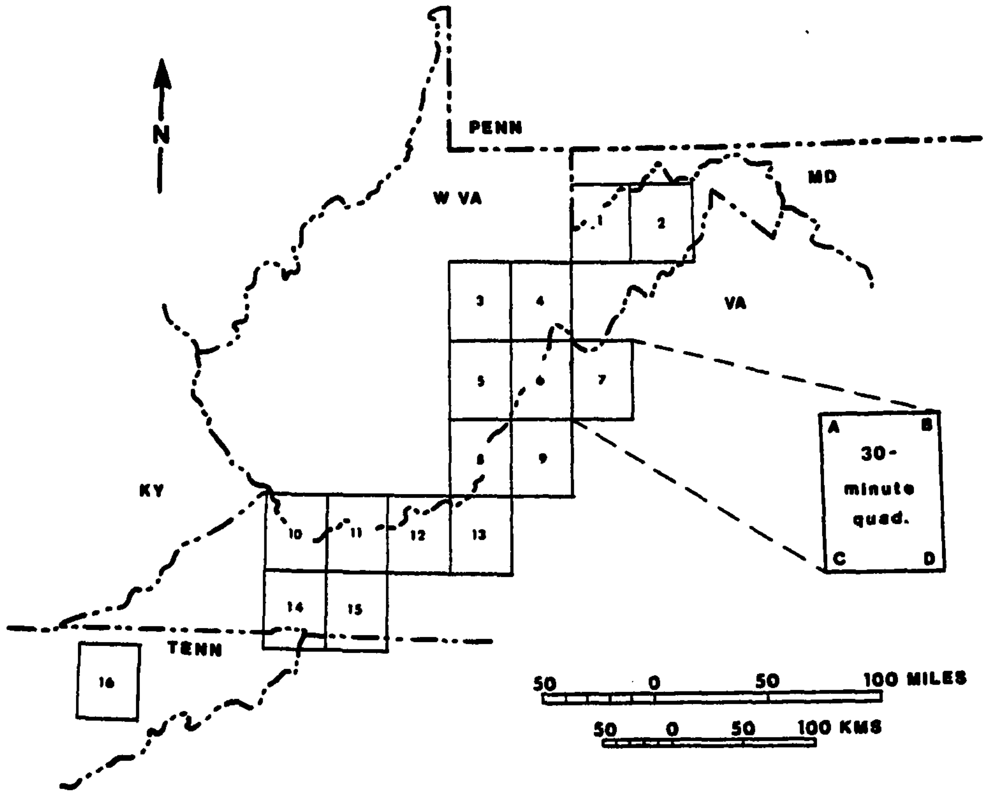


Fig. 13.- Location of paleocurrent data. Distribution of azimuths in each 15-minute quadrangle is summarized in Table 6.

TABLE 6

SUMMARY OF PALEOCURRENT DATA – SOLE MARKS

15-minute quadrangle	Number of observations in 20° classes 20	40	60	80	100	120	140	160	180	200	220	240	260	280	300	320	340	360	Total Number Obs.	Vector Mean	Vector Magnitude (%)	Standard Deviation
1D														1	3				4	288	97.5	15.0
2D												1			2				3	272	91.4	29.5
3D										1	1	1			1		1	1	6	272	55.5	62.7
4A	3	1							1	1	4	9	6	13	3	6	4	11	62	285	62.9	52.3
4C													1						1			
4D													3	3	1	1			8	273	94.2	21.1
5D														1					1			
6A							1			1	2								4	190	78.7	45.3
6B											1	4	2	1					8	241	96.2	17.1
6C										1	2	4	5	6	1				19	252	91.7	24.4
6D												2							2	235	99.9	3.5
7A	1											7	12	7	1	2			30	258	90.7	26.9
8A											1	2	16	10	6	1			36	266	94.2	20.0
8B												3	1	1	1	1			8	260	83.7	36.0
8C													1	2					3	259	99.4	7.5
8D												1	2	11	6		1		21	275	94.7	19.5
9A												1	1		1				3	254	93.1	26.2
9B										1	2	4	3	8	4	1			23	258	88.0	29.5
9C													3	1		2			6	275	90.0	28.5
10D														1	4				5	285	99.3	7.5
11C													4	6	1				11	264	98.2	11.6
11D	1										4	19	46	19	5				94	251	94.9	19.4
12C											3	6	8	9	3	2	1		32	260	87.2	30.2

TABLE 6 - cont'd

15-minute quadrangle	Number of observations in 20° classes																		Total Number Obs.	Vector Mean	Vector Magnitude (%)	Standard Deviation
	20	40	60	80	100	120	140	160	180	200	220	240	260	280	300	320	340	360				
12D	3											9	17	37	12	2			80	269	92.0	24.4
13A												1	2	2					5	253	96.3	17.7
13B									1			5	5	1	2				14	247	86.2	32.8
13C												1	1		1				3	260	88.7	33.9
13D															2	1			3	296	98.6	11.6
14A	1												6	14	3				39	270	96.1	17.4
14B											1		1	3	6	1			12	278	92.7	23.5
15B											3	2	6						11	237	96.6	15.8
16A														1					1			
16B													1	3					4	263	99.8	4.5
ALL DATA	9	1					1		2	5	24	82	152	176	69	20	7	12	560	263	86.8	31.5

tions were made by physical rotation of present linear trends marked on a compass. Where this direct method was difficult to apply, the raw data were tilt corrected in the laboratory with a stereonet. This method requires the strike and dip of the bedding and the trend of the vertical plane which contains the linear structure in question. The two methods gave results within a few degrees of each other.

In processing the paleocurrent data, procedures are used which allow the most accurate assessment of the nature of the dispersal patterns and the depositional system. These include examination of the entire data set, vertical profiles, maps of vector means determined for various size areas on present-day and palinspastic bases, and the comparison of paleocurrent patterns for different sedimentary structures. Vector means rather than arithmetic means are used on all maps and profiles, as the former are a much better measure of central tendency (Potter and Pettijohn, 1977, p. 376). The VECMEN program written and modified from several sources by James M. Parks of Lehigh University was used for the determination of vector means.

Regionally, the Brallier Formation paleocurrents show a homogeneous westerly trend (Fig. 14), perpendicular to the north-south depositional strike (Dennison and Hasson, 1976, p. 278), and transverse to the basin axis. This trend shows little variation from central Pennsylvania to eastern Tennessee, a distance of approximately 600 kilometers along depositional strike. In addition, Upper Devonian turbidite paleocurrents are very similar in New York state (Sutton, 1959; McIver, 1970; Potter and others, in press), indicating the same

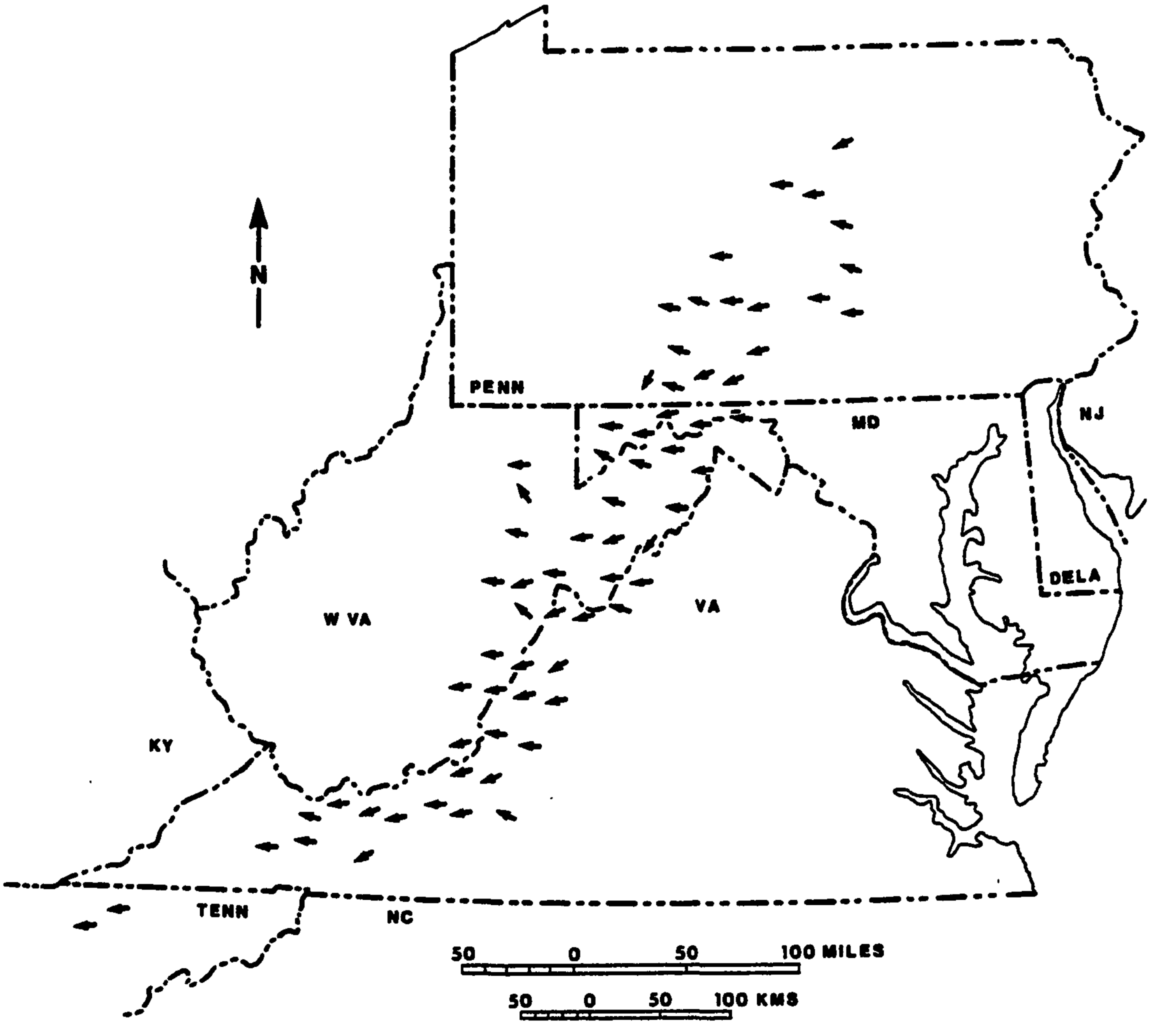


Fig. 14.- Paleocurrent map of Upper Devonian turbidites in the Appalachian basin. Data are from sole marks and are averaged over 15-minute quadrangles. Note the consistent westerly trend for mearly 600 kilometers along depositional strike. The data in Pennsylvania and Maryland are from McIver (1961).

dispersal pattern persists for nearly 750 kilometers along depositional strike. Absent are indications of any longitudinal flow (parallel to the basin axis) which according to Potter and Pettijohn (1977, p. 332) is the rule in turbidite systems.

What effect does averaging the raw data over 15 minute quadrangles have on the patterns observed, i.e., how much has the data been smoothed? Figure 15 shows that the data are quite consistent whether averaged over 30 minute quadrangles, 7-1/2 minute quadrangles, or individual outcrops. Even if all of the data from substratal lineations in Virginia, West Virginia, and Tennessee are plotted on a single rose diagram (Fig. 16) a remarkably distinct unimodel distribution results, demonstrating that even over large areas the paleocurrents show little variation.

Although the raw data used in Figure 14 are corrected for a local tilt of the strata there remains the possibility of directional error induced by differential tectonic foreshortening and distortion of the rocks. In order to determine the importance of this process I calculated rotations and replotted the corrected paleocurrent data on a palinspastic base map (Fig. 17). The palinspastic map was prepared by Dennison (Dennison and Woodward, 1963, Fig. 3) and was constructed by the equal area method for the area in which the Brallier Formation crops out. Clearly, the calculated rotations are no more accurate than is this map. In addition, because of the manner in which the data were collected I cannot correct for any reorientations due to thickening the thinning. The method used also

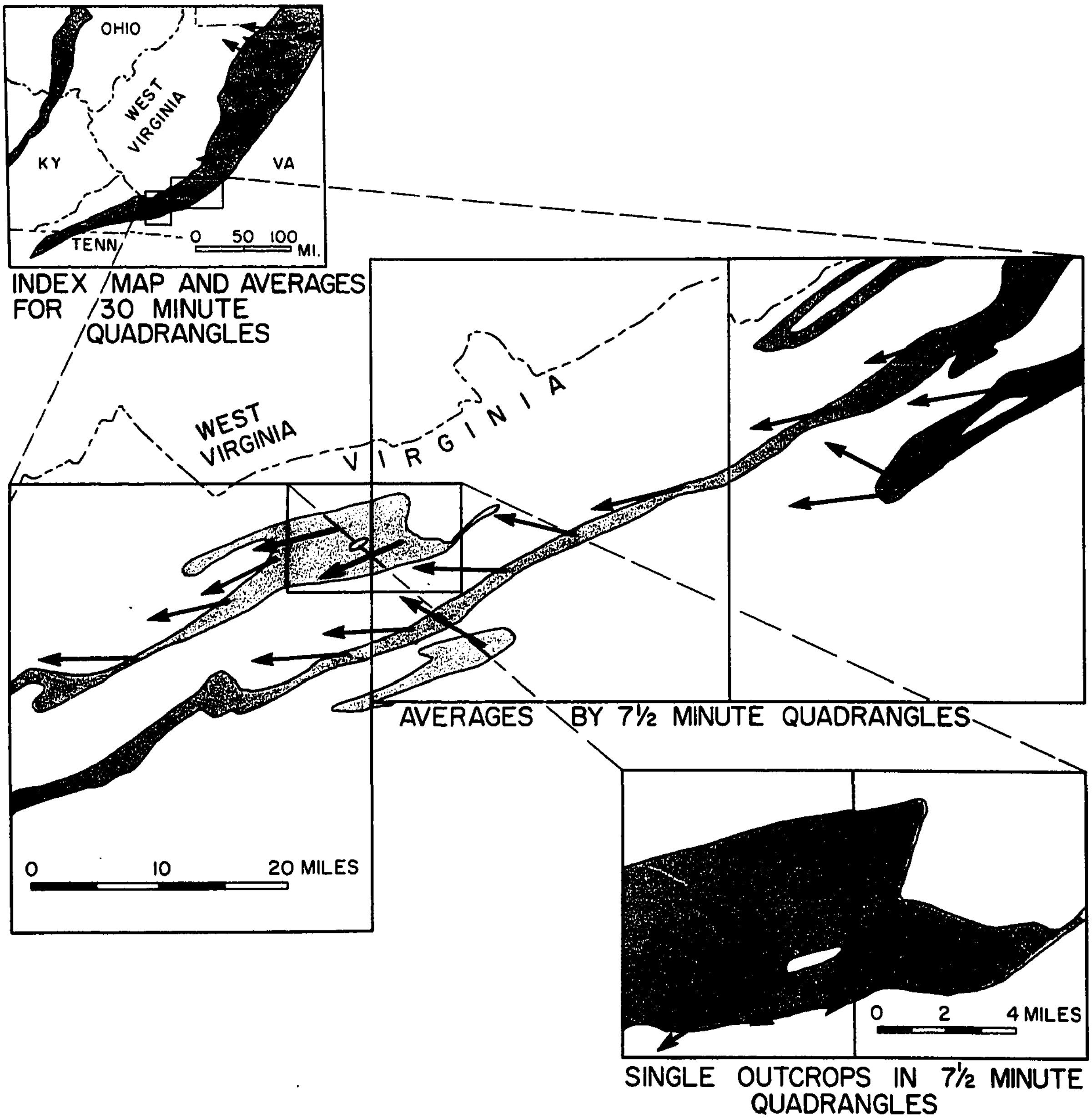


Fig. 15.- Paleocurrent data averaged at three different scales. Note consistency of trend in each case. Outcrop of Brallier Formation is shaded

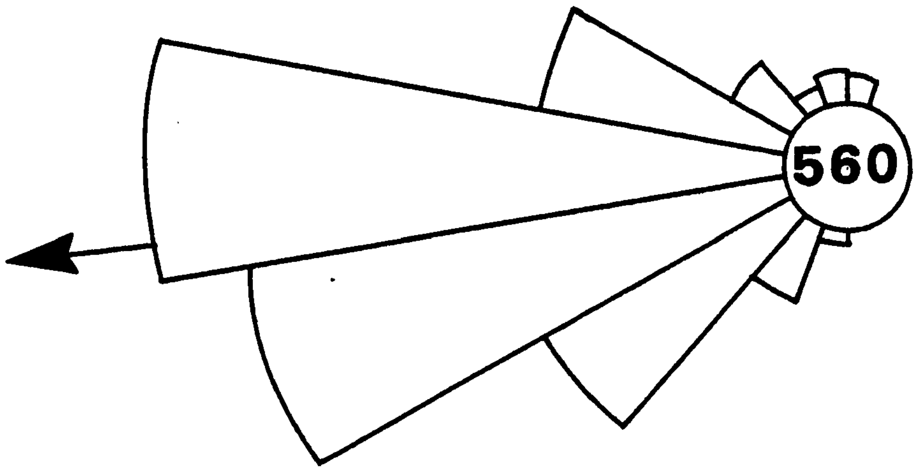


Fig. 16.- Rose diagram of all sole mark observations. All data treated as vectoral.

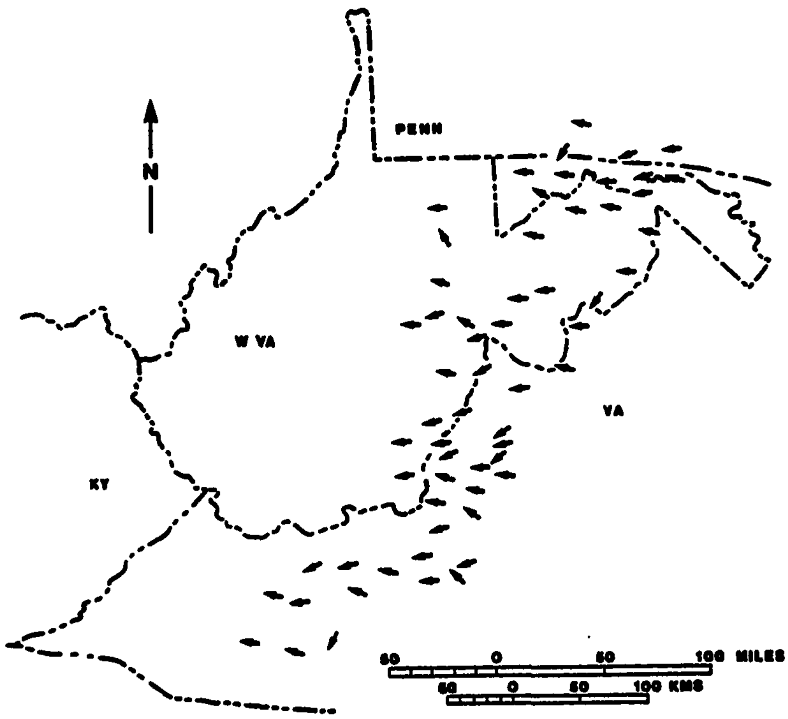


Fig. 17.- Palinspastic paleocurrent map of Upper Devonian turbidites in the Appalachian basin. Data same as in Figure 14. Base map from Dennison and Woodward (1963, Fig. 3).

assumes homogeneous deformation, an assumption which is not truely valid for the size areas which were considered. The minimum area for which rotations can be calculated is limited, however, by the scale of the palinspastic base map. In spite of these shortcomings I feel there is value in the calculation of rotations and in examination of the resulting map. The details of the method of calculating the rotations are discussed in Appendix 2.

When plotted on the palinspastic base map the azimuths as well as the positions of data points change (Fig. 17). In Figure 17 single arrows are plotted for the same 15-minute quadrangles as in Figure 14, except where the rotations varied by more than 5 degrees within a quadrangle. In these cases, the data are subdivided into smaller, more homogeneous areas for which single arrows are plotted. The data points are also plotted at their restored (pre-deformation) positions. The restoration process involves closkwise rotation of some azimuths and counterclockwise rotation of others. A maximum rotation of 32 degrees occurs in southwestern Virginia, and in general the amount of rotation is greatest in that area. The average correction factor is approximately 10 degrees. The resulting paleocurrent map (Fig. 17) shows slightly greater variability than the previous map (Fig. 14), but the same overall transverse flow pattern is still apparent.

The paleocurrent maps of Figures 14 and 17 summarize data from different stratigraphic horizons. Marker beds have not been recognized in the Brallier Formation and are generally absent in turbidite sequences (Pettijohn and others, 1972, p. 500). Because of this it was impossible to investigate the areal variations of paleocurrent patterns in rocks representing small time intervals, of say several hundred thousand years. How then is it possible to determine whether the homogeneous pattern in Figure 14 is the result of averaging divergent paleocurrent patterns of narrow stratigraphic range? This question can be answered by examining the trends of directional structures in vertical profiles. A uniform paleocurrent pattern can result by averaging data from two overlapping units with divergent paleocurrent patterns (Fig. 18), however, these divergent patterns ought to be recognizable in vertical profiles through the region of overlap. Vertical profiles of Brallier paleocurrents show an overall uniformity and absence of distinct divergent trends (Figs. 19 and 20). The meaning of this vertical homogeneity will be discussed later.

What are the paleocurrent systems like in other turbidite sequences and how do they compare with the one discussed here? One might expect the nature of the paleocurrent system to vary with the geometry of the basin. It seems reasonable that round basins should have centripetal supply and elongate basins lateral supply as discussed by Kuenen (1958, p. 331). However in many flysch basins, which are elongate troughs, the dominant direction of transport is longitudinal rather than lateral. The Apennine flysch (ten Haaf, 1959), the eastern Carpathians (Contescu, 1974), the Upper Mississippian of the Ouachita geosyncline (Cline, 1970), and the lower Paleozoic of Nova Scotia (Schenk, 1970) are a few examples of this situation. In the Martinsburg flysch of the Appalachian basin two opposite directions of longitudinal paleocurrents occur (McBride, 1962). Basically two explanations have been offered for longitudinal paleocurrents. One, which Kuenen (1958)

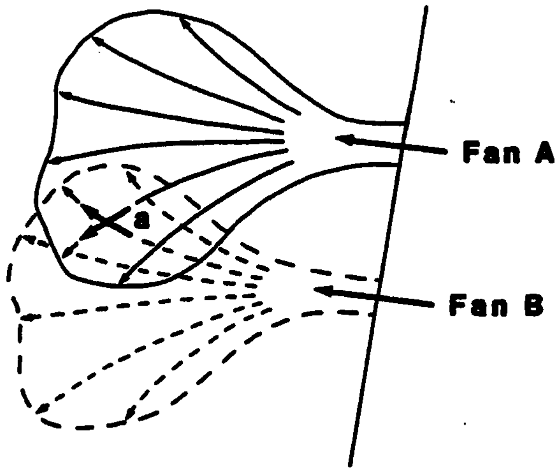


Fig. 18.- Sketch showing how two overlapping fans (or turbidites) may have divergent flow patterns. Averaging the azimuths of divergent structures at *a* will create the impression of a more uniform dispersal pattern than actually exists. The divergent flow patterns of fan A and B should be detectable in vertical profiles.

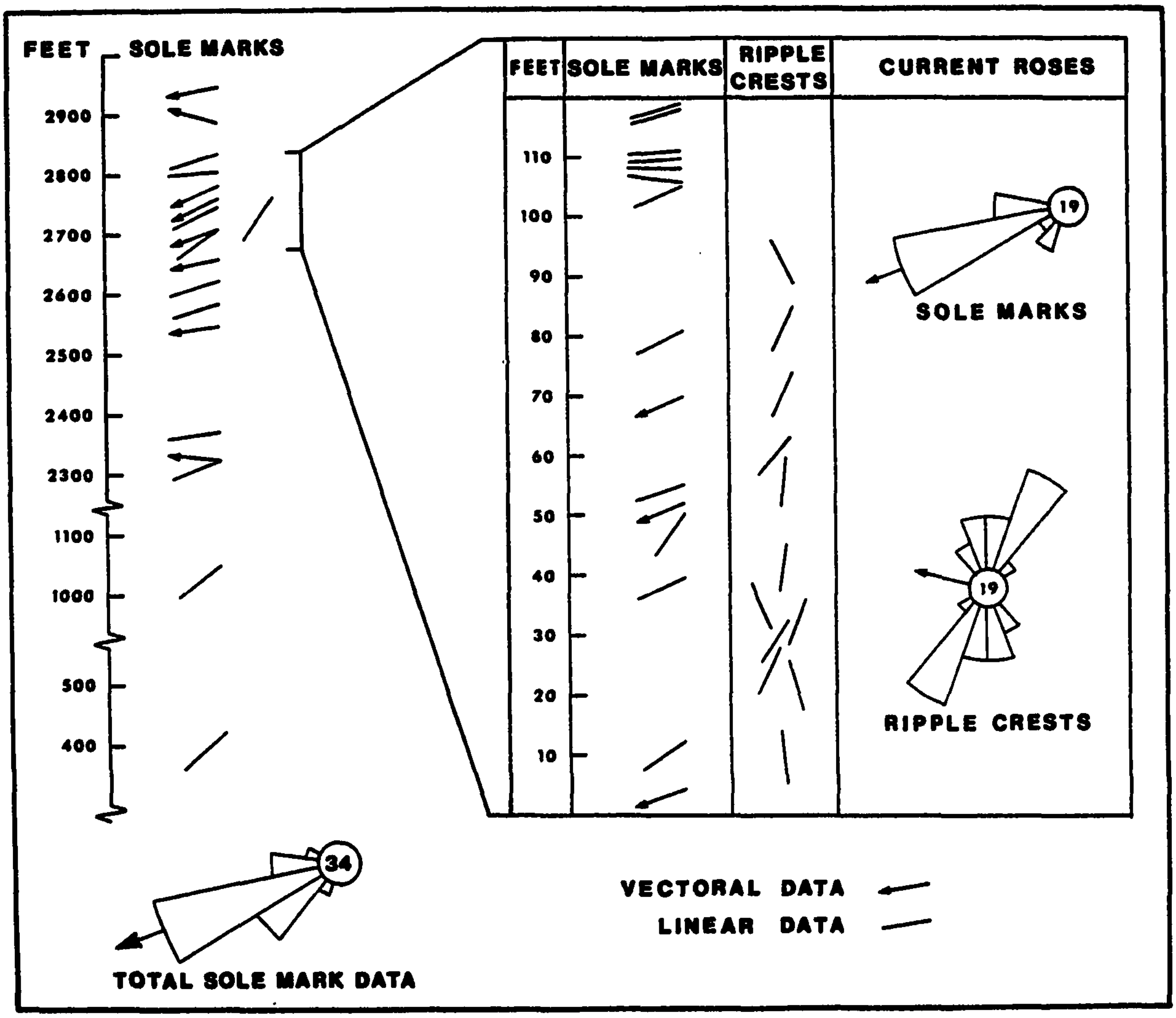


Fig. 19.- Vertical profile of paleocurrents through the Bastian section (Section 9, Appendix 3). Note the homogeneity.

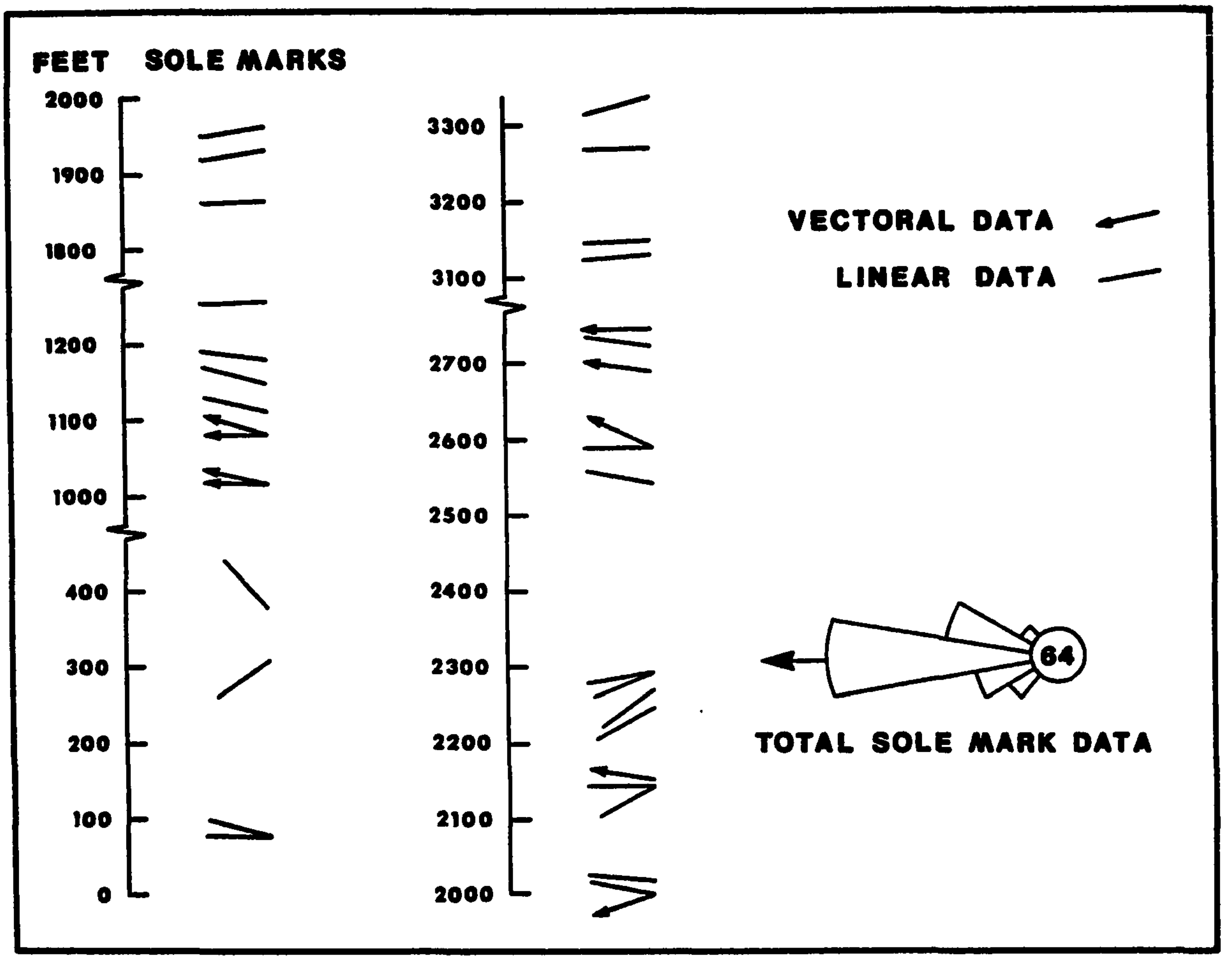


Fig. 20.- Vertical profile of paleocurrents through the Cloyds Mountain section (Section 5, Appendix 3). Note the homogeneity.

favored, is that a large river debouching into the end of the trough directly initiated longitudinal currents. The other explanation is that sediment was supplied laterally but that turbidity currents did not begin to deposit until they were deflected longitudinally along the floor of the trough (Kuenen, 1958). This second possibility seems most reasonable where transverse, oblique, and longitudinal paleocurrents are all represented.

A review of the present literature shows that longitudinal transport is the rule in turbidite systems (Potter and Pettijohn, 1977, p. 332). It is therefore most intersting that in the Appalachian basin, an elongate geosynclinal trough, Upper Devonian turbidites show almost exclusively transverse paleocurrents. There are several implications of such a dispersal pattern.

The absence of longitudinal paleocurrents is strong evidence that no sediment was input longitudinally, at least for the facies and area studied here. One may still ask, however, why were the transverse turbidity currents not deflected longitudinally? There are several possible explanations. First, and simplest, turbidity currents may not have reached the axis of the basin. This idea is not appealing because it requires either the deposition of turbidites on the sides of the basin or that the basin had a terraced profile (see Contescu, 1974, Fig. 12) which subsurface data does not support. Cheema (1977, p. 67) however, favored this explanation for the absence of turbidite flow parallel to the basin axis in Upper Devonian strata in the subsurface of north-central West Virginia. A second possibility is that turbidity currents reached the basin axis and were deflected but at that time had lost most of their energy and were too weak to erode the bottom and thus form sole marks. It seems unlikely that this could be true for all the turbidites of the Brallier Formation. Thirdly, the basin axis may not have been inclined steeply enough to cause deflection of turbidity currents which reached it. In this case, turbidity currents which reached the basin axis would expand laterally and quickly dissipate. This phenomena is known as "ponding". As discussed above, the Appalachian basin is an elongate trough and the Upper Devonian is a progradational sequence so it is unlikely that turbidity currents did not reach the basin axis. Given this, only the inclination of the basin axis determines whether flows are deflected. Therefore, I favor this third explanation for the exclusively transverse paleocurrents.

The transverse dispersal pattern suggests that sand bodies ought to be transverse rather than longitudinal. This knowledge is important to the exploration for hydrocarbons and should greatly increase efficiency in exploiting turbidite sand reservoirs.

It is apparent that the dispersal pattern of these Upper Devonian turbidites is regionally homogeneous. How does the variability of paleocurrents in other turbidite systems compare with this pattern in both areal and vertical views? I know of no published palinspastic paleocurrent maps of turbidites so I must restrict comparisons to my map using the present-day base. Many turbidite systems show much greater variability, for example the Ordovician of the Appalachians (McBride, 1962), the Ordovician-Silurian sequence of Arctic, Canada (Trettin, 1970), the Mississippian of the Marathon basin (McBride, 1970), the Cretaceous of the eastern Carpathians (Contescu, 1974), and the Upper Mississippian of the Ouachita basin (Morris, 1974). Some vertical profiles through the Ordovician turbidites of the Appalachian basin show considerable uniformity of paleocurrents while others are highly variable (McBride, 1962, Fig. 34). Several of the above examples consist of a fairly homogeneous longitudinal system of paleocurrents and a more variable transverse system (Trettin, 1970; Contescu, 1974; Morris, 1974). The Ordovician of the Appalachians shows two opposing longitudinal paleocurrent systems (McBride, 1962). A very few turbidite systems show but one homogeneous paleocurrent system. In these cases the flow is predominantly longitudinal. Two examples are the Apennine flysch of Italy (ten Haaf, 1959), and the Cretaceous sediments of Chile (Scott, 1966). In other words, while it is not unusual for a turbidite system to show a homogeneous paleocurrent pattern, it is very unusual for such a system to show a single, homogeneous <u>transverse</u> paleocurrent pattern. The only example of this that I know of, other than the Upper Devonian of the Appalachian basin, is the Mississippian Borden Formation of Kentucky (Moore and Clarke, 1970, Fig. 3; Kepferle, 1978, Fig. 7; Maynard and Lauffenburger, 1978, Fig. 4). Maynard and Lauffenburger (1978, Fig. 3 and 4) showed that turbidites in the Borden Formation have uniform westerly paleocurrents which in places are oblique to the isopach lines of individual beds. Interestingly, the depositional systems of the Borden Formation and the Brallier Formation are similar except that the Borden was deposited on the craton and the Brallier was deposited in a geosyncline.

Potter and Pettijohn (1977, p. 176) suggest that uniformity versus disorder in turbidite paleocurrent systems reflects the difference between a single distant source and a diversity of local sources. I can certainly think of situations where this statement is valid but it does not seem to be for the system studied here. A single source at the end of an elongate basin will in most cases produce a more homogeneous paleocurrent pattern than will a multitude of transverse sources. This is so because the slope of the basin flanks will guide turbidity currents along a path parallel to the basin axis. Turbidite paleocurrents also tend to be more uniform, for a given size area, at points farthest from their source. This is so because the radius of curvature of submarine fans increases in the up-fan direction, as does topographic irregularity. The Upper Devonian turbidites of the Appalachian basin have a homogeneous paleocurrent pattern not because flow was confined to the axis of an elongate trough nor because they all were deposited far from their source. What then is the significance of this areally and vertically homogeneous dispersal pattern?

The areal homogeneity for more than 600 km along depositional strike strongly suggests that turbidity currents had multiple point sources of origin. Had their been only a few sources, distinct dispersal patterns radiating from these points would be evident (see Sullwold, 1960). As a submarine fan grows, it becomes a topographically positive feature which induces flow divergences because of its sub-arcuate slopes. If the deposits at a given place on the sea floor were formed by the coalescence of a few large long-lived submarine fans, divergent paleocurrent patterns associated with each fan ought to be seen in a vertical profile through the deposit (see Fig. 18). In profiles through the

Brallier Formation only small irregular divergencies in paleocurrents are present (Figs. 19 and 20). Therefore, I suggest that the Upper Devonian paleoslope was one of little topographic relief on which small short-lived turbidite lobes were continually built and abandoned as the loci of turbidity currents shifted.

Comparison of Different Directional Features

Most of the paleocurrent data collected are from sole marks. These features are easy to find and measure and are the most reliable indicators of turbidite flow patterns. Limited data, however, was also collected from ripple marks and wood fragments.

Ripple marks have been used successfully by some workers to map turbidite paleocurrents (Sullwold, 1960). However, I found them to be generally undesirable features to measure in the Brallier Formation. Ripples in the Brallier are of the linquoid variety, having discontinuous, sinuous crests (Fig. 21). Because of this it is difficult to estimate an average crest trend, especially at small exposures. Cross-lamination associated with the linguoid ripples has tangential, trough geometry and hence has divergent dip directions. In addition, it is difficult to determine the direction of true cross-lamination dip in indurated sediments. Paleocurrent data from ripple marks in the Brallier Formation (Fig. 22) shows general agreement with sole mark data although the ripples show considerably greater variability. The direction of sediment transport indicated by ripple marks varies from northwesterly to southwesterly. Sole mark and ripple cross-lamination trends compared

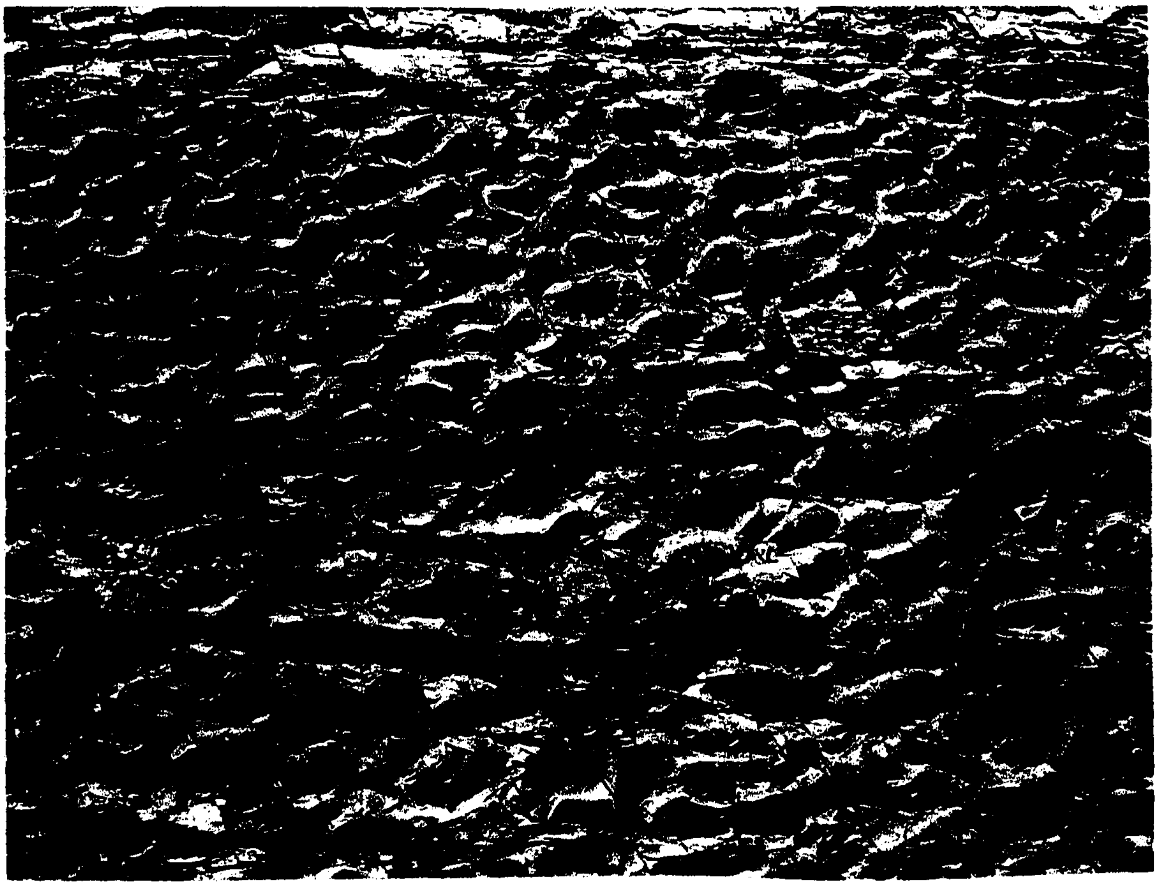


Fig. 21.- Linguoid ripples on the upper surface of a siltstone bed in the Brallier Formation. Arrow in lower-right is 60 cm long and indicates mean flow direction.

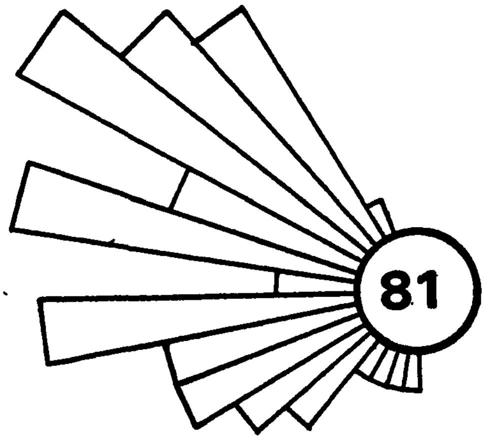


Fig. 22.- Rose diagram of ripple cross-lamination trends in Brallier Formation siltstones.

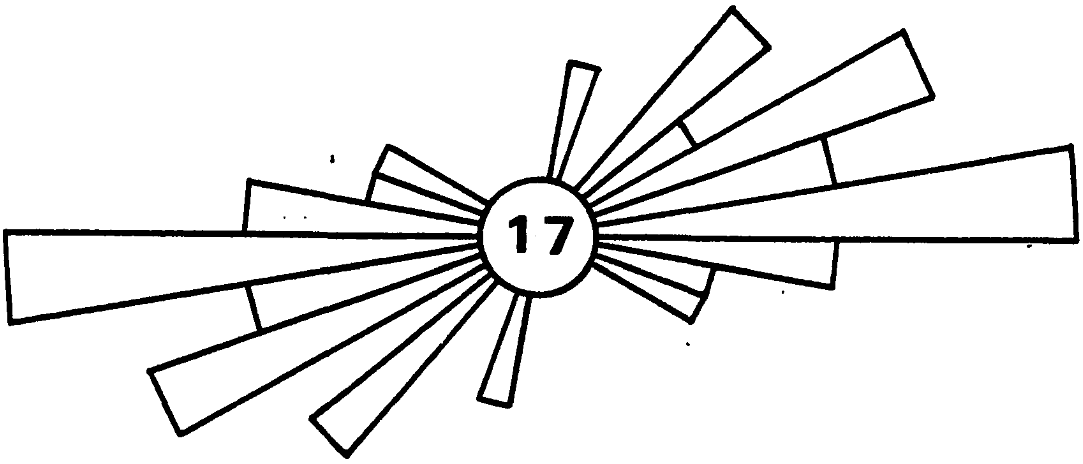


Fig. 23.- Rose diagram of elongate wood fragment trends in Brallier Formation siltstones.

in vertical profile may show slight divergences (Fig. 19). In Figure 19 the vector mean for sole marks differs from the vector mean for cross-lamination by 34 degrees. This divergence indicates either reworking of turbidites by bottom currents or that individual turbidity currents changed direction with time. The current directions of turbidity currents and contour currents ought to be at right angles to one another (Stow and Lovell, 1979, p. 279). Therefore it is improbable that the divergence between the sole marks and cross-lamination represents reworking of turbidites by currents flowing parallel to the slope (see also Kelling, 1964; Hsu, 1964, p. 384-384).

Preferentially oriented elongate wood fragments are common in the Brallier Formation. Such features indicate the line of current but not the sense of the current. The distribution of wood fragment trends measured in the Brallier Formation agree well with data from sole marks and indicates that wood fragments orient parallel to currents with perhaps a slight tendency for some wood fragments to align perpendicular to currents. (Fig. 23). Although the data are limited, comparison of Figures 22 and 23 suggests wood fragments may be less variable indicators of paleocurrents than linguoid ripples.

SEDIMENTARY STRUCTURES

Siltstones

In The Brallier Formation siltstone occurs as distinct even beds which display many of the features of turbidites (Table 7). The differences between the siltstones of the Brallier and other turbidites can mainly be attributed to the restricted fine grain size of the Brallier rocks (predominantly less than 70 μm). Siltstone strata range in thickness from a few millimeters to a meter or more. The thickest bed observed is 1.5 m, however bed thickness averages about 5 cm and rarely exceeds 30 cm except in siltstone bundles. In outcrop, siltstone beds are even and persistent, but bedding does become less even and continuous near the top of the Brallier and the base of the "Chemung" Formations. Thin beds commonly show pinch and swell thickness variations because of rippling of their upper surface (Fig. 24).

Sole marks are common features of the siltstone beds of the Brallier Formation and generally become more abundant towards the top of the formation (Fig. 19). They include flute molds (Fig. 25), groove molds (Fig. 26), prod marks (Fig. 27), bounce marks (Fig. 27), ridge and furrow structure (Fig. 28), small load casts (Fig. 29) and sole marks of organic origin. All sole marks are relatively small, a few centimeters in length, although one groove mold 2.4 m long was observed. The chance of finding sole marks on a given bed is small but they are present at most outcrops where a number of beds are exposed. Sole marks of organic origin occur

TABLE 7

COMPARISON OF THE BRALLIER FORMATION WITH ANCIENT AND MODERN TURBIDITES

Ancient and modern turbidites (Adapted from Kepferle, 1977, Table 4)	Brallier Formation: Similar	Brallier Formation: Partly similar
1. Alternating fine- and coarse-grained strata.................	X	
2. Individual beds are even and laterally continuous...........	X	
3. Fine-grained beds tend to be uniform......................	X	
4. Coarse-grained beds are generally graded, but grading varies and may be obscure......		X
5. Lower surfaces of the coarse-grained beds commonly show sole marks.....................	X	
6. The bases of coarse-grained beds are abrupt; the tops may be somewhat less abrupt or gradational into the overlying shale.........................	X	
7. Internal bedding shows the entire Bouma-sequence (Bouma, 1962) locally, truncated base or missing parts being more common than a complete cycle...	X	
8. Trace fossils are largely restricted to sole marks and trails on upper bed surfaces...	X	
9. Subaerial and shallow-water features are absent............	X	
10. Shallow-water fauna are absent except where displaced and incorporated into the coarse-grained beds...................	X	
11. Large-scale crossbedding is absent........................	X	

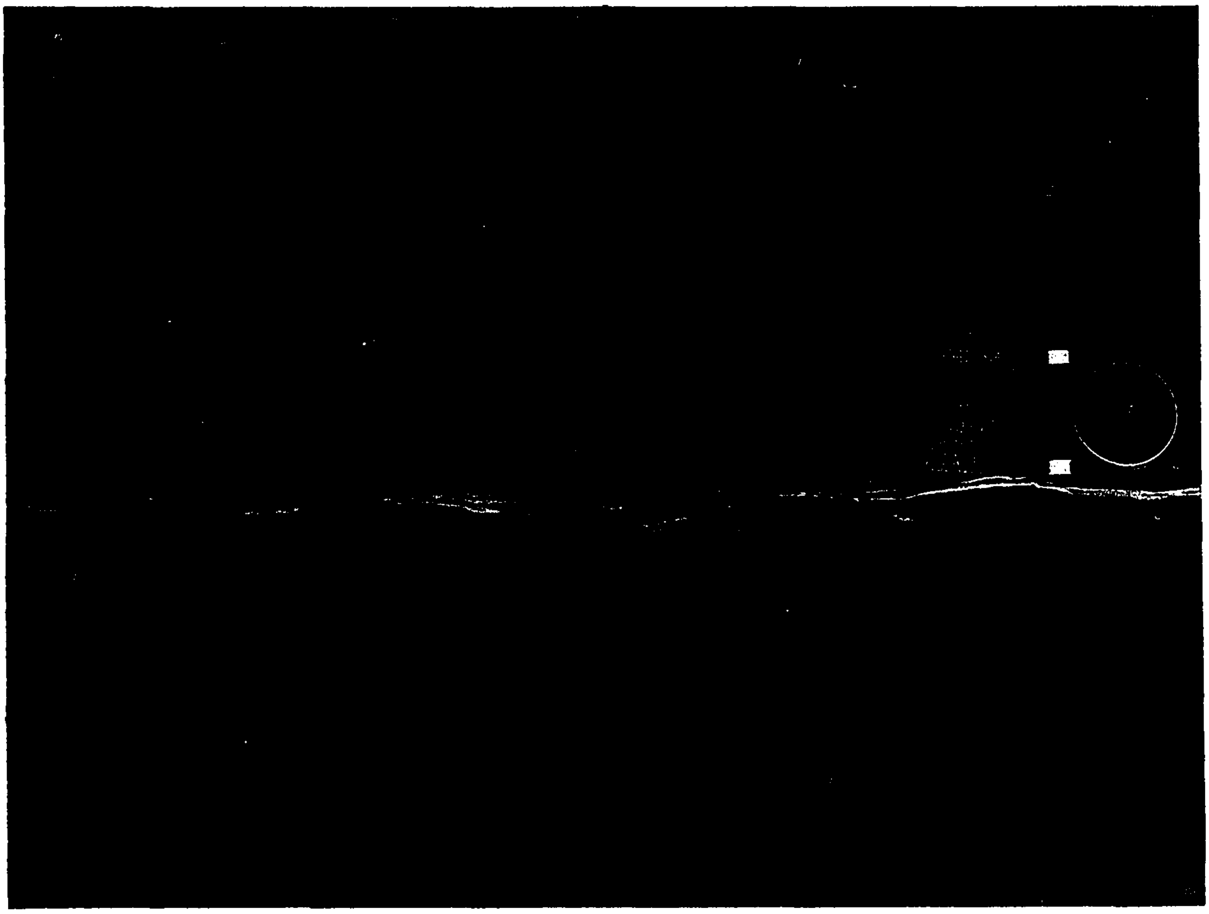


Fig. 24.- Rippled siltstone bed with T_{ce} Bouma sequence. Brallier Formation, Virginia Highway 16 section, unit 34 (Section 10, Appendix 3).

Fig. 25.- Flute molds. Brallier Formation, Bastian section, unit 40 (Section 9, Appendix 3). Current from upper right to lower left.

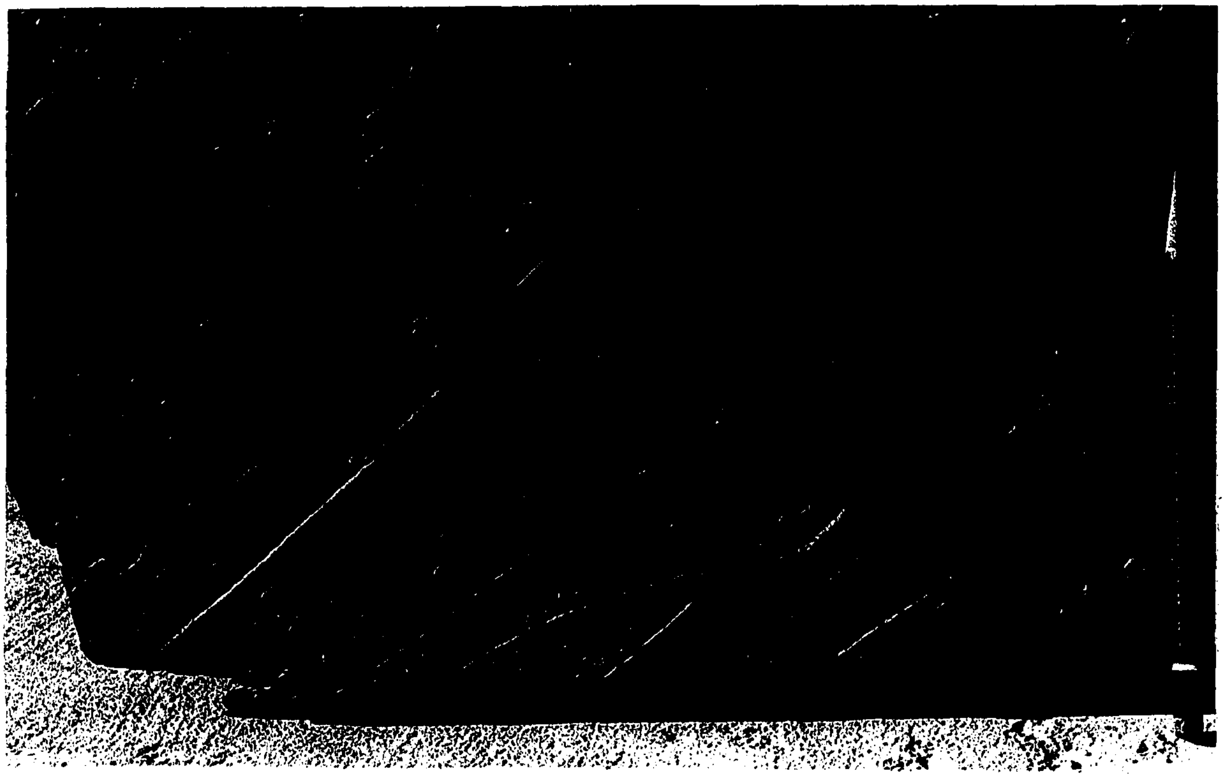


Fig. 26.- Groove molds. Brallier Formation, Bastian section, unit 40 (Section 9, Appendix).

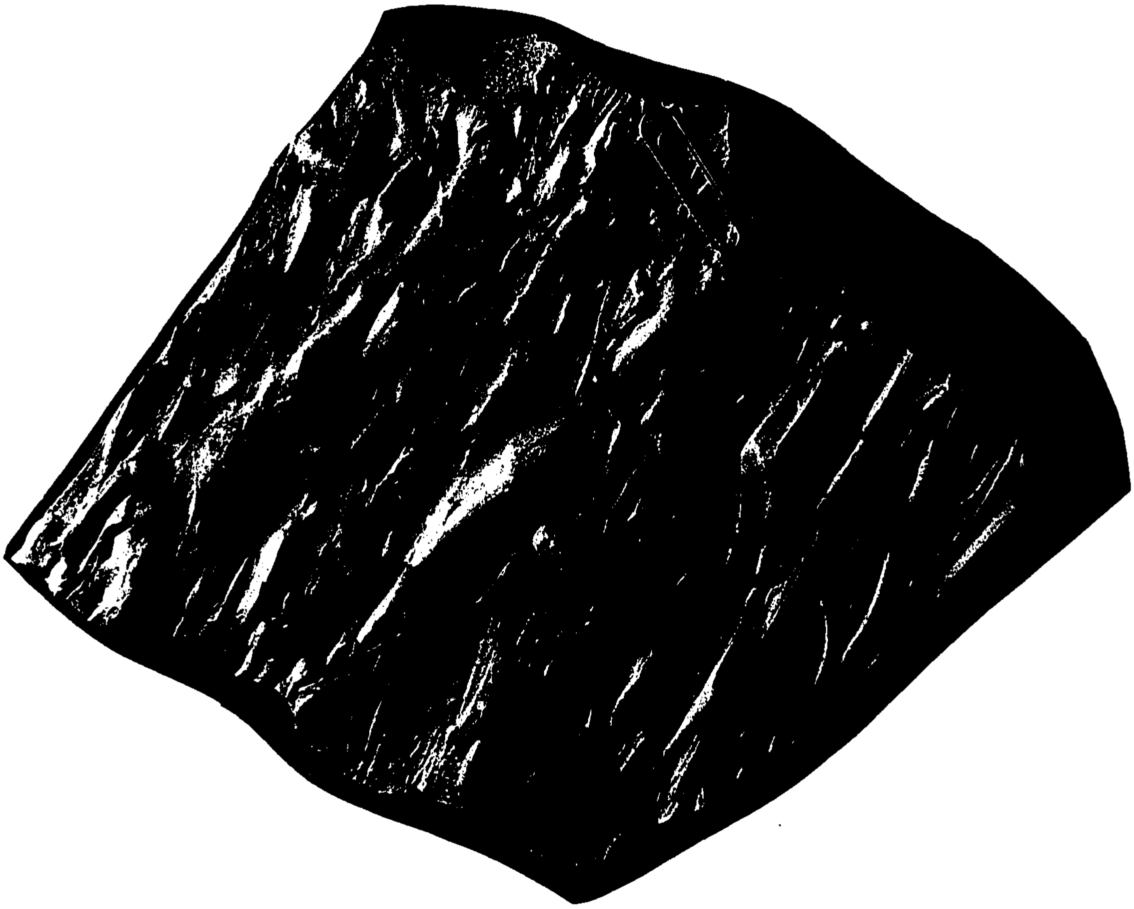


Fig. 27.- Prod and bounce marks. Brallier Formation, Bastian section, unit 40 (Section 9, Appendix 3). Current from upper right to lower left.

Fig. 28.- Ridge and furrow structure. Brallier Formation, Marion section, unit 5 (Section 12, Appendix 3). Current is from upper right to lower left.

Fig. 29.- Load casts. Brallier Formation, Marion section, unit 5 (Section 12, Appendix 3). Current from upper right to lower left.

as hypichnial ridges (Martinson, 1970) which resemble the genus Paleophycus (Fig. 30). They are straight, non-branching, less than 10 cm long, up to 1 cm wide, and less than 5 mm in relief. Individual ridges taper into the bed at their ends and commonly intersect one another.

Siltstone beds of the Brallier Formation show a variety of internal sedimentary structures, which in single beds are arranged in partial Bouma (1962) sequences (Fig. 31). Experimental evidence indicates that with increasing flow regime silts progress through the same sequence of sedimentary structures as do sands, except that dunes may not develop (Rees, 1966; Southard and Harms, 1972; Mantz, 1978). Dune cross-bedding, however, very rarely occurs in turbidites anyway. The complete Bouma sequence (Fig. 31), rarely observed in the Brallier siltstones, consists of a structureless basal layer, *a*, which is generally graded, a lower division of plane lamination, *b*, a division of cross-lamination and/or convolute lamination, *c*, an upper division of plane lamination, *d*, and a pelitic division, *e*. In some situations the layer of turbiditic mud, *e*, can be distinguished from an overlying layer of hemipelagic mud, *f* (Hesse, 1975, Fig. 1). The partial Bouma sequences seen in the Brallier Formation are base-truncated (Fig. 32), that is the *a*, or the *a* and *b* divisions of the Bouma sequences are absent. The Bouma sequence of sedimentary structures is characteristic of turbidites and has been experimentally related to stratification sequences produced by deposition from a steadily decreasing flow regime (Simons, and others, 1965, Fig. 21). In addition, it correlates with a decreasing rate of deposition and an increasing importance of traction (Middleton and Hampton,

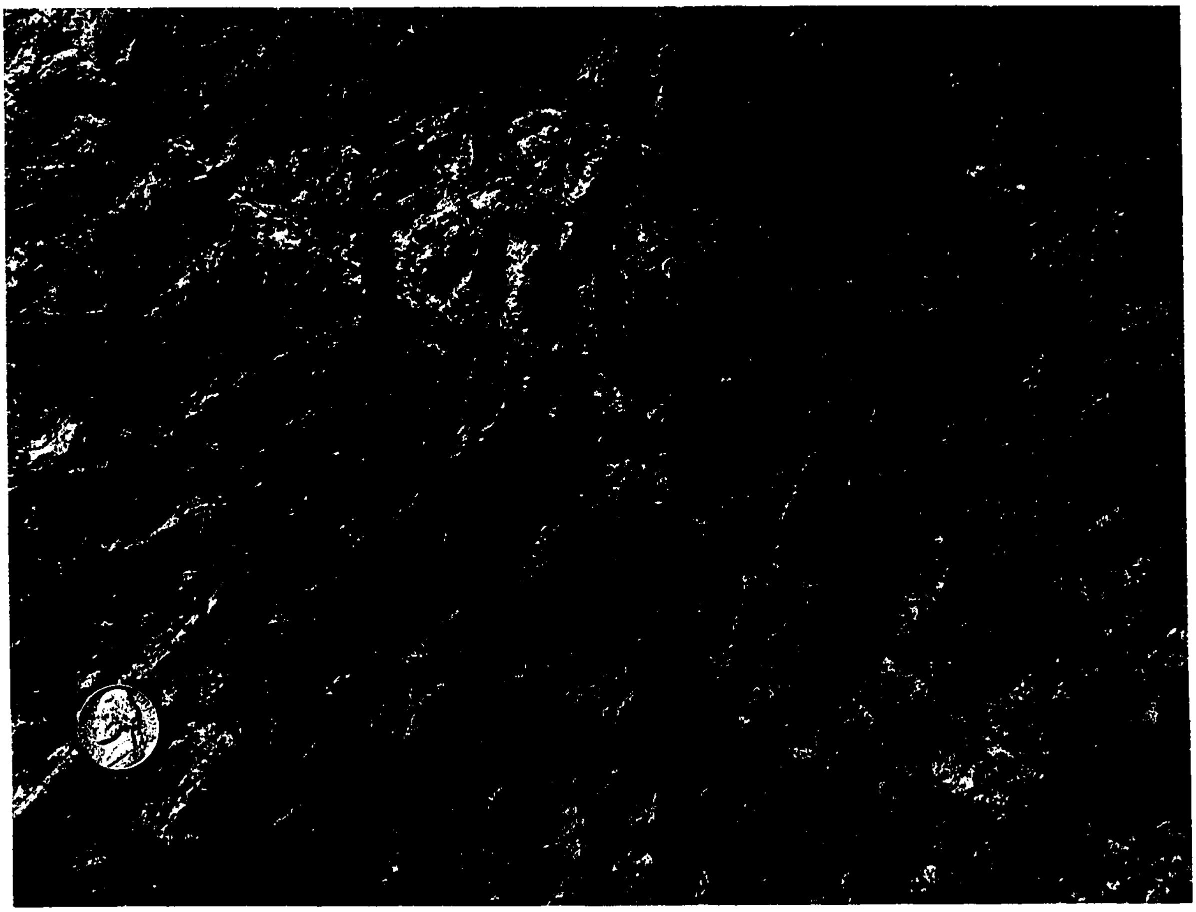


Fig. 30.- Hypichnial ridges resembling Paleophycus. Brallier Formation, Marion section, unit 5 (Section 12, Appendix 3).

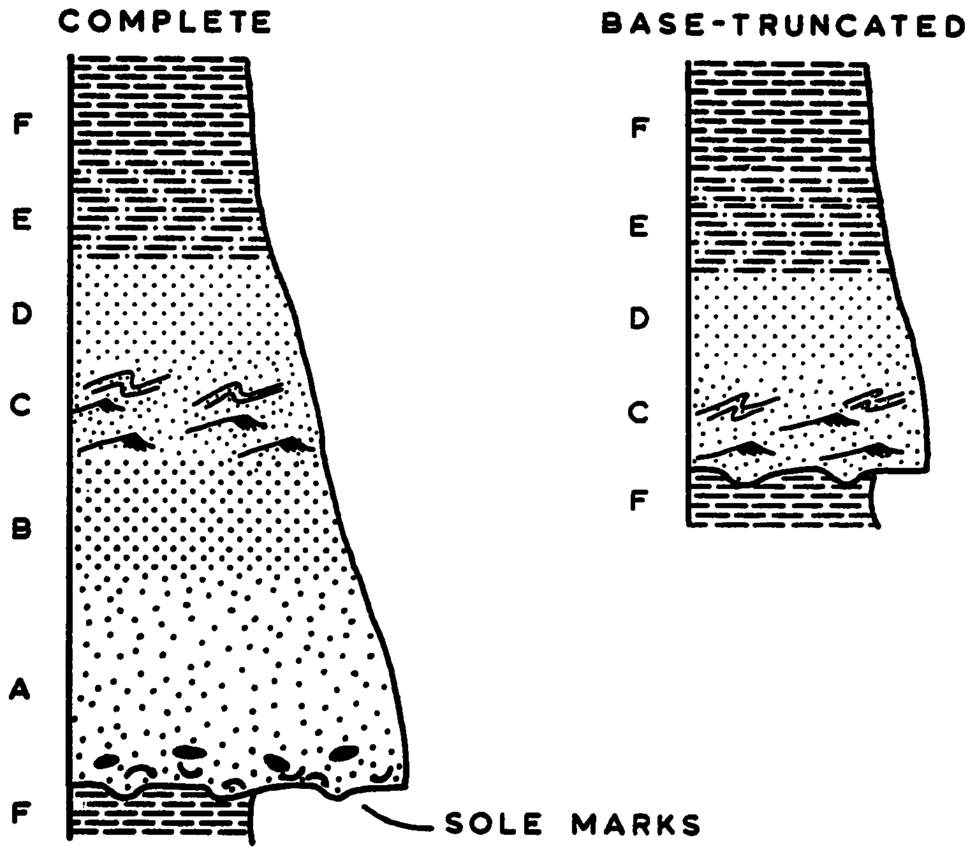


Fig. 31.- Idealized complete and base-truncated Bouma sequences. Divisions of Bouma sequence indicated at left. Sole marks, clay chips, and fossils may be present at base of bed.

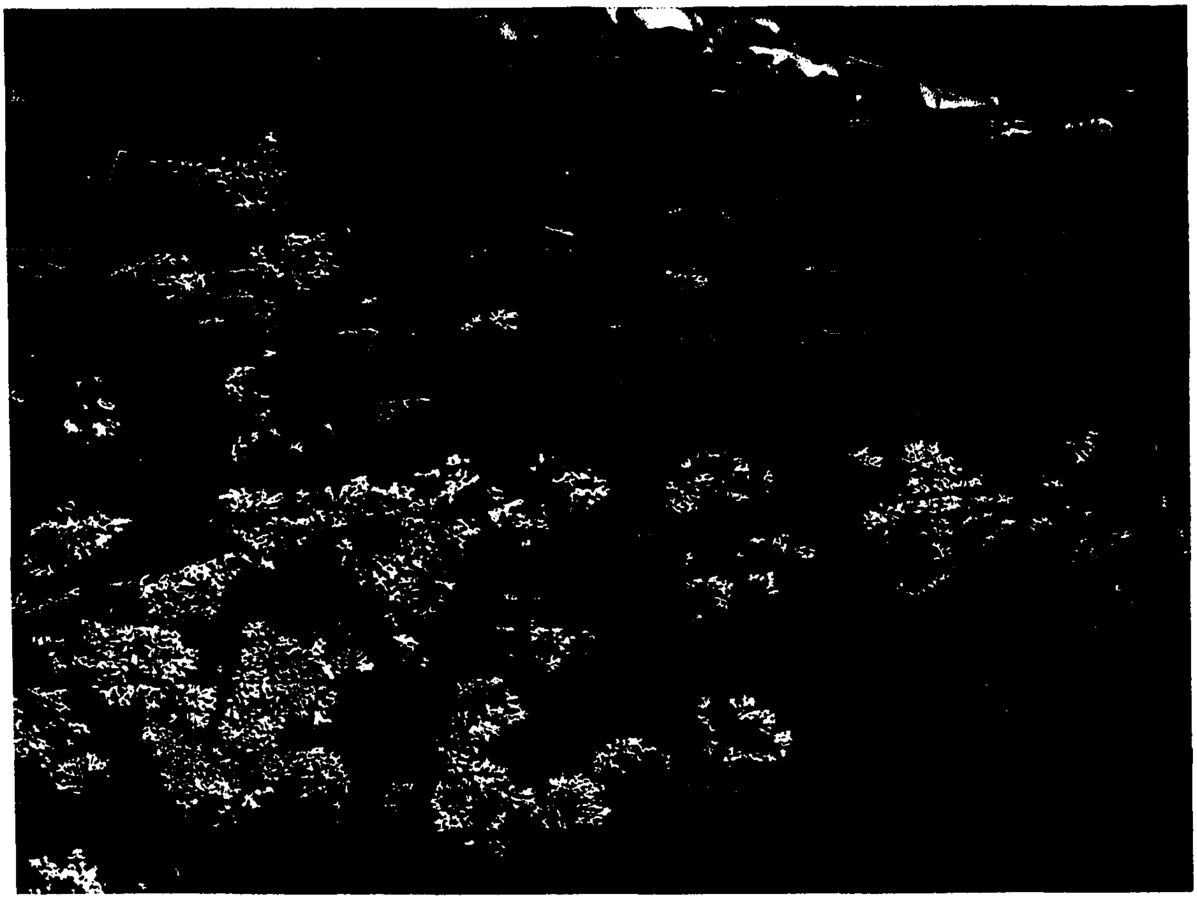


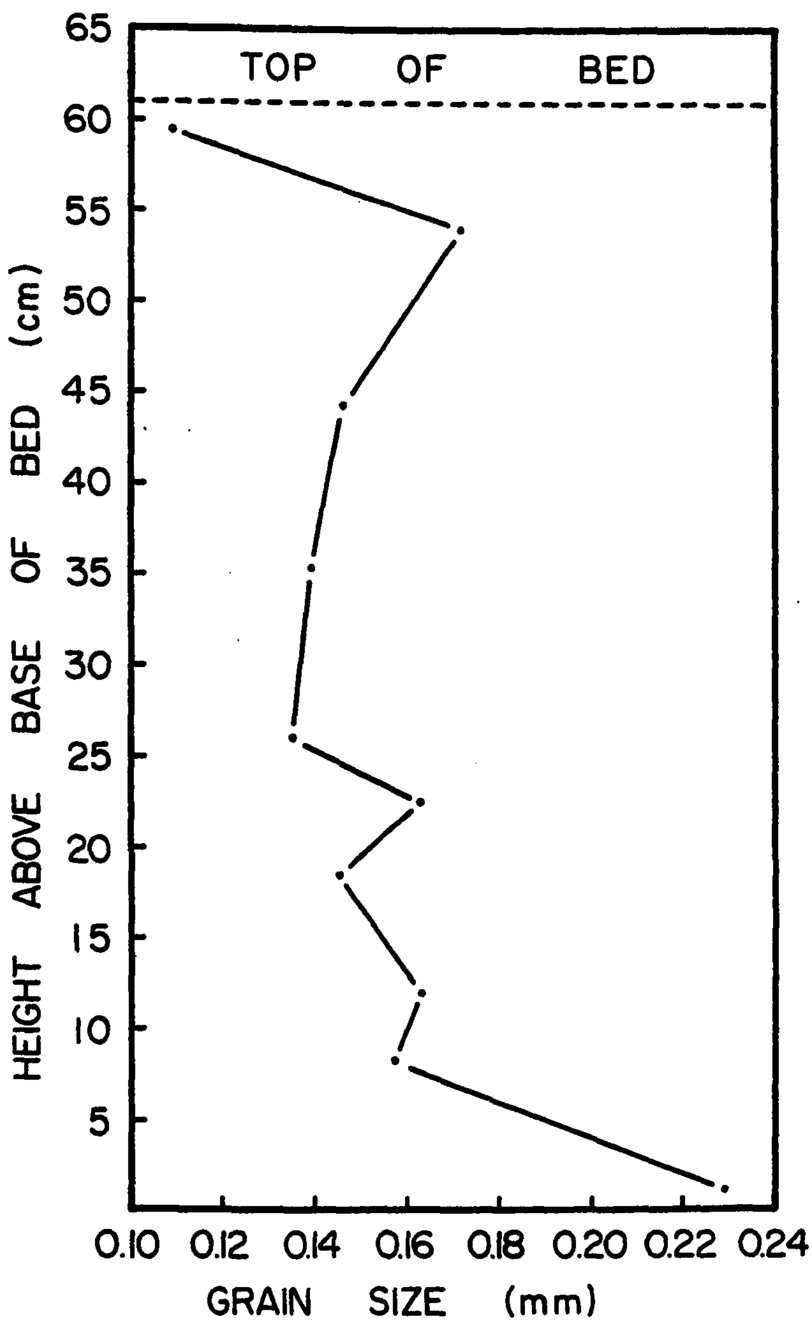
Fig. 32.- Sandstone bed showing a T_{bcde} Bouma sequence. Brallier Formation, Cloyds Mountain section, unit 14 (Section 5, Appendix 3).

1973, p. 12). From this knowledge it is possible, by analyzing the internal sequence of sedimentary structures in turbidites, to determine relative flow intensity. In general, the more divisions of the Bouma sequence which are absent at the base of a bed, the lower the flow regime at the time of deposition.

Grading is obscure or lacking in most siltstones of the Brallier Formation (Fig. 33). This is probably because of the limited grain size present. With a maximum grain size of only coarse silt or very fine sand the possibility of size separation or development of textural contrast is limited. Even the "Chemung" Formation which probably represents the proximal source facies of the Upper Devonian turbidites is relatively fine-grained (very-fine to medium sand). In outcrop, grading in Brallier siltstones is expressed by a decrease in parting thickness upward in the bed and a top contact which is gradational with the overlying shale. One instance of inverse grading (an upward increase in grain size) was observed. The bed was 21 cm thick and consisted of a structureless basal portion which graded upward into faint lamination and finally into pronounced laminae of alternating coarse and fine grained material. The inverse grading and occurrence of this bed in proximal facies suggest it is a grain flow deposit.

The lower division of plane lamination is common in Brallier Formation siltstones. It consists simply of millimeter thick laminae of slightly different texture. Parting lineation may also be associated with this division (Fig. 34).

Fig. 33.- Plot showing coarse fraction grading in siltstone bed. Brallier Formation, Bastian section, unit 2 (Section 9, Appendix 3).


TOP OF BED
HEIGHT ABOVE BASE OF BED (cm)
65
60
55
50
45
40
35
30
25
20
15
10
5
0.10 0.12 0.14 0.16 0.18 0.20 0.22 0.24
GRAIN SIZE (mm)

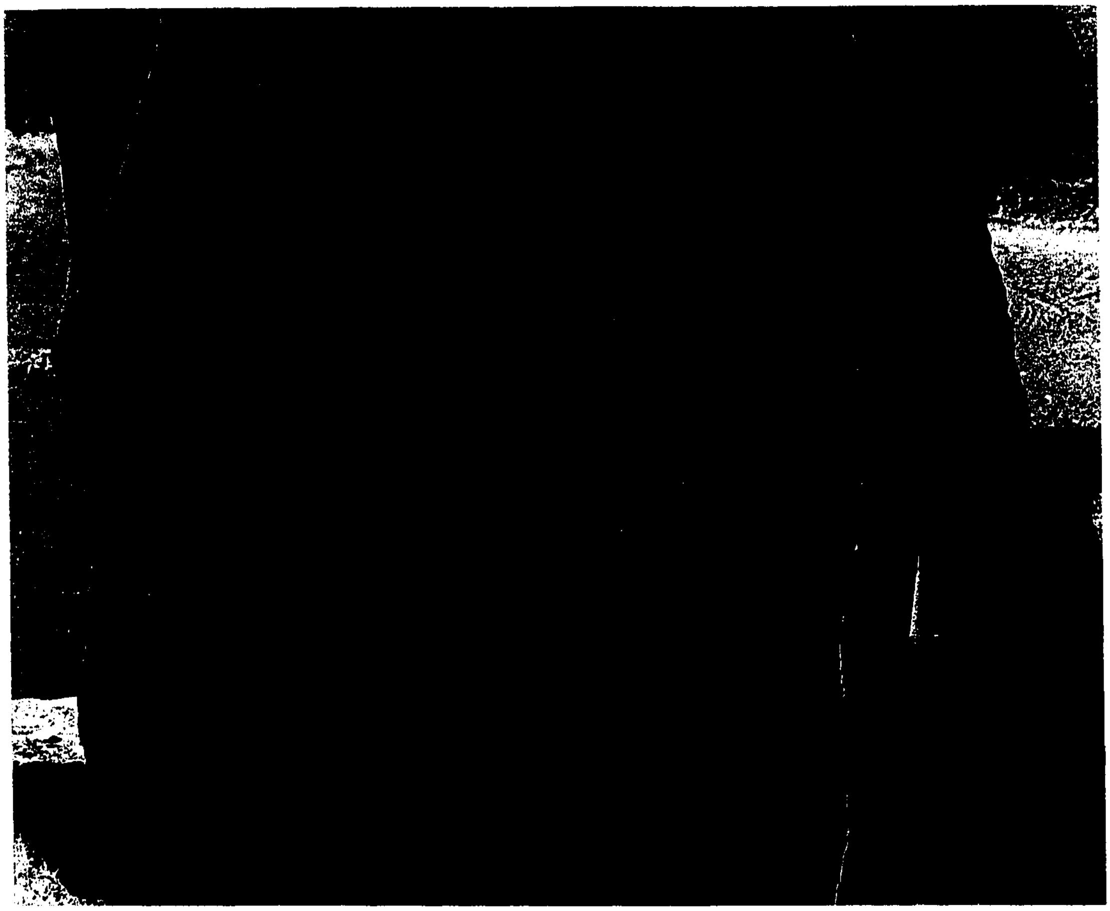


Fig..34.-- Parting lineation in Bouma *b* unit. Brallier Formation, Bastian section, unit 40 (Section 9, Appendix 3).

Cross-lamination of division *c* is ubiquitous and shows tangential trough geometry. It is the product of linguoid ripples which are preserved on the top surface of many beds (Fig. 21). Sets of cross-lamination are 1 to 2 cm thick. Convolute lamination is rarely present in division *c*.

The upper division of plane lamination, division *d*, was rarely observed in the siltstones of the Brallier Formation. I feel that its absence, however, may be more apparent than real. Where it was observed, it showed a tendency to weather to a "shaly" recess, hence it frequently may have been overlooked and considered as part of the "shale" interbeds.

Grazing traces are common the top surfaces of siltstone beds (Fig. 35). Inclined feeding burrows within the siltstone beds are less common and largely restricted to the upper part of the Brallier Formation. These include Cylindrichnus (Fig. 36), Teichichnus, and tubular burrows up to 1 cm across which are straight or curved and sometimes branching. Both Cylindrichnus and Teichichnus are clay filled while the third type may be clay or silt filled.

Mudstone, Claystones, and Shales

I found no criteria which could be used to distinguish turbiditic and hemipelagic pelitic layers in the Brallier Formation. The common occurrence, however, of siltstone beds which grade upward into finer-grained lithologies suggests that at least part of the shales, mudstones, and claystones are of turbiditic origin. The siltstones which

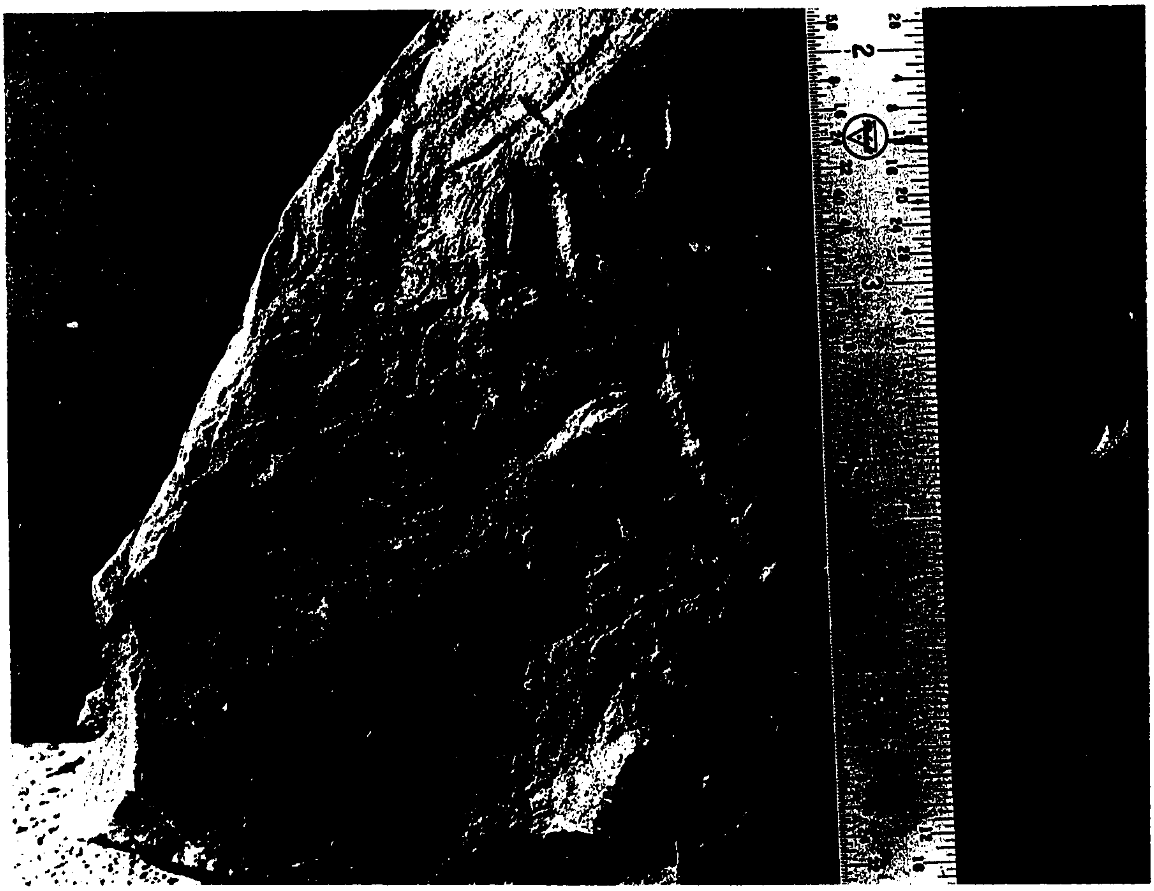


Fig. 35.- Grazing traces on upper surface of rippled siltstone bed, Brallier Formation, unit 40 (Section 9, Appendix 3).

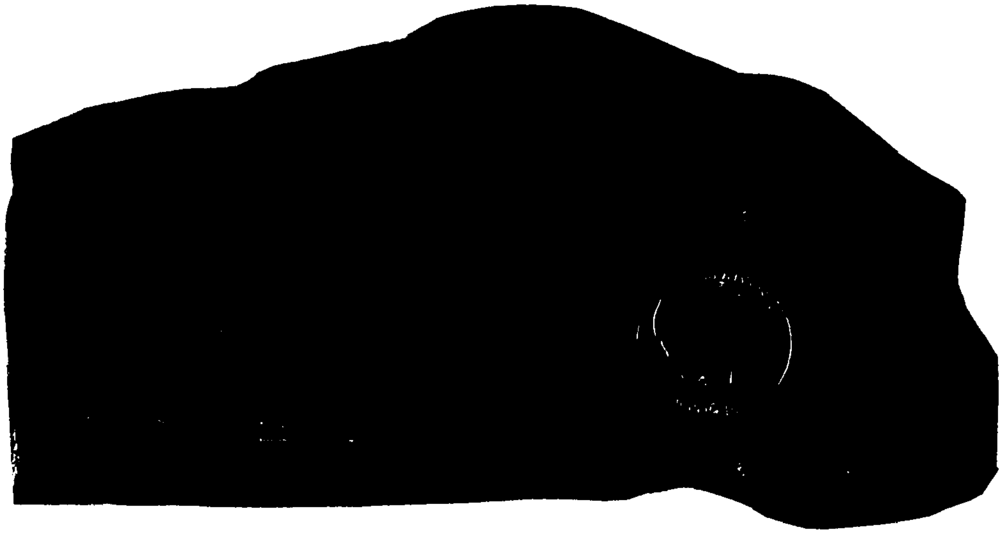


Fig. 36.- Trace fossil Cylindrichnus in siltstone bed. This trace is believed to be a feeding burrow. Note longitudinal striations in clay fill of burrow. Brallier Formation, Bastian section, unit 40 (Section 9, Appendix 3).

are interbedded with dark gray or black shales typically have sharply defined upper contacts, perhaps suggesting that these shales are hemipelagic. Olive gray mudstones in the Brallier generally show evidence of bioturbation which could indicate slow, hemipelagic deposition or simply that other conditions favorable for a burrowing infauna existed.

Mudstones in the Brallier are typically olive gray, part with a hackly edge into subconchoidal pieces, and by definition lack any sort of lamination. Bioturbation is very common. The burrows are small (less than 1 cm wide), horizontal, and some resemble the trace fossil Pteridichnites biseriatus. The siltier mudstones form resistant faces in outcrop and locally show spheroidal weathering. In places mudstone occurs with non-bedded siltstone identical to the mudstone except in silt content. Locally a small number of Ambocoelia sp. brachiopods are present in the mudstone.

Claystones are similar to the mudstones except in silt content and are less resistant to weathering. They are mostly olive gray but highly bioturbated yellowish gray to light gray claystones occur as well. In these claytstones biolamination is common.

Brallier shales range from nearly silt-free clayshales to very silty mudshales. All three types of lamination discussed earlier occur in the shales of the Brallier Formation but textural lamination is by far the dominant type. Next in abundance are laminae of quartz silt. Most of the shales are olive gray but dark gray to black shales are very common in southwestern Virginia and predominate in the eastern Tennessee exposures of the Chattanooga Shale. The dark gray and black shales have less disseminated silt, thinner more even parting, and better developed textural lamination than do the olive gray shales. Burrowing is also more common in the olive gray shales.

Laminae of quartz silt are abundant in some shales of the Brallier Formation, especially in southwestern Virginia, and in the gray silty shale unit of the Chattanooga Shale in east Tennessee (Fig. 37). Very little work has been done on the origin of silt laminae in shales, even though they are exceedingly common and occur in shales from a variety of depositional environments. Compared to sandstones, the study of sedimentary structures in very fine grained sedimentary rocks is only nascent. However, as their association with energy resources becomes more apparent research in this field is sure to become more active.

What can be said about the origin of silt laminae in the shales of the Brallier Formation? Several lines of evidence indicate they are neither simple pelagic deposits nor layers of windblown silt as suggested for laminae occurring in the Chattanooga Shale of central Tennessee by Conant and Swanson (1961, p. 54). Furthermore, I believe these laminae are more likely the distal and/or lateral equivalents of turbidite siltstone beds.

The silt laminae in the shales of the Brallier Formation are likely either windblown, pelagic, or turbiditic, hence these three origins are considered in detail below. But first, what are the salient features of the silt laminae in question?

Table 8 summarizes the characteristics determined for the silt

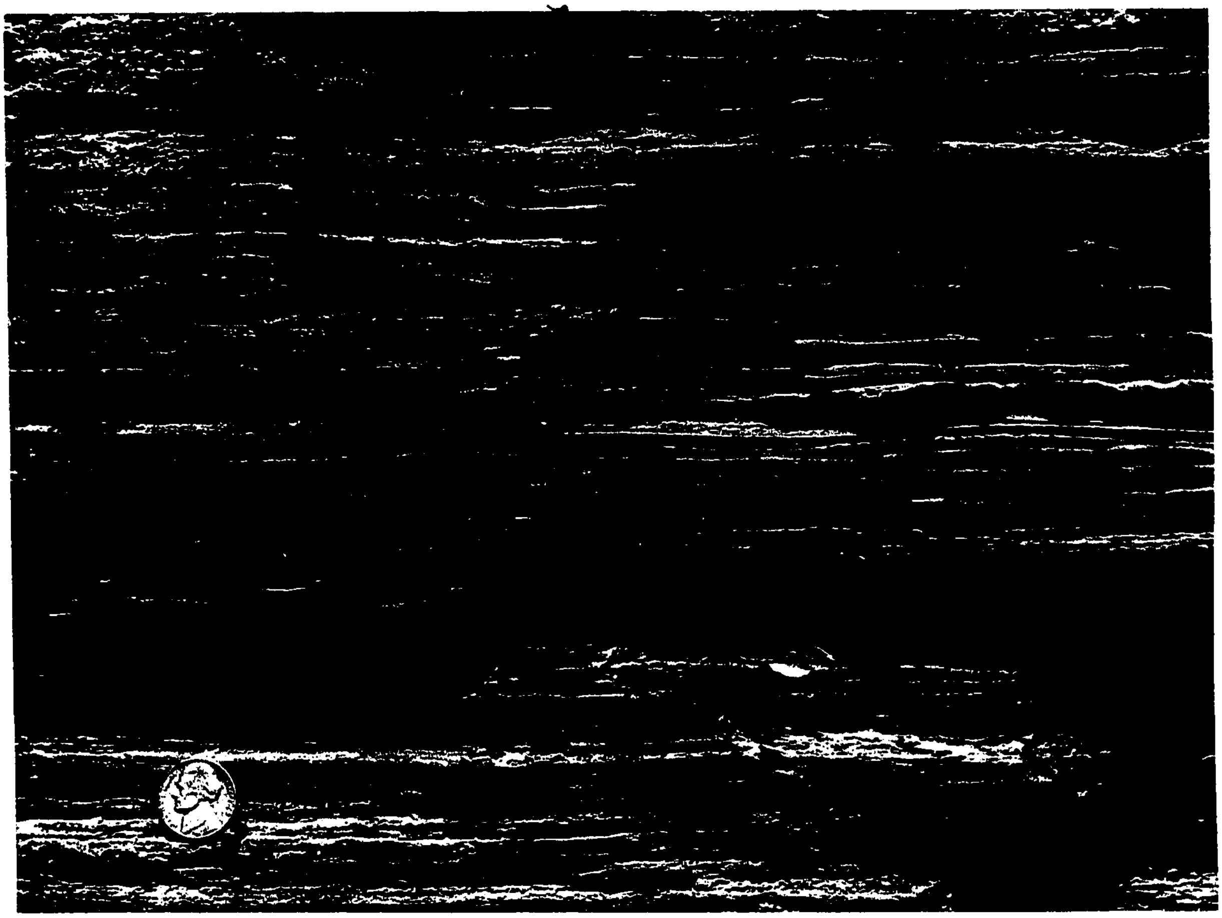


Fig. 37.- Silt laminae in mudshale of gray silty shale unit of the Chattanooga Shale. Note evenness and persistence of laminae. Flat Gap section, unit 2 (Section 21, Appendix 3).

TABLE 8

CHARACTERISTICS OF SILT LAMINAE IN BRALLIER FORMATION SHALES

Grainsize	Maximum grainsize ranges from 32 to 187 μ and averages 76 μ (s.d. = 36μ).
Thickness	Averages 0.3 mm. Predominantly 0.07 to 0.6 mm.
Continuity	Mostly continuous in thin section and hand specimen.
Contacts	Sharp in hand specimen. Sharp to gradational in thin section; upper contact most commonly gradational.
Geometry	Predominantly even but some pinch and swell.
Structure	Predominantly structureless. A few graded lamina and graded groups of laminae. Thickest laminae may show cross-lamination.

laminae. Observations of laminae thickness and abundance were made at outcrops, in hand specimens, and in thin section. The nature of laminae contacts was primarily studied in thin section. Maximum grain size was also determined in thin section by measurement of the ten largest grains.

With the exception of loess deposits (Smith, 1942) and desert sand dunes (Bagnold, 1973), sedimentologists have failed to adequately investigate the competency of winds to transport sediment. A few studies of windblown particles have been made however, by workers in the soil and atmospheric sciences (Prospero and Carlson, 1972; Jackson and others, 1971). These studies are basically of two types, studies of aerosols directly sampled and studies of sedimentary particles interpreted to be of windblown origin. Some questions relevant to the recognition of windblown silt laminae in ancient rocks are, what is the competency and capacity of wind to transport particles in suspension, what size distributions do aerosols have, and what conditions are required for the entrainment of sediment by wind, i.e., what must the source area be like?

For sediment to be carried out to sea by wind, it must be moved in suspension (sedimentary particles do not saltate very well on the surface of water). It is therefore the characteristics of particles transported in this manner that are of interest. Aerosols are suspensions of solid particles or liquids carried by a gas. Compared to the eolian deposits of desert or coastal dunes, aerosols are very fine grained. The difference in size reflects the difference in transport mechanism. In forming dunes, wind transports particles in saltation or intermittent suspension, while the particles of aerosols are transported only in suspension. Limited data indicate that in aerosols, 80 percent of the particles are typically finer than 20 microns in diameter and maximum grain size of aerosols seldom exceeds 60 microns (Rex and Goldberg, 1958; Pitty, 1968; Rex and others, 1969; Jackson and others, 1971; Prospero, written communication, 1978). The range of particle sizes in aerosols and in the silt laminae of Brallier shales overlap (Table 8), but the laminae in the shales tend to be coarser grained. The difference however, is not sufficient to rule out a windblown origin.

The extant literature clearly indicates that significant amounts of sediment can be entrained by wind only in arid regions. Windom (1975) reviewed the eolian contribution to four major basins of the World Ocean: the Equatorial North Atlantic, the North Pacific, the South Pacific, and the Indian Ocean. In each case, an arid source area is indicated for the windblown sediment. The Equatorial North Atlantic receives airborne dust from the Sahara Desert; the North Pacific from arid regions in Asia; the South Pacific from Australian deserts; and the Indian Ocean is supplied with dust from the arid west coast of Australia. In the Sahara, and probably these other areas, heating of surface air causes deep convective mixing to heights of several thousand meters, and is responsible for the entrainment of dust (Prospero and Carlson, 1972). It appears that unless the Late Devonian source lands of the Appalachian basin were dry and hot, transport of significant amounts of sediment to the basin by wind would be unlikely. The ubiquitous occurrence of wood fragments in these Upper Devonian rocks suggests the source lands were relatively moist and, hence, not a suitable source of windblown sediment.

The most likely kind of pelagic silt laminae which could be analogous to the laminae in the Brallier Formation are not deep sea abyssal deposits but prodeltaic ones. Furthermore, most quartz silt in abyssal deposits appears to be windblown (Rex and Goldberg, 1958; Prospero and Carlson, 1972). Prodeltaic deposits consist mainly of clay with silt laminae and stringers, which commonly show cross-lamination (Coleman, 1976, p. 73-89). Cross-lamination indicates traction and hence such layers cannot be entirely pelagic in origin. Pelagic silt laminae may be produced in prodeltaic settings following high river discharges. It is doubtful that laminae produced in this way would be any different from turbidite silt laminae. In both cases the depositional mechanism is that of settling of grains from a cloud of suspended sediment. Grading may be expected to develop in the deposition of both pelagic and turbidite silts. Turbidite silt laminae may possibly be distinguished by having sharp erosional bases but this is speculative. Piper (1978) described features of turbidite silts which may be helpful in their identification, but probably the best criteria for distinguishing pelagic and turbidite silt laminae are their vertical and lateral associations.

Some of the silt laminae in these Upper Devonian shales are graded. The grading, best developed in the shales of east Tennessee and extreme southwest Virginia, consists of both an upward decrease in the size of quartz silt and upward increase in clay matrix. Grading of individual silt laminae, however, is not indicative of any particular depositional mechanism. Silt populations introduced by wind, delta plumes, or turbidity currents, will all produce graded laminae as the different size grains settle out of suspension. In addition to graded individual laminae there are graded groups of laminae, analogous to Piper's (1977, p. 166) division E1 of turbidite muds. Piper (1977, p. 170) discounts a bottom current origin for such graded sets because they would require an unusually regular pattern of bottom current flow in terms of velocity/time relationships. In the TDG-DOE-4 core, siltstone layers identical to Piper's (1977) Type 1 turbidite silt (graded sorted medium and coarse silt; Fig. 38) were found in an interval probably time equivalent to the lower part of the Flat Gap section (Section 21, Appendix 3) in which silt-laminated shales and turbidite siltstones occur. I should point out that the features described above do not represent the typical occurrence of silt laminae in these shales. Isolated ungraded laminae are by far more abundant. While the similarity of these examples with turbidite muds and silts does not constitute proof of their origin, it does suggest one compatible with our meager knowledge of fine-grained rocks.

Relationships in the Brallier Formation indicate how a turbidite bed can "pinchout" into silt laminae in shale. I have already discussed how, as turbidity currents decay, they form progressively fewer

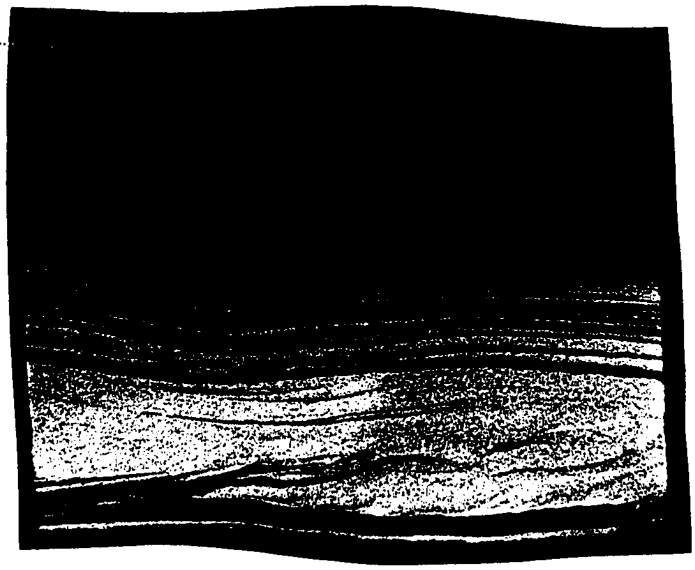


Fig. 38.- Sample of Chattanooga Shale resembling type 1 turbidite silt of Piper (1978). Note the T*cde* Bouma sequence and upward decrease in thickness and abundance of silt laminae. Sample is 4.7 cm side. TDG-DOE-4 core, 391.1.

of the basal divisions of the Bouma sequence, so that in the down current direction the beds deposited become increasingly base-truncated. The same changes also occur laterally. Figure 39 shows a T_{abcde} siltstone bed in which the *d* division of the Bouma sequence is well developed and consists of interlaminated siltstone and shale. At the margins of such a bed the *a*, *b*, and *c* units will be absent and its only expression will be a few thin silt laminae of division *d*.

At Flat Gap, Tennessee (Section 21, Appendix 3) a coarsening- and thickening-upward sequence (units 1 through 9), begins at the base with shale containing a few thin silt laminae, followed by shale with many thicker silt laminae, followed by distinct beds of turbidite siltstone. This transition occurs within 30 m of section. The turbidite siltstone bundle at Flat Gap passes laterally into shale with silt laminae (Plate 2, in pocket), identical to the shales which underlie the bundle at Flat Gap. These vertical and lateral relationships suggest that the turbidite siltstone beds and the silt laminae in the shale have genetic affinities, specifically, that the silt laminae are the distal and lateral equivalents of turbidites.

Fig. 39.- Siltstone bed with T*abcde* Bouma sequence. Note upward decrease in thickness and abundance of silt laminae in Bouma *d* unit. Sample is 8 cm wide. Brallier Formation, Hayters Gap section (Section 14, Appendix 3).

FACIES

Facies analysis has proven useful in interpreting the origin, distribution, and internal relationships of the Brallier Formation as well as the entire Upper Devonian clastic sequence in the southern part of the Appalachian basin. This analysis is based on observations made during the measurement and description of twenty-three sections and at over fifty other localities where section was not measured. Additional data was collected from the two eastern Tennessee cores which were studied.

I have distinguished six lithofacies of the Brallier Formation and adjacent strata by gross lithology, silt/shale ratio, bedding thickness and character, and physical and biogenic structures. The names assigned to these facies are: delta front, turbidite slope, siltstone bundle, interlobe slope, lobe margin, and basinal black shale. Their salient features are summarized in Table 9.

Facies Interpretation

Delta Front Facies

High sand/shale ratio, thick beds, lenticular bedding (Fig. 40), crossbedding (Fig. 41), and abundant and diverse marine fossils in the sandstone beds of this facies (Table 9) indicate a shallow, current-agitated environment. Fossils include abundant crinoids and brachiopods, and fewer molluscs. Common coquina lenses at the base of cross-

TABLE 9

SUMMARY OF FACIES

FACIES	LITHOLOGY AND THICKNESS	SILT/SHALE	COARSE-GRAINED BED THICKNESS (MODE AND RANGE)	SEDIMENTARY STRUCTURES
Delta front	Fine sandstone to siltstone and olive gray mudstone. 10's - 100's of m.	Moderate to very high	$\bar{X}$ 30 cm R 10 cm - 2 m	Lenticular to irregular bedding, cross bedding, fossiliferous (moderately abundant and diverse), coquinas common. Coarsening and thickening-upward sequences.
Turbidite slope	Siltstone and olive gray mudstone or shale. 3 - 30 m.	Low to high	$\bar{X}$ 6 cm R 1 - 30 cm	Even persistent beds with base-truncated Bouma sequences (*Tbcde*, *Tcde*) common, tops of beds commonly rippled, organic and inorganic sole marks very common. Coarsening- and thickening-upward sequences in upper Brallier Formation.
Siltstone bundle-Channel deposit?	Siltstone to very fine sandstone with minor shale. 5 - 22 m	High to very high	$\bar{X}$ 10 cm R 2 cm - 1.5 m Beds greater than 30 cm are characteristic.	Even, sharply defined beds; structureless non-graded beds common; *Ta*, *Tab*, and *Tabc* Bouma sequences; tops of beds may be rippled and slightly gradational with shale; shale clasts and bed amalgamation common; wood fragments common; sole marks generally uncommon; rare load structures. Most bundles show fining- and thinning-upward sequences.
Interlobe slope	Olive gray mudstone and minor shale 3 - 60 m	0 to very low	$\bar{X}$ 3 cm R 1 - 10 cm	Mudstone: distinct horizontal burrows, 3-5 mm wide, some resembling Pteridichnites biseriatus; Ambocoelia sp.; Siltstone: base-truncated Bouma sequences (*Tcde*, *Tde*; tops of beds commonly rippled.
Lobe margin	Olive gray to dark gray silt-laminated shale, and minor yellowish gray burrowed claystone. 15 cm - 210 m	0 to very low	Less than 3 cm, if present. Silt laminae 1-2 mm thick are very common.	Shale: even, persistent silt laminae less than 2 mm thick are very common; siderite layers up to 2 cm thick locally common. Claystone: distinct to indistinct horizontal burrows less than 2 mm wide, giving mottled appearance where disseminated and biolamination where concentrated in layers.
Basinal	Black shale Up to 30 m	0 to very low	$\bar{X}$ 3 cm R 1.5 - 10 cm	Shale: dominantly clayshale with textural lamination; silt laminae less than 2 mm thick locally common. Siltstone beds, if present, generally have *Tce* Bouma sequences and rippled tops.

Fig. 40.- Delta front facies. Note high sand/shale ratio and thick beds. Brallier Formation, Cloyds Mountain section, unit 54 (Section 5, Appendix 3). Mattock handle is 1 m long.

Fig. 41.- Trough crossbedding in delta front facies sandstone. Brallier Formation, Cloyds Mountain section, unit 54 (Section 5, Appendix 3).

bedded strata indicate winnowing of the sea floor, and thickening- and coarsening-upward sequences (Plate 1, in pocket) indicate cycles of facies progradation. The delta front facies comprises the uppermost Brallier Formation and lower "Chemung" Formation. It is conformably overlain by non-marine red beds of the Hampshire Formation in the northern part of the study area and thins distally to the west and south. Delta front facies are not present in eastern Tennessee. Several shallow water nearshore environments have been recognized in similar strata of the Foreknobs Formation along the Allegheny Front in West Virginia (cited in McGhee, 1975, p. 133). These include shelf, sand bar, and bar protected environments.

Turbidite Slope Facies

Thin bedding, moderate to high silt/shale ratio, and base-truncated Bouma sequences in the siltstone beds of the turbidite slope facies (Table 9, Fig. 42) indicate that small to medium turbidity currents frequently interrupted the more or less continuous hemipelagic sedimentation of mud. The delta front facies overlies and is gradational with the turbidite slope facies which also thins distally and is absent in southwestern Virginia and eastern Tennessee. The turbidite slope facies is commonly recurrent in long stratigraphic sections and shows variable silt/shale ratios. Bed thickness and silt/shale ratio generally increase up section, indicating an increase in proximity to the source. This increase in proximity was accompanied by an increase in oxygenation of the water column as indicated by the

Fig. 42.- Turbidite slope facies. Note even, persistent siltstone beds. Brallier Formation, Cloyds Mountain section, unit 34 (Section 5, Appendix 3). Mattock handle is 1 m long.

occurrence of a few vertical feeding burrows in the siltstone beds. In the Upper Brallier Formation, thickening- and coarsening-upward sequences occur (Plate 1, in pocket), but elsewhere megasequences are poorly developed in the turbidite slope facies. Evidence for channeling appears to be absent in the turbidite slope facies. Soft bodied infauna were locally capable of reworking the mud deposited between turbidites, suggesting bottom conditions were generally dysaerobic. Sedimentary structures in the siltstone beds of the turbidite slope facies are typical of "distal" turbidites although stratigraphic evidence indicates some were deposited proximally.

Sedimentologic variation within the turbidite slope facies was investigated by utilizing a vertical-profile technique. A 36 m thick section of 630 siltstone beds was described in bed-by-bed detail. Individual beds range from less than 1 cm to 34 cm in thickness. For each siltstone-shale couplet (siltstone bed and its overlying shale bed) the thickness of both the siltstone and shale bed, as well as the sequence of sedimentary structures in the siltstone bed were recorded. These data were analyzed by making vertical profiles of proximity indices (Walker, 1967);[1] silt thicknesses, shale thicknesses, and couplet thicknesses.

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[1]Walker (1967) proposed the idea of a proximity index for turbidites. The ABC proximity index is defined as P = A + 1/2 B, where P is the proximity index in percent, A is the percentage of beds in a given group which begin with the Bouma *a* unit, and B is the percentage of beds in the group which begin with the Bouma *b* unit. A value of 100 percent indicates all the beds in the group begin with the Bouma *a* unit, while a value of 0 percent indicates all the beds in the group begin with either the Bouma *c* or *d* units. Proximity index is proportional to flow regime (see Simons and others, 1965, Fig. 21) and correlates in a general way with distance from source because of the gradual downcurrent decline in flow regime which causes an increase in base-truncated sequences.

The plots may be described as showing many random variations and several somewhat irregular megasequences (Figs. 43-46). Each of the four variables shows an overall decrease in value upwards. In this section the megasequences are predominantly of the thinning-upward type, or decreasing-upward in the case of proximity index. This is atypical of most occurrences of turbidite slope facies in the upper Brallier Formation. The correlation between the four parameters is variable. Silt and shale thicknesses (Figs. 44 and 45) show poor to good correspondence, perhaps suggesting that the shale interbeds are in large part hemipelagic. Silt and couplet thicknesses (Figs. 44 and 46) on the other hand show very good correspondence. This is to be expected because the section is mostly siltstone so that the couplet thickness is primarily determined by the thickness of the siltstone beds. Proximity index and silt thickness (Figs. 43 and 44) show a varying degree of correlation, ranging from strongly negative to strongly positive. The major cause of the discrepancies is the abundance of very thin strata which appear structureless, and are therefore assigned to the Bouma *a* division for the calculation of proximity indices. Where such strata are common, and they appear to be very common in sequences of silt grade turbidites (Piper, 1978), bed thickness is probably a much better "proximity" indicator than the ABC proximity index (proximity may refer to the ultimate source or to channels).

Megasequences in the turbidite slope facies of the Brallier Formation are generally less conspicuous than those figured by Walker and Mutti (1973, Fig. 13 and 14) in the flysch of northern England

Fig. 43.- Vertical profile of proximity index (Walker, 1967) calculated for 25 bed groups. Brallier Formation, Bastian section, unit 40 (Section 9, Appendix 3).

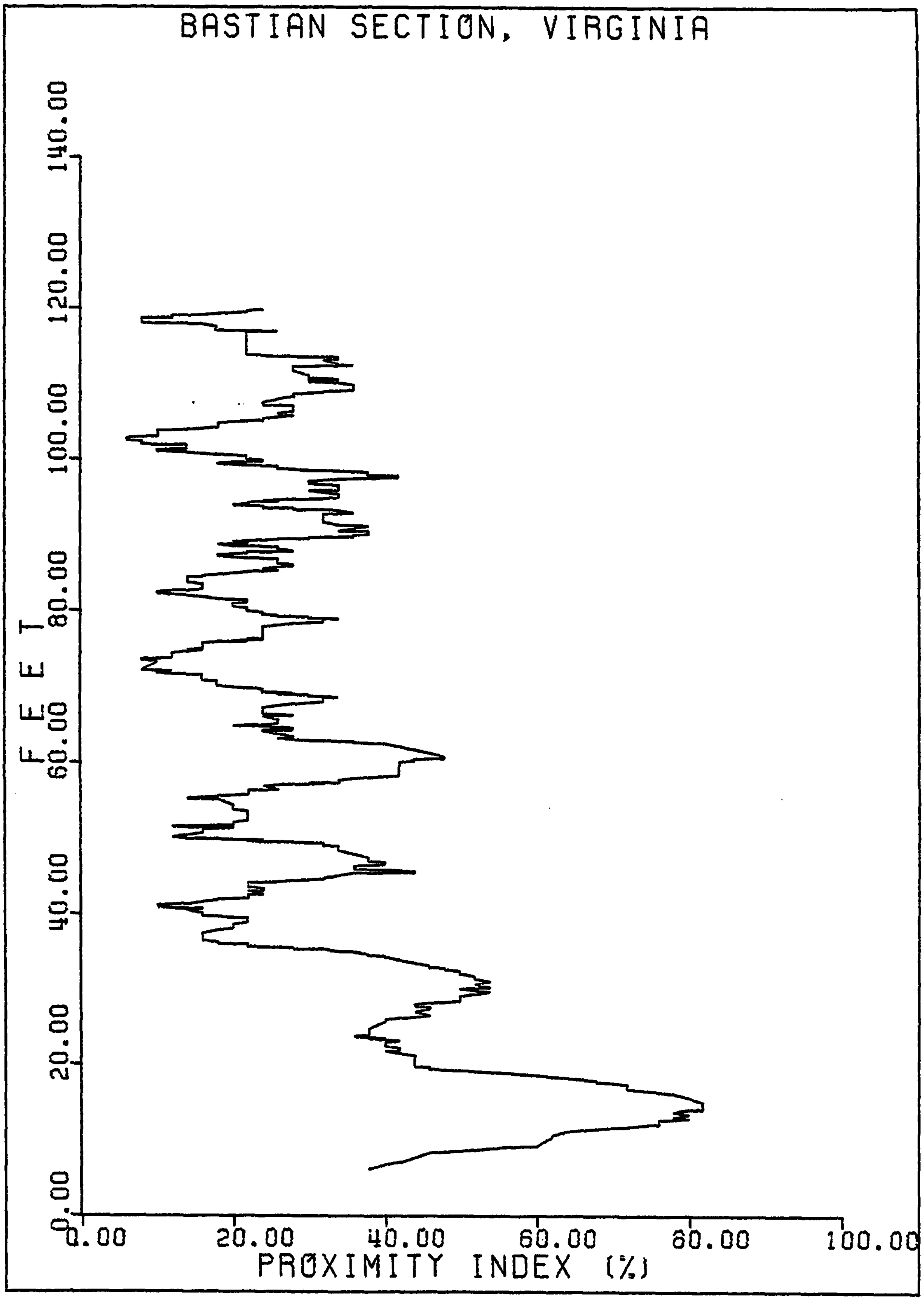

BASTIAN SECTION, VIRGINIA
FEET
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
0.00
20.00
40.00
60.00
80.00
100.00
PROXIMITY INDEX (%)

Fig. 44.- Vertical profile of siltstone bed thickness. Twenty five bed moving average. Brallier Formation, Bastian section, unit 40 (Section 9, Appendix 3).

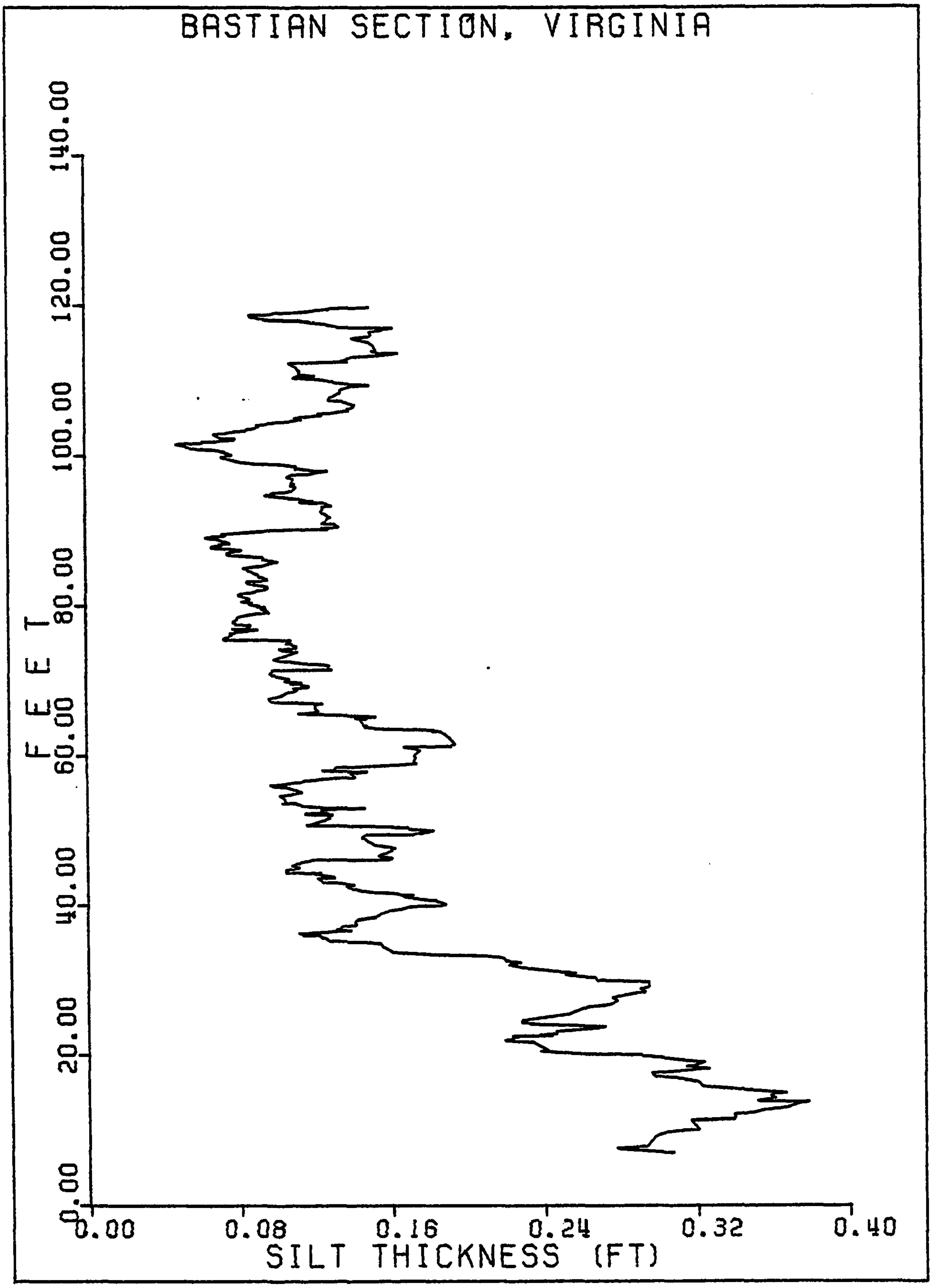

BASTIAN SECTION, VIRGINIA
FEET
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
0.00
0.08
0.16
0.24
0.32
0.40
SILT THICKNESS (FT)

Fig. 45.- Vertical profile of shale bed thickness. Twenty five bed moving average. Brallier Formation, Bastian section, unit 40 (Section 9, Appendix 3).

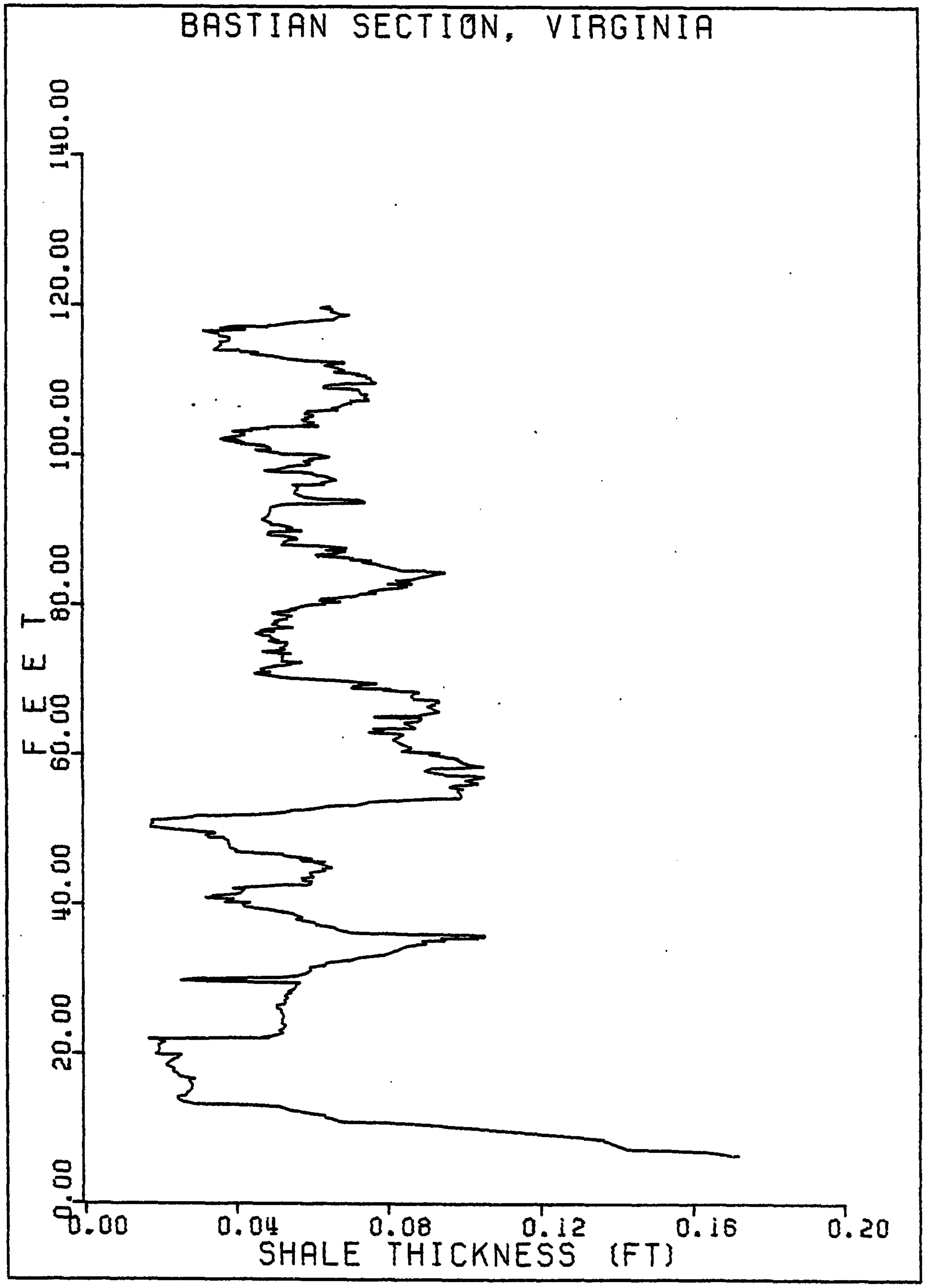
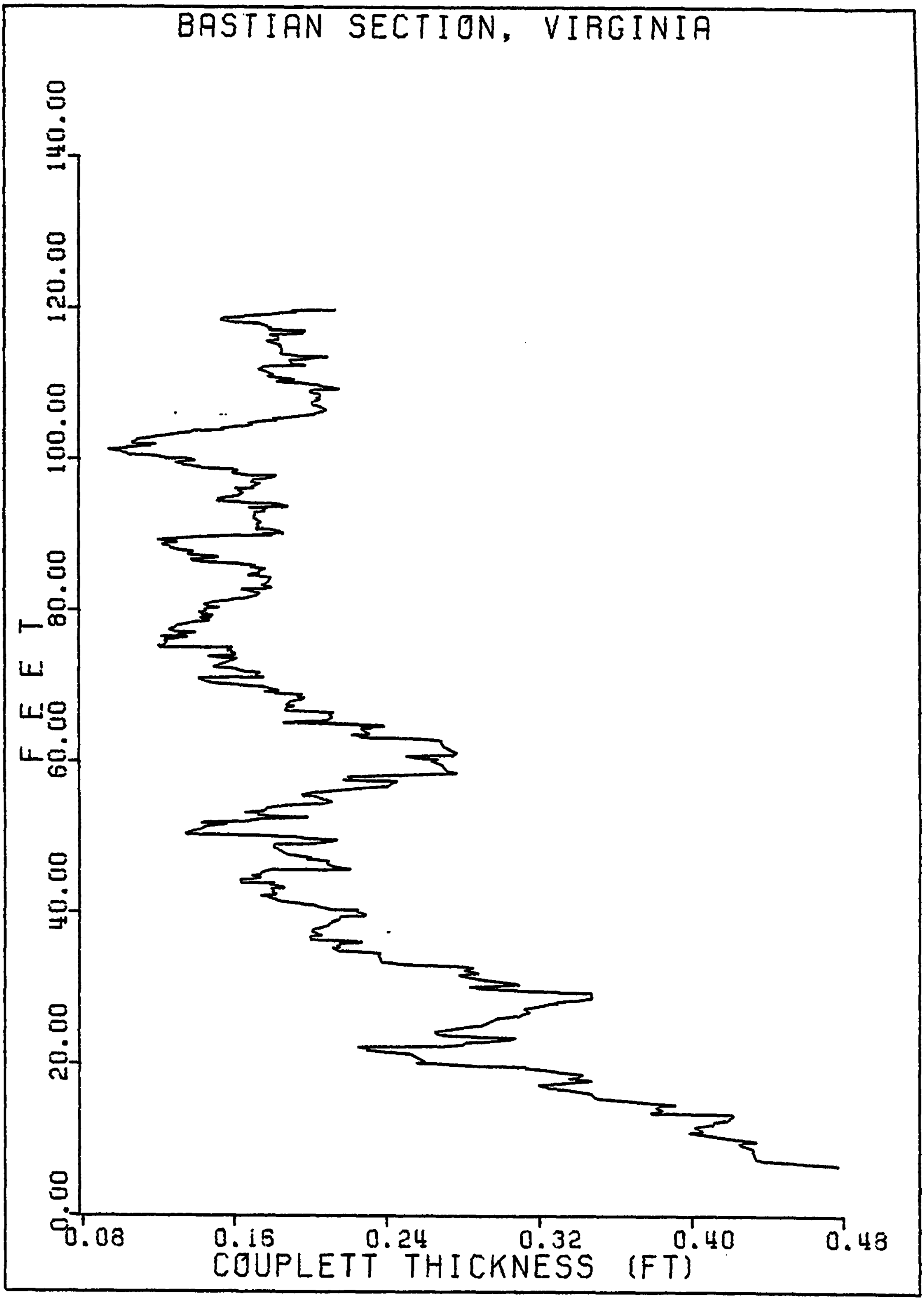

BASTIAN SECTION, VIRGINIA
FEET
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
0.00
0.04
0.08
0.12
0.16
0.20
SHALE THICKNESS (FT)

Fig. 46.- Vertical Profile of couplet thickness. Twenty five bed moving average. Brallier Formation, Bastian section, unit 40 (Section 9, Appendix 3).



BASTIAN SECTION, VIRGINIA
FEET
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
0.08
0.16
0.24
0.32
0.40
0.48
COUPLETT THICKNESS (FT)

and the northern Apennines of Italy. They involve less variation in bed thickness and grainsize, and do not appear to be associated with major channeling. Inasmuch as the development of megasequences requires either steady progradation in an area or migrating channels, these data suggest frequently shifting sediment lobes on the slope and few or shallow channels.

Siltstone Bundle Facies-Channel Deposits?

Thickly bedded siltstone bundles are common features of the Brallier Formation (Fig. 47) and occur throughout the section, although they are most common in the lower half. Individual bundles are 3 to 22 m thick and their lateral extent, parallel to depositional strike (estimated by tracing their topographic expression as linear ridges), is at most a few kilometers and less than 1 kilometer in most cases. Thick siltstone beds, high silt/shale ratio, top-truncated Bouma sequences, bed amalgamation, and the occurrence of shale clasts (Tables 9 and 10) collectively indicate rapid deposition from relatively large, high flow intensity turbidity currents. Sole marks are rare in the siltstone bundles (Section 12 is an exception), however, the capacity of the turbidity currents to erode the bottom is demonstrated by common shale clasts up to 25 cm long. The shale clasts in the siltstone beds are identical to the interbedded shales. In vertical profile the eight siltstone bundles which were described in bed by bed detail show predominantly thinning-upward sequences (Figs. 48-55). Upward decreases in proximity indices accompany the thinning-upward trends but are less well developed (Figs. 48-55). In as much as thinning- and fining-upward

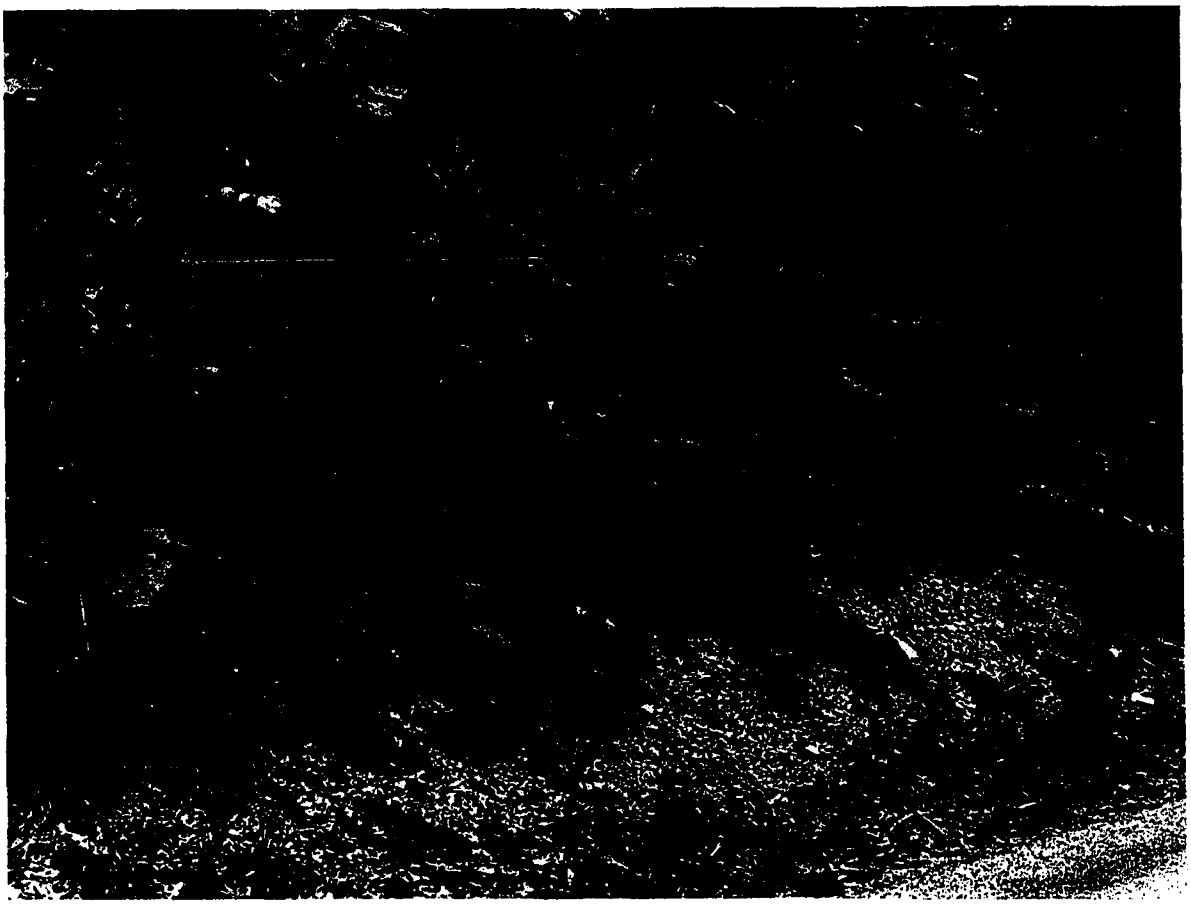


Fig. 47.- Turbidite siltstone bundle. Note abundance of thick even siltstone beds. Hammer for scale in lower left. Brallier Formation, White Gate section, unit 2 (Section 6, Appendix 3).

TABLE 10

Bedding Features of Siltstone Bundles

Characteristic	Clifton Forge	White Gate	Gauley Ridge	Bastian	South Gap	Marion	Flat Gap	Back Creek	Average
Thickness (m)	12	11	8	7	7	12	10	23	13
Percent siltstone	70	62	67	56	61	67	52	62	64
Number of siltstone beds	47	49	30	26	26	46	43	72	42
Mean siltstone bed thickness (cm)	21	26	20	17	16	22	15	20	21
Mean shale bed thickness (cm)	9	16	6	14	11	11	14	12	12
ABC proximity index (%)	I.D.*	69	70	75	61	74	54	I.D.	67

(Column heads fall under the spanning heading "Section".)

*Insufficient data

Fig. 48.- Profile of siltstone bundle, Brallier Formation, Bastian section, unit 2 (Section 9, Appendix 3). Five bed moving average.

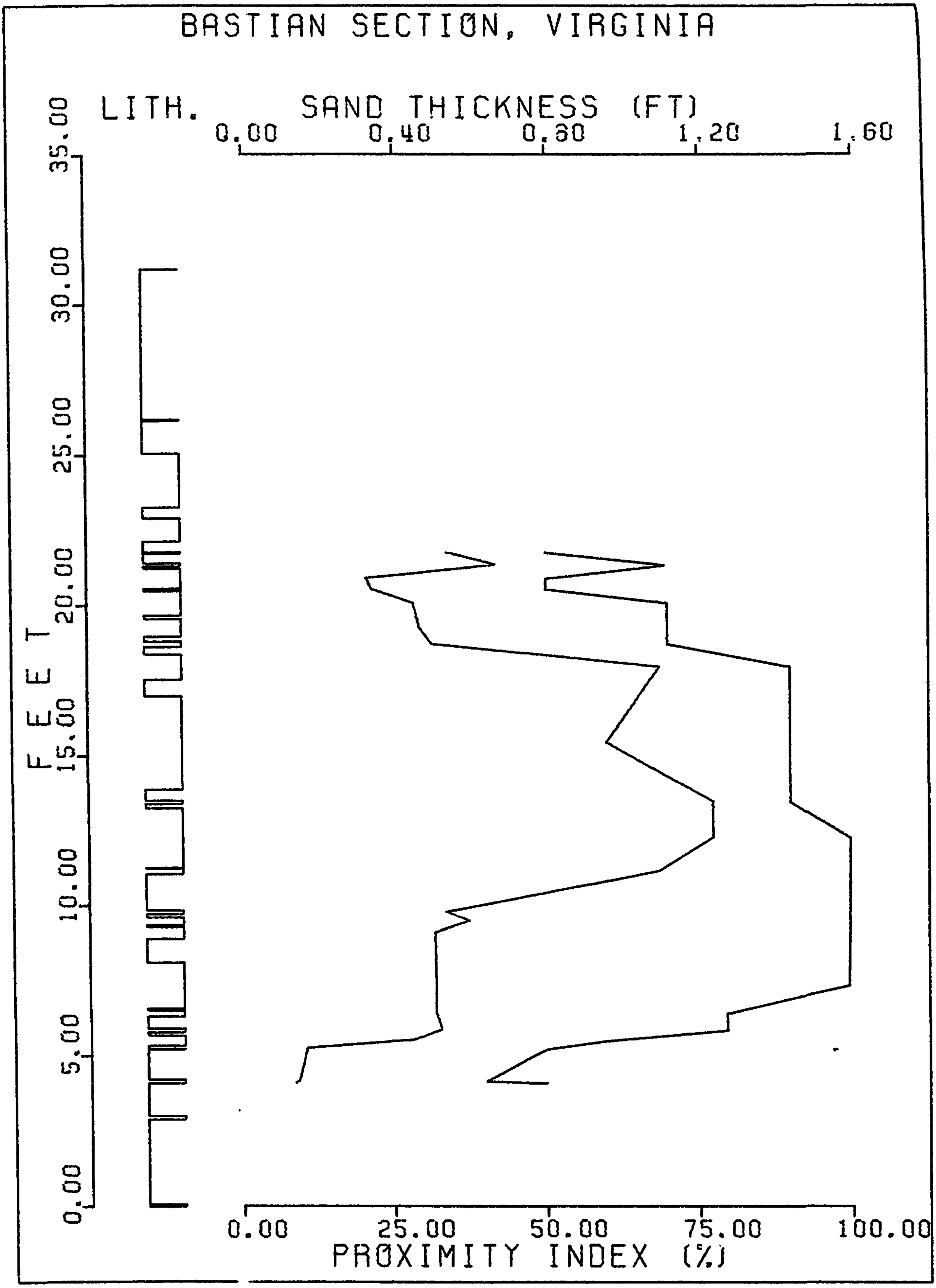

BASTIAN SECTION, VIRGINIA
LITH.
SAND THICKNESS (FT)
0.00
0.40
0.80
1.20
1.60
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
FEET
0.00
25.00
50.00
75.00
100.00
PROXIMITY INDEX (%)

Fig. 49.- Profile of siltstone bundle, Brallier Formation, White Gate section, unit 2 (Section 6, Appendix 3). Five bed moving average.

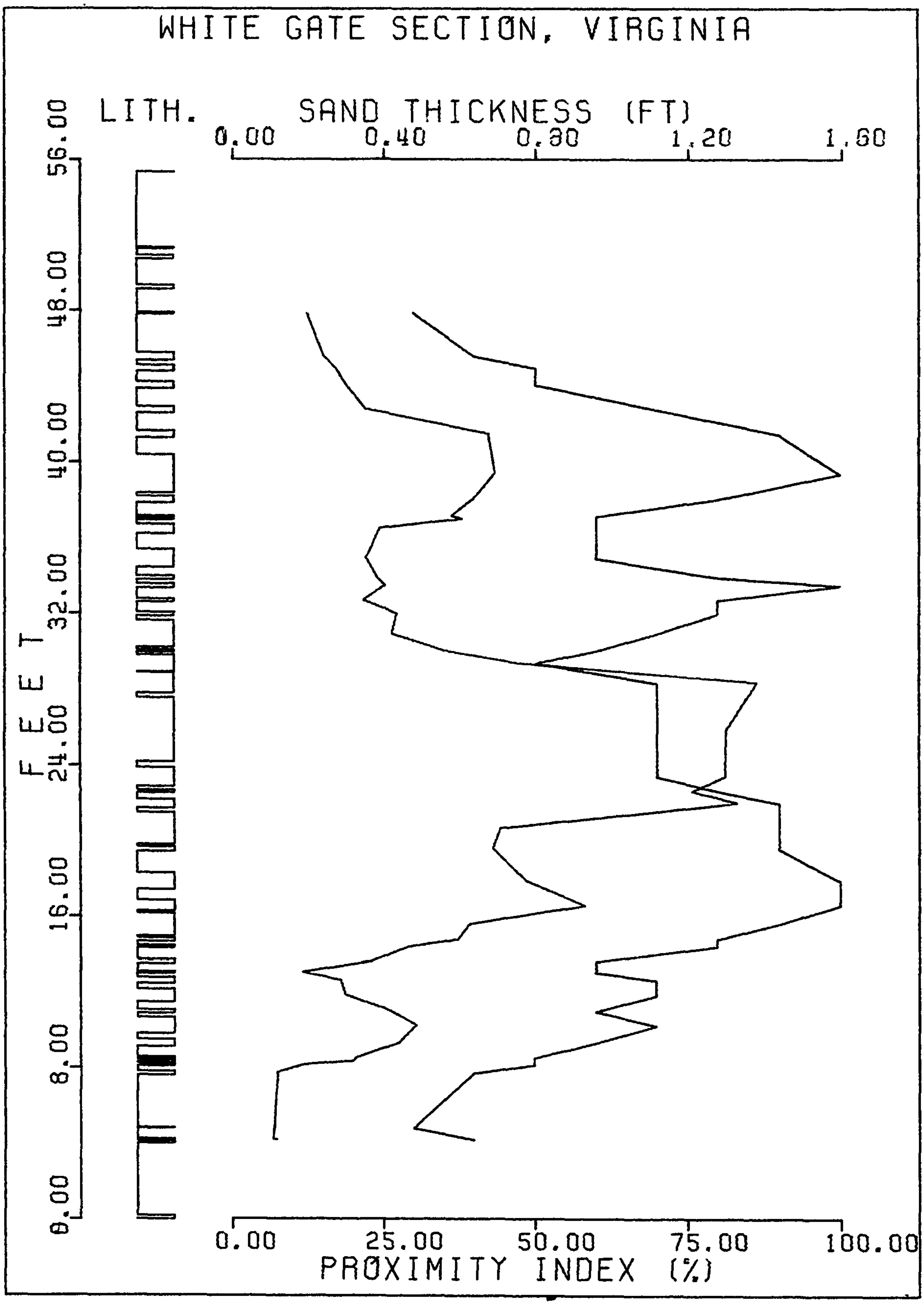

WHITE GATE SECTION, VIRGINIA
LITH.
SAND THICKNESS (FT)
0.00
0.40
0.80
1.20
1.60
FEET
0.00
8.00
16.00
24.00
32.00
40.00
48.00
56.00
0.00
25.00
50.00
75.00
100.00
PROXIMITY INDEX (%)

Fig. 50.- Profile of siltstone bundle, Brallier Formation, Gauley Ridge section, unit 2 (Section 7, Appendix 3). Five bed moving average.

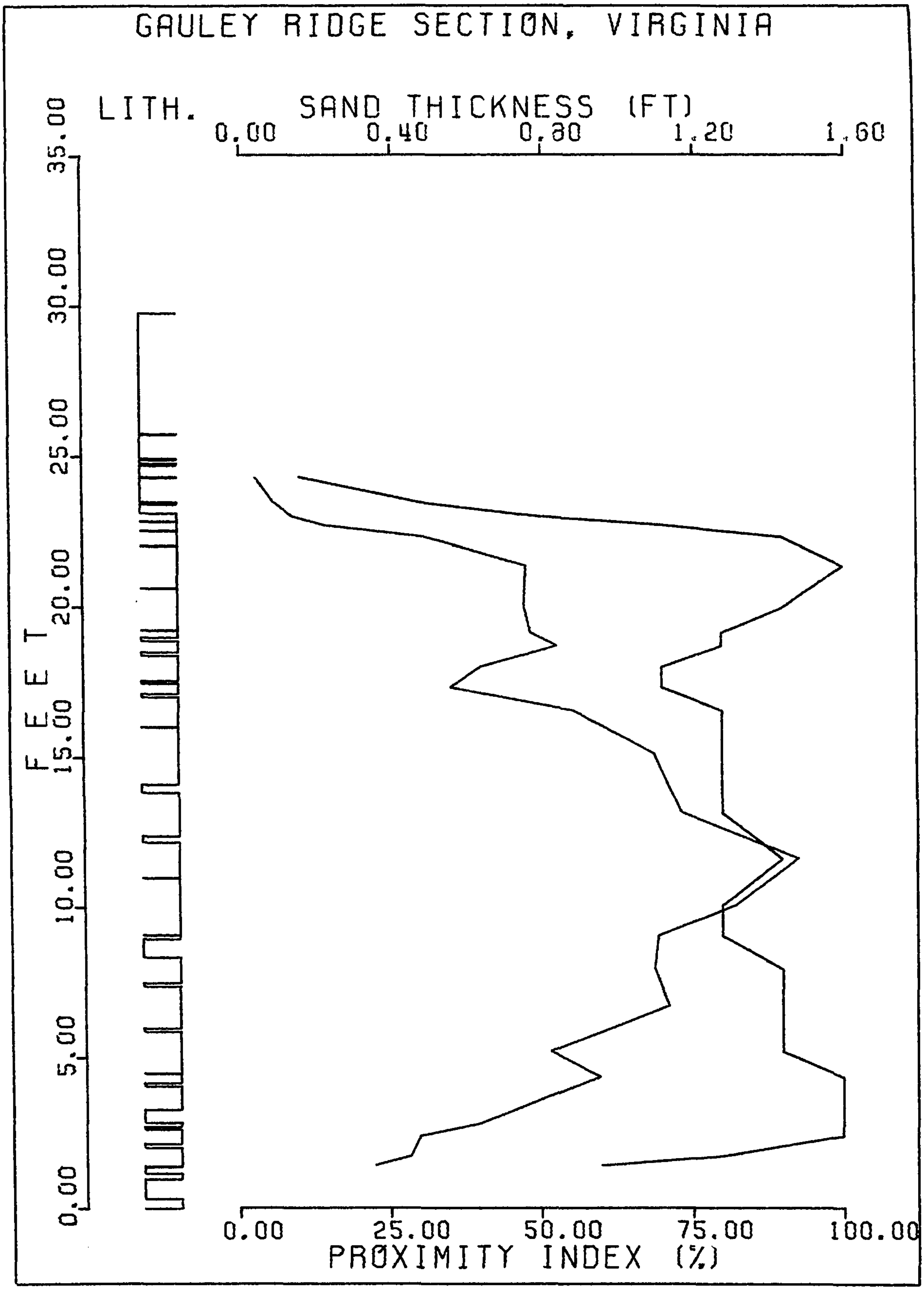

GAULEY RIDGE SECTION, VIRGINIA
LITH.
SAND THICKNESS (FT)
0.00
0.40
0.80
1.20
1.60
FEET
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
0.00
25.00
50.00
75.00
100.00
PROXIMITY INDEX (%)

Fig. 51.- Profile of siltstone bundle, Brallier Formation, Marion section, unit 5 (Section 12, Appendix 3). Five bed moving average.

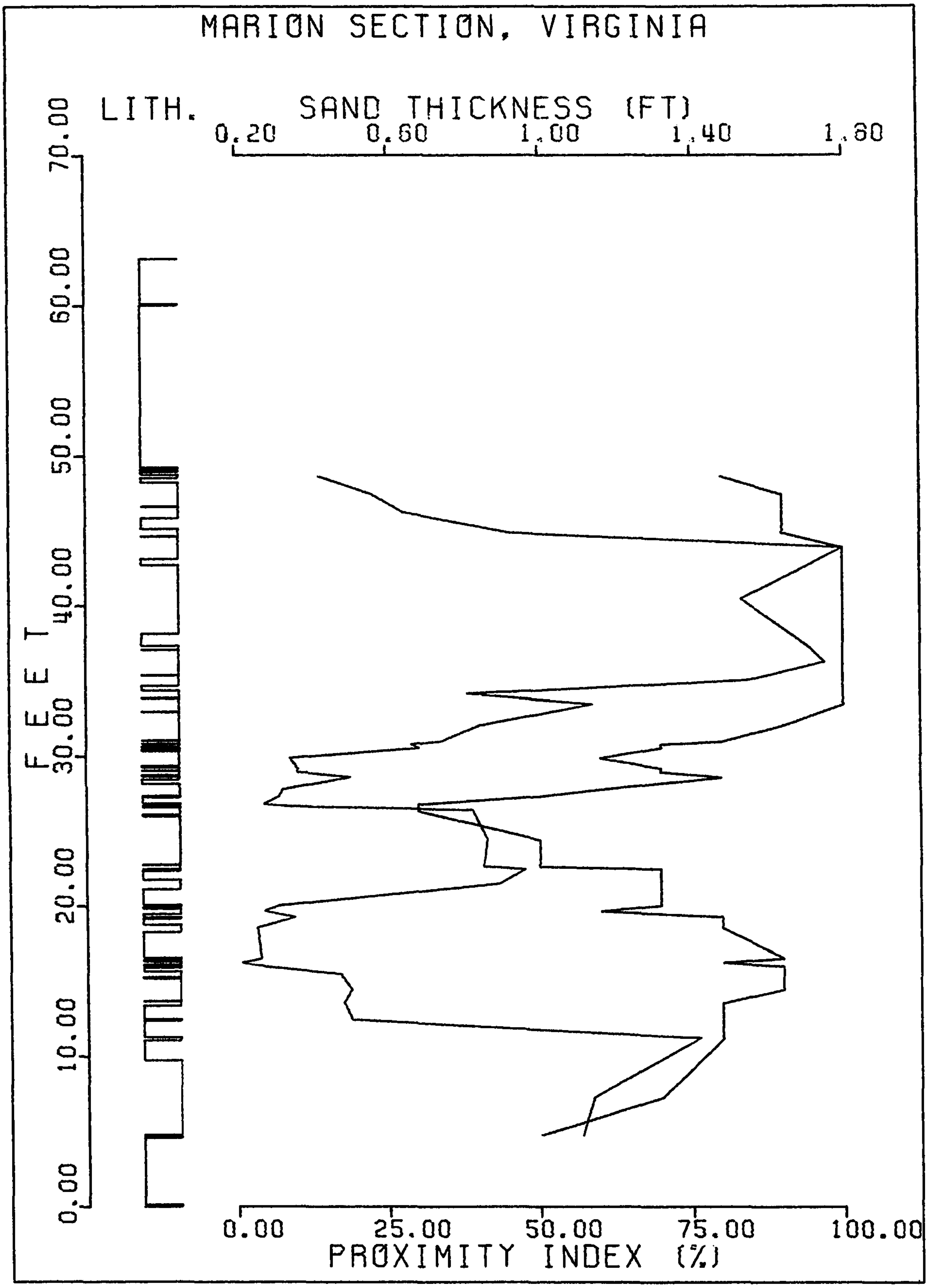

MARION SECTION, VIRGINIA
LITH.
SAND THICKNESS (FT)
0.20
0.60
1.00
1.40
1.80
FEET
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
0.00
25.00
50.00
75.00
100.00
PROXIMITY INDEX (%)

Fig. 52.- Profile of siltstone bundle, Brallier Formation, South Gap section, unit 2 (Section 8, Appendix 3). Five bed moving average.

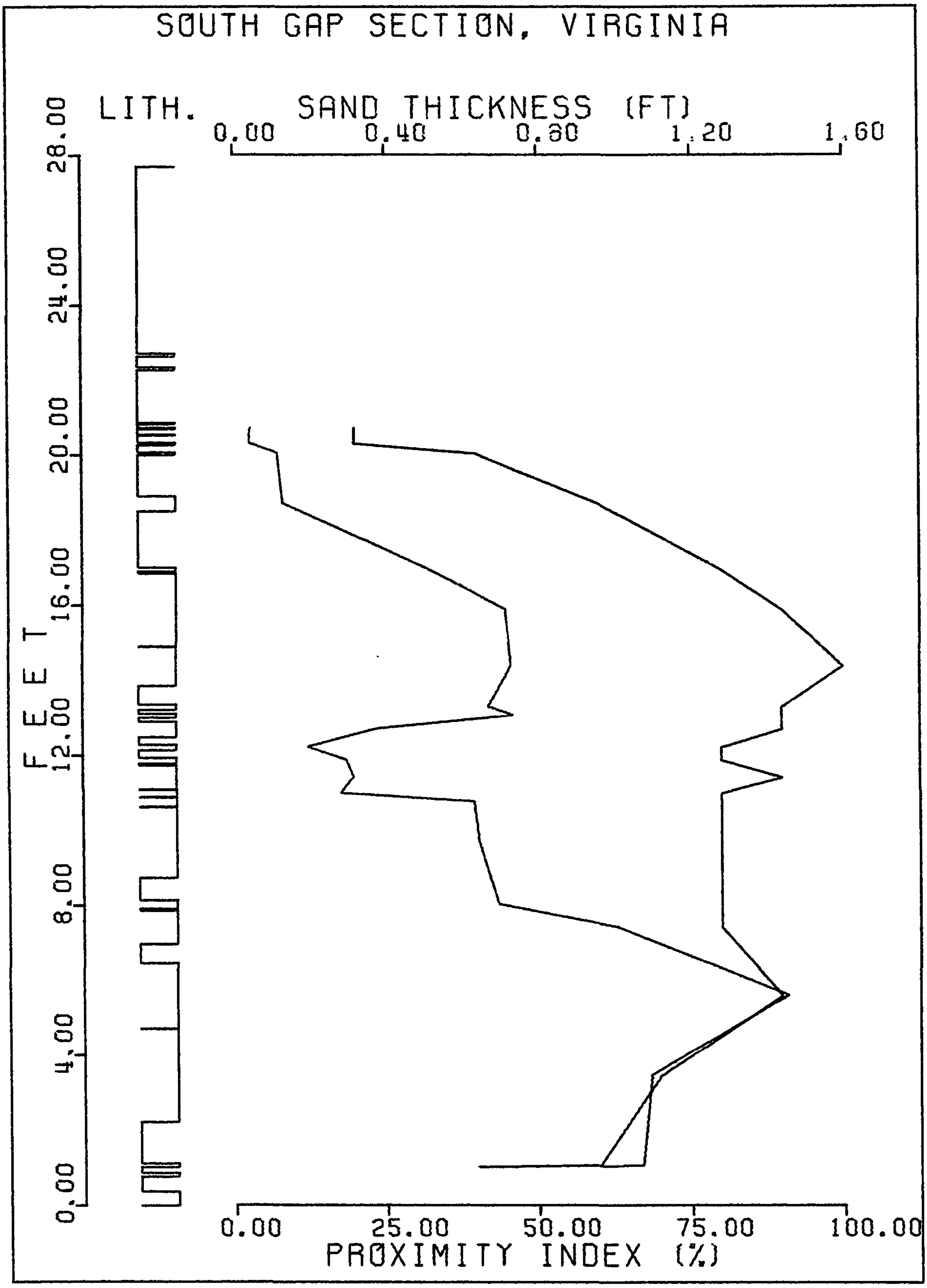

SOUTH GAP SECTION, VIRGINIA
LITH.
SAND THICKNESS (FT)
0.00
0.40
0.80
1.20
1.60
FEET
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
0.00
25.00
50.00
75.00
100.00
PROXIMITY INDEX (%)

Fig. 53.- Profile of siltstone bundle, gray silty shale unit, Chattanooga Shale, Flat Gap section, units 7-9 (Section 21, Appendix 3). Five bed moving average.

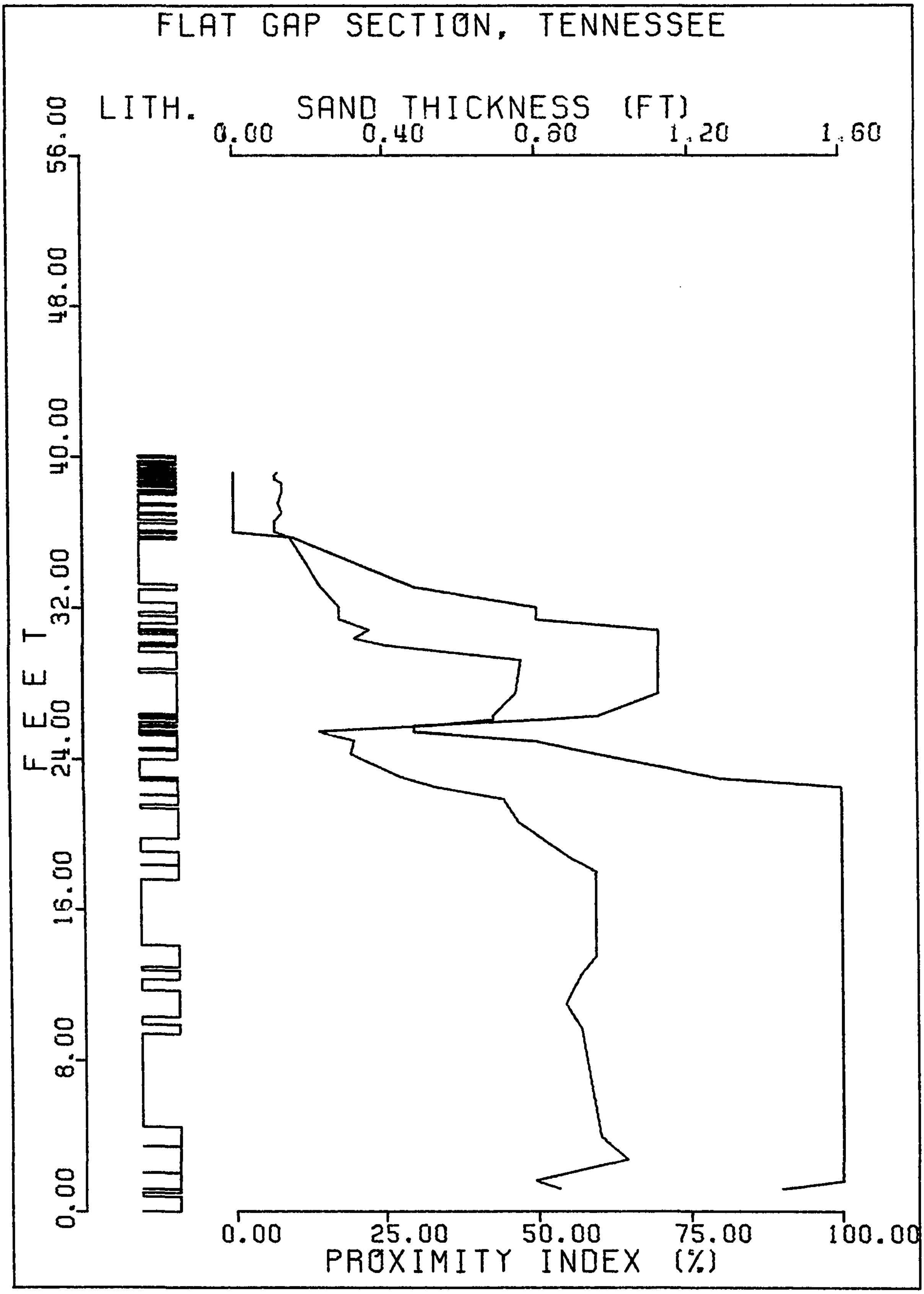

FLAT GAP SECTION, TENNESSEE
LITH.
SAND THICKNESS (FT)
0.00 0.40 0.80 1.20 1.60
FEET
0.00 8.00 16.00 24.00 32.00 40.00 48.00 56.00
0.00 25.00 50.00 75.00 100.00
PROXIMITY INDEX (%)

Fig. 54.- Profile of siltstone bundle, Brallier Formation, Clifton Forge section, unit 1 (Section 4, Appendix 3). Five bed moving average.

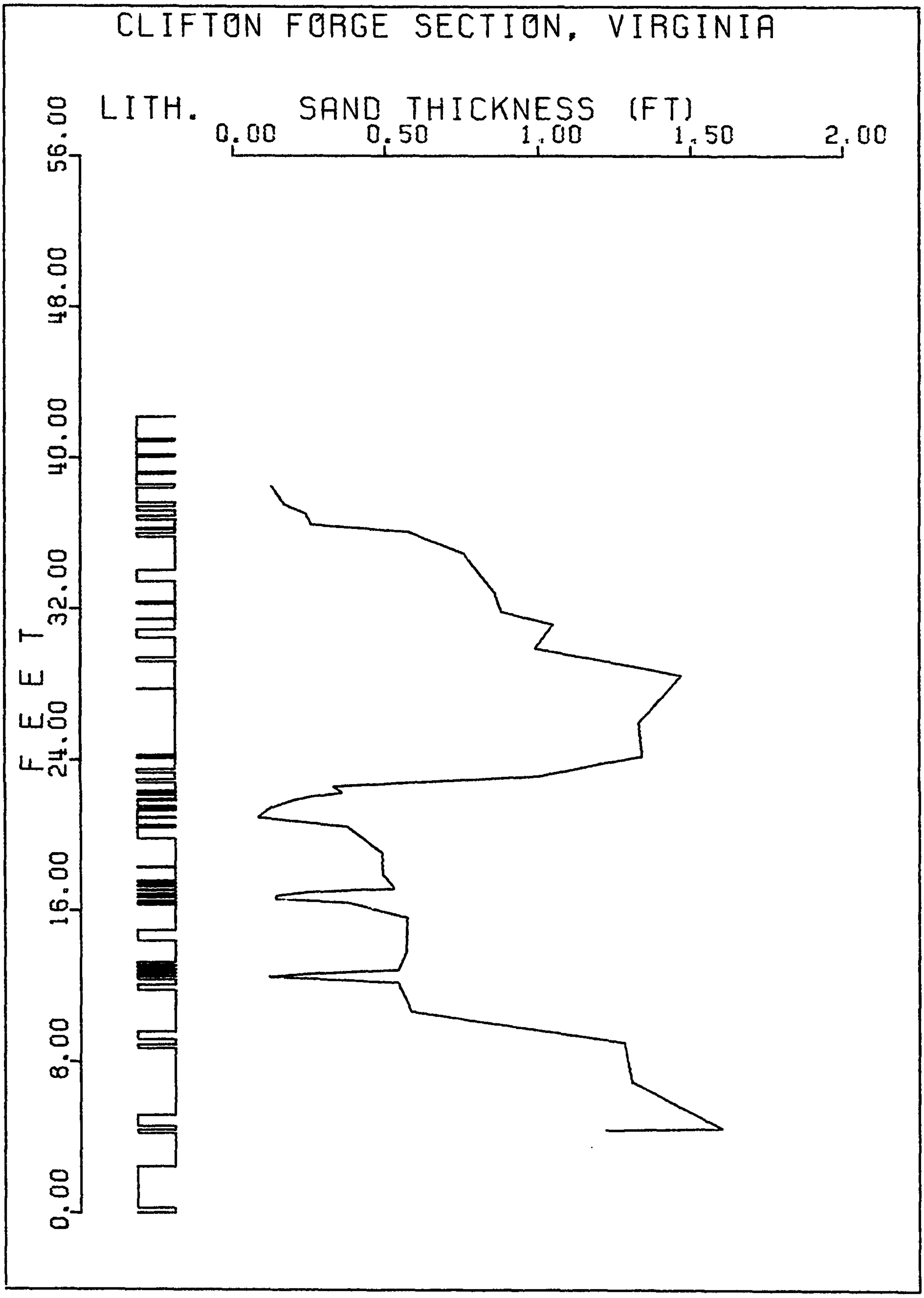
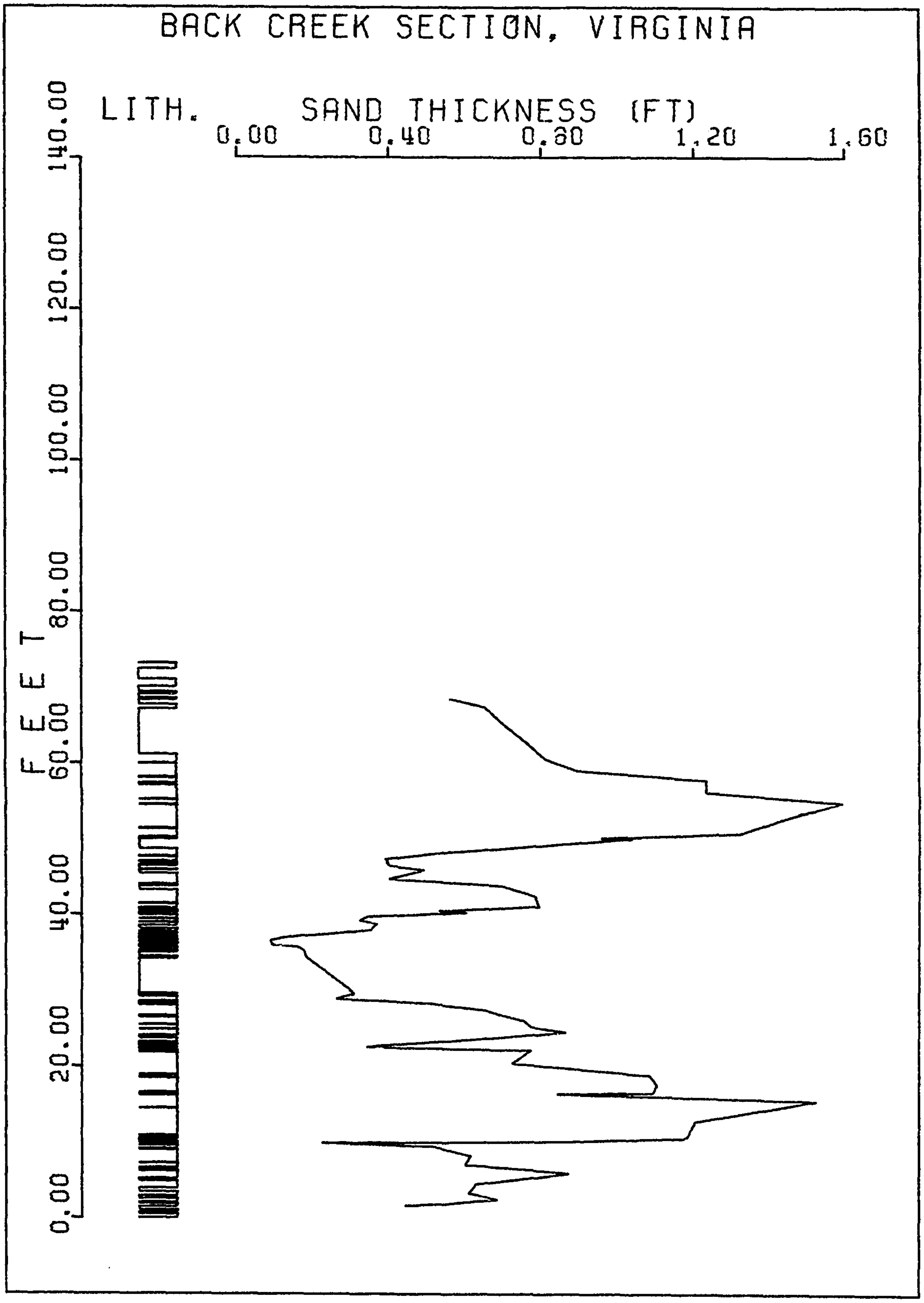

CLIFTON FORGE SECTION, VIRGINIA
LITH.
SAND THICKNESS (FT)
0.00
0.50
1.00
1.50
2.00
FEET
0.00
8.00
16.00
24.00
32.00
40.00
48.00
56.00

Fig. 55.- Profile of Back Creek Siltstone Member (usage of Avary and Dennison, 1978) of Brallier Formation, exposed along U. S. Highway 250, 0.4 kilometers east of Back Creek, Hightown quadrangle, Virginia.


BACK CREEK SECTION, VIRGINIA
LITH.
SAND THICKNESS (FT)
0.00
0.40
0.80
1.20
1.60
FEET
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00

sequences are evidence for channel filling (Walker, 1978, p. 953-956), this data indicates that siltstone bundles in the Brallier Formation are channel deposits. No channel margin features were observed, however. Subsurface data in West Virginia indicate that similar Upper Devonian turbidite bundles there are elongate, linear bodies 5 to 18 m thick that trend perpendicular to depositional strike (Cheema, 1977). These bundles are almost certainly channel deposits. The lateral dimensions of siltstone bundles in the Brallier Formation are compatible with those of gullies on prodelta slopes (Shepard, 1955) and mid fan channels (Normark, 1978, p. 912). Available evidence suggests that these siltstone bundles are either shallow channel deposits or deposits of the axial portions of small sediment lobes.

Interlobe Slope Facies

The pervasive bioturbation of the mudstones, the sparse body fossils, and rarity of thin turbidite siltstone beds in the interlobe slope facies (Table 9; Fig. 56) suggest it was predominantly deposited by relatively slow hemipelagic sedimentation of mud on a dysaerobic sea floor. Ambocoelia sp. brachiopods are locally common in the mudstones but are thought to have been epifaunal sessile organisms (McGhee, 1975, p. 117), so bioturbation must have been the work of soft-bodied infauna. The mudstones have low organic carbon contents, mostly less than 0.3 percent (Table 5 and Fig. 12). Turbidite sedimentation was limited to a few thin siltstone beds with T_{cde} or T_{de} Bouma sequences, which I interpret to mean that the mudstones accumulated

Fig. 56.- Interlobe slope facies. Note resistant mudstone and absence of siltstone beds. Brallier Formation, Cloyds Mountain section, unit 40 (Section 5, Appendix 3). Mattock handle is 1 m long.

lateral to or basinward of the loci of turbidity currents. Repeated occurrences of mudstone units 3 to 60 m thick between more "proximal" facies is more reasonably explained by lateral shifting of environments that by repeated cycles of facies progradation and retreat. I therefore interpret these mudstones as slope sediments which were deposited lateral to areas of active turbidite sedimentation.

Lobe Margin Facies

The lobe margin facies consists of bioturbated claystone and shale with abundant silt laminae (Table 9 and Fig. 57). This facies predominates in southwestern Virginia and eastern Tennessee. Earlier I presented evidence for interpreting the silt laminae in the shales of the lobe margin facies as turbidites. The near absence of siltstone beds and finer grain size of the shales and claystones suggest that this facies was deposited in areas farther from active turbidite sedimentation than the interlobe slope facies. The bioturbation in the claystones of the lobe margin facies (Fig. 57) is finer, that is, the burrows are smaller, than in the mudstones of the interlobe slope facies. Raff and Raff (1970) have shown that body size is inversely proportional to an organism's tolerance of anoxic conditions. Thus, the lobe margin facies was probably deposited in a less oxic, more distal environment than the interlobe slope facies.

Basinal Facies

Basinal black shales with minor siltstone turbidites and locally common silt laminae (Table 9 and Fig. 58) occur in the lower part of

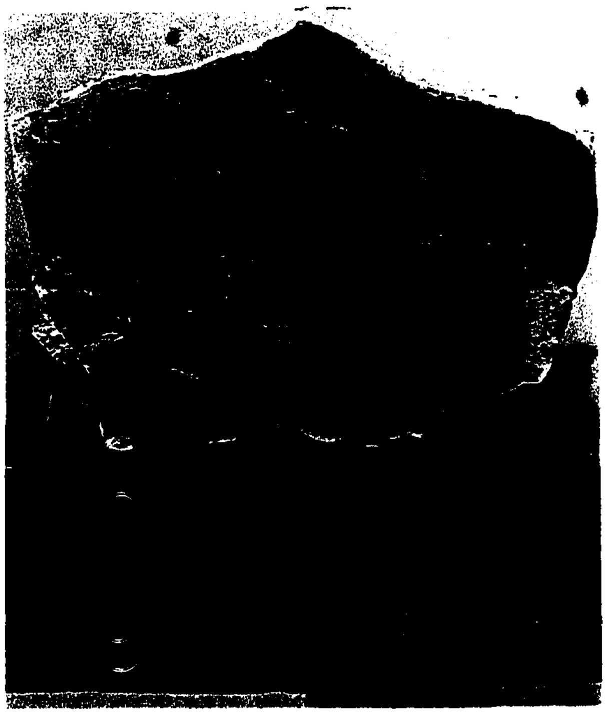


Fig. 57.- Lobe margin facies. Top: bioturbated claystone with yellowish gray burrow mottles. View is parallel to bedding. Perpendicular to bedding the mottles appear as thin biolaminae and streaks. Bottom: shale with abundant silt laminae interpreted as turbidites.

Fig. 58.- Basinal facies consisting of black shale with a few thin siltstone beds. Brallier Formation, Virginia Highway 16 section, unit 32 (Section 10, Appendix 3). Mattock handle is 1 m long.

the Brallier Formation and Millboro Shale in distal outcrops in southwestern Virginia. Subsurface data further indicate that this facies thickens westward and interfingers with the eastern turbidite facies (Fig. 3). These black shales probably were deposited by hemipelagic sedimentation in a stagnant quiet water environment as indicated by their high organic carbon content (Fig. 12), well developed textural lamination, and absence of bioturbation.

REVIEW OF THE SUBMARINE FAN MODEL

What we know about submarine fans and turbidite depositional systems is mainly based on studies of modern submarine fans, and ancient flysch sequences. The submarine fans which have been most studied are those off the west coast of North America (Nelson and others, 1970; Normark, 1970; Normark and Piper, 1972). For these examples and few others we have good descriptions of fan geometry, physiography, lithology, and facies distribution. Dispersal patterns can in turn be inferred from these data. Several workers have attempted to integrate their observations of turbidite facies in ancient rocks with what is known about the physiography and facies distribution of modern fans (Walker and Mutti, 1973; Walker, 1978).

The present-day facies model for turbidites centers primarily on our knowledge of modern submarine fans simply because that is where the best data are. Because it is from the perspective of this model that we tend to look at turbidite sequences, a brief review of its salient features is in order. Much of what follows is based on the work of Nelson and others (1970), Normark (1970), Normark and Piper (1972), Nelson and Kulm (1973), Nelson and Nilsen (1974), Whitaker (1974), Normark (1978), and Walker (1978). The data base consists mostly of many reflection profiles and shallow sediment cores.

Submarine fans are typically divided into three physiographic regions (Fig. 59): a channeled upper fan, fed by a submarine canyon; a mid fan region with many distributary channels on its upper part,

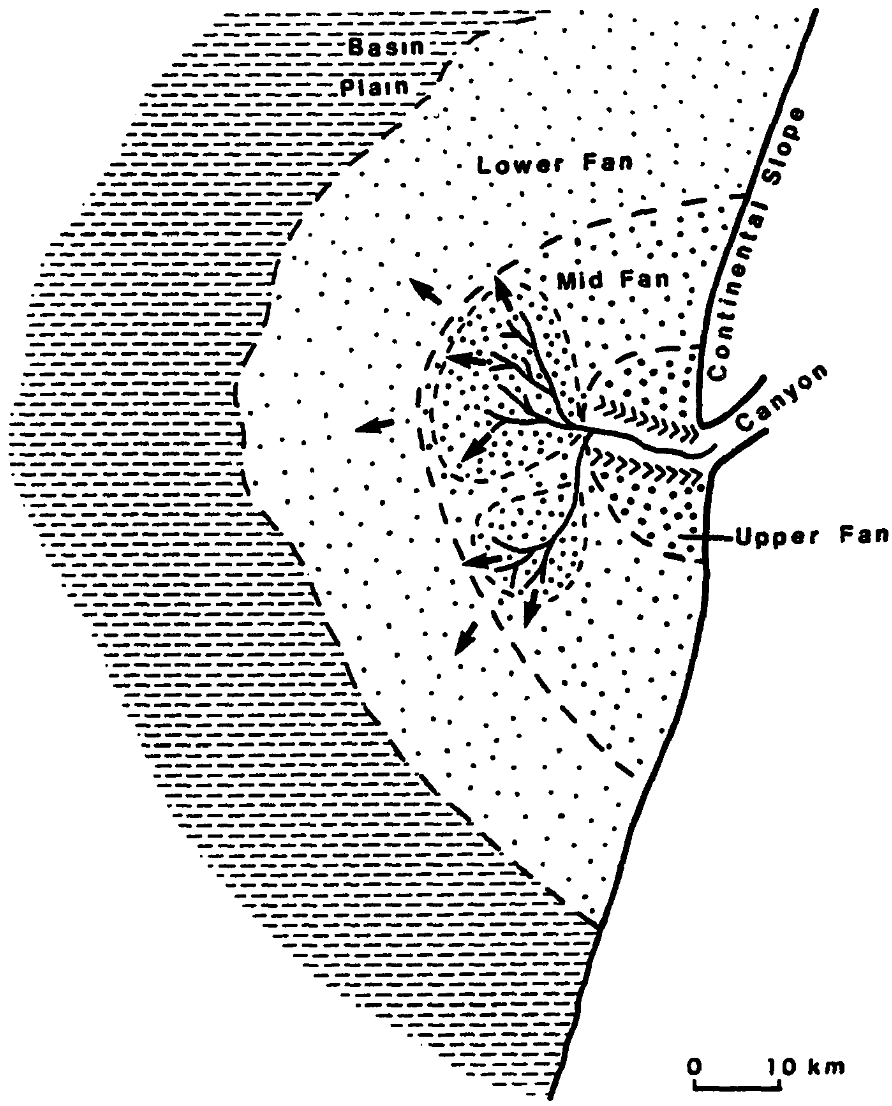


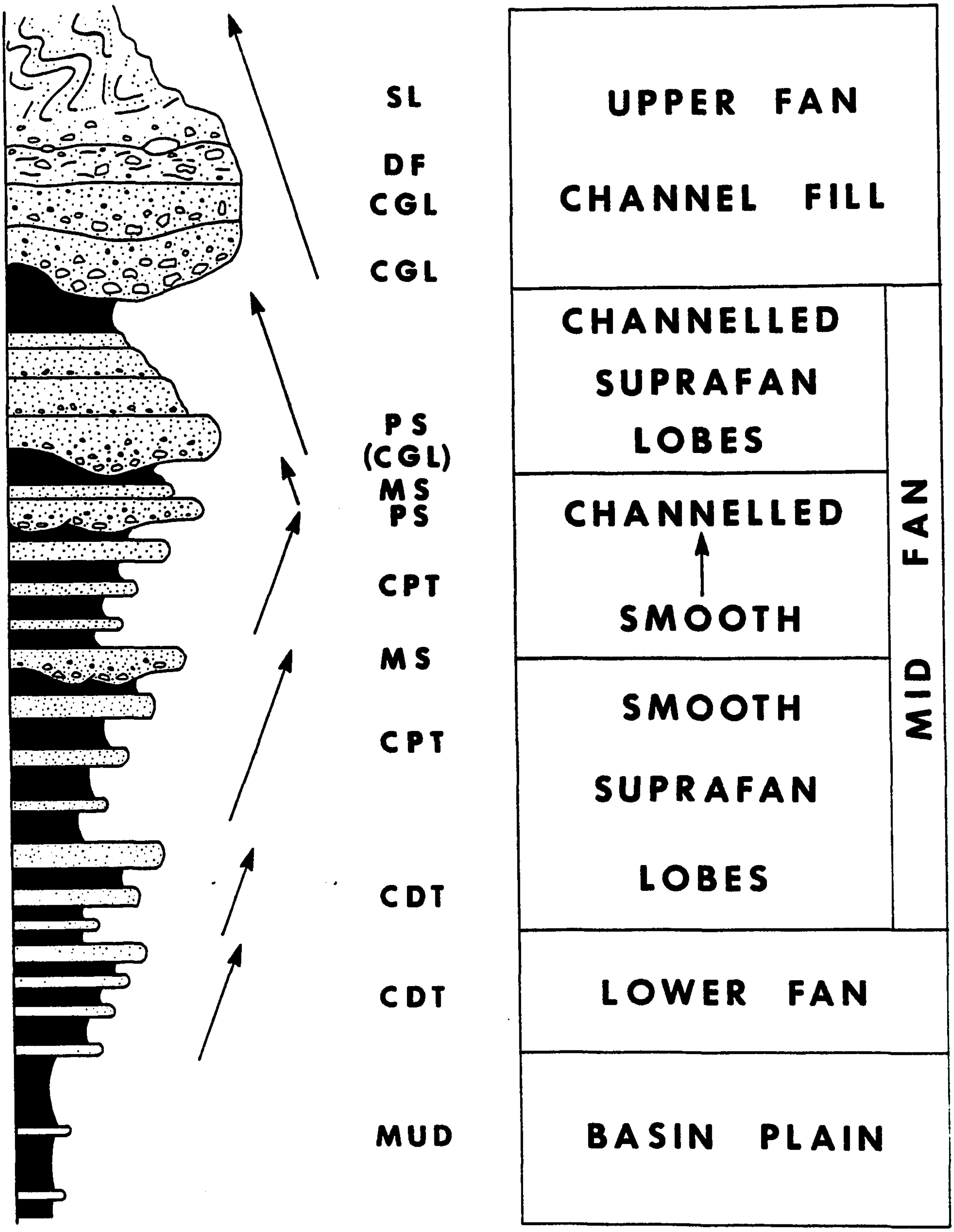
Fig. 59.- Physiography of a typical submarine fan. There is a general down-fan decrease in grain size and radial dispersal pattern. Modified from Normark (1978, Fig. 1).

and smooth depositional lobes on its lower part; and a smooth lower fan region which merges distally with the basin plain. Grainsize, bed thickness, sand/shale ratio, and relief all generally decrease in the down-fan direction. Similar gradients also occur laterally, away from channel axes. Bouma sequences also become more base-truncated laterally and in the down-fan direction. The upper fan has the most rugged topography because of the extensive levee development, and remnant abandoned channels. Rapid and profound morphological changes take place in the mid fan area. Gradients flatten abruptly and the fan profile becomes convex upward, as opposed to the normal concave upward profiles of the upper and lower fan. This depositional bulge, characteristic of the lower mid fan has been called the "suprafan" by Normark (1970). The upper fan channel bifurcates into a system of sinuous distributary channels on the upper mid fan. These distributary channels lack the levee development typical of the upper fan channel. The lower fan is characterized by the lowest gradients and smoothest surface. Channels are generally absent or inconspicuous on the lower fan because of their very low relief.

The progradation of a submarine fan such as depicted in Figure 59 produces a distinctive stratigraphic sequence of facies which overall coarsens upward (Fig. 60).

The channel deposits of the submarine canyon and upper fan valley consist of the thickest, most poorly bedded, coarsest, least structured, and most poorly sorted sands and gravels. Thick beds forming lenticular bodies, disturbed bedding, slump blocks, and pebbly mudstones are

Fig. 60.- Schematic stratigraphic sequence produced by a prograding submarine fan. Inclined arrows indicate thickening- and coarsening-upward, or thinning- and fining-upward sequences; CDT, classic distal turbidites; CPT, classic proximal turbidites; MS, massive sandstones; PS, pebbly sandstones; CGL, conglomerate; DF, debris flows; and SL, slumps. Modified from Walker (1978, Fig. 14).


SL
DF
CGL
CGL
PS
(CGL)
MS
PS
CPT
MS
CPT
CDT
CDT
MUD
UPPER FAN
CHANNEL FILL
CHANNELLED
SUPRAFAN
LOBES
CHANNELLED
SMOOTH
SMOOTH
SUPRAFAN
LOBES
MID FAN
LOWER FAN
BASIN PLAIN

typical of the submarine canyon. The upper fan channel deposits are usually massive and lack sedimentary structures typical of the Bouma sequence. Clast-supported conglomerates, debris flows, and slump deposits comprise the upper fan channel fill. Mud interbeds are typically thin, silty, and poorly developed. Minor thin fine-grained turbidites and mud occur on the upper fan channel levees and interchannel areas.

The channels of the mid fan contain lenticular, massive and pebbly sandstone beds and thinner, finer grained turbidites. Sands of the mid fan valley are most likely to have the entire Bouma sequence. Laterally shifting channels produce thinning-upward megasequences on the channeled mid fan. Mid fan interchannel deposits are mud with interbeds of classic "proximal" to classic "distal" turbidites. The outer, smooth portion of suprafan depositional lobes consists of classic "distal" to classic "proximal" turbidites in coarsening- and thickening-upward sequences possibly with channeled massive sandstones at their top.

The lower fan has fewer and thinner turbidites than the mid fan region, and their Bouma sequences are generally more base-truncated. Coarsening- and thickening-upward sequences are commonly present.

Basin plain deposits consist of mud, possibly with a few thin turbidite beds.

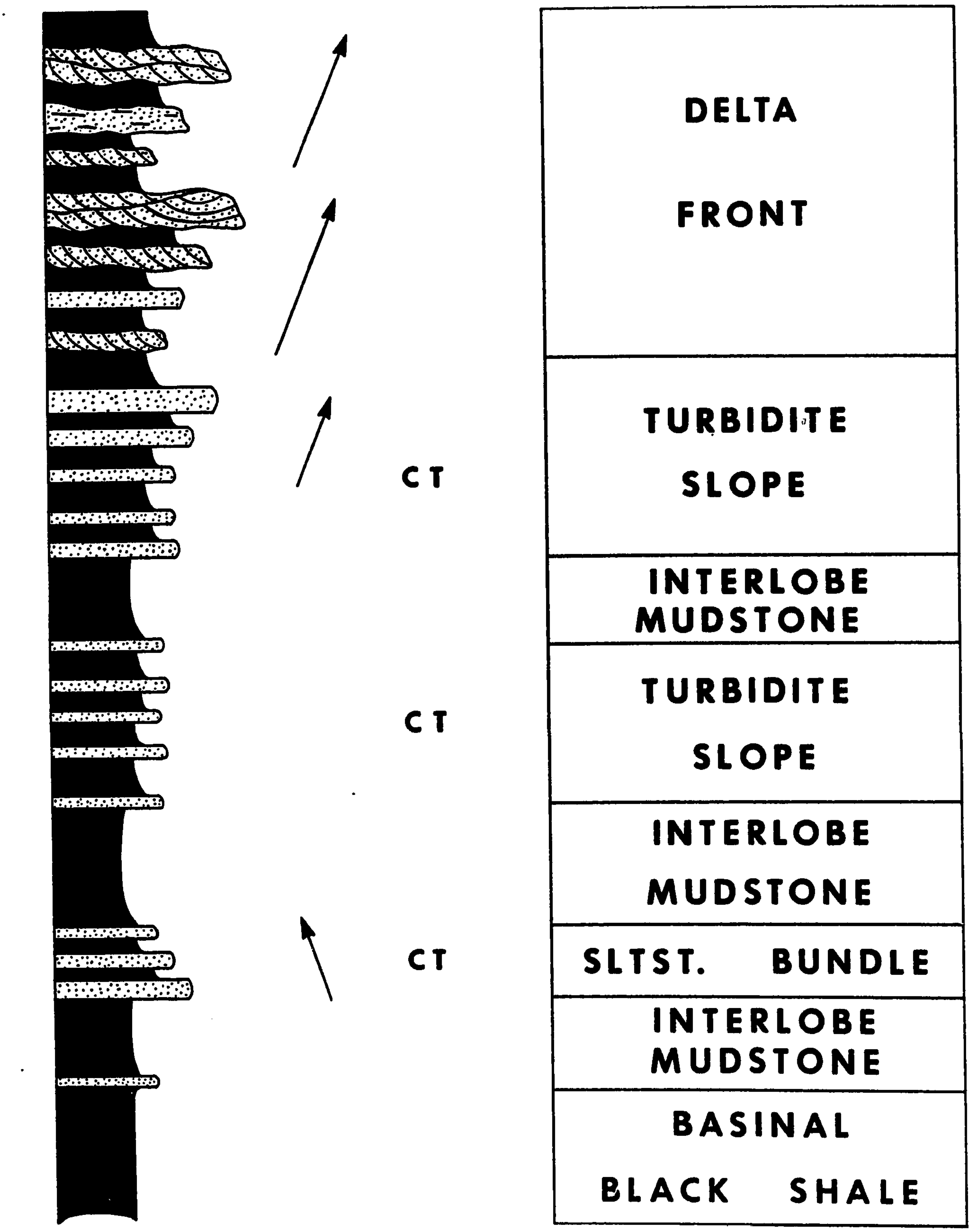
Before continuing with a discussion of how well this depositional model applies to the Brallier Formation I should point out that a submarine fan is a physiographic entity, unique in its geometry but not necessarily in its other aspects. Similarly, the sub-environments of submarine fans (upper fan valley, channeled mid fan, etc.) are unique in their physiography and position but not necessarily in terms of lithology, sedimentary structures or grainsize. This is primarily true because of the similarity between down-fan gradients and lateral gradients away from channel axes. Rarely do sedimentologists "recognize" ancient submarine fans by their geometry (two exceptions are Sullwold, 1960, and Niem, 1977) or the sub-environments of ancient fans by their distinguishing physiographic features. With the exception of detailed subsurface studies, physiography is very difficult to reconstruct in turbidite systems. Instead, the less diagnostic assemblages of lithologies, bed thickness, sedimentary structures, and grain size and especially their vertical sequence are relied on to distinguish sub-environments of submarine fan systems.

BRALLIER DEPOSITIONAL MODEL

As Potter and Pettijohn (1977, p. 332) perceptively pointed out, sedimentologists are inclined to take ideas and observations generated in the study of one basin or area and apply them uncritically to new situations. Thus we look for the features of modern submarine fans and Alpine flysch in other turbidite sequences. I found, however, that significant discrepancies arise when trying to fit these models to the Brallier Formation.

The Brallier Formation is finer grained and thinner bedded than most modern submarine fan and ancient flysch deposits (Fig. 61). Grain size in the Brallier sequence is largely in the silt to very fine sand range and siltstone and sandstone bed thickness averages less than 10 cm. The entire stratigraphic sequence from basinal shales to non-turbiditic deltaic sandstones and mudrocks includes only the classic turbidites member of the resedimented coarse clastic family (Fig. 61). Differences also exist in the proximal facies, especially in the stratigraphic transition from turbidites to non-turbidites. In the Brallier Formation this transition is gradual and characterized by thickening-upward sequences of classic turbidites of the turbidite slope facies, and crossbedded traction deposits of the delta front facies (Fig. 61). Contrasting with this are the channeled thinning-upward sequences of massive and pebbly sandstones, conglomerates, debris flows, and slumps which characterize the proximal deposits of modern

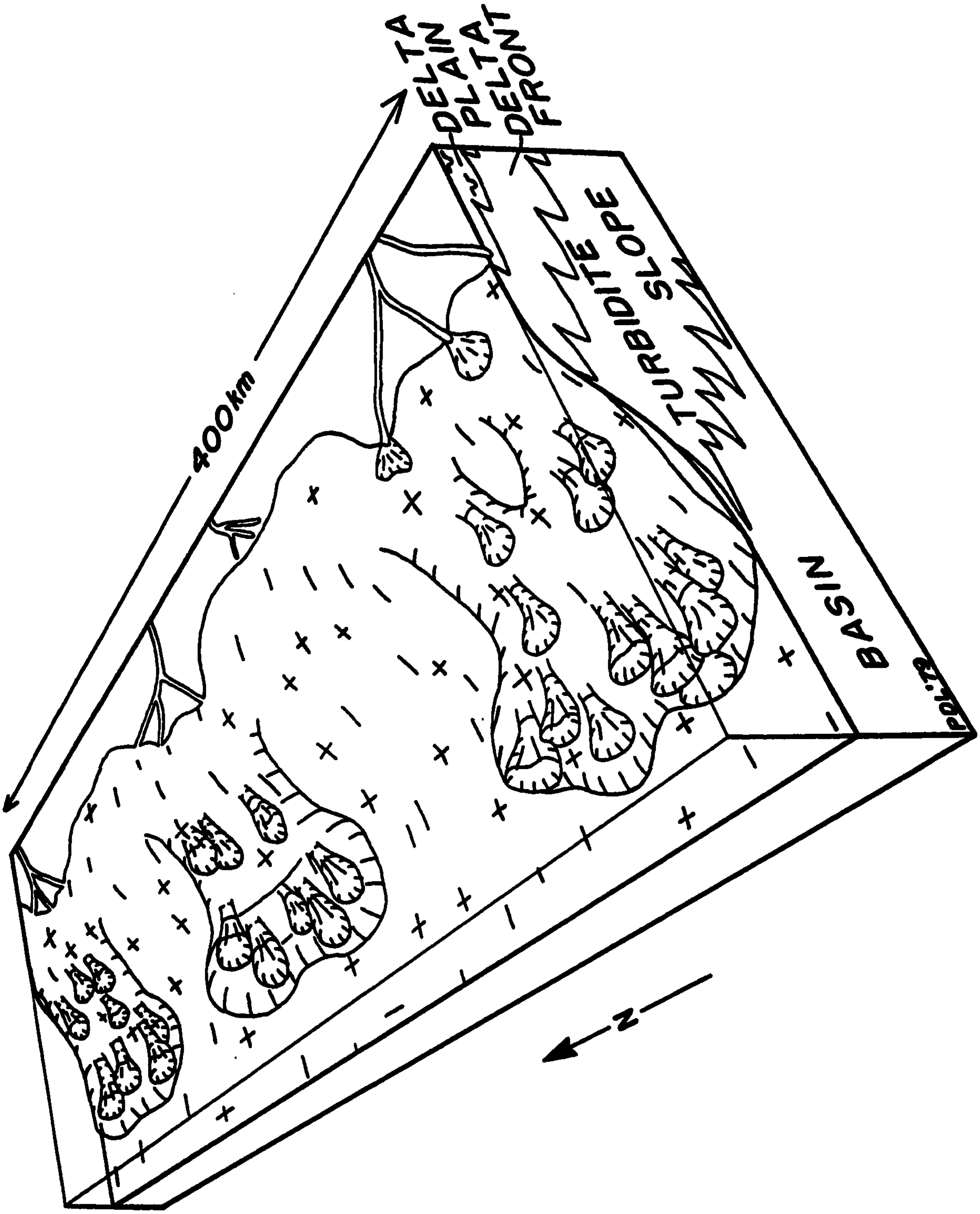
Fig. 61.- Schematic representation of the Upper Devonian stratigraphic sequence in western Virginia. Inclined arrows indicate thickening- and coarsening-upward, or thinning- and fining-upward sequences; CT, classic turbidites. Total thickness is approximately 1000 m.


CT
CT
CT
DELTA
FRONT
TURBIDITE
SLOPE
INTERLOBE
MUDSTONE
TURBIDITE
SLOPE
INTERLOBE
MUDSTONE
SLTST. BUNDLE
INTERLOBE
MUDSTONE
BASINAL
BLACK SHALE

submarine fans (Fig. 60). It is evident that the Brallier despositional system was of lower flow intensity than those of most modern submarine fans and ancient flysch sequences.

The facies relationships and homogeneous transverse paleocurrent pattern indicate that the Late Devonian slope of the Appalachian basin was not fed by submarine canyons. Instead, prograding deltas probably spread sediment directly onto the slope (Fig. 62). The absence of canyon and channeled upper fan facies indicates that the slope was previously unsculptured by rivers, as some shelf margins were during the Pleistocene, or that turbidity currents were too weak or scattered in their occurrence to incise the slope. The predominance of thickening-upward sequences in the proximal facies and vagueness of megasequences elsewhere in the turbidite slope facies suggest turbidity currents were generally unchanneled. The continuity and evenness of bedding also support this. The uniformity of paleocurrents suggests that sediment sources for turbidity currents shifted frequently. This is to be expected in deltaic environments because of the routine switching of deltas and distributaries. Major delta lobes of the Mississippi River have shifted about every 1000 years (Coleman, 1976, p. 26) and distributaries shift position even more frequently. Although turbidity current sources were not stable for long periods of time small sediment lobes no doubt developed downslope of these sources. These small ephemeral lobes coalesced in time to form an apron of turbidites along the Late Devonian slope and base-of-slope (Fig. 62). Kepferle (1978, p. 232) described a similar system in the Mississippian Borden

Fig. 62.- Interpretative reconstruction of the Late Devonian paleo-slope. Small ephemeral turbidite lobes coalesced in time along the slope and base-of-slope.


DELTA PLAIN
DELTA FRONT
400km
TURBIDITE
SLOPE
BASIN
N

Formation of Kentucky and Indiana as a fan apron. Bioturbated mudstone accumulated by hemipelagic sedimentation on the slope lateral to areas of active turbidite deposition. Lower on the slope, at the margins of the turbidite lobes, hemipelagic bioturbated claystone and shale with turbidite silt laminae were deposited. The slope environment was generally dyaerobic and inhabited only by soft bodied organisms. Black shales accumulated by hemipelagic sedimentation of mud and organic matter basinward of the turbidites in quiet, stagnant water.

The Upper Devonian paleoslope was probably very low, most likely less than 0.2 degrees. One line of evidence is the apparent absence of major slumping, so conspicuous of other turbidite sequences. Slumping of mud slopes as low as 0.6 degrees is very common on the Mississippi River prodelta (Shepard, 1955). Also, because the Brallier is sedimentologically similar to lower fan environments one can infer that their slopes are similar. If the paleoslope were steeper than lower fan slopes, the Brallier turbidites would show different sedimentation styles because of the increased velocity and erosive capacity of the currents. Modern lower fan gradients range from about 0.06 degrees to 0.15 degrees (Nelson and others, 1970, p. 277 and 284).

Water depth in the basin receiving the Brallier turbidites is difficult to estimate. Using Klein's (1974) stratigraphic method of estimating water depth in deltaic sequences the water could not have been more than 1000 m in depth. This value is based on a stratigraphic thickness of 915 m for the rocks between the basinal shales and the topset deltaic sandstones, and 60 m of water overlying these topset deposits. It is considered a maximum value because it does not allow for penecontemporaneous subsidence. At present no better estimate is possible because marker beds have not been recognized in the Brallier Formation. For comparison, I applied Klein's model to the overlying Lower Mississippian deltaic deposits which also include turbidites. Using the measured sections of Bartlett (1974) in southwestern Virginia and Hasson (1972) in eastern Tennessee, calculated water depths range from 140 to 210 m. It is to be expected that water depths will be shallower during the later phase of basin filling represented by these Lower Mississippian clastics. However, the five fold difference in water depths calculated from the Upper Devonian and Lower Mississippian deltaic sequences supports the idea that subsidence contributed to the comparatively large estimated value for Late Devonian water depth given above. The topography of the Lower Mississippian Borden delta in southern Illinois suggests that the Upper Devonian black shales in that area were deposited in at least 183 m of water (Lineback, 1966, p. 22). It is probable that the Late Devonian sea was shallower in cratonal areas such as Illinois than in the Appalachian basin.

The cause or initiating mechanism of the turbidity currents is unknown. Turbidity currents are commonly thought to be initiated by submarine slumping of sediments on a slope and indeed some turbidite sequences have major slump structures in their proximal facies (Cline, 1970; McBride, 1970). However, I have observed no such features in my study area although Walker (1971) observed some slump structures in the Upper Devonian sequence of central Pennsylvania. Where evidence for slumping is absent alternative initiating mechanisms such as storm surges and high river discharges should be considered. The relative thin and uniform thickness of turbidites in the Brallier Formation indicate that whatever mechanism responsible for triggering the turbidity currents was of uniformly low intensity.

Although turbidites were deposited along most of the slope from New York to Tennessee, near the Virginia-Tennessee border (Fig. 1, Sections 15-20) little or no coarse clastics were deposited (Plate 1, in pocket). Only muds of the interlobe slope, lobe margin, and basinal facies accumulated. Turbidity currents occurred frequently to the north and somewhat less frequently to the south in eastern Tennessee. These features probably reflect the absence of a delta feeding silt and sand to the slope in this area. The gray silty shale unit of the Chattanooga Shale in eastern Tennessee, however, appears to be the manifestation of a delta farther south. It is a lens of mudshale, siltstone, and sandstone, which in part consists of turbidite siltstone beds and turbidite silt laminae in shale. The gray silty shale unit is the southernmost occurrence of Upper Devonian silt and sand in the Appalachian basin. As a whole it shows pronounced coarsening- and thickening-upward (Plate 2, in pocket) from black clayshale (Fig. 63), to mudshale with abundant silt laminae (Fig. 64), to turbidite siltstone beds (Fig. 65), to thick massive sandstone beds (Fig. 66). Distinct turbidite siltstone beds are only present at the Flat Gap section (Section 21, Appendix 3), where they are 15 to 70 cm thick, and at the U.S. Highway 25 section (Section 22, Appendix 3), where one bed was observed (Plate 2, in pocket).

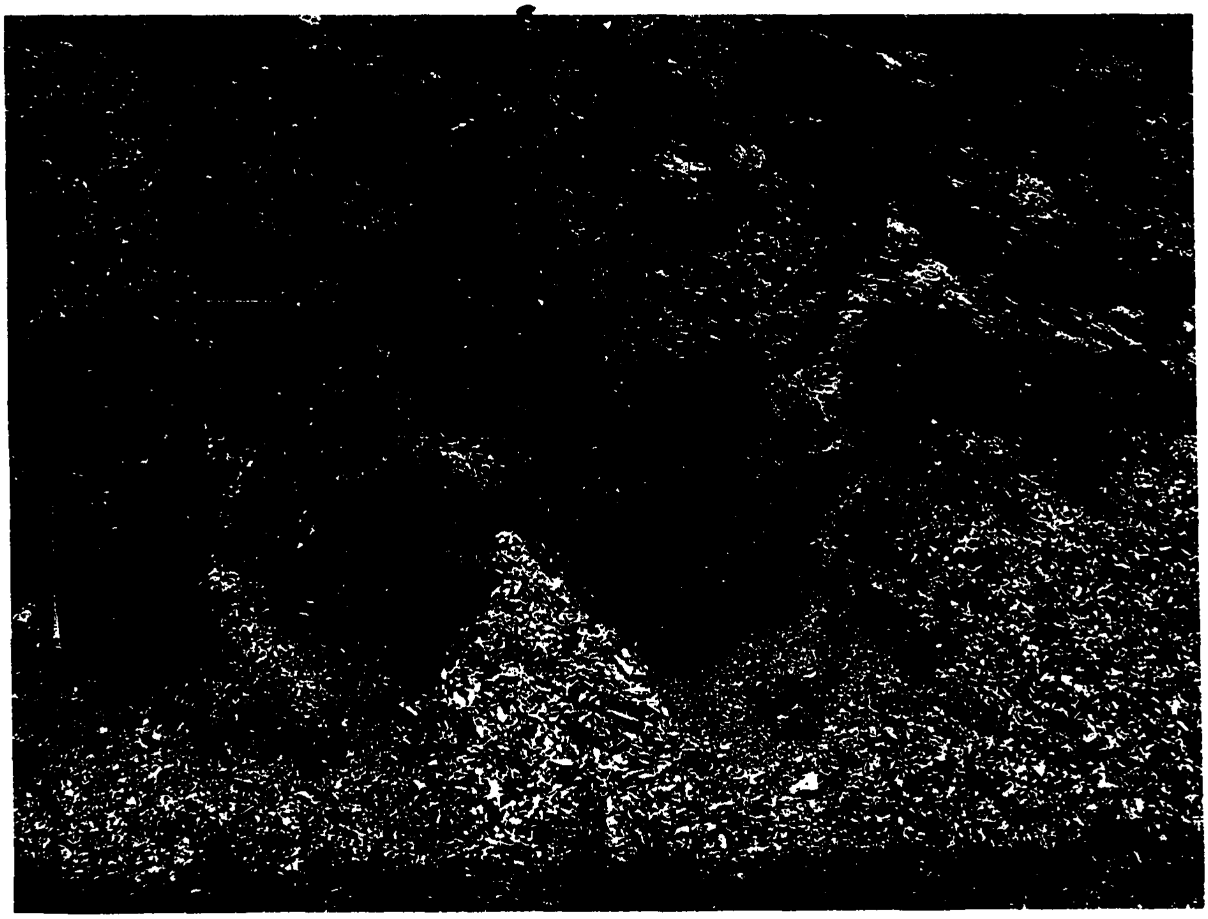


Fig. 63.- Black clayshale, unit 1, Flat Gap section (Section 21, Appendix 3). Mattock handle is 1 m long.

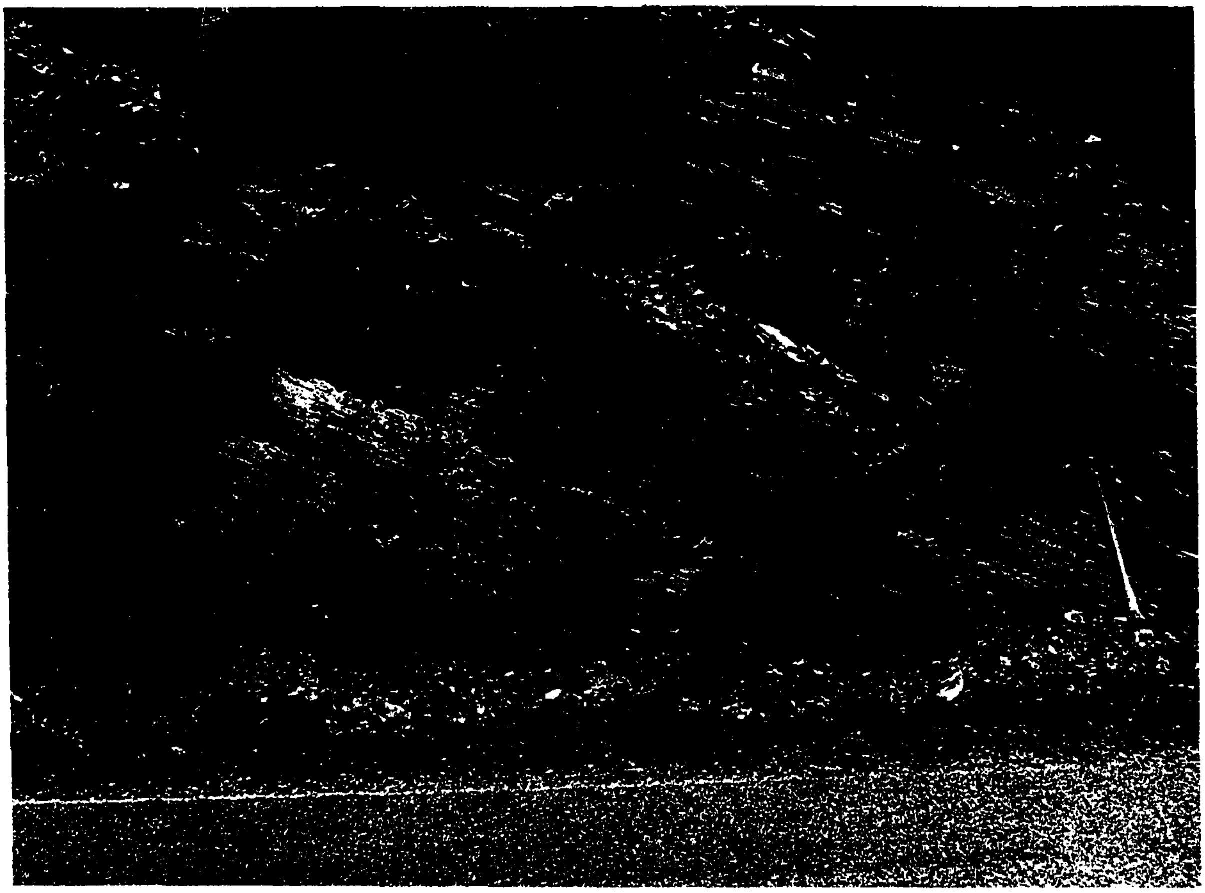


Fig. 64.- Mudshale with abundant silt laminae, unit 3, Flat Gap section (Section 21, Appendix 3). Mattock handle is 1 m long.

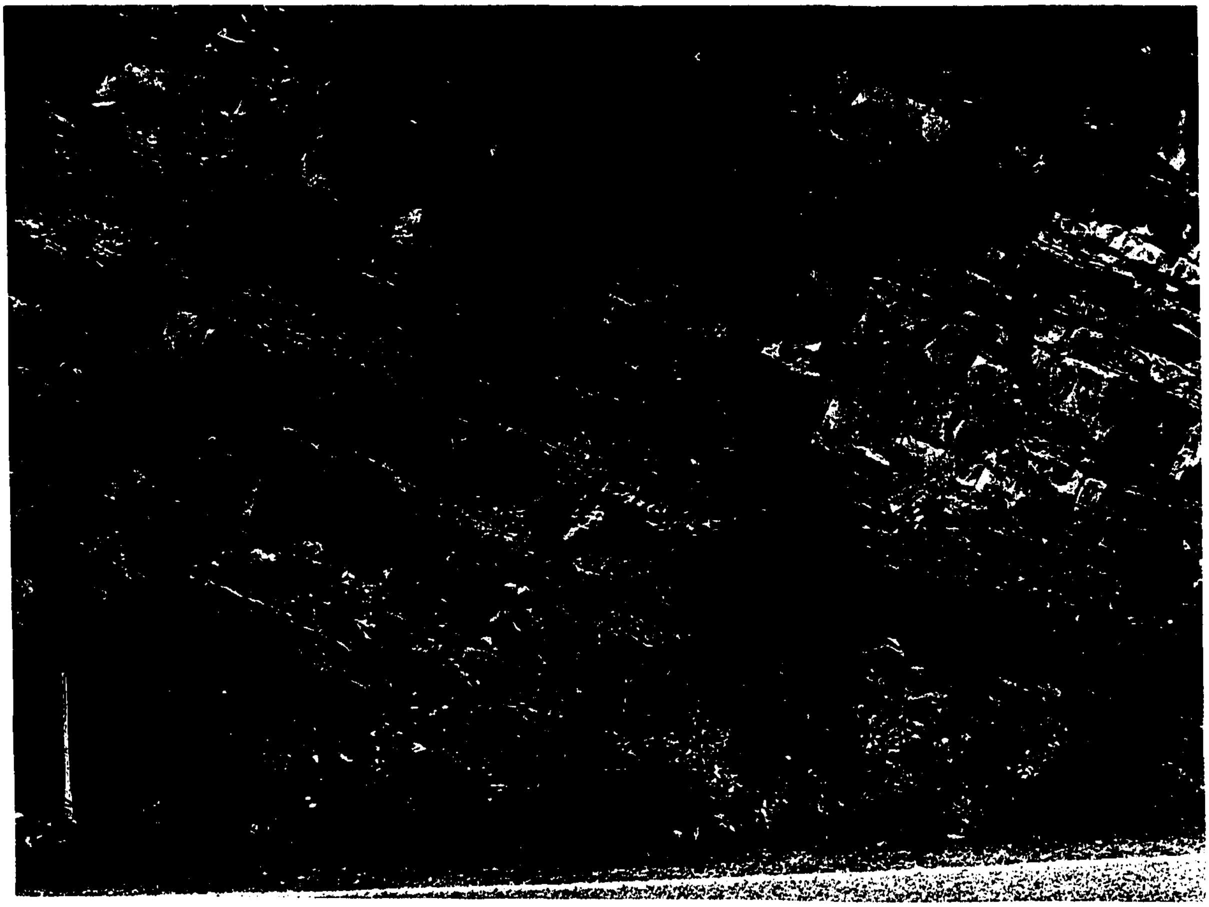


Fig. 65.- Turbidite siltstone beds, units 7-9, Flat Gap section (Section 21, Appendix 3). Mattock handle is 1 m long.

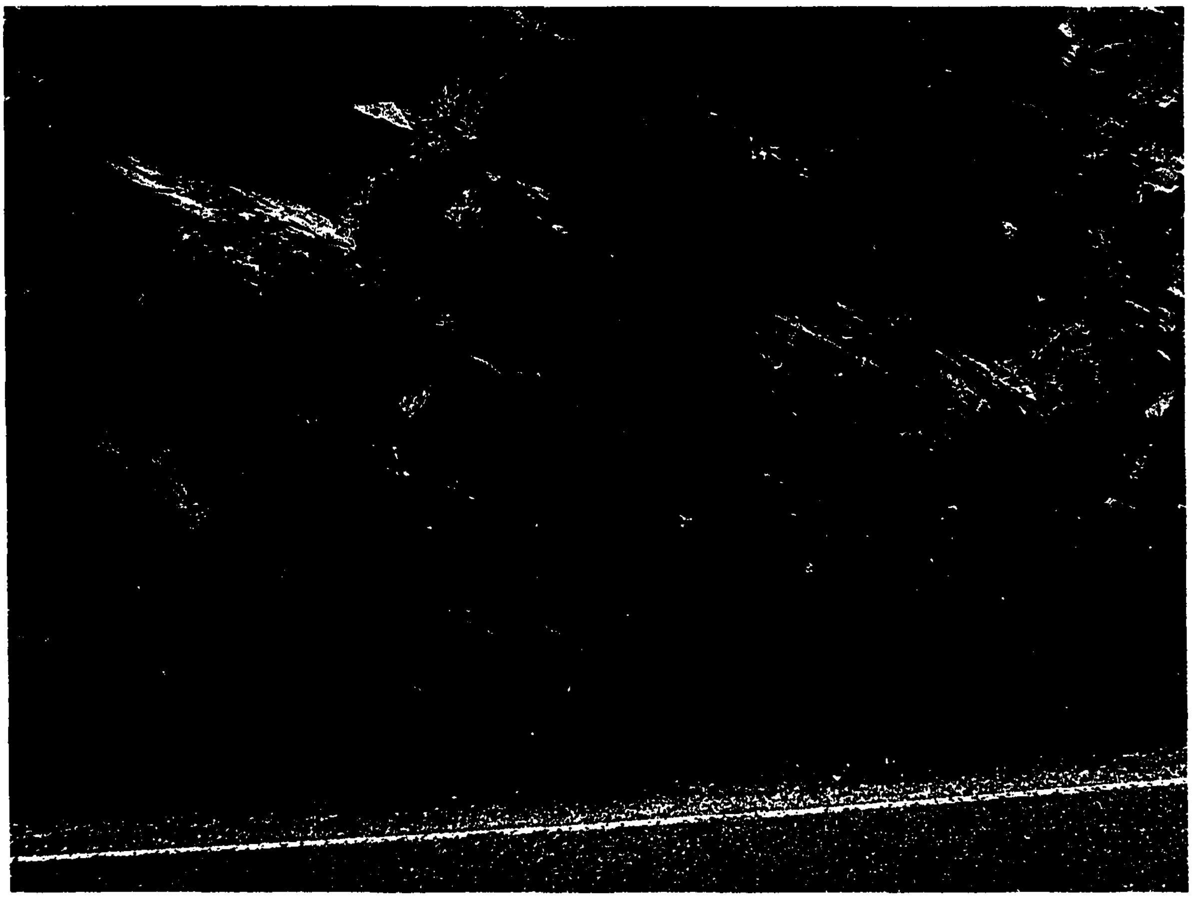


Fig. 66.- Thick massive sandstone beds, unit 14, Flat Gap section (Section 21, Appendix 3). Mattock handle is 1 m long.

Physical sedimentary structures are generally not visible in the massive sandstone beds, although most are intensely bioturbated. Burrows are very indistinct except for a few Scalarituba-like traces. Because it is unlikely that thick turbidites could be so completely bioturbated, I interpret these sandstones as the product of normal bottom currents. Silt laminae in the mudshales are predominantly 0.5 to 5 mm thick. Most are single even laminae but a few of the thicker ones are cross-laminated. These silt laminae, interpreted earlier in this thesis as turbidites, are the thickest and coarest strata in both the eastern Tennessee cores and the Little War Gap section (Section 20, Appendix 3).

Distinctive gamma ray signatures and the occurrence of the Foerstia zone aid the correlation of measured sections and cores through the gray silty shale unit in eastern Tennessee. Foerstia is a widespread fossil brown algae of limited stratigraphic distribution and is thought to be a good time marker (Schopf and Schwietering, 1970). In Plate 2 (in pocket) the middle of the Foerstia zone is used as a datum except for the TDG-DOE-4 core and the Little War Gap section where no Foerstia remains were found. Correlation of these two sections is based on lithologic succession alone and should be considered tentative. The gray silty shale unit is lensoid in geometry. Distinct beds of turbidite siltstone are restricted to a unit in the Flat Gap section which grades into silt-laminated shale to the northeast and southwest (Plate 2, in pocket). Two thinning-upward sequences, 6.1 and 3.4 m thick, in the turbidites at Flat Gap suggest possible channeling (Walker, 1978, p. 953-956).

In the Greendale syncline belt the gray silty shale unit is traceable for approximately 34 kilometers parallel to depositional strike (projected on to a north-south line), from Little War Gap in the northeast to near Joppa, Tennessee, in the Southwest (Plate 2, in pocket). Except for the silt-laminated shale, the massive sandstones are the most extensive facies, traceable for approximately 18 kilometers parallel to depositional strike and for a greater distance southwestward of their thickest occurrence than northeastward. The unit of turbidite siltstones has the least lateral continuity, probably less than 8 kilometers.

Based on its geometry and distribution of facies, I interpret the gray silty shale unit of the Chattanooga Shale as a turbidite lobe deposited basinward of a westward prograding delta. This delta must have been located somewhere to the east of where these turbidites now crop out, in northeastern Tennessee or northwestern North Carolina. This lobe differs from modern submarine fans in its facies distribution in most of the respects that the Brallier Formation does. Turbidite siltstone beds 15 to 70 cm thick with T_{a-}, T_{b-}, and T_{c-} Bouma sequences were deposited along the axis of the lobe possibly in a channel. Concurrently, a few thin turbidite siltstones with T_{c-} Bouma sequences, turbidite silt laminae, and hemipelagic mud were deposited laterally to, and basinward of these turbidite beds. The massive sandstone beds which overlie the units of turbidite siltstone beds, and shale with turbidite silt laminae were probably deposited by traction currents landward of the turbidity currents and then reworked by burrowing organisms.

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PRODELTA TURBIDITES

There are few other descriptions of prodelta turbidite sequences. Examples include the Mississippian Borden Formation of Kentucky (Moore and Clarke, 1970; Kepferle, 1978; Maynard and Lauffenburger, 1978) the Eocene Matalija Sandstone of California (Link, 1975), and the Namurian Shale Grit sequence of northern England (Allen, 1960; Walker, 1966 and 1978). How do these sequences compare with the Brallier Formation?

Cratonic prodelta turbidites occur as four siltstone members in the Borden Formation of Kentucky and adjacent areas. The following discussion of these turbidites is based on the work of Moore and Clarke (1970) and Kepferle (1978). Two of the recurrent turbidite siltstone units of the Borden Formation are the Farmers Siltstone Member, described by Moore and Clarke and the Kenwood Siltstone Member described by Kepferle. The Farmers ranges in thickness from 12 to 73 m and the Kenwood from 0 to 33 m. The turbidites are of silt grade and range in thickness from 3 cm to 6.1 m, averaging about 30 cm. T_{bcde} and T_{be} Bouma sequences predominate. Common substratal markings indicate a homogeneous transverse paleocurrent system without longitudinal transport. Both the Farmers and Kenwood Siltstones lack evidence of slumping. In the Kenwood, Kepferle (1978) was able to delineate two thin fans, less than 35 m thick and 10 to 15 kilometers in width. The turbidites of the Kenwood were of low to moderate flow intensity and locally confined in channels on the prodelta slope. In summary, the turbidites of the Borden Formation are very similar in their occurrence and sedimentology to those of the Brallier Formation. The major differences appear to be that the Brallier is much thicker and was deposited in a geosyncline rather than on the craton.

Link (1975) also described a submarine fan complex in a prograding deltaic system. The stratigraphic transition from distal and proximal turbidites to deltaic sediments occurs within the Eocene Matalija Sandstone. The Matalija Sandstone is a thickening- and coarsening-upward sequence, the lower part of which shows a distinct gradation from thin-bedded distal turbidites to thick-bedded proximal turbidites in a thickness of about 500 m. Mean grain size of both the turbidites and deltaic sediments is medium sand. The transition from proximal turbidites to shallow marine complexes is rapid, yet gradational, and laterally continuous. This transition is marked by a thickening of beds and slight coarsening of grain size, an increase in bioturbation, and increase in large channel-like features, large clasts, disturbed bedding, pebbly sandstones, shell debris, and large-scale low-angle crossbedding. Directly overlying and gradational with the transition interval are units containing shallow-marine fauna and features of traction currents. Features of the proximal turbidites indicate moderately high energy flows. These include thick beds (commonly 1 to 3 m thick) showing evidence of amalgamation, a few slump structures, channels (1 to 6 m thick), and mudstone clasts up to 2 m long. Link (1975) postulates that the Matalija delta was a steep slope delta and that slumping and sliding on the delta front and flanks initiated turbidity currents. The submarine fan was not fed by a system of submarine channels crossing the shelf and slope but by a prograding deltaic complex. Overall, the Matalija Sandstone depositional system is similar to but of higher flow intensity than that of the Brallier Formation. The vertical transition from turbidites to topset deltaic sediments is notably similar in the two systems. The differences are perhaps related to the steepness of the delta slope, the intensity of triggering events, or a combination of the two.

A third example of turbidites in a deltaic system is the Namurian sequence (Late Carboniferous) of northern England. The Mam Tor Sandstone, or distal turbidite part of the sequence, was interpreted in terms of a prograding delta complex by Allen (1960). More recently Walker (1966, 1978, p. 959-961) has described the entire regressive coarsening-upward sequence from basinal black mudstones to shallow water deltaic sandstones as one of the few ancient examples of a complete submarine fan. Paleocurrents are transverse to depositional strike and show an unusually wide spread for turbidites, suggesting an irregular depositional surface and/or several sources of turbidity currents. Walker interprets the Mam Tor Sandstones (100-300 m thick) as lower fan or basin plain, the lower part of the Shale Grit (130-240 m thick) as smooth suprafan lobes, the upper part of the Shale Grit as braided suprafan, and the Grindslow Shales (100-200 m thick) as prograding slope deposits. Capping this sequence is the Kinderscout Grit (150 m thick) which represents the shallow water deltaic complex. Channels become larger and more abundant upward in the Namurian sequence. Nine major channels with depths up to 20 m and fining-upward fill occur in the upper Shale Grit. Thickening- and coarsening-upward sequences up to 120 m thick are also present. These sequences contain massive and pebbly sandstones in their upper parts and show common scouring and bed amalgamation. Bedding in the Shale Grit ranges from 60 cm to 3 m in thickness. Mean grain size is fine to very fine sand but beds are commonly pebbly. Seven major channels, similar to those in the Shale Grit, but up to 50 m thick and at least 1 kilometer wide occur in the Grindslow Shales. These channels however, are stratigraphically surrounded by mudstones. The Shale Grit fan system clearly has much greater affinities with the classic submarine fan model than it does with the Brallier Formation. The Brallier lacks major channels typical of the upper fan and upper mid fan environments, and contains no thick massive and pebbly sandstone beds. The only apparent similarity is that the two systems occur within deltaic complexes and that turbidite sequences grade upward into shallow water deltaic sediments.

The many modern submarine fans along continental rises are not very analogous to turbidite sequences deposited on prodeltas in epeiric seas. In this sense the present may be a poor key to the past largely because of the Pleistocene sea level tragedy (see Passega, 1962). There are few examples of modern prodeltaic turbidites in marine environments although slumping of delta front slopes is very common (Shepard, 1955; Matthews and Shepard, 1962). There are several good examples of lacustrine prodeltaic turbidites, however.

Density underflows in man-made Lake Mead were among the first documented modern turbidity currents (Grover and Howard, 1938; Gould, 1951). Turbid water is supplied to the east end of the lake by the Colorado River. Most of the sand and coarse silt is deposited immediately on the delta platform and front. Most of the fine silt and clay, however, proceeds directly downslope as low density, low velocity turbidity currents. These turbidity currents, which are confined to the submerged river channel, have deposited approximately 50 percent of the sediment in Lake Mead, or about 9.78×10^8 tons (Gould, 1951). High river discharges in the fall and winter initiate turbidity currents which sometimes flow the entire length of the lake, a distance of 193 kilometers.

Turbidity currents are also generated on the foreslope of the Rhône delta in Lake Geneva because of the greater turbidity and lower temperature of the incoming river water (Houbolt and Jonker, 1968). Off the delta, a sublacustrine channel up to 200 m wide and 15 m deep with well developed levees leads down the delta foreslope to a depth of 200 m where the levees disappear. At a depth of approximately 280 m the channel merges with a fan-shaped sand body (suprafan?) which reaches to the deepest part of the lake (309 m) and covers approximately 4 square kilometers (Houbolt and Jonker, 1968, Fig. 1). The delta foreslope averages 1.2° and has a concave-upward profile. In addition to the main channel several shorter minor channels occur on the upper foreslope. The main channel sediment consists of fine to medium sand along its bottom and mud with fine sand layers along its levees. The sand layers are commonly graded. The fan-shaped body below 200 m depth consists of fine to medium sand which shows grading and some cross-lamination. The margins of the fan consist of graded fine to medium sand layers alternating with mud. Lateral to channel levees the delta foreslope is dominantly mud with very thin-bedded silts. The basin plain sediments are muds with minor amounts of sand. The vertical sequence of these offlapping sediments consists of, from base to top: basin plain muds with very little sand; lower delta foreslope deposits composed of small coalescing fan sands and intercalations of muddy lower slope deposits, with sand content decreasing upward; upper delta foreslope muds with minor channel sand bodies; and sand delta front and platform deposits.

As a result of the discharging of taconite tailings by the Reserve Mining Company a small delta and submarine fan have been built in Lake Superior in approximately 17 years (Normark and Dickson, 1976). The subaerial delta platform is in excess of 1.5 kilometers wide and the fan covers an area of approximately 20 square kilometers. The delta front extends from the lake shoreline to a depth of 180 m at a mean slope of 17°. Unlike the Rhône delta (Houbolt and Jonker, 1958) this slope has no prominent channels although 3 to 5 m thick density currents have been observed on it (Normark and Dickson, 1976, p. 1023). At a depth of 180 m there is an abrupt change in slope to 1.5° in the pro-delta area associated with the beginning of fan morphology. Two sub-parallel leveed fan valleys cross the upper fan at the base of the delta slope. The fan valleys are less than 0.5 kilometer in width and approximately 5 kilometers long (Normark and Dickson, 1976, Fig. 4 and 5). The main valley is a maximum of 20 m deep while the subsidiary valley rarely exceeds 5 m in depth. Both fan valleys terminate downslope in low relief suprafans with many smaller channels. The largest of the two suprafans, which are only a few meters thick, covers an area of 5.6 square kilometers. On the fan, coarse sand is confined to the upper fan valleys and suprafan, however most of the fan is composed of silt which makes up the levee complexes. Sands and thick silt units are absent beyond the suprafans. Deposition has resulted in a relatively flat lobe of sediment rather than the half cone physiography common on the middle and lower segments of submarine fans.

The three modern examples discussed above demonstrate the existence of turbidity current processes in prodeltaic settings. Furthermore, the overall sedimentologic aspect and physiography of the Rhône and Reserve fans compare well with my depositional model for the Brallier Formation.

CONCLUSIONS

Upper Devonian Turbidites of the Appalachian Basin

1). The present-day turbidite facies model, based mainly on modern submarine fans and ancient flysch sequences, does not adequately describe the depositional system of the Brallier Formation.

2). The Brallier Formation turbidites are finer grained and thinner bedded than the deposits of most modern submarine fans and ancient flysch systems.

3). The entire stratigraphic sequence from basinal to topset deltaic deposits contains only the classic turbidites member of the resedimented coarse clastic family.

4). The stratigraphic transition from turbidites to the overlying deltaic traction deposit is gradual and lacks the facies characteristic of the proximal parts of modern submarine fans.

5). Turbidite paleocurrents indicate a homogeneous transverse dispersal pattern, atypical of flysch sequences, which suggests that turbidity currents had multiple sources.

6). The Brallier turbidites were deposited on a relatively smooth surface lacking major channels.

7). Turbidites were deposited on a series of small ephemeral turbidite lobes of low flow intensity which coalesced in time to form a laterally extensive wedge.

8). The turbidite lobes were fed by deltas rather than submarine canyons or upper fan channels.

9). Bioturbated olive gray mudstone accumulated by hemipelagic sedimentation on the slope, lateral to areas of active turbidite deposition.

10). Bioturbated claystone and shale with turbidite silt laminae were deposited at the margins of turbidite lobes and on the lower reaches of the slope.

11). Black shales were deposited by hemipelagic sedimentation of mud and organic matter basinward of the turbidite lobes.

12). The ultimate source for the Brallier Formation was an eastern complex of sedimentary and low-grade metasedimentary rocks.

Prodeltaic Turbidites

Some prodeltaic turbidite sequences differ significantly from the present-day turbidite facies model and Alpine flysch-type sequences (Fig. 67). It also appears that a continuum may exist from low flow intensity prodeltaic turbidite sequences, such as the Brallier and Borden Formations, and high flow intensity prodeltaic turbidite sequences such as the Namurian Shale Grit sequence. The slope and tectonics of the receiving basin are important controlling parameters.

Prodeltaic and Alpine flysch-type turbidite systems may have characteristically different vertical sequences of proximal facies (Fig. 67). These differences are attributable to the coarser grain size and pronounced channeling in Alpine Flysch-type systems. These two features, as well as the greater flow intensity of turbidity currents, are probably related to the more tectonically active nature of flysch basins and their shorter, steeper supplying rivers (Fig. 67). The proximal facies of flysch basins are sometimes not preserved because these sequences are synorogenic and the nearshore deposits are commonly thrust out or eroded away. Because their basins are less tectonically active, prodeltaic turbidite sequences tend to be thinner than flysch sequences. The dispersal pattern of prodeltaic turbidites is dominantly uniform and transverse to the basin axis or margin. Flysch sequences, however, typically have a dispersal pattern which is mainly parallel to the basin axis with subsidiary oblique or transverse trends. This relationship implies that sand bodies will also have different trends in these two types of systems.

CHARACTERISTIC	PRODELTAIC	ALPINE FLYSCH-TYPE
Proximal facies and vertical sequence	CLASSIC TURBIDITES and CROSSBEDDED DELTA FRONT SANDSTONES. COARSENING- and THICKENING-UPWARD. RARE SHALLOW CHANNELS.	MASSIVE and PEBBLY SANDSTONES, CONGLOMERATES, DEBRIS FLOWS, and SLUMPS. FINING- and THINNING-UPWARD. DEEP CHANNELS common.
Grainsize	FINE to medium.	COARSE, VERY COARSE, to fine.
Flow intensity	WEAK to moderate.	HIGH to moderate.
Dispersal pattern	TRANSVERSE (normal to basin axis or margin), UNI-DIRECTIONAL, with SMALL VARIANCE.	LONGITUDINAL (parallel to basin axis or margin), BI- or MULTI-DIRECTIONAL.
Orientation of sand bodies	TRANSVERSE.	LONGITUDINAL, ± transverse.
Tectonics	QUIESCENT.	ACTIVE.
Thickness	10 - 1000 meters.	1000's of meters.
Supply system	LONG, LOW GRADIENT RIVER SYSTEMS.	SHORT, STEEP GRADIENT RIVER SYSTEMS.

Fig. 67.- A generalized summary of the contrasting characteristics of prodeltaic and Alpine flysch-type turbidite sequences.

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Appendix 1

Petrographic Analyses

PETROGRAPHIC ANALYSIS OF SILTSTONES

SAMPLE	QUARTZ		FELDSPAR			ROCK FRAGMENTS				MICA			MATRIX	CEMENT		PYRITE	HEAVIES	ORGANICS	OTHER
	MONOCRYSTALLINE	POLYCRYSTALLINE	PLAGIOCLASE	MICROCLINE	ORTHOCLASE	METAMORPHIC	QUARTZ-POLYMINERALIC	CHERT	SEDIMENTARY	MUSCOVITE	CHLORITE	BIOTITE		CARBONATE	SILICA				
BS1-1	44.5	1.0	T	--	--	5.5	--	--	--	1.0	0.5	--	26.0	21.5	--	1.0	--	--	--
BS1-2	47.0	T	T	--	--	10.0	--	--	--	3.5	T	--	34.5	3.5	--	1.5	--	--	--
BS1-4a	55.5	3.5	T	--	--	10.0	--	1.5	--	1.0	T	--	22.5	1.5	2.0	1.0	0.5	--	1.0
BS1-4j	52.0	1.0	0.5	--	--	10.0	--	--	--	4.0	--	--	31.5	--	--	--	--	--	1.0
CF-1	44.5	4.0	T	--	--	4.0	--	1.0	--	3.5	1.0	0.5	39.0	--	--	1.5	T	--	1.0
CF1-5	50.5	2.5	--	--	--	5.5	--	--	0.5	T	--	--	30.5	--	--	2.0	--	--	8.5
MA1-1	36.5	7.5	T	--	--	11.0	1.5	2.5	0.5	6.0	5.0	3.5	25.0	--	0.5	0.5	T	--	--
MA1-2	52.5	0.5	0.5	--	1.0	17.0	1.0	--	--	5.5	1.0	0.5	19.0	--	--	1.5	--	--	--
MC1-6a	43.5	5.5	--	--	--	18.0	2.5	0.5	--	6.0	2.5	1.0	18.5	--	--	1.0	T	--	0.5
MC1-10	50.0	1.5	T	--	--	5.5	--	4.5	--	4.0	0.5	--	33.5	--	--	--	T	--	0.5
MH2-1	48.5	6.5	T	--	--	6.0	--	--	1.0	5.5	1.0	--	15.0	14.5	0.5	1.5	T	--	--
MH2-2	52.5	2.5	1.0	--	--	2.5	--	1.5	1.5	2.5	6.0	--	22.5	5.5	1.5	0.5	--	--	--
MH2-3	42.0	0.5	T	--	--	3.5	--	--	--	5.5	4.5	0.5	35.0	5.5	--	2.0	--	0.5	0.5
MH3-1	40.5	7.0	T	--	T	3.0	2.0	0.5	--	1.0	T	--	4.0	3.0	3.5	--	T	--	35.5
MH3-2	33.5	14.0	T	--	--	4.0	2.0	0.5	1.0	3.5	3.5	--	27.0	6.5	3.5	--	T	--	1.0
MH3-3	56.5	4.5	0.5	--	--	14.0	2.0	2.5	--	1.0	3.0	--	14.5	--	--	--	0.5	--	1.0
*WS1-1	66.0	1.0	1.0	--	--	6.0	1.5	1.0	--	3.5	2.5	--	7.5	7.0	--	2.5	T	0.5	--
*WS1-2	73.5	2.5	0.5	--	--	3.5	1.5	--	1.0	3.0	2.0	--	10.0	T	--	1.5	T	1.0	--
ST1-1	38.0	2.0	T	--	T	3.5	2.5	0.5	T	1.0	1.5	--	16.5	32.5	--	0.5	--	--	1.5
ST1-3	60.0	1.5	--	--	--	8.0	--	1.0	--	3.5	1.0	1.0	20.0	--	--	2.5	T	0.5	1.0
ST1-10	55.5	1.5	0.5	--	--	7.5	1.5	T	--	4.5	2.5	--	25.0	--	--	0.5	--	--	1.0
ST1-12	48.0	1.5	--	--	--	6.5	4.0	--	--	2.0	2.0	1.5	21.5	--	--	--	--	--	13.0
ST1-13	52.5	1.0	T	--	--	4.0	4.5	1.0	--	2.0	2.0	0.5	18.5	6.0	--	--	--	0.5	7.5
ST1-18	56.5	4.5	T	--	--	9.0	2.5	1.0	--	2.5	2.0	--	21.5	T	--	--	T	--	0.5
ST1-24	58.0	--	T	--	--	4.5	--	--	--	2.5	--	--	25.5	7.0	--	2.5	T	--	--
ST1-30	64.5	3.5	T	--	--	7.0	1.5	0.5	--	1.0	1.0	--	13.5	6.0	0.5	--	0.5	--	0.5
ST3-1	69.5	0.5	T	--	1.5	4.5	1.0	--	--	1.5	2.0	--	15.5	--	1.0	--	--	--	2.0
ST3-10c	61.5	6.0	0.5	--	--	6.5	3.0	--	--	3.0	1.0	--	17.0	--	1.5	--	T	--	--
ST3-15	62.5	9.0	0.5	--	1.5	4.0	1.5	1.5	--	0.5	1.0	--	10.0	--	4.0	T	T	4.0	--
ST3-23b	54.5	6.0	T	--	--	5.0	--	T	2.5	3.5	1.0	--	1.5	22.0	--	--	0.5	--	3.5
ST3-24	55.0	8.5	1.0	--	2.0	5.5	--	0.5	8.0	--	2.0	--	15.5	T	0.5	0.5	0.5	--	0.5
ST3-25a	72.0	2.5	T	--	0.5	11.0	--	0.5	--	1.5	3.5	--	8.0	--	0.5	--	T	--	--
ST3-25g	67.0	2.5	T	T	--	7.5	--	1.0	--	3.0	2.5	T	15.5	--	--	1.0	--	--	--
HG1-22	58.5	2.5	0.5	--	1.0	10.5	3.0	--	1.0	3.5	1.0	0.5	17.0	--	0.5	--	--	--	1.0
HG1-27	53.5	6.0	T	--	--	12.5	3.5	1.0	2.0	1.5	0.5	--	16.0	--	2.5	--	--	--	1.0
**T1S-6	83.5	4.0	0.5	--	2.5	1.0	1.5	--	--	0.5	T	--	5.0	--	--	T	--	--	1.5
**T1N-6	78.0	2.5	0.5	--	0.5	4.0	--	--	--	2.0	T	--	7.0	--	--	3.0	--	--	2.5
**T1N-5	74.0	7.0	0.5	--	0.5	1.5	1.0	--	--	2.0	T	--	8.0	--	0.5	2.0	--	--	3.0
**T1N-3a	53.0	4.0	2.0	0.5	--	6.0	2.5	1.0	--	6.0	T	0.5	15.5	--	--	5.0	0.5	1.0	0.5
**T1S-4	69.5	7.0	--	--	--	0.5	1.0	0.5	--	0.5	--	--	16.0	--	1.5	--	--	0.5	3.0

*"Chemung" Formation
**Chattanooga Shale, gray silty shale unit
All other samples are from the Brallier Formation

PETROGRAPHIC ANALYSIS OF MUDSTONES, CLAYSTONES, AND SHALES

SAMPLE	QUARTZ		FELDSPAR	ROCK FRAGMENTS			MICA			MATRIX	OTHER	
	MONOCRYSTALLINE	POLYCRYSTALLINE		METAMORPHIC	QUARTZ-POLYMINERALIC	CHERT	MUSCOVITE	CHLORITE	BIOTITE		ORGANIC	
BR1-3	11.0	--	--	--	--	--	4.5	1.0	--	81.0	1.5	1.0
BR1-5	5.0	--	--	--	--	--	1.0	--	--	92.5	T	1.5
GC1-4	12.0	0.5	--	--	1.0	0.5	4.5	T	--	78.5	--	3.0
HI1-1	19.0	1.0	--	--	1.5	--	5.0	3.5	--	59.5	2.5	8.0
HI1-7	22.0	--	--	--	--	--	3.0	--	--	52.0	21.0	2.0
MC1-1	10.0	--	--	--	--	--	2.0	2.0	--	77.5	0.5	8.0
MC1-2	11.5	--	--	--	--	0.5	3.0	1.0	--	83.0	0.5	0.5
MC1-3	8.0	--	--	--	--	--	3.5	0.5	--	67.0	18.0	3.0
MC1-3	18.0	--	T	0.5	1.0	0.5	2.0	1.5	--	73.0	1.0	2.5
MCD-182	10.0	--	--	--	--	--	5.5	--	--	84.5	--	--
MH2-4	12.5	--	--	--	--	--	6.5	3.0	T	73.5	2.5	2.0
MH2-5	16.5	--	--	0.5	--	--	4.0	1.0	--	61.0	1.0	16.0
R16-BLK	10.0	--	--	0.5	--	--	4.0	0.5	--	74.0	9.5	1.5
ST1-34	2.5	--	--	--	--	--	3.0	--	--	94.5	--	--
ST1-46	10.5	--	--	--	--	--	2.0	--	--	87.5	--	--
ST1-50	22.5	1.5	--	0.5	--	1.0	4.0	0.5	--	63.0	1.0	6.0
ST1-57	18.5	--	T	0.5	--	--	2.5	3.5	T	71.5	1.0	2.5
ST1-65	8.5	--	--	--	--	--	0.5	T	0.5	90.0	--	0.5
ST1-79	14.5	--	--	1.0		0.5	6.0	--	--	71.0	2.0	5.0
ST3-888	30.0	--	--	T	--	--	5.0	--	--	62.5	--	2.5
*T-70	38.0	2.5	0.5	1.5	1.0	--	6.0	0.5	--	38.5	2.0	9.5
*T-1N-1	58.5	2.5	T	1.5	--	1.5	4.5	1.0	--	13.0	16.0	1.5
*T1N-12a	46.0	2.5	2.0	2.0	2.5	0.5	1.5	T	--	20.0	15.5	7.5

*Chattanooga Shale, gray silty shale unit
All other samples are from the Brallier Formation

Appendix 2

Calculation of Rotations of Directional Features

In the text I presented a figure showing orientation of substratal lineations, incorporating corrections for deformation and for rigid-body rotation and displacement, based on analysis of a palinspastic map. Here I explain how the orientation was computed.

The orientations of linear elements that behave as passive markers in rocks undergoing folding are affected by three processes, rigid body displacement, pure deformation, and rotation. Rigid body displacement is simply a change in the position of a body with no change in its shape or orientation. Pure deformation is the change in shape of a body and can affect orientations of directional features. Rotation involves only a change in orientation. In nature all three of these processes occur simultaneously and affect the location and orientation of directional features. The pure deformation and rotation generally are three dimensional, so that both the plunge and the azimuth of a linear element generally change as a result of folding. However, for the area I am studying, the data with which one can compute rotations and deformations is two-dimensional. I have a palinspastic map indicating the approximate pattern of distorted grid lines (Fig. A) that are now straight (latitudes and longitudes, Fig. B). Furthermore, I generally corrected the azimuths of directional features in the field by the usual method of rotating to horizontal the beds and the contained directional features about the local strike of the beds. Therefore I cannot correct for reorientation due to thickening or thinning. The plunges of folds are small, so there was no need to correct for plunge (Potter and Pettijohn, 1977, p. 373).

Method of Calculating Rotation

One can think of the present-day system of rectilinear longitudes and latitudes (Fig. B) to be a deformed state resulting from deformation, rotation and rigid-body displacement of rock bounded by the warped lines of longitude and latitude shown on the palinspastic map (Fig. A). We know the orientation of a directional feature in the deformed (current) state and we wish to know its orientation in the undeformed state. In order to estimate the orientation of directional features in their undeformed state it is necessary to assume that the distortion of the longitude and latitude grid elements reflects distortion of the rocks in the area and that strain was homogeneous on the scale of one quarter of a grid element considered (15-minute quadrangle).

Let Figure C1 be a quadrangle in its post-deformation state. Its width is a and its height is b. Let the inscribed line, g-h, represent a directional feature in the deformed state. The line projects onto the horizontal x-axis as dx and onto the vertical z-axis as dz. Angle alpha (α) represents the azimuth of the directional feature. Let Figure C2 be the distorted quadrangle in its predeformation state. Angle α' is the original orientation of the directional feature, which we want to compute. The projection of the line g'-h' onto the x'-axis is dx' and onto the z'-axis is dz'. Other important distances are indicated in Figure C.

The tangent of the azimuth of the line g'-h' is $\tan\alpha' = dx'/dz'$. We can express the projections dx' and dz' of the line g'-h' in the predeformation state in terms of the projections, dx and dz, of the same

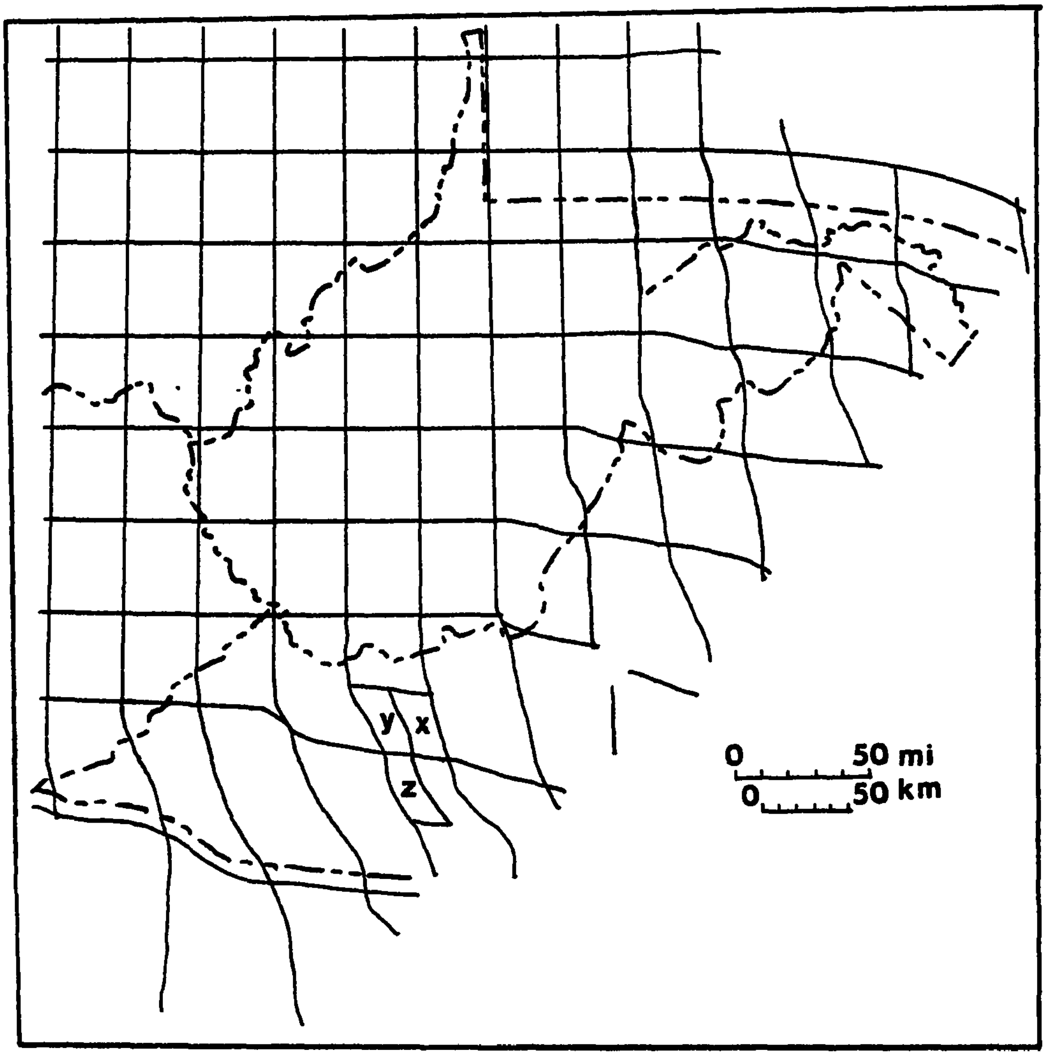


Fig. A.- Palinspastically restored system of longitudes and lattitudes (30-minute spacing). Quadrangles "X", "Y", and "Z" are discussed in the text. After Dennison and Woodward (1964, Fig. 3)

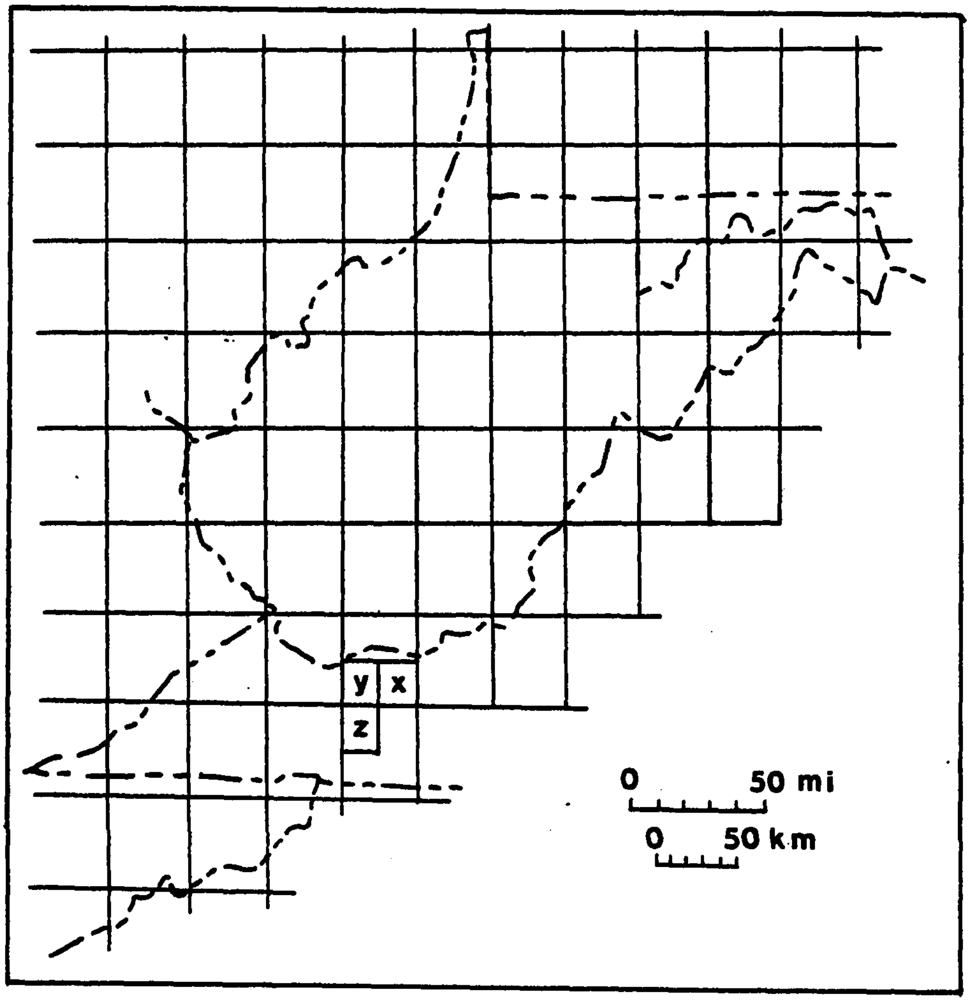


Fig. B.- Present-day rectilinear system of longitudes and lattitudes (30-minute spacing). Quadrangles "X", "Y", and "Z" are the same as in Figure A.

line in the post-deformation state through the following equations, which can be derived by inspection of Figures C1 and C2.

$$dx' = (a'/a)dx + (c'/b)dz \quad (1a)$$

$$dz' = (e'/a)dx + (b'/b)dz \quad (1b)$$

Thus,

$$dx'/dz' = \tan\alpha' = [(a'/a)\tan\alpha + (c'/b)]/[(e'/z)\tan\alpha + (b'/b)] \quad (2)$$

using the relation, $dx/dz = \tan\alpha$.

By measuring the dimensional quantities $\underline{a}$,$\underline{b}$,$\underline{a}'$,$\underline{b}'$,$\underline{c}'$ and $\underline{e}'$, shown in Figure C, we can use equation (2) to compute the original azimuth, α', of a directional feature in terms of its current azimuth, α.

It is rather difficult to visualize reorientations predicted by equation (2), because the equation contains many terms. One can obtain a rough estimate of the reorientation by computing the rigid-body rotation of the grid pattern. If deformations are small, the original azimuth of a directional feature is determined by correcting the final aximuth by the angle of rotation, Φ.

$$\alpha' \simeq \alpha + \Phi \quad (3a)$$

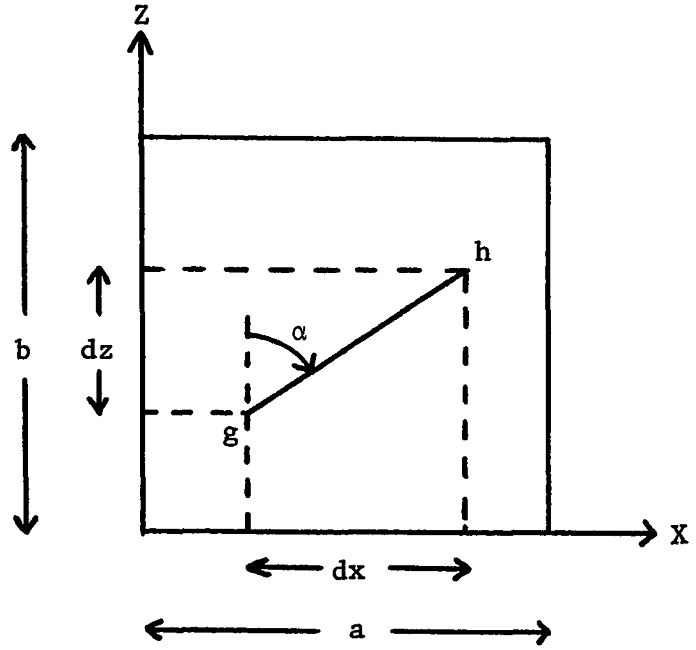
where the rotation is approximately,

$$\Phi \simeq (1/2)(\beta - \Theta) \quad (3b)$$

and Θ and β are angles defined in Figure C2.

The equations presented above are for a quadrangle that is uniformly deformed and rotated, whereas it is clear in Figure A that the quadrangles are inhomogeneously deformed and rotated. In the computations of orientations of substratal lineations presented in Figure 17, I subdivided each quadrangle into four and computed orientations for each

1.



2.

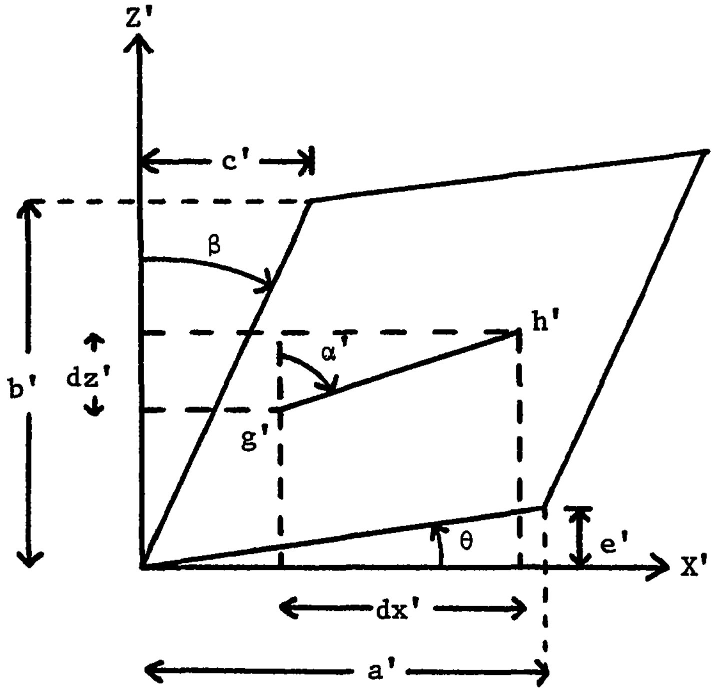


Fig. C.- 1.) quadrangle in its post-deformation state. 2.) same quadrangle in its pre-deformation state.

subdivision separately.

Let us consider specific examples, where equations (3) adequately correct the orientation of substratal lineations, and where equation (2) is clearly required to obtain correct results. For example, for the 15-minute quadrangle "X", shown in Figure B, $a'/z = 0.74$, $c'/b = -0.49$, $e'/a = 0.13$, $b'/b = 1.38$. The final azimuth of the substratal lineations in this area is $\alpha = 251^{\circ}$. Using equation (3b), the approximate angle of rotation is $\Phi = -7^{\circ}$, so that, using equation (3a), we estimate the original orientation to have been $\alpha' \simeq 244^{\circ}$. Using equation (2), we compute the original orientation to have been $\alpha' = 238^{\circ}$, so that the exact correction is -13°. In this example, therefore, we could use the approximate method to estimate the sense and magnitude of the correction of the azimuth of substratal lineations. For many other examples both the sense and the magnitude of the correction can be in serious error when the approximate method is used.

Let us consider the 15-minute quadrangle "Y", shown in Figure B. The final azimuth of substratal lineations is $\alpha = 264^{\circ}$. Using the exact method, equation (2), we compute the original azimuth to have been $\alpha' = 262^{\circ}$, whereas, using the approximate method, equations (3), we compute $\alpha' \simeq 249^{\circ}$. As a final example, let us consider the 15-minute quadrangle "Z", shown in Figure B. The final azimuth is $\alpha = 237^{\circ}$, and the original azimuth is computed to have been $\alpha' = 205^{\circ}$, a correction of -32°. Therefore, the correction factor can be large. Further, consideration of distortion as well as rotation for this example doubles the correction factor. The correction factor determined with the approximate method, equations (3), is -14°, whereas that with the exact method, equation (2), is -32°.

As discussed in the text, the corrected orientations of substratal lineations, taking into account the rotation and deformation of the rocks regionally, slightly modifies the pattern of orientations, but does not qualitatively affect the pattern. It is important to note, for measurements in highly deformed areas, that each measurement of substratal lineation must be corrected before the measurements are treated statistically to determine the mean orientations. The procedure outlined here should be used for making the corrections.

Appendix 3

Measured Sections

Lithologic names used in the following section descriptions are those discussed in the text under the classification of mudrocks. Colors refer to those of the rock-color chart (Goddard and others, 1963). Estimates of siltstone percentage were made in the field with bar comparators and were checked frequently with bed by bed measurements. Designations such as Ta, Ta-e, and Tb- are used to describe Bouma sequences in siltstone beds. Subscripts refer to specific Bouma units, for instance, Ta-e describes a complete Bouma sequence and Tb- indicates only that the bed or beds begin with the Bouma b unit.

SECTION 1

Rt. 250 Section

Incomplete section of the lower one half of the Brallier Formation exposed for 0.6 mile in road cuts along south side of U.S. Highway 250, 1.1 miles west of town of Head Waters, Highland County, Virginia (McDowell Quadrangle). Base of section located approximately 80 feet east of Cowpasture River at first curve in road (636635 East, 4242923 North, Universal Transverse Mercator grid). Section measured, described, and sampled using Jacob's staff, Abney level, tape and compass and gamma-ray profile taken with scintillometer by Paul D. Lundegard and Neil D. Samuels, Aug. 29-30, 1977 and June 6-9, 1978.

	Thickness (feet) Unit	Cum.
Devonian (incomplete):		
Brallier Formation (incomplete):		
36. Mudstone and very minor claystone (80 percent) and siltstone and very-fine-grained sandstone (20 percent). Mudstone is olive gray (5Y4/1); rare, distinct horizontal burrows 3 to 5 mm across and about 3 cm long; parting thickness is variable up to 1 cm. Siltstone and very-fine-grained sandstone in beds 0.05 to 1.0 ft thick, mode is about 0.1 ft; groups of 3 or 4 beds 0.3 - 0.6 ft thick common, amalgamation of beds rare; ripple lamination common in beds less than 0.2 ft thick; Ta Bouma sequences predominate in thicker beds; current formed sole markings include bulbous flute marks at 2.4 ft above base oriented 298° and 305° with blunt ends toward east...	61.4	1385.4
35. Interbedded mudstone and clayshale (70 percent) and siltstone (30 percent). Mudstone shows rare silt laminae less than 1 mm thick; spheroidal weathering common; clayshale is texturally laminated; silt-free; partings 1 to 5 mm thick. Siltstone in beds up to 0.25 ft thick, mode is 0.1 to 0.15 ft; ripple lamination very common; Tcd Bouma sequences common; sharp, planar bases and gradational tops...........................	25.6	1324.0
34. Claystone, olive gray (5Y4/1), weathers light olive gray (5Y5/2) to subconchoidal chunks; silt-free to slightly silty; rare silt laminae 1 to 2 mm thick; rare 1 cm thick		

	Thickness (feet) Unit	Cum.
silt layers with planar lamination; abundant, indistinct, yellowish gray (5Y8/1) burrows locally form biolamination (color lamination) 1 to 2 mm thick............................	8.2	1298.4
33. Siltstone (50 percent) mudstone (25 percent) and clayshale (25 percent). Siltstone is in 14 beds up to 1.0 ft thick, mode is 0.2 to 0.3 ft; Ta Bouma sequences common, Tbcd, Tcd sequences less common. Mudstone shows partings 2 to 5 mm thick. Clayshale in upper one third of unit; texturally laminated; silt-free; partings less than 2 mm thick......	10.2	1290.2
32. Mudstone and interbedded claystone (80 percent) and siltstone (20 percent). Mudstone and claystone are light olive gray (5Y5/2) to moderate olive brown (5Y4/4) weather light olive gray (5Y5/2). Mudstone shows rare silt laminae less than 1 mm thick; rare, distinct horizontal burrows; spheroidal weathering common. Claystone comprises less than 20 percent of unit; indistinct, yellowish gray (5Y8/1) horizontal burrows very common. Siltstone in beds 0.05 to 0.6 ft thick, mode is 0.2 ft; Tc Bouma sequences common, Tbc sequences rare; non-bedded, non-laminated siltstone comprises less than 10 percent of unit....................................	39.8	1280.0

NOTE: Low angle fault separates units 32 and 31. Section description continued near top of upper fault block.

31. Claystone with minor mudstone and clayshale (85 percent) and siltstone (15 percent). Claystone, clayshale and mudstone are olive gray (5Y4/1); claystone is silt-free; both claystone and mudstone show common, distinct horizontal burrows 3 to 5 mm across; spheroidal weathering common; partings 2 to 4 mm thick. Clayshale is compositionally laminated with quartz silt laminae 1 mm thick or less. Siltstone in beds up to 0.6 ft thick, mode is 0.1 ft or less; Tc Bouma sequences common in beds less than 0.2 ft thick; planar and cross lamination common;

		Thickness (feet) Unit	Cum.
	Ta and Tb sequences common in thicker beds; siltstone also occurs as indistinctly bedded layers up to 1.5 cm thick..................	100.2	1240.2
30.	Claystone, yellowish gray (5Y8/1); silt-free, intensely bioturbated with indistinct, horizontal burrows; forms slight recess on outcrop face................................	3.0	1140.0
29.	Mudstone (90 percent) and siltstone (10 percent). Mudstone shows distinct horizontal burrows 3 to 5 mm across; partings 5 to 10 mm thick; spheroidal weathering common. Siltstone in beds up to 0.3 ft thick, mode is 0.2 ft; Tbc and Tc Bouma sequences common....................................	13.5	1137.0
28.	Interbedded mudstone and claystone (85 percent) and siltstone (15 percent). Interbedded mudstone and slightly silty claystone show rare silt laminae less than 1.5 mm thick and distinct horizontal burrows 3 to 5 mm across. Claystone in lower 1.0 ft of unit in beds up to 0.2 ft thick; indistinct, yellowish gray horizontal burrows abundant. Siltstone occurs predominantly in upper 4 feet of unit in one bed 1.5 ft thick plus a few beds 0.2 to 0.4 ft thick; thinner beds with Tc Bouma sequences common in lower part of unit......	18.5	1123.5
27.	Covered..................................	10.0	1105.0
26.	Mudstone (45 percent) mudshale (40 percent) with interbedded claystone (10 percent) and siltstone (5 percent). Mudstone is olive gray (5Y4/1) weathers moderate olive brown (5YR4/4) to small brittle chips; distinct horizontal burrows 3 to 5 mm across common; irregular partings 5 mm thick. Mudshale predominates from 18 ft to 34 ft below top; like mudstone in color but compositionally laminated; abundant silt laminae less than 1 mm thick; horizontal burrows very rare; partings 1 to 3 mm thick. Claystone occurs as highly burrowed thin interbeds in mudstone		

	Thickness (feet) Unit	Cum.
and mudshale. Siltstone in beds up to 0.6 ft thick, mode is less than 0.15 ft; Tbc Bouma sequences rare........................	50.7	1095.0
25. Siltstone (85 percent) and clayshale (15 percent). Siltstone is in five beds, from top to bottom of unit the thickness and Bouma sequence of each bed is: 0.3 ft (Tab), 0.45 ft (Tbc), 0.3 ft (Tb), 1.6 ft (Tb) and 0.5 ft; micaceous. Clayshale is olive gray (5Y4/1), weathers light olive gray (5Y5/2); texturally laminated; distinct horizontal burrows 3 to 5 mm across; partings 1 to 3 mm thick..................................	3.8	1044.3

NOTE: Fault of unknown displacement separates units 24 and 25. Section continues on upper block of fault.

24. Mudstone (90 percent) and siltstone (10 percent). Mudstone shows distinct horizontal burrows 3 to 5 mm across; partings 2 to 5 mm thick. Siltstone in a few beds 0.2 to 0.6 ft thick plus approximately 10 beds less than 0.1 ft thick.....................	25.9	1040.5
23. Mudstone and clayshale with very minor claystone (55 percent) and siltstone (45 percent). Mudstone is very silty; partings up to 1.5 cm thick. Clayshale is moderate olive brown (5Y4/4), weathers light olive gray (5Y5/2); texturally laminated; rare silt laminae less than 0.5 mm thick. Covered zone between 26.4 to 30.4 ft below top contains no obvious resistant beds. Siltstone in beds up to 2.2 ft thick, mode is less than 0.2 ft, mean is 0.35 ft; some amalgamation of beds; Tc Bouma sequences common, Ta and Tbc sequences also present; sole markings include groove casts at 17 ft below top oriented 242°, and flute marks at 48 and 49 ft below top oriented 308°, 302°, 277°, 280°, and 287° with blunt ends toward east. Beds strike 133° dip 41° SE..........	62.9	1014.6
22. Mudstone, with minor clayshale near top of unit, grades downward into claystone, and		

	Thickness (feet) Unit	Cum.
less than 5 percent siltstone. Mudstone, claystone and clayshale are olive gray (5Y7/1) to moderate olive brown (5YR4/4), weather light olive gray (5Y5/2). Mudstone shows irregular partings 2 to 5 mm thick. Clayshale is slightly silty; partings 2 to 3 mm thick. Claystone is silt-free; distinct horizontal burrows 3 to 5 mm across common. At 21.4 ft below top is a 0.6 ft zone of claystone with abundant, indistinct yellowish gray burrows. Siltstone in beds up to 0.3 ft thick, mode is less than 0.15 ft; Ta and Tb Bouma sequences common......................	46.7	951.7
21. Very poorly exposed. Mudstone and claystone like unit 18 with several resistant siltstone beds; one 0.7 ft bed in middle of unit......................................	18.0	905.0
20. Mudstone (80 percent) claystone (10 percent) and siltstone (10 percent). Mudstone is olive gray (5Y4/1), weathers light olive gray (5Y5/2) with moderate brown (5YR3/4) limonitic stain; silty; two types of distinct horizontal burrows common, one less than 1 mm across and another between 3 and 5 mm across; irregular partings 2 to 5 mm thick; spheroidal weathering common. Claystone in beds up to 0.6 ft thick; indistinct, yellowish gray, horizontal burrows common. Siltstone in 10 beds up to 1.6 ft thick, mode is less than 0.2 ft. Covered from 39 to 43.5 ft below top.....................................	57.8	887.0
19. Siltstone and very-fine-grained sandstone (60 percent) and mudstone with very minor claystone (40 percent). Siltstone and sandstone in single beds up to 2.2 ft thick and amalgamated beds up to 4.4 ft thick, mode is 0.1 ft, mean is 0.2 ft; amalgamation of beds common; Tbc and Tc Bouma sequences very common, Ta, Tab and Tabc sequences less common; abundant current formed sole markings include flute marks and groove casts with average orientation of 250°, blunt ends of		

		Thickness (feet) Unit	Cum.
	flutes toward east. Mudstone is moderate olive brown (5Y4/4) weathers with moderate brown (5YR3/4) limonitic stain; silt laminae less than 1 mm thick rare; distinct horizontal burrows 3 to 5 mm across rare; partings 2 to 5 mm thick. Covered zone between 25.5 and 32.2 feet below top. Beds strike 134°, dip 32° to 40° E...............................	88.9	829.2
18.	Mudstone, with minor interlaminated claystone (85 percent) and siltstone (15 percent). Mudstone like unit 16. Intensive horizontal burrowing produces biolamination on the order of a few mm thick between 25 and 28 feet below top. Siltstone in beds up to 0.2 ft thick, mode is 0.1 ft; Tbc and Tc Bouma sequences common.......................	40.5	740.3

NOTE: Fault with approximately 30 feet of displacement separates units 18 and 17. Beds correlatable across fault.

		Unit	Cum.
17.	Siltstone (60 percent) and claystone (40 percent). Siltstone in eight beds, which range in thickness from 0.05 to 2.1 ft; Ta Bouma sequence in two thicker beds, Tc and Tcd common in thinner beds; straight or slightly curved organic sole markings common. Claystone is light olive brown (5Y5/6) weathers light olive gray (5Y5/2); silt-free to slightly silty; rare silt laminae less than 1.5 mm thick; partings 2 to 10 mm........	10.4	699.8
16.	Mudstone (85 percent) and siltstone (15 percent). Mudstone shows rare silt laminae less than 1.5 mm thick; distinct horizontal burrows 2 mm across common; irregular partings 2 to 5 mm thick; spheroidal weathering common. Siltstone in beds up to 0.4 ft thick, mode is 0.2 ft; current formed sole markings common, include groove casts oriented 238° and 240° and abundant flute marks at 17 ft below top oriented 236° and 238° with blunt ends toward east. Beds strike 134°, dip 26° SE......................	26.6	689.4

	Thickness (feet) Unit	Cum.
15. Mudstone and minor claystone (95 percent) and siltstone (5 percent). Mudstone is olive gray (5Y3/2), weathers spheroidally to olive gray (5Y4/1) chips and blades; distinct horizontal burrows less than 4 mm across are common and are straight to curving, non-branched and weather moderate brown (5YR4/4); partings 4-10 mm thick. Claystone is intensely bioturbated with indistinct yellowish gray (5Y8/1) horizontal burrows. Siltstone in beds up to 0.5 ft thick, mode is 0.15 ft; Tc most common Bouma sequence, Ta sequences much less common...............	72.6	662.8
14. Siltstone and very-fine-grained sandstone; olive gray (5Y4/1); in four beds which range in thickness from 0.3 to 2.3 ft; beds are amalgamated; Ta and Tb Bouma sequences; thickest bed shows bulbous sole markings which lack clear orientation................	4.4	590.2
13. Mudstone with minor clayshale and claystone (90 percent) and siltstone (10 percent). Mudstone is olive gray (5Y4/1); distinct horizontal burrows 3 to 5 mm across, non-branching, resemble <u>Pteridichnites</u> <u>biseriatus</u> (common between 31 and 41 feet below top); spheroidal weathering common. Claystone is light olive gray (5Y5/2); abundant indistinct yellowish gray burrows. Clayshale contains common silt laminae less than 1 mm thick. Siltstone is light olive gray (5Y5/2); beds up to 0.65 ft thick, mode is 0.15 ft; cross lamination very common; organic sole markings..................................	83.0	585.8
12. Clayshale (70 percent) and siltstone (30 percent). Clayshale is olive gray (5Y4/1); texturally laminated; silt-free to slightly silty; partings 3 mm thick. Siltstone in beds up to 0.7 ft thick, mode is 0.15 ft; Tc Bouma sequences are most common with few Tbc sequences; current-formed sole markings include flute marks oriented 254° and 263°		

	Thickness (feet) Unit	Cum.
with blunt ends toward east and groove casts oriented 272° and 267°. Beds strike 139°, dip 36° SE..................................	13.5	502.8
11. Mudstone with minor clayshale and claystone (85 to 90 percent) and siltstone (10 to 15 percent). Mudstone like unit 9 except lacking burrows; weathers light olive gray (5Y5/2). Clayshale is light olive gray (5Y5/2); common silt laminae less than 1 mm thick, many show cross lamination. Claystone in upper 1.5 ft of unit is light olive gray (5Y6/1) to yellowish gray (5Y8/1), weathers light olive gray (5Y5/2) to subconchoidal chunks; abundant indistinct horizontal burrows; forms slight recess in outcrop. Siltstone like unit 9 in beds less than 0.3 ft thick; more abundant in upper 5 ft of unit..................................	22.5	489.3
10. Covered..................................	6.2	466.8
9. Mudshale (50 percent) and siltstone (50 percent). Mudshale contains parallel silt laminae less than 1 mm; partings 2 to 5 mm thick. Siltstone in 3 beds; 2.2 ft, 0.5 ft and 0.3 ft thick; Tab, Tb and Tbc Bouma sequences respectively; wavy, parallel partings 2 to 5 mm thick common............	5.6	460.6
8. "Back Creek Siltstone member" of Avary and Dennison (1978). Siltstone and very-fine-grained sandstone (70 percent) and clayshale and mudstone (30 percent). Siltstone and sandstone are light olive gray (5Y5/2) to olive gray (5Y4/1); beds up to 5.1 ft thick, mode is less than 0.2 ft, mean is 0.4 ft; Tbc and Tc most common Bouma sequences, Ta, Tabc and Tac sequences less common; rippled upper surfaces common. Clayshale is light olive gray (5Y5/2); color and silt laminated; silt laminae less than 1 mm thick; slightly silty; partings 2 to 5 mm thick. Mudstone predominates between 35 and 30 ft below top; moderate		

	Thickness (feet) Unit	Cum.
olive brown (5Y4/4) weathers light olive gray (5Y5/2) to olive gray (5Y4/1); irregular partings 3 to 10 mm thick..................	71.8	455.0
7. Mudstone with less than 10 percent siltstone. Mudstone is light olive brown (5Y5/6) to moderate yellowish brown (10YR5/4), weathers spheroidally to light olive gray (5Y5/2) blades; abundant distinct horizontal burrows 3 to 5 mm across; rare silt laminae less than 1 mm thick. Siltstone in beds less than 0.2 ft thick, mode is 0.1 ft; Ta and Tb Bouma sequences common; carbonized wood fragments abundant along some bedding planes; organic sole markings common...............	37.4	383.2
6. Siltstone (55 percent) and claystone with very minor mudstone (45 percent). Siltstone in seven beds, which range in thickness from 0.5 to 2.1 ft; Ta and Tc Bouma sequences common; rippled tops common. Claystone is silt-free to slightly silty; distinct, slightly curved horizontal burrows 3 to 4 mm across common; partings 1 cm thick.......	13.0	345.8
5. Claystone (95 percent) and siltstone (5 percent). Claystone is dusky yellow (5Y6/4) to light olive brown (5Y5/6) weathers light olive gray (5Y5/2); like unit 7. Siltstone in two beds, 0.3 and 0.4 ft thick...........	17.8	332.8
4. Covered....................................	170.0	315.0
3. Clayshale and mudshale (85 percent), claystone (10 percent) and siltstone (5 percent). Clayshale, mudshale and claystone are moderate olive brown (5Y5/4); shales contain common silt laminae; partings 1 to 3 mm thick. Claystone has subconchoidal partings 3 to 10 mm thick. Siltstone in beds less than 0.2 ft thick; Tbc and Tc Bouma sequences common..................................	55.0	145.0
2. Covered....................................	67.0	90.0

	Thickness (feet) Unit	Cum.
1. Mudshale (80 percent) and siltstone (20 percent). Mudshale is olive gray (5Y4/1), weathers light olive gray (5Y5/2); texturally laminated; rare silt laminae less than 1 mm thick; partings 2 to 4 mm thick; shale becomes platy in upper half of unit. Siltstones in beds less than 0.15 ft thick; Tc Bouma sequences common..................	23.0	23.0
Total Brallier Formation..............	1385.4	

SECTION 2

Rimel Section

Incomplete section of Brallier Formation exposed in roadcut on northeast side of West Virginia Route 39, 0.1 mile west of its junction with West Virginia Route 92 at Rimel, Pocahontas County, Minnehaha Springs quadrangle, West Virginia (591750 meters East, 4220000 meters North, Universal Transverse Mercator grid). Section is in upper one-third of Brallier Formation. Section measured, described, and sampled using Jacob's staff, Abney level, and tape by Paul D. Lundegard and Robert J. Lundegard, November 27, 1977.

	Thickness (feet) Unit	Cum.
Brallier Formation (incomplete):		
9. Siltstone (55 percent) in beds up to 0.3 ft thick, modal bed thickness is 0.2 ft, with interbeds of mudshale (45 percent) predominantly less than 0.15 ft thick. Siltstone is medium gray (N5), weathers olive gray (5Y4/1); bed thickness is very uniform, beds predominantly show Tc- Bouma sequences, flat, sharp bases and rippled top surfaces; wood fragments less than 1 cm long on some bedding planes; a few of the thicker beds have flute and groove molds; 0.2 ft thick bed at 6 ft above base of unit has flute molds trending 243° with blunt ends towards east. Mudshale is olive gray (5Y4/1); shows textural lamination; numerous silt		

	Thickness (feet) Unit	Cum.
laminae up to 1 cm thick; parting is 2 to 4 mm thick..................................	22.0	107.4
8. Siltstone (75 percent) in beds up to 1.1 ft thick, modal bed thickness is 0.1 ft, with interbeds of mudshale (25 percent) predominantly less than 0.2 ft thick. Unit 8 is distinguished from unit 9 by presence of several beds greater than 0.3 ft thick. Siltstone is medium gray (N5), weathers olive gray (5Y4/1); 75 percent of beds show Tc-Bouma sequences; horizontal burrows are common on top surface of beds; 0.5 ft thick bed 2.4 ft above base has abundant flute molds trending 278° with blunt end towards east. Mudshale is medium gray (N5), weathers olive gray (5Y4/1); shows textural lamination; parting is 1 to 4 mm thick.................	19.8	85.4
7. Clayshale (60 percent) with beds of siltstone (40 percent) up to 0.25 ft thick. Clayshale is medium gray (N5) to medium dark gray (N4); shows textural lamination; parting is 2 to 4 mm thick. Siltstone beds show Tc-Bouma sequences............................	5.1	65.6
6. Siltstone, coarse-grained, to sandstone, very-fine-grained (85 percent) in beds less than 0.1 ft thick to 0.3 ft thick, with interbeds of clayshale (15 percent). Siltstone and sandstone beds show Tc- Bouma sequences. Clayshale is olive gray (5Y3/2); shows textural lamination; slightly silty....................................	1.9	60.5
5. Clayshale, olive gray (5Y3/2); shows textural lamination; slightly silty; parting is 3 mm thick................................	1.7	58.6
4. Siltstone and very-fine-grained sandstone (75 percent) in beds up to 1.0 ft thick, with interbeds of clayshale as in unit 5 (25 percent) less than 0.3 ft thick. Eight siltstone beds greater than 0.4 ft thick are distinctive of unit 4; these thicker beds show Ta- or Tb- Bouma sequences. Tiny		

	Thickness (feet) Unit	Cum.
carbonized wood fragments are common in siltstone beds; horizontal burrows are common on top surfaces of beds; 1.0 ft thick bed at 6.7 ft below top of unit shows Tbc Bouma sequence and abundant flute and groove molds trending 283°. Minor beds of dark gray (N3) shale showing textural lamination.	18.9	56.9
3. Clayshale (75 percent) with beds of siltstone (25 percent) up to 0.45 ft thick, predominantly less than 0.1 ft thick. Clayshale is olive gray (5Y3/2); locally has a light brown (5YR5/6) weathering stain; shows textural lamination. Siltstone beds predominantly show Tc- Bouma sequences and rippled upper surfaces; current-formed sole markings and hypichnial ridges are common; 0.2 ft thick bed at 1.8 ft above base of unit has bounce molds trending 247°; 0.45 ft thick bed at 3.5 ft below top of unit has groove molds trending 295°.............	17.5	38.0
2. Siltstone (65 to 85 percent) in beds up to 1.0 ft thick, modal bed thickness is 0.15 ft, with interbeds of clayshale to mudshale (15 to 35 percent). Siltstone is medium gray (N5), weathers light olive gray (5Y3/2); beds predominantly show Tc- Bouma sequences, flat, sharp bases and rippled top surfaces; two beds, 1.0 ft and 0.8 ft thick show Tbc- Bouma sequences at 4.0 ft and 11.2 ft above base of unit, respectively; burrows are common and of 3 types; hypichnial ridges, horizontal burrows on top surfaces of beds, and high-angle burrows penetrating beds from the top; these latter burrows are non-branching, straight to slightly curved, 5 to 10 mm wide, and either silt- or clay-filled. Shale is olive gray (5Y3/2); shows textural lamination; locally silty; horizontal burrows less than 5 mm wide are common; parting is 3 to 5 mm thick.................	15.8	20.5
1. Clayshale (90 percent) with beds of siltstone (10 percent) less than 0.1 ft thick. Clay-		

	Thickness (feet) Unit	Cum.
shale is olive black (5Y2/1), weathers olive gray (5Y4/1); shows textural lamination; slightly silty; parting is 3 mm thick. Siltstone is medium gray (N5); beds show Tc- Bouma sequences and rippled top surfaces.	4.7	4.7
Total Brallier Formation (incomplete)..	107.4	

SECTION 3

Minnehaha Springs Section

Incomplete section of Brallier Formation exposed in roadcut along northeast side of West Virginia Route 39, 1.3 miles southeast of Minnehaha Springs, Pocahontas County, Minnehaha Springs quadrangle, West Virginia (589200 meters East, 4222500 meters North, Universal Transverse Mercator Grid). Bedding strikes 48 degrees northeast, and dips 37 degrees southeast. Base of section is estimated to be less than 500 feet above the base of the Brallier Formation. Section measured, described, and sampled using Jacob's staff, Abney level, and tape by Paul D. Lundegard and Robert J. Lundegard, November 26, 1977.

Devonian (incomplete):	Thickness (feet) Unit	Cum.
Brallier Formation (incomplete):		
7. Mudshale (75 percent) with beds of siltstone (25 percent) up to 0.35 ft thick, predominantly less than 0.15 ft thick. Siltstone decreases in abundance upward. Mudshale is olive gray (5Y4/1) to medium gray (N5), weathers olive gray (5Y4/1) to grayish red (5R4/2); reddish weathering is prominent in upper 25 ft of unit; shows textural lamination; silt laminae 5 to 10 mm thick are common. Siltstone beds have flat sharp bases, and show predominantly Tc- Bouma sequences; top surfaces of beds are commonly rippled and show horizontal burrows.........	37.0	135.0
6. Clayshale (55 percent) with beds of siltstone (45 percent) up to 0.65 ft thick, predominantly less than 0.1 ft to 0.3 ft		

	Thickness (feet) Unit	Cum.
thick. Clayshale is medium gray (N5), weathers olive gray (5Y4/1); shows textural lamination; a few silt laminae; distinct horizontal burrows. Siltstone is medium gray (N5); micaceous; beds predominantly show Tc- Bouma sequences; top surfaces of beds are commonly rippled and show horizontal burrows..........................	11.0	98.0
5. Clayshale as in unit 6 (85 percent) with beds of siltstone (15 percent) up to 0.25 ft thick. Siltstone beds predominantly show Tc- Bouma sequences; top surfaces of beds are commonly rippled and show horizontal burrows..................................	11.2	87.0
4. Siltstone to very-fine-grained sandstone (75 percent) in beds 0.1 ft to 2.2 ft thick, no distinct modal bed thickness, with interbeds of clayshale to mudshale (25 percent). Unit 4 was described in bed by bed detail. Siltstone and sandstone are medium gray (N5), weather light olive gray (5Y6/1); micaceous; tiny wood fragments are common; clay galls are common in thicker beds; beds have sharply defined bases and slightly gradational tops; 50 percent of beds show Ta- Bouma sequences, 32 percent show Tb- Bouma sequences, 18 percent show Tc- Bouma sequences; the unit ABC proximity index (Walker, 1967) is 66 percent; beds commonly have rippled top surfaces. Shale is medium dark gray (N4), weathers olive gray (5Y4/1); shows textural lamination; a few silt laminae; horizontal burrows up to 5 mm wide.................................	24.4	75.8
3. Mudshale (98 percent) with beds of siltstone (2 percent) up to 0.35 ft thick, predominantly less than 0.1 ft thick. Mudshale is olive gray (5Y4/1); shows weak textural lamination; horizontal burrows up to 5 mm wide; parting is 1 to 5 mm thick. Siltstone beds predominantly show Tc- Bouma sequences and rippled top surfaces..........	33.6	51.4

	Thickness (feet) Unit	Cum.
2. Siltstone (65 percent), 3 beds, each 0.6 ft thick, with interbeds of clayshale (35 percent). Siltstone is medium gray (N5), weathers light olive gray (5Y6/1). Clayshale is olive gray (5Y4/1); shows textural lamination..................................	2.8	17.8
1. Mudshale to clayshale with a very few beds of siltstone less than 0.15 ft thick. Shale is olive gray (5Y4/1); shows weak textural lamination; finely micaceous; non-branching horizontal burrows up to 5 mm wide are very common. Siltstone is light olive gray (5Y6/1) to olive gray (5Y4/1); beds predominantly show Tc- Bouma sequences and rippled top surfaces; a few beds show sinusoidal lamination.......................	15.0	15.0
Total Brallier Formation (incomplete)..	135.0	

SECTION 4

Clifton Forge Section

Incomplete section of Brallier Formation exposed in roadcut on North side of U.S. Highway 60, approximately 0.3 mile east of its junction with Virginia Highway 42 in Rockbridge County, Clifton Forge quadrangle (609200 meters ast, 4187200 meters orth, Universal Transverse Mercator grid). Section is of a thickly bedded siltstone bundle. Bedding strikes 44 degrees east and dips 55 degrees southeast. Section measured and described using Jacob's staff, Abney level, and tape by Paul D. Lundegard, September 1, 1977.

Brallier Formation (incomplete):	Thickness (feet) Unit	Cum.
2. Clayshale to mudshale (80 percent) with beds of siltstone (20 percent) up to 0.15 ft thick. Siltstone decreases in abundance upward. Shale weathers light olive gray (5Y5/2); shows textural lamination; silty in places; some horizontal burrows less than		

	Thickness (feet) Unit	Cum.
4 mm wide; parting is 3 to 5 mm thick. Siltstone weathers light olive gray (5Y5/2); beds predominantly show Tc- Bouma sequences..................................	14.0	54.0
1. Siltstone and very-fine-grained sandstone (70 percent) in beds 0.1 ft to 3.5 ft thick, 40 percent of beds are greater than 0.5 ft thick, modal bed thickness is 0.3 to 0.5 ft; interbeds are shale as in unit 2 (30 percent). Unit 1 was measured and described in bed by bed detail. Siltstone and sandstone weather light olive gray (5Y5/2); base of beds are sharp and flat; tops of beds are sharp or gradational; a few beds are graded; approximately 60 percent of beds show Ta- Bouma sequences; beds with rippled top surfaces are common; wood fragments are common; micaceous. Unit 1 forms a resistant protrusion. Using Jacob's staff and Abney level, the base of unit 1 was estimated to be less than 350 ft above the top of the Millboro Shale......................	40.0	40.0
Total Brallier Formation (incomplete)..	54.0	

SECTION 5

Cloyds Mountain Section

One of the best and most nearly complete sections of the Brallier Formation in southwest Virginia, exposed in roadcuts along Virginia Highway 100, Pulaski County, Staffordsville quadrangle, Virginia. Lower one-third of section is unusually well exposed. Base of section is at shale pit behind French's Chapel at base of Cloyds Mountain (523800 meters East, 4116300 meters North, Universal Transverse Mercator grid). Section continues generally southward up Cloyds Mountain to 0.1 mile north of its crest. Section was measured, described and sampled using Jacob's staff, Abney level, surveying altimeter and tape by Paul Lundegard and Neil Samuels, on August 26, and 27, 1977, by Paul Lundegard on December 18 and 19, 1977, January 1, 2, and 3, 1978, and August 28, 29, and 30, 1978. Radioactivity profile was measured using scintillometer by Paul Lundegard and Neil Samuels on June 4 and 5, 1978.

	Thickness (feet)	
Devonian (incomplete):		
"Chemung" Formation (incomplete):	Unit	Cum.
92. Sandstone, very-fine-grained to fine-grained, dusky yellow (5Y6/4), weathers light olive gray (5Y6/1); beds 0.8 ft to 2.5 ft thick; plane laminated; fossiliferous streaks up to 0.3 ft thick; fossils include Spirifer sp. and crinoid columnals. Unit 92 is directly across highway from "Watch for Fallen Rocks" sign........................	21.0	3840.0
91. Mostly covered with small exposures of olive gray mudstone........................	11.0	3819.0
90. Sandstone, very-fine-grained to fine-grained, dusky yellow (5Y6/4), weathers light olive gray (5Y6/1), beds 0.7 ft to 1.5 ft thick; plane laminated; several highly fossiliferous layers with Spirifer sp., Chonetes sp., and crinoid columnals all common; many whole brachiopod valves are at an angle to bedding. Unit 90 is very resistant.........	18.0	3810.5
89. Sandstone, very-fine-grained (70 percent), in beds 0.1 ft to 3.0 ft thick, modal bed thickness is 0.9 ft, with interbeds of mudstone (30 percent). Sandstone beds are predominantly plane laminated; several lensoid beds in upper half of unit; several beds weather spheroidally, probably because of convolute lamination; fossiliferous streaks and layers very common, especially at the base of beds; crinoid columnals some of which are articulated are the most abundant fossil, Camarotoechia sp., Spirifer sp., and Chonetes sp. brachiopods are also present. Mudstone is olive gray (5Y4/1) and has hackly parting...	40.0	3792.5
88. Mudstone (60 to 70 percent) with beds of very-fine-grained sandstone (30 to 40 percent) 0.4 ft to 2.0 ft thick, modal bed thickness is 0.7 ft. Mudstone is olive gray (5Y3/2), weathers light olive gray (5Y5/2); resistant, very silty, weathers to		

	Thickness (feet) Unit	Cum.
hackly chips. Sandstone beds are plane laminated; a few beds weather spheroidally probably because of convolute lamination; fossiliferous streaks containing crinoid columnals, and *Camarotoechia* sp., and *Chonetes* sp. brachiopods are common, especially at base of beds. Minor shear zone in middle of unit 88..................................	79.5	3752.5
87. Mudstone as in unit 88 (90 percent) with beds of siltstone (10 percent) 0.1 to 0.2 ft thick..................................	21.0	3673.0
86. Sandstone, very-fine-grained (50 percent), in beds 0.3 ft to 1.7 ft thick, with interbeds of mudstone as in unit 88 (50 percent). Sandstone beds show plane lamination or low-angle crossbedding; a few fossiliferous streaks containing crinoid columnals and brachiopod shell fragments....	6.2	3652.0
85. Sandstone, very-fine-grained (95 percent), in beds 0.5 ft to 1.5 ft thick, with minor interbeds of mudstone in unit 88 (5 percent). A resistant unit. Sandstone beds are plane laminated; a few fossiliferous streaks containing crinoid columnals and very few *Spirifer* sp. Unit 85 is described at sharp bend in highway 0.15 mile north of crest of Cloyd's Mountain........................	7.3	3645.8
Total "Chemung" Formation (incomplete).	204.0	
Brallier Formation:		
84. Siltstone, coarse-grained, and sandstone, very-fine-grained (60 to 70 percent), in beds 0.4 ft to 2.0 ft thick with interbeds of mudstone (30 to 40 percent). Siltstone and sandstone are medium gray (N5), weather light olive gray (5Y5/2); beds are indistinct from mudstone interbeds; beds are plane laminated. Mudstone is olive gray (5Y4/1) and very silty. Unit 84 is described across highway from "Maximum Safe Speed 25" sign...	13.1	3638.5

		Thickness (feet) Unit	Cum.
83.	Covered..................................	22.8	3625.4
82.	Siltstone, coarse-grained, and sandstone, very-fine-grained (50 percent), in beds 0.3 ft to 1.3 ft thick, modal bed thickness is 0.5 ft, with interbeds of mudstone as in unit 84 (50 percent). Fossiliferous streaks and lenses are common in siltstone and sandstone beds; crinoid columnals common, <u>Camarotoechia</u> sp., <u>Spirifer</u> sp. brachiopods, and <u>Modiola</u> (?) pelecypods. Two intervals of mudstone without coarse clastic beds, 5.9 and 4.5 ft thick, at 9 and 32 ft above base of unit, respectively. Top of unit 82 is at sharp bend in highway............	50.6	3602.6
81.	Mudstone (95 percent) with a few beds of siltstone (5 percent) 0.15 to 0.8 ft thick in lower half of unit. Mudstone is olive gray (5Y5/2), weathers to small hackly chips. Siltstone beds are predominantly plane laminated; a few fossiliferous streaks containing crinoid columnals and brachiopod fragments................................	31.6	3552.0
80.	Siltstone and very-fine-grained sandstone (75 percent) in beds 0.4 ft to 1.3 ft thick with interbeds of mudstone as in unit 81 (25 percent). Siltstone and sandstone beds are fossiliferous; <u>Camarotoechia</u> sp. and crinoid columnals concentrated in layers concordant with bedding; wood fragments; siltstone bed 1.3 ft thick at top of unit is crossbedded and highly fossiliferous in basal 0.5 ft............................	7.4	3520.4
79.	Mudstone as in unit 81 (90 to 95 percent) with beds of siltstone (5 to 10 percent) 0.1 to 0.4 ft thick......................	16.0	3513.0
78.	Siltstone, coarse-grained (50 to 60 percent), in beds up to 1.0 ft thick, beds greater than 0.4 ft thick are very common, with interbeds of mudstone (40 to 50 percent). Siltstone is light olive gray (5Y5/2); beds		

	Thickness (feet) Unit	Cum.
are predominantly structureless or plane laminated; beds indistinct in places; 1.0 ft thick bed with low-angle crossbedding at 43 ft above base of unit; 0.4 ft thick bed with fine groove molds trending 254° at 28 ft above base of unit; a few beds are fossiliferous; fossils include crinoid columnals, Fenestellina sp. bryozoans, and Camarotoechia sp., Spirifer sp. brachiopods. Mudstone is olive gray (5Y4/1); very silty; nearly as resistant as siltstone; minor mudshale with textural lamination throughout unit..................	161.3	3497.0
77. Covered......................................	22.2	3335.7
76. Mudstone and minor claystone (85 percent) with beds of siltstone (15 percent) up to 0.3 ft thick, modal bed thickness is 0.15 ft Mudstone and claystone are olive gray (5Y4/1) to light olive gray (5Y5/2); a few distinct horizontal burrows, 3 to 5 mm wide and weathering moderate brown (5YR4/4); hackly parting 5 to 10 mm thick. Siltstone beds are concentrated in lower 8 ft of unit; Tc- and Tb- Bouma sequences predominate. Top of unit is at sharp bend in highway.....	23.4	3313.5
75. Mudstone as in unit 76 (50 to 70 percent) with beds of siltstone (30 to 50 percent) up to 1.2 ft thick, modal bed thickness is 0.15 ft. Several siltstone beds with sole markings; groove mold trends 268° at 8.2 ft below top of unit; middle 7 ft of unit is thinner bedded and 30 percent siltstone.................................	17.6	3290.1
74. Mudstone as in unit 76 (60 percent) and claystone (30 percent), with beds of siltstone (10 percent) up to 0.9 ft thick, modal bed thickness is 0.1 ft. Mudstone and claystone are alike except for disseminated silt content; some spheroidal weathering in lower 12 ft of unit; pelecypod sampled at 7 ft above base of unit.		

	Thickness (feet) Unit	Cum.
Siltstone beds greater than 0.3 ft thick show Ta- and Tb- Bouma sequences; beds less than 0.3 ft thick show Tc- and Tb- Bouma sequences..................................	73.3	3272.5
73. Siltstone (40 to 60 percent) in beds up to 1.2 ft thick, with interbeds of claystone and mudstone (40 to 60 percent); modal siltstone bed thickness is generally less than 0.15 ft but up to 0.45 in some 5 ft intervals. Siltstone is light olive gray (5Y6/1); beds are even, persistent, and sharply defined; internal structures are difficult to see because of intense weathering; beds greater than 0.3 ft thick show Ta- and Tb- Bouma sequences, beds less than 0.15 ft thick show Tc- and Tb- Bouma sequences; convolute lamination in several beds; flute molds common, mean trend of 265°. Claystone is light olive brown (5Y5/6), weathers light olive gray (5Y5/2); becomes mudstone upward; some indistinct horizontal bioturbation, weathering yellowish gray (5Y8/1); minor shale with textural lamination and a few silt laminae less than 1 mm thick. Base of unit 73 at "Maximum Safe Speed 25" sign..	96.7	3199.2
72. Covered. Few resistant siltstone beds, probably less than 10 percent. Sanitary landfill behind low hill which parallels highway..................................	84.0	3102.5
71. Claystone (90 percent) with beds of siltstone (10 percent) up to 1.2 ft thick, modal bed thickness is 0.1 to 0.15 ft. Claystone is moderately bioturbated; unbioturbated portions are dark gray (N3) and weather medium gray (N5); bioturbated portions are yellowish gray (5Y8/1) to medium light gray (N6) and weather grayish orange (10YR7/4); burrowing is indistinct and horizontal; individual burrows appear to be less than 2 mm wide; some irregular biolamination and streaks; weathers to		

	Thickness (feet) Unit	Cum.
chunks and small flakes; minor light olive brown (5Y5/6) to light olive gray (5Y5/2) claystone and mudstone. Two highly fractured siltstone beds at top of unit, 1.2 ft and 0.8 ft thick, respectively..................	36.0	3018.5
70. Covered. Several resistant beds of siltstone....................................	5.0	2982.5
69. Claystone (50 to 60 percent) with beds of siltstone (40 to 50 percent) up to 0.7 ft thick, modal bed thickness is 0.3 ft. Claystone is yellowish gray (5Y8/1); probably bioturbated as in unit 71. Siltstone is highly weathered; yellowish gray (5Y8/1) on weathered surface. Unit 69 forms rounded protrusion on outcrop......................	16.6	2977.5
68. Claystone as in unit 71 (90 percent) with beds of siltstone (10 percent) up to 1.0 ft thick, modal bed thickness is 0.15 ft. Claystone becomes darker and less bioturbated upward; faint textural lamination and rare silt laminae less than 2 mm thick where unbioturbated................................	15.4	2960.9
67. Claystone as in unit 71 (50 to 60 percent) with beds of siltstone (40 to 50 percent) up to 0.6 ft thick, modal bed thickness is 0.25 ft. Siltstone content is approximately 75 percent in 5 ft thick zone 5 ft above base of unit. Unit 67 forms a slight protrusion.................................	19.0	2945.5
66. Claystone as in unit 71 with a very few siltstone beds up to 0.25 ft thick. A few grouped silt laminae up to 3 mm thick in claystone..................................	11.5	2926.5
65. Claystone as in unit 71 (95 percent) with 4 beds of siltstone (5 percent) 0.3 to 0.6 ft thick. Base of unit 65 is exposed in drainage ditch along chainlink fence, uphill from entrance to sanitary landfill..........	42.5	2915.0

	Thickness (feet) Unit	Cum.
64. Covered. Thickness estimated from map locations of outcrops, strike and dip data, and altitude data obtained with a surveying altimeter accurate to ± 3 ft................	70.0	2872.5
63. Clayshale to mudshale, dark gray (N3) in lower 1.0 ft, medium dark gray (N4) in remainder, weathers medium dark gray (N4); weak textural lamination; very finely micaceous; parting is 3 to 10 mm thick; a few 1 to 2 cm thick siltstone layers gradational with surrounding shale and laminated or cross-laminated. Unit 63 is described at apex of hairpin turn in highway..................................	19.6	2802.5
62. Siltstone, coarse-grained, and sandstone, very-fine-grained (60 percent), in beds up to 1.4 ft thick, modal bed thickness is 0.5 ft with interbeds of mudshale (40 percent). Siltstone and sandstone are medium gray (N5) to medium dark gray (N4); beds mainly show Ta- Bouma sequences, beds less than 0.1 ft thick show Tc- Bouma sequences; upper parts of a few beds have parallel undulatory lamination with wavelengths of 30 to 40 cm and amplitudes of 3 to 5 cm. Mudshale is grayish black (N2), weathers dark gray (N3); shows textural lamination; a few silt laminae less than 1 mm thick, parting is 1 to 3 mm thick; blackish red (5R2/2) iron stain on parting surfaces; weathers to brittle platy chips....................................	9.1	2782.9
61. Clayshale or claystone. Prominent lateral changes in nature of unit 61; clayshale at road level, changing to predominantly bioturbated claystone at top of outcrop. Clayshale is grayish black (N2) to black (N1), weathers medium dark gray (N3) to grayish black (N2); strong textural lamination; finely micaceous; parting is 1 to 3 mm thick; finely divided pyrite and iridescent grayish black (5R2/2) iron stain on parting		

	Thickness (feet) Unit	Cum.
surfaces; weathers to brittle, platy chips, lower 3.0 ft of unit is slightly lighter in color and silty. Claystone is medium dark gray (N4), weathers medium gray (N5) to medium dark gray (N4); weakly to strongly bioturbated; bioturbated portions weather yellowish gray (5Y8/1); individual burrows are less than 3 mm wide and predominantly horizontal; burrows have diffuse boundaries; some zones up to 2 cm thick are completely bioturbated; these appear as yellowish gray, discontinuous laminae or beds.........	12.3	2773.8
60. Claystone (90 percent) with beds of siltstone (10 percent) up to 0.35 ft thick, modal bed thickness is 0.1 ft. Claystone is medium dark gray (N4) to dark gray (N3), weathers medium gray (N5); locally slightly silty; finely micaceous; parting is 5 mm thick; brittle. Siltstone is medium gray (N5); beds show Tc- Bouma sequences; finely micaceous...................................	5.7	2761.5
59. Siltstone and very-fine-grained sandstone (60 percent) in beds 1 cm to 0.7 ft thick, modal bed thickness is 0.25 ft, with interbeds of clayshale (40 percent). Siltstone and sandstone are medium gray (N5) and micaceous; 50 percent of beds are cross-laminated; several beds show undulatory lamination with wavelengths of approximately 40 cm; one crossbedded sandstone bed 0.5 ft thick near base of unit; a few molds of brachiopods and crinoid columnals. Clayshale is dark gray (N3), weathers medium dark gray (N4); weak textural lamination; locally slightly silty; parting is 3 to 5 mm thick; brittle.........................	7.3	2755.8
58. Clayshale (90 percent) with beds of siltstone and very-fine-grained sandstone (10 percent) up to 0.25 ft thick, modal bed thickness is less than 0.1 ft. Clayshale is medium dark gray (N4), shows textural lamination; locally slightly silty;		

	Thickness (feet) Unit	Cum.
finely micaceous; parting is 2 to 5 mm thick. Siltstone and sandstone are medium gray (N5); beds show Tc- and a few Tb- Bouma sequences, top surfaces of beds are rippled; one bed with fragments of brachiopod shells and crinoid columnals; abundant groove molds at 2.4 ft above base of unit have mean trend of 268°..................................	10.7	2748.5
57. Siltstone, coarse-grained, and sandstone, very-fine-grained (75 percent) in beds up to 0.8 ft thick, modal bed thickness is 0.25 ft, with interbeds of clayshale (25 percent) less than 0.2 ft thick. Siltstone and sandstone are medium gray (N5); thin fossiliferous lenses with Spirifer sp. most abundant; sole markings trend 274° at base of unit. Clayshale is olive gray (5Y4/1), weathers light olive gray (5Y5/2); weak textural lamination; tiny black shreds of organic matter, parting is 3 to 5 mm thick..	6.3	2737.8
56. Clayshale (75 percent) with beds of siltstone (25 percent) 1 cm to 0.3 ft thick. Clayshale is olive gray (5Y4/1) weathers light olive gray (5Y5/2); weak textural lamination; tiny black shreds of organic matter; parting is 2 to 5 mm thick; weathers to brittle, platy chips. Siltstone is olive gray (5Y4/1) to medium gray (N5); finely micaceous; beds show cross-lamination to sinusoidal lamination, abundant groove molds show a mean trend of 278°............	8.0	2731.5
55. Siltstone and very-fine-grained sandstone (80 percent) in beds up to 2.0 ft thick, with interbeds of clayshale (20 percent) less than 0.3 ft thick. Siltstone and sandstone are medium gray (N5) and micaceous; tiny black shreds of organic matter; Spirifer sp., pelecypods (?), and crinoid columnals are common; beds 0.6 ft to 2.0 ft thick are plane laminated or crossbedded; beds less than 0.2 ft thick are cross-laminated or		

	Thickness (feet) Unit	Cum.
plane laminated; trough crossbedding in the upper parts of several beds, strata thicken from the crests towards the troughs. Clayshale is medium dark gray (N4) to olive gray (5Y4/1), weathers light olive gray (5Y5/2); shows textural lamination; tiny black shreds of organic matter; parting is 3 mm thick..................................	8.0	2723.5
54. Siltstone, coarse-grained, and sandstone, very-fine-grained in 5 beds 1.0 ft to 2.5 ft thick, separated by shale partings. Siltstone and sandstone are medium dark gray (N4), weather light olive gray (5Y5/2); finely micaceous; trough crossbedding features 1 to 2 m across as in unit 55, trough axis in middle of unit trends 080°-260°, beds otherwise show plane lamination or lamination inclined at low angle to bedding; carbonized wood fragments up to 5 mm long; fossils include <u>Spirifer</u> sp., <u>Schizobolus</u> sp. and <u>Rhipidomella vanuxemi</u> (Hall), and crinoid columnals; fossils are weakly oriented, generally unbroken and disarticulated; occur as concentrations at the base of beds, as lenses within beds, and disseminated in beds....................................	8.7	2715.5
53. Siltstone to fine-grained sandstone (90 percent), in beds 0.2 ft to 1.4 ft thick, with interbeds of clayshale (10 percent) less than 0.25 ft thick. Siltstone and sandstone are medium gray (N5), weather light olive gray (5Y5/2); finely micaceous; carbonized wood fragments 1 to 4 mm long; beds are dominantly even but several thicker beds pinch and swell; trough crossbedding as in unit 55; two beds 0.3 ft thick with undulatory top surfaces and form concordant lamination, at 9.0 ft above base of unit; wavelengths of undulations are approximately 45 cm, two crests trend 250° and 270°; wood fragments at 4.0 ft		

	Thickness (feet) Unit	Cum.
above base of unit trend 277°; low relief flute molds at 19.2 ft above base of unit trend 277°. Clayshale is dark gray (N3), weathers medium dark gray (N4); shows textural lamination; silt-free; parting is 1 to 2 mm thick. Bed of claystone, 0.1 ft thick, at 8.7 ft above base of unit; yellowish gray (5Y8/1); plastic and sticky when wet; forms recess in outcrop..........	25.3	2706.8
52. Siltstone and very-fine-grained sandstone (80 percent) in beds up to 1.0 ft thick, modal bed thickness is 0.3 ft, with interbeds of mudshale (20 percent) less than 0.15 ft thick. Siltstone and sandstone are medium gray (N5) to light olive gray (5Y6/1), weathers light olive gray (5Y5/2); micaceous; evenly bedded; less than 5 percent of beds have rippled top surfaces; beds greater than 0.3 ft thick show predominantly Ta- Bouma sequences; a few beds show low-angle inclined lamination; remainder of beds are plane laminated or cross-laminated; several beds are fossiliferous; fossils include unbroken and unabraded *Camarotoechia* sp. and *Spirifer* sp. in all orientations; a few clay-filled vertical burrows less than 1 cm wide. Mudshale is olive gray (5Y4/1), weathers light olive gray (5Y5/2); shows textural lamination; parting is 3 to 5 mm thick. Unit 52 is gradational with units 53 and 51 in abundance of coarse clastic beds and bed thickness..............................	30.4	2681.5
51. Mudstone (65 percent), minor claystone and clayshale (5 percent) with beds of siltstone to very-fine-grained sandstone (30 percent) up to 1.4 ft thick, modal bed thickness is 0.7 ft. Mudstone and claystone are dark gray (N3) to olive gray (5Y4/1); finely micaceous; tiny black shreds of organic matter; a few yellowish gray (5Y8/1) burrow mottles; irregular parting 5 to 20 mm thick;		

	Thickness (feet) Unit	Cum.
weathers to subequidimensional chunks; clayshale resembles claystone but shows textural lamination. Siltstone and sandstone are medium gray (N5), weather light olive gray (5Y5/2); Ta- Bouma sequences predominate; content grading in some beds...	40.0	2651.1
50. Claystone (60 percent) and 3 prominent beds of coarse-grained siltstone, each 0.7 ft thick. Claystone is medium gray (N5) to dark gray (N3), weathers olive gray (5Y4/1); slightly silty; a few yellowish gray (5Y8/1) burrow mottles. In ascending order, unit 50 consists of a siltstone bed 0.7 ft thick, structureless, inversely graded, groove molds trend 262° and 270°; 1.1 ft of claystone as above; a siltstone bed 0.7 ft thick, cross-laminated in upper 0.15 ft, structureless at base, sole markings; 1.1 ft of claystone as above; a siltstone bed 0.7 ft thick, basal contact is sharp and top contact is gradational, plane laminated and inversely graded, each laminae is thicker and coarser than the one below, groove molds trend 276°. Beds gently folded..................................	4.8	2611.1
49. Mudstone, claystone and minor clayshale (85 percent) with beds of siltstone and very-fine-grained sandstone (15 percent) up to 0.6 ft thick, modal bed thickness is 0.2 ft. Mudstone in lower two-thirds of unit; claystone and clayshale in upper third of unit. Mudstone and claystone are olive gray (5Y4/1) to medium gray (N5), weather light olive gray (5Y5/2); very few silt laminae less than 2 mm thick; upper 27.8 ft of unit is weakly bioturbated; burrow mottles weather light gray (N7) to yellowish gray (5Y8/1); burrows are horizontal; moderate brown (5YR4/4) spores (?) on bedding planes; clayshale resembles claystone but shows textural lamination. Siltstone and sandstone are medium gray (N5); finely		

		Thickness (feet) Unit	Cum.
	micaceous; beds less than 0.2 ft thick show Tc- Bouma sequences; thicker beds show Tc- or Tbc- Bouma sequences; flute molds trend 282° to 302°. Beds are gently folded in upper half of unit..........................	78.8	2606.3
48.	Covered. Culvert under road and "Pavement Narrows" sign in middle of unit 48..........	45.0	2527.5

NOTE: Units 47 through 30 are described at long continuous roadcut on east side of Virginia Highway 100. High voltage power lines parallel road on hill above outcrop.

47.	Mudstone (60 to 80 percent) with beds of siltstone (20 to 40 percent) up to 0.8 ft thick, predominantly less than 0.15 ft thick. Mudstone is light olive gray (5Y5/2); poorly bedded; irregular parting 5 mm thick. Siltstone beds have flat, sharp bases and undulatory, rippled top surfaces; Tc- or Tbc- Bouma sequences; very few crinoid columnals..................	54.2	2482.5
46.	Siltstone and very-fine-grained sandstone (60 percent) in beds up to 1.0 ft thick, modal bed thickness is 0.25 ft, with interbeds of mudstone (40 percent). Siltstone and sandstone are olive gray (5Y4/1); micaceous; laminated to cross-laminated; sinusoidal lamination grades upward into cross-lamination in a few beds; 0.9 ft thick bed at 9.5 ft above base shows convolute lamination. Mudstone is olive gray (5Y4/1) to medium gray (N5), weathers light olive gray (5Y5/2); hackly parting 3 to 5 mm thick; very silty. Small, high angle fault of uncertain displacement in upper part of unit.........................	21.3	2428.3
45.	Clayshale to mudshale (50 to 60 percent) with beds of siltstone (40 to 50 percent) up to 0.9 ft thick, 90 percent of beds are less than 0.25 ft thick. Siltstone ranges from 20 to 70 percent in some five ft intervals. Shale is dark greenish gray (5GY4/1) to olive gray (5Y4/1), weathers moderate brown		

	Thickness (feet) Unit	Cum.
(5YR3/4); shows textural lamination; locally silty; parting is 1 to 3 mm thick; few moderate brown (5YR4/4) spores (?) on bedding planes. Siltstone beds less than 0.2 ft thick are laminated or cross-laminated and have rippled top surfaces; micaceous; some woody fragments along bedding planes. "Trucks Use Right Lane" sign is across highway from top of unit.....	87.8	2407.0
44. Clayshale as in unit 45 (95 percent) with minor beds of siltstone (5 percent) up to 0.45 ft thick, 90 percent of beds are less than 0.1 ft thick. Siltstone is medium gray (N5), weathers light olive gray (5Y5/2); beds are predominantly cross-laminated, and have flat, sharp bases and rippled top surfaces; a few carbonized wood fragments..............................	11.7	2319.2
43. Siltstone (60 percent, but variable over small intervals) in beds up to 1.1 ft thick, 90 percent of beds are less than 0.2 ft thick, with interbeds of clayshale (40 percent). Siltstone is medium gray (N5), weathers olive gray (5Y4/1); micaceous; evenly bedded; thicker beds show Tb-Bouma sequences; bases of beds are sharp; tops of beds are either sharp or gradational with the overlying shale; top surfaces of beds are rippled; groove molds trend 230° to 260°; very few crinoid columnals. Clayshale is medium gray (N5) to olive gray (5Y4/1), weathers light olive gray (5Y5/2) to olive gray (5Y4/1); shows weak textural lamination; parting is 3 mm thick; a few light brown (5YR5/6) spores (?) on bedding planes. Three highly fossiliferous limestone beds 0.15 to 0.4 ft thick below power line support structure in middle of unit; each bed weathers olive gray (5Y4/1), and consists of a grain supported aggregate of crinoid columnals near base of beds and brachiopod shell fragments near top of beds; the matrix material is silt and clay; shells are		

	Thickness (feet) Unit	Cum.
subparallel with bedding in both concave-up and convex-up positions; rounded clay galls up to 1.5 cm in diameter are common; fossils include Atrypa spinosa Hall, Carnifella sp., and Spirifer sp. Culvert under highway near top of unit..........................	105.0	2307.5
42. Clayshale (80 percent) with beds of siltstone (20 percent) up to 0.3 ft thick, modal bed thickness is 0.15 ft. Clayshale is olive gray (5Y3/2), weathers light olive gray (5Y5/2); shows textural lamination; slightly silty; parting is 3 to 5 mm thick; light brown (5YR5/6) spores (?) on bedding planes. Siltstone is medium gray (N5), weathers olive gray (5Y3/2), and is finely micaceous..................................	7.2	2202.5
41. Siltstone (70 percent) in beds up to 1.0 ft thick, 20 percent of beds are greater than 0.2 ft thick, with interbeds of clayshale (30 percent). Siltstone is medium gray (N5), weathers olive gray (5Y4/1); top surfaces of beds are rippled; very few crinoid columnals, finely micaceous, sole markings in lower 10 ft trending 240° to 280°. Clayshale is light olive gray (5Y5/2), weathers olive gray (5Y4/1); shows textural lamination; locally slightly silty; parting is 1 to 3 mm thick. Culvert under highway near middle of unit.................	47.8	2195.3
40. Mudstone, medium dark gray (N4), weathers olive gray (5Y5/2); hackly parting 5 mm thick; crinoid columnals and Ambocoelia (?) occur both as fossiliferous streaks and disseminated in mudstone; weathers to small irregular pieces and spheroidally in places. A few distinct siltstone beds. Some slight structural disturbances in this unit........	78.4	2147.5
39. Siltstone (50 to 60 percent) in beds up to 6.6 ft thick, approximately 60 percent of beds are greater than 0.3 ft thick, with interbeds of mudstone (40 to 50 percent)		

	Thickness (feet) Unit	Cum.
generally less than 0.3 ft thick. Siltstone is medium gray (N5), weathers light olive gray (5Y5/2); evenly bedded; sole markings are common and show a mean trend of 262°; Ta- and Tb- Bouma sequences predominate; basal contacts of beds are sharp; top contacts are either sharp or gradational; a few hypichnial ridges and fossiliferous streaks. Upper 6.6 ft of unit is massive, argillaceous siltstone with no internal stratification; possibly several amalgamated beds; weathers to a rounded profile; top contact is abrupt; a few crinoid columnals and Ambocoelia sp. Mudstone is dark gray (N3) to olive gray (5Y4/1), weathers olive gray (5Y4/1) to medium dark gray (N4); irregular parting 3 to 5 mm thick; a few Ambocoelia (?); some zones distinctly bioturbated................................	67.8	2069.1
38. Mudstone, olive gray (5Y4/1), weathers light olive gray (5Y5/2); hackly parting 7 to 10 mm thick; a few Ambocoelia sp., some are articulated. Curve warning sign at base of unit....................................	8.8	2001.3
37. Mudstone (85 to 90 percent) with beds of siltstone (10 to 15 percent) up to 0.35 ft thick, modal bed thickness is 0.15 ft. Mudstone is olive gray (5Y4/1), brownish black (5YR2/1) weathering stain is common; hackly parting 5 to 10 mm thick; very silty. Some structural disturbance in middle of unit.	9.0	1992.5
36. Siltstone (60 to 70 percent) in beds up to 1.0 ft thick, beds greater than 0.25 ft thick are common, with interbeds of mudstone (30 to 40 percent). Ta- Bouma sequences predominate in siltstone beds; plane lamination or sinusoidal lamination is present in the upper parts of some beds; groove molds at base of unit trend 260°. Mudstone is olive gray (5Y4/1) to light olive gray (5Y5/2), weathers light olive gray		

	Thickness (feet) Unit	Cum.
(5Y5/2) to brownish black (5YR2/1); hackly parting 5 to 10 mm thick; very silty........	7.7	1983.5
35. Mudstone (95 percent) with minor beds of siltstone (5 percent) less than 0.1 ft thick. Mudstone is olive gray (5Y4/1) to light olive gray (5Y6/1), weathers olive gray (5Y4/1) to light gray (N7); hackly parting 5 mm thick; becomes less silty upward; a few *Ambocoelia* sp............................	11.0	1975.8
34. Siltstone (up to 70 percent, decreasing in abundance upwards) in beds up to 1.3 ft thick, modal bed thickness is 0.2 ft, with interbeds of mudshale or mudstone. Siltstone is medium gray (N5) to light olive gray (5Y5/2), weathers light olive gray (5Y5/2); evenly bedded; thinning upward in unit; groove mold at 11 ft above base of unit trends 260°; trace fossil *Cylindrichnus* in upper 10 ft of unit, 10 to 15 cm long, less than 1 cm wide and clay-filled. Mudstone is olive gray (5Y4/1); micaceous; hackly parting 3 to 5 mm thick. Mudshale in lower 3.5 ft of unit is medium dark gray (N4), weathers medium gray (N5); shows textural lamination; parting is less than 3 mm thick. Base of unit 34 is immediately below power line support structure..........	32.3	1964.8
33. Mudstone, medium light gray (N6) to olive gray (5Y4/1); strongly bioturbated; bioturbated portions weather yellowish gray (5Y8/1); a few robust, costate brachiopods (*Camarotoechia*?).........................	7.0	1932.5
32. Mudstone (70 percent) with beds of siltstone (30 percent) 1 cm to 0.6 ft thick, modal bed thickness is 0.1 ft. Mudstone is olive gray (5Y4/1), weathers light olive gray (5Y5/2); micaceous; hackly parting 3 to 5 mm thick. Siltstone is light olive gray (5Y6/1), weathers olive gray (5Y4/1); micaceous; beds predominantly show Tb-		

	Thickness (feet) Unit	Cum.
Bouma sequences; beds less than 0.15 ft thick have rippled top surfaces............	9.9	1925.5
31. Siltstone (80 percent) in beds up to 0.9 ft thick, modal bed thickness is 0.4 ft, with interbeds of mudstone (20 percent). Siltstone is medium gray (N5), weathers light olive gray (5Y5/2); micaceous; Tb- Bouma sequences; trace fossil Cylindrichnus near top of unit; a few crinoid columnals concentrated in layers. Mudstone is olive gray (5Y4/1), weathers dusky brown (5YR2/2); very silty; micaceous; hackly parting 5 to 10 mm thick. Resistant unit, forms vertical face.......................................	15.6	1915.6
30. Mudstone as in unit 31 (80 percent) with beds of siltstone (20 percent) up to 0.9 ft thick, modal bed thickness is 0.15 ft. Siltstone is medium gray (N5), weathers light olive gray (5Y5/2); finely micaceous; groove mold in lower five ft of unit trends 260°................................	27.5	1900.0
29. Covered. High voltage power lines cross over highway near middle of unit. Thickness estimated geometrically from map locations of outcrops, strike and dip data, and altitude data obtained with surveying altimeter accurate to ± 3 ft. Offset to exposures along east side of Virginia Highway 100, 100 ft north of where small creek passes under road......................	590+	1872.5
28. Mudstone (85 percent) and mudshale (10 percent) with minor beds of siltstone (5 percent) up to 0.15 ft thick. Mudstone is olive gray (5Y4/1), very silty, hackly parting 3 to 5 mm thick. Mudshale is grayish black (N2); shows textural lamination; muds occur as three beds 3.6, 1.4, and 2.0 ft thick at 7.2, 20.1 and 26.2 ft above base of unit, respectively. Groove mold at 17.0 ft above base of unit trends 268°.....................................	40.8	1282.5

	Thickness (feet) Unit	Cum.
27. Clayshale (85 percent) with beds of siltstone (15 percent) up to 0.5 ft thick. Clayshale is medium gray (N5) to grayish black (N2), weathers dark gray (N3); shows textural lamination; silt laminae and streaks up to 1 mm thick are common; parting is 2 mm thick; brittle. Unit 27 grades downward into unit 26 by increase in siltstone abundance and bed thickness; siltstone abundance increases from 10 percent at top of unit 27 to 30 percent at base of unit 27........................	42.4	1241.7
26. Siltstone (60 percent) in beds up to 0.6 ft thick, modal bed thickness is 0.2 ft, with interbeds of mudshale (40 percent). Siltstone is medium gray (N5) to light olive gray (5Y5/2); weathers light olive gray (5Y5/2); micaceous; increases in abundance and bed thickness to a maximum in middle of unit where siltstone comprises 80 percent of section; abundant flute and groove molds trend 280° to 284°; a few distinct siltstone beds grade upward into less resistant argillaceous siltstone. Shale character is variable. Mudshale is predominantly olive gray (5Y4/1); weathers light olive gray (5Y5/2); shows textural lamination, irregular parting 3 to 5 mm thick; also present are intervals of dark gray (N3) to black (N1) mudshale and clayshale, 1 ft to 6 ft thick, which comprise 15 percent of the unit; this shale shows textural lamination, smooth parting 1 to 4 mm thick, grayish brown (5YR3/2) iron stain on parting surfaces. Upper 20 ft of unit 26 forms a vertical face on outcrop....................................	131.7	1199.5
25. Mudshale (80 percent) and clayshale (5 percent) with beds of siltstone (15 percent) 1 cm to 0.35 ft thick, modal bed thickness is 0.1 ft. Siltstone abundance increases from 10 percent at base of unit to 20 percent at top of unit. Mudshale is olive		

	Thickness (feet) Unit	Cum.
gray (5Y3/2); shows textural lamination; parting is 4 mm thick. Clayshale is dark gray (N3), occurs in zones less than 1.4 ft thick, shows textural lamination, partings are 2 mm thick, grayish brown (5YR3/2) iron stain on parting surfaces; soft; forms recesses in outcrop. Sole markings are common; flute and groove molds trend 269° to 283°; convolute lamination in one siltstone bed 0.3 ft thick at 34 ft above base of unit..................................	83.3	1067.8
24. Covered. "Maximum Safe Speed 50" sign at base of unit 24..............................	30.0	984.5
23. Mudstone (95 percent) with minor beds of siltstone (5 percent) up to 0.2 ft thick, modal bed thickness is less than 0.1 ft. Mudstone is olive gray (5Y3/2); parting is 4 mm thick; weathers to small, brittle chips. Siltstone beds are laminated or cross-laminated..............................	35.0	954.5
22. Siltstone (50 percent) in beds 1 cm to 0.8 ft thick, with thin interbeds of mudstone (50 percent) less than 0.25 ft thick. Siltstone is olive gray (5Y3/2); bed thickness increases upward; irregular parting 1 cm thick is common in highly weathered siltstone beds. Mudstone is olive gray (5Y3/2), weathers light olive gray (5Y5/2), parting is 3 to 5 mm thick; minor dark gray (N3) shale showing textural lamination. Unit 22 forms protrusion of outcrop.................	20.7	919.5
21. Clayshale (95 percent) with minor beds of siltstone (5 percent) less than 0.1 ft thick. Abundance of siltstone beds increases slightly upward in unit. Clayshale is dark gray (N3) to olive gray (5Y2/1), weathers olive gray (5Y4/1); shows textural lamination; slightly silty, becomes more silty upward in unit; parting is 2 to 4 mm thick. Siltstone beds are cross-laminated..	20.4	884.5

	Thickness (feet) Unit	Cum.
20. Clayshale to mudshale (70 to 80 percent) with beds of siltstone (20 to 30 percent) up to 0.5 ft thick, modal bed thickness is 0.15 ft. Siltstone abundance increases to a maximum of 40 percent in upper half of unit, where bed thickness is also at a maximum; beds 1 to 2 cm thick are very common. Shale is olive gray (5Y4/1), weathers light olive gray (5Y5/2); shows textural lamination; parting is 3 to 5 mm thick. Siltstone is medium gray (N5), weathers light olive gray (5Y6/1); a few beds with sole markings, mainly hypichnial ridges resembling Paleophycus; convolute lamination in 0.5 ft thick bed 22 ft below top of unit. "Help Prevent Forest Fires" sign across highway from middle of unit..................................	32.0	864.1
19. Mudshale to clayshale (80 to 85 percent) with beds of siltstone (15 to 20 percent) up to 0.25 ft thick, modal bed thickness is less than 0.1 ft. Shale is dark gray (N3) to grayish black (N2), weathers medium dark gray (N4) to dark gray (N5); shows textural lamination; silty at base of unit; parting is 1 to 4 mm thick; blackish red (5R2/2) iron stain on parting surfaces; weathers to smooth, even chips. Unit 19 is gradational with unit 20 in siltstone abundance and bed thickness................	42.8	832.1
18. Clayshale, (98 percent) with a few beds of siltstone (2 percent) less than 0.1 ft thick. Clayshale is olive gray (5Y3/2), weathers light olive gray (5Y5/2); shows textural lamination; a few silt laminae less than 2 mm thick; locally slightly silty; parting is 1 to 3 mm thick.................	52.2	789.3
17. Covered; minor exposures of olive gray mudshale in ditch..........................	55.0	737.1

	Thickness (feet) Unit	Cum.
16. Mudstone (98 percent) with a few beds of siltstone (2 percent) up to 0.5 ft thick, predominantly less than 0.1 ft thick. Mudstone is olive gray (5Y3/2) to light olive gray (5Y5/2), weathers olive gray (5Y4/1); hackly parting, 3 to 5 mm thick; some distinct horizontal burrows 3 to 5 mm wide, weathering light brown (5YR5/6). Unit 16 is similar in appearance to unit 18.	212.0	682.1
15. Covered....................................	50.0	470.1
NOTE: Unit 14 is described in ditch approximately 30 ft off highway.		
14. Mudshale (60 percent) with beds of siltstone (40 percent) up to 1.1 ft thick, in a thickening- and coarsening-upward sequence; modal bed thickness is 0.1 ft. Siltstone abundance ranges from 30 percent in lower 5 ft of unit to 70 percent in upper 5 ft of unit. Mudshale is olive gray (5Y4/1), weathers light olive gray (5Y5/2); shows textural lamination; parting is 2 to 5 mm thick. Siltstone is medium gray (N5), weathers light olive gray (5Y6/1); sole markings; two beds 1.1 ft thick at top of unit, lower bed shows Tbc Bouma sequence, upper bed shows Tbcde Bouma sequence........	20.0	420.1
13. Covered. Offset to exposures on west side of highway along creek bank.................	14.6	400.1
12. Siltstone and very-fine-grained sandstone (50 percent) in beds 0.1 ft to 1.3 ft thick, with thin interbeds of mudshale (50 percent). Siltstone and sandstone bed thickness and abundance increase towards middle of unit. Siltstone and sandstone are medium gray (N5) to light olive gray (5Y6/1); evenly bedded, except for very thin beds with undulatory, rippled top surfaces; minor amalgamation of beds; sole markings, mainly hypichnial ridges resembling _Paleophycus_ and groove molds trending 318°; micaceous,		

	Thickness (feet) Unit	Cum.
mica content increases upward in some beds; tiny black fragments of organic matter. Mudshale is olive gray (5Y4/1), weathers light olive gray (5Y5/2) to light gray (N7); shows textural lamination; micaceous; parting is 2 to 5 mm thick..................	19.4	385.5

NOTE: Units 9 to 11 are described at exposures low on hill, west side of road. Top of unit 11 is directly above culvert where creek passes under highway.

	Unit	Cum.
11. Mudshale (95 percent) with minor beds of siltstone (5 percent) predominantly less than 0.1 ft thick. Mudshale is olive gray (5Y4/1), weathers light olive gray (5Y5/2); shows weak textural lamination; very few silt laminae 1 to 2 mm thick; parting is 3 to 5 mm thick............................	29.1	366.1
10. Covered....................................	12.0	337.0
9. Mudshale (85 percent) with beds of siltstone (15 percent) up to 0.4 ft thick, modal bed thickness is less than 0.1 ft. Mudshale is medium dark gray (N4), weathers light olive gray (5Y5/2); shows weak textural lamination; parting is 2 to 5 mm thick. Siltstone is medium gray (N5); beds are predominantly cross-laminated; upper surfaces of beds are rippled; groove mold at 4 ft above base of unit trends 235°....................	18.4	325.0
8. Covered. Offset to exposure at top of shale pit behind French's Chapel.................	121.6	306.6
7. Clayshale, dark gray (N3), weathers medium dark gray (N4); shows strong textural lamination; color lamination less than 0.5 mm thick; silt-free; smooth parting 2 to 5 mm thick............................	28.5	185.0
6. Claystone, olive gray (5Y4/1) to yellowish gray (5Y8/1), weathers light olive gray (5Y5/2) to yellowish gray (5Y8/1); weakly to completely bioturbated; burrows are		

	Thickness (feet) Unit	Cum.
indistinct, horizontal, 1 to 2 mm wide and weather yellowish gray (5Y8/1); biolamination and streaks are common; bioturbation increases toward silty zone in middle of unit. In upper 2.0 ft of unit there are several 0.1 to 0.3 ft thick siltstone beds; in the interval 1 to 3 ft below top of unit there are several thin interbeds of grayish black (N2) clayshale showing fine textural lamination; upper 1.0 ft of unit is claystone, light brownish gray (5YR6/1), weathers brownish gray (5YR4/1); many tiny dark flecks of organic material...	22.2	156.5
5. Clayshale, olive gray (5Y4/1), weathers light olive gray (5Y5/2); silt-free; shows textural lamination and few silt laminae less than 1 mm thick. Several cross-laminated and plane laminated siltstone beds less than 0.1 ft thick; at top of unit there is a 0.6 ft thick bed of very-fine-grained sandstone......................	46.0	134.3
4. Claystone, olive gray (5Y4/1) to medium light gray (N6), weathers light olive gray (5Y5/2); silt-free; moderately bioturbated; burrows are indistinct, horizontal, and less than 5 mm wide; bioturbated portions weather yellowish gray (5Y8/1); biolaminae up to 3 mm thick are common; tiny pelecypods 2 to 5 mm wide.............................	3.2	88.3
3. Claystone and clayshale, medium dark gray (N4) to olive gray (5Y4/1), weather light olive gray (5Y5/2); micaceous; slightly silty; weak textural lamination in clayshale; minor burrow mottling as in unit 4; parting is 2 to 5 mm thick. A few siltstone beds 1 to 2 cm thick, either laminated or cross-laminated; a 2 cm thick bed at 5.6 ft below top of unit has groove mold and parting lineation trending 271° and 285°, respectively..............................	35.4	85.1

	Thickness (feet) Unit	Cum.
2. Sandstone, very-fine-grained, single bed, light olive gray (5Y5/2); micaceous; mica content increases upward; shows Tab Bouma sequence; crinoid columnals are abundant in basal 0.1 ft and diminish in abundance upward....................................	1.3	49.7
Total Brallier Formation...............	3580.8	
Millboro Shale (incomplete):		
1. Mudshale, dark gray (N3) to olive black (5Y2/1), weathers medium dark gray (N4); shows weak textural lamination; finely micaceous; parting is 5 to 10 mm thick. A few indistinct siltstone beds 1 to 2 cm thick in lower 10 ft of unit; non-resistant; plane laminated or cross-laminated; weather dark yellowish orange (10YR6/6). A few sideritic layers less than 0.1 ft thick are also present in lower 10 ft of unit and weather dark yellowish orange (5YR6/6). Several beds of less resistant shale up to 0.4 ft thick; these beds weather medium gray (N5), and show incipient spheroidal weathering and parting 1 to 2 cm thick.....................	48.4	48.4
Total Millboro Shale (incomplete)......	48.4	

SECTION 6

White Gate Section

Section of siltstone bundle in Brallier Formation, exposed in roadcut along Virginia Route 601, 0.5 mile north of Sassin Church, Pulaski County, White Gate quadrangle, Virginia (519000 meters east, 4112900 meters north, Universal Transverse Mercator grid). Section measured, described, and sampled using Jacob's staff, Abney level, and tape by Paul D. Lundegard, August 27, 1978.

Devonian (incomplete):	Thickness (feet) Unit	Cum.
Brallier Formation (incomplete):		
3. Clayshale (95 percent) with beds of siltstone (5 percent) less than 0.1 ft thick. Clayshale is olive gray (5Y3/2) weathers light olive gray (5Y5/2); shows textural lamination; parting is 2 to 4 mm thick. Siltstone beds are cross-laminated..................................	6.1	50.9
2. Siltstone (66 percent) in beds less than 0.1 ft to 3.4 ft thick, modal bed thickness is 0.2 ft, 50 percent of beds are greater than 0.35 ft thick; interbeds are clay-shale as in unit 3 (44 percent). Unit 2 was measured and described in bed by bed detail. Siltstone is medium gray (N5), weathers light olive gray (5Y6/1); evenly bedded; base of beds are flat and sharply defined; 57 percent of beds show Ta- Bouma sequences, 30 percent show Tb- Bouma sequences, 11 percent show Tc- Bouma sequences; unit ABC proximity index (Walker, 1967) is 75 percent................	35.6	44.2
1. Clayshale as in unit 3 (90 percent) with 8 beds of siltstone (10 percent) up to 0.2 ft thick; 5 beds show Tb- Bouma sequences; 3 beds are structureless and less than 0.1 ft thick.....................	9.2	9.2
Total Brallier Formation (incomplete)..	50.9	

SECTION 7

Gauley Ridge Section

Incomplete section of lower Brallier Formation exposed in road-cuts on both sides of Virginia Route 606 at prominent northeast trending ridge, called Gauley Ridge, 1.2 miles east of Holly Brook, Bland County, Mechanicsburg quadrangle, Virginia (502560 meters east, 4115620 meters north, Universal Transverse Mercator grid). Gauley Ridge is formed by a siltstone bundle (Unit 2). Section measured, described and sampled at exposures on north side of road using Jacob's staff, Abney level, and tape by Paul D. Lundegard, September 22, 1977.

Devonian (incomplete):	Thickness (feet) Unit	Cum.
Brallier Formation (incomplete):		
5. Mudshale, with a few beds of siltstone (less than 1 percent) less than 0.1 ft thick. Mudshale is light olive gray (5Y5/2), and weathers light olive gray (5Y5/2); shows weak textural lamination; micaceous; parting is 3 to 5 mm thick; numerous indistinct horizontal burrows give some bedding planes a rough, irregular surface; burrows are less than 5 mm wide; weathers to small platy or tabular chips. Siltstone beds are cross-laminated..........	50.0	150.0
4. Covered......................................	13.0	100.0
3. Clayshale with a few beds of siltstone (less than 2 percent) less than 2 cm thick. Clayshale is light olive gray (5Y5/2), and weathers light olive gray (5Y5/2); shows textural lamination; locally silty; parting is 5 mm thick. Siltstone beds are plane laminated or cross-laminated...............	9.8	87.0
2. Siltstone and very-fine-grained sandstone (85 percent) in beds up to 2.3 ft thick, modal bed thicknesses of 0.2 ft and 1.5 ft with interbeds of clayshale (15 percent). Unit 2 was described in bed by bed detail. Siltstone and sandstone are medium gray (N5); micaceous; rounded, flat, clay galls up to 4 cm long are common; tiny, unoriented wood fragments are abundant near the tops of several beds; on outcrop scale beds are strikingly parallel and even; ripple marks form small scale irregularities on top surfaces of many beds; sole markings are rare; 60 percent of beds show Ta- Bouma sequences, 20 percent show Tb- Bouma sequences, and 13 percent show Tc- Bouma sequences; over 40 percent of beds are cross-laminated in their upper parts; the unit ABC proximity index (Walker, 1967) is 70 percent. Clayshale interbeds are generally less than 0.2 ft thick; medium dark gray (N4), weather medium dark gray (N4) to medium gray (N5); show textural lamination; parting is 1 to 5 mm thick......	25.6	77.2

	Thickness (feet) Unit	Cum.
1. Clayshale and mudshale (98 percent) with a few beds of siltstone (2 percent) less than 0.25 ft thick. Lower third of unit is light olive gray (5Y5/2) clayshale, with minor beds of medium gray (N5) mudshale; upper two-thirds of unit is predominantly medium gray mudshale; textural lamination is best developed in medium gray shale; parting is 3 to 5 mm thick in light olive gray shale and 2 to 4 mm thick in medium gray shale; some horizontal burrows less than 5 mm wide. At 18.5 ft above base of unit there is a 0.4 ft thick bed of light gray (N7) claystone with abundant medium gray (N5) burrow mottles; this bed is silt-free and weathers to a recess. Siltstone beds are cross-laminated, or ripple drift cross-laminated; several beds grade into surrounding shales; ripple crests at 27.0 ft above base of unit trend 155° with current towards the southwest..............	51.6	51.6
Brallier Formation (incomplete)........	150.0	

SECTION 8

South Gap Section

Section of siltstone bundle in basal Brallier Formation, exposed at top of South Gap-Virginia Route 606 exit ramp along Interstate Highway 77-north, Bland County, Rocky Gap quadrangle, Virginia (491800 meters east, 4118350 meters north, Universal Transverse Mercator grid). Section measured and described using tape by Paul D. Lundegard, July 19, 1978.

Devonian (incomplete):

Brallier Formation (incomplete):

3. Clayshale, olive gray (5Y4/1), weathers light olive gray (5Y5/2); shows textural lamination; parting is 2 to 3 mm thick......	20.0	57.0

	Thickness (feet) Unit	Cum.
2. Siltstone (60 percent) in beds 1 cm to 2.5 ft thick, modal bed thickness is less than 0.2 ft, 30 percent of beds are greater than 0.4 ft thick; interbeds are clayshale as in unit 3 (40 percent). Unit 2 was measured and described in bed by bed detail. Siltstone is medium gray (N5), weathers light olive gray (5Y6/1); beds show sharp basal contacts and sharp or slightly gradational upper contacts; 46 percent of beds show Ta- Bouma sequences, 30 percent show Tb- Bouma sequences, 12 percent show Tc- Bouma sequences, and 12 percent show plane lamination interpreted to represent the Bouma Td division; the unit ABC proximity index (Walker, 1967) is 61 percent; clay galls occur in 2 beds; 1.9 ft thick bed at 8.8 ft above base of unit grades from very-fine-grained sandstone at its base to siltstone at its top...	22.0	37.0
1. Clayshale as in unit 3....................	15.0	15.0
Total Brallier Formation (incomplete)..	57.0	

SECTION 9

Bastian Section

One of the best and most nearly complete sections of the Brallier Formation in southwest Virginia, exposed mainly in roadcuts along U.S. Highway 21-52 from the town of Bastian, southward to 0.4 mile south of the crest of Brushy Mountain in Bland County, Bastian quadrangle.

Base of section is 200 feet south of junction of U.S. Highway 21-52 and Virginia Route 615 on east side of U.S. Highway 21-52 in the town of Bastian (486700 meters East, 4111500 meters North, Universal Transverse Mercator grid). Uppermost Brallier Formation and "Chemung" Formation, units 41 through 62, are described at roadcuts from the crest of Brushy Mountain south for approximately 0.4 mile. Section was measured and described using Jacob's staff, Abney level, surveying altimeter and tape by Paul Lundegard, August 30 and 31, and September 1, and 2, 1978.

Devonian (incomplete):	Thickness (feet) Unit	Cum.
"Chemung" Formation (incomplete):		
62. Sandstone, very-fine-grained (75 percent, decreasing upward to 30 percent in upper 15 ft) in beds up to 1.2 ft thick, predominantly 0.2 to 0.6 ft thick, with interbeds of mudshale (25 to 60 percent). Sandstone is olive gray (5Y4/1) to light olive gray (5Y5/2) with tiny limonite specks on fresh surfaces; beds are uneven to discontinuous; low-angle crossbedding and plane lamination common; fossiliferous, especially at 2 ft above base; fossils include crinoid columnals, _Camarotoechia_ sp., _Spirifer_ sp. brachiopods, and _Lyriopecten_ sp., and _Nucula_ (?) pelecypods. Mudshale is moderate olive brown (5Y4/4), weathers light olive gray (5Y5/2); shows textural lamination, parting is 3 to 5 mm thick; beds folded and culvert under road at base of unit..............................	45.0	3384.5
61. Mudstone, dark yellowish brown (10YR4/2), weathers light olive gray (5Y5/2); very silty; hackly parting; strongly bioturbated; a few distinct horizontal burrows less than 7 mm wide; a few imprints of brachiopods. Beds steeply inclined. Unit 61 forms slight recess in outcrop..........................	6.2	3339.5
60. Siltstone, coarse-grained, and sandstone, very-fine-grained (80 percent) in beds up to 0.8 ft thick, predominantly 0.2 to 0.6 ft thick, with interbeds of mudshale as in unit 62 (20 percent). Siltstone and sandstone beds are uneven to discontinuous; beds show predominantly plane or undulatory lamination with some crossbedding; flaggy parting; very fossiliferous; fossils include _Camarotoechia_ sp. brachiopods, _Leptodesma_ sp. pelecypods, and crinoid columnals; highly fossiliferous lens 0.8 ft thick at 3.0 ft below top of unit. Dip of beds increases abruptly at top of unit...	14.4	3333.3
59. Mudshale to mudstone (60 percent) with beds of coarse-grained siltstone (30 percent) up to 0.3 ft thick, modal bed thickness is		

	Thickness (feet) Unit	Cum.
0.1 ft. Mudshale and mudstone are olive gray (5Y4/1), weather light olive gray (5Y5/2); mudshale shows textural lamination. Siltstone is light olive gray (5Y5/2); beds are uneven; fossiliferous; fossils include <u>Camarotoechia</u> sp. Unit 59 is gradational with unit 60; bed thickness increases slightly at top of unit 59........	14.4	3318.9
58. Sandstone, very-fine-grained, olive gray (5Y4/1) with limonite specks on fresh surface, weathers light olive gray (5Y5/2); beds are 0.3 ft to 1.4 ft thick; cross-bedded; clay galls; highly fossiliferous; contains <u>Camarotoechia</u> sp. and other brachiopods; some bioturbation.............	3.0	3304.5
57. Mudstone, olive gray (5Y4/1), weathers light olive gray (5Y5/2)...........................	2.0	3301.5
56. Deformed zone; beds tightly folded and faulted; poorly exposed; stratigraphic thickness uncertain........................	40.0	3299.5
55. Sandstone, very-fine-grained, and siltstone, coarse-grained (50 percent), in beds 0.3 to 0.1 ft thick with interbeds of mudstone (50 percent). Sandstone and siltstone are light olive gray (5Y5/2) to moderate olive brown (5Y4/4); beds are concentrated in 3 groups; show plane lamination, undulatory lamination and crossbedding; a few fossils in middle of unit. Mudstone is light olive gray (5Y5/2); very silty; hackly parting; bioturbated; contains <u>Camarotoechia</u> sp. brachiopods, and <u>Nucula</u> sp., and <u>Leptodesma</u> (?) pelecypods. Dip of beds increases at top of unit................................	36.0	3259.5
54. Poorly exposed; sandstone, very-fine-grained, light olive gray (5Y5/2); platy; one bed 1.2 ft thick, shows low-angle crossbedding in 0.8 ft sets............................	13.0	3223.5

	Thickness (feet) Unit	Cum.
53. Covered; culvert under road marked by white post in middle of unit......................	9.0	3210.5
52. Siltstone, coarse-grained, and sandstone, very-fine-grained (75 percent), in beds 0.3 ft to 1.5 ft thick, modal bed thickness is 0.7 ft, with interbeds of mudstone (25 percent). Siltstone and sandstone beds are plane laminated or crossbedded; some indistinct horizontal bioturbation; 2 flaggy beds in middle of unit 1.0 to 1.5 ft thick. Mudstone is light olive gray (5Y5/2); very silty; strongly bioturbated; hackly parting............................	16.8	3201.5
51. Mudstone as in unit 52 (90 to 95 percent) with beds of coarse-grained siltstone (5 to 10 percent) 0.1 to 0.4 ft thick. Several siltstone beds appear to pinch out into mudstone..........................	15.6	3184.7
50. Sandstone, very-fine-grained, and siltstone, coarse-grained (85 percent), in beds 0.2 ft to 1.5 ft thick with interbeds of mudstone as in unit 52 (15 percent) predominantly less than 0.15 ft thick. Sandstone and siltstone are light olive gray (5Y5/2); beds are predominantly plane laminated; some low-angle crossbedding; many beds strongly bioturbated; low-angle clay-filled burrows up to 1 cm wide; faint remnant lamination or cross-lamination in some bioturbated zones.........................	38.8	3169.1
Total "Chemung" Formation (incomplete).	254.2	

Brallier Formation:

49. Mudstone (75 percent) with beds of siltstone (25 percent) up to 0.5 ft thick, modal bed thickness is 0.3 ft. Mudstone is light olive gray (5Y5/2); strongly bioturbated, burrows are predominantly low-angle and less than 7 mm wide; hackly parting. Siltstone occurs

	Thickness (feet) Unit	Cum.
as even, well defined beds and also as strongly bioturbated argillaceous siltstone with very indistinct bedding; burrows are horizontal to inclined, up to 1 cm wide, and have clayey fillings; branching of burrows is rare; a few similar burrows are present in the distinct siltstone beds; small talus cone is present below 4 ft thick interval of bioturbated argillaceous siltstone at 17 ft above base of unit; crossbedded distinct siltstone, 0.5 ft thick at 10 ft below top of unit...........	64.3	3130.3
48. Mudstone as in unit 49 (95 percent) with minor beds of siltstone (5 percent) up to 0.6 ft thick, modal bed thickness is less than 0.1 ft. Six feet of section is covered where culvert, marked by white post, passes under road near middle of unit.	59.5	3066.0
47. Covered. "Winding Road" sign facing north near middle of unit........................	47.0	3066.5
46. Mudstone (50 to 60 percent) with beds of siltstone (40 to 50 percent) up to 0.8 ft thick, modal bed thickness is 0.4 ft. Mudstone is moderate olive brown (5Y4/4), weathers light olive gray (5Y5/2); some distinct horizontal burrows. Ta- Bouma sequences are very common in siltstone beds; sole markings are common; flute molds near middle of unit trend 258°. Gentle fold near top of unit......................	62.1	2959.5
45. Clayshale (85 percent) with beds of siltstone (15 percent) up to 0.5 ft thick, modal bed thickness is 0.15 ft. Clayshale is moderate olive brown (5Y4/4), weathers light olive gray (5Y5/2); shows textural lamination; silt-free; parting is 5 mm thick. Tbcde and Tcde Bouma sequences predominate in siltstone beds; sole markings are common; flute molds near middle of unit trend 284°.......	4.1	2897.4

	Thickness (feet) Unit	Cum.
44. Clayshale as in unit 45 (70 percent) with beds of siltstone (30 percent) up to 0.8 ft thick, modal bed thickness is 0.25 ft; 7 siltstone beds 0.5 ft thick or greater are distinctive of unit 44. Siltstone is light olive gray (5Y5/2); Tb- and Tab- Bouma sequences predominate......................	18.2	2893.3
43. Clayshale as in unit 45 (90 percent) with beds of siltstone (10 percent) up to 0.7 ft thick, predominantly less than 0.2 ft thick. In siltstone beds Tc- and Tbc- Bouma sequences predominate; top surface of beds are commonly rippled. Minor claystone where textural lamination is absent in fine-grained interbeds. "Deer Trail Park Campground" sign on hill above outcrop....................................	15.6	2875.1
42. Covered. "Goins" home across road from base of unit....................................	12.0	2859.5
41. Claystone (65 percent) with beds of siltstone (35 percent) up to 0.5 ft thick, modal bed thickness is 0.15 ft. Claystone is light olive gray (5Y5/2); slightly silty; numerous distinct horizontal burrows. Siltstone beds are even, and commonly have rippled top surfaces; Tabc and Tc Bouma sequences are common; low relief sole markings; groove molds 2 ft above base of unit trend 252°. Middle 5 ft of unit is more thinly bedded; beds in this interval are less than 0.15 ft thick and cross-laminated. Unit 41 is described at roadcut next to "Maximum Safe Speed 30" sign, 0.05 mile south of crest of Brushy Mountain...........................	23.0	2847.5
40. Siltstone (80 percent) in beds up to 1.0 ft thick, modal bed thickness is 0.2 ft, with interbeds of clayshale or mudshale (20 percent) less than 0.15 ft thick. Siltstone is medium gray (N5), weathers light olive gray (5Y6/1); beds have sharp bases and		

	Thickness (feet) Unit	Cum.
sharp or gradational tops; Ta-, Tb-, and Tc- Bouma sequences occur throughout unit; Tc- sequences are most common overall; abundant sole markings include flute, groove, bounce, and prod molds, and hypichnial ridges; current formed sole marking orientations measured throughout unit have a strong average trend of 250°; carbonized plant fragments and clay galls are locally very common; convolute lamination and imprints of brachiopod shells occur in a few siltstone beds. Vertical and high-angle burrows are common in siltstone beds in upper 10 ft of unit; these include Cylindrichnus, Teichichnus, and simple burrows about 5 mm wide which are clay filled, straight to slightly curved, and rarely branched; horizontal burrows on the top surface of siltstone beds are common throughout unit. Shale is medium dark gray (N4), weathers medium gray (N5) to light olive gray (5Y5/2); shows textural lamination; locally silty; silt laminae are locally common. Upper 117 ft of unit 40 is described at high, steep exposures above Virginia Route 612, 300 feet from its junction with U.S. Highway 21-52; lower 53 ft of unit 40 is described at exposures along U.S. Highway 21-52, 400 ft downhill from the same junction. Top of unit 40 was correlated with base of unit 41 by tracing individual beds to the crest of Brushy Mountain, and measuring from there to base of unit 41 with Jacob's staff and Abney level. Upper 117 feet of unit 40 were measured and described in bed by bed detail.............	170.0	2824.5
39. Covered; thickness uncertain due to structural disturbance at base of unit 40...	10.0	2654.5

NOTE: Unit 38 is described at high roadcut on west side of U.S. Highway 21-52, 0.25 mile north of Virginia Route 612.

	Thickness (feet) Unit	Cum.
38. Siltstone (75 percent) in beds up to 0.9 ft thick, modal bed thickness is 0.3 ft with interbeds of clayshale (25 percent). Siltstone is medium gray (N5); in lower 70 ft, Tc- and Tb- Bouma sequences predominate; from 70 ft above base to 25 ft below top of unit, Ta- Bouma sequences are most common; upper 25 ft of unit is thinner bedded than remainder of unit and Tc- and Tbc- Bouma sequences predominate. In general, beds less than or equal to 0.1 ft thick show Tc- Bouma sequences. Abundant current formed sole markings with a mean trend of 252°; a few beds contain clay galls; inclined, clay-filled burrows near tops of a few beds. Clayshale is medium dark gray (N4), weathers medium gray (N5); shows textural lamination; parting thickness is 2 mm or less..................	106.5	2644.5

NOTE: Units 37 through 32 are described at low outcrop on east side of U.S. Highway 21-52, 0.3 mile north of Virginia Route 612.

37. Clayshale (75 to 80 percent) with beds of siltstone (20 to 25 percent) up to 1.1 ft thick, modal bed thickness is 0.2 ft. Siltstone beds 0.2 to 0.3 ft thick are distinctive of unit 37. Clayshale is grayish black (N2), weathers medium dark gray (N4); shows very fine textural lamination; very slightly silty; parting is less than 3 mm thick with grayish red (5R4/2) iron stain on parting surfaces. Five ft thick interval at 20 ft above base of unit includes many siltstone beds less than 1.5 cm thick; these beds are mostly plane laminated or cross-laminated...	42.5	2538.0
36. Clayshale as in unit 37 (90 to 95 percent) with beds of siltstone (5 to 10 percent) up to 0.1 ft thick, modal bed thickness is 2 to 3 cm. Siltstone beds are even and persistent; Ta- Bouma sequences predominate.	9.0	2495.5

	Thickness (feet) Unit	Cum.
35. Clayshale as in unit 37 (80 percent) with beds of siltstone (20 percent) up to 0.5 ft thick, modal bed thickness is 0.2 ft. Ta- and Tb- Bouma sequences predominate in siltstone beds..........................	12.0	2486.5
34. Clayshale as in unit 37 (greater than 95 percent) with beds of siltstone (less than 5 percent) up to 0.5 ft thick. At 4.0 feet above base of unit there are 2, 0.5 ft thick, structureless (Ta) siltstone beds....................................	9.0	2474.5
33. Clayshale as in unit 37 (70 percent) with beds of siltstone (30 percent) up to 1.0 ft thick, modal bed thickness is 0.2 ft. Approximately 60 percent of siltstone beds show Ta- Bouma sequences, the remainder show Tbc- and Tc- Bouma sequences; a 1.0 ft thick siltstone bed at 6.5 ft below top of unit..........................	12.5	2465.5
32. Clayshale as in unit 37 (95 percent) with beds of siltstone (5 percent) up to 0.5 ft thick, modal bed thickness is 0.1 ft. Tc- and Tbc- Bouma sequences predominate in siltstone beds; at 3.0 ft below top of unit there is a 0.5 ft thick structureless (Ta) siltstone bed.........................	16.5	2453.0

NOTE: Between outcrops where units 31 and 32 were measured there is a steep, vetch covered gully with a cement gutter at its base. Units 31 through 26 are described at roadcut on west side of U.S. Highway 21-52.

31. Clayshale (50 percent) and claystone (25 percent) with beds of siltstone (25 percent) up to 1.2 ft thick, modal bed thickness is 0.3 foot; siltstone beds 0.2 to 0.4 ft thick are distinctive of unit 31. Clayshale is grayish black (N2), weathers medium dark gray (N4); shows textural lamination; parting is 1 to 3 mm thick. Claystone is medium dark gray (N4), weathers medium gray (N5)

	Thickness (feet) Unit	Cum.
to medium light gray (N6); contains a few carbonized wood fragments. Upper 6 ft of unit is 40 percent siltstone in 4 structureless (Ta) beds 0.3 ft to 1.2 ft thick..................................	22.0	2436.5
30. Siltstone (60 percent) in beds up to 0.9 ft thick, modal bed thickness is 0.3 ft, with interbeds of clayshale as in unit 31 (30 percent). Siltstone beds predominantly show Ta- Bouma sequences. Unit 30 is thicker bedded than units 31 and 29; an abrupt increase in the abundance of siltstone, and in siltstone bed thickness occurs at base of unit 30..................	13.0	2414.5
29. Clayshale and minor claystone, both as in unit 31 (80 percent) with beds of siltstone (20 percent) up to 1.2 ft thick, modal bed thickness is 0.15 to 0.2 ft.......	17.0	2401.5
28. Clayshale as in unit 31 (80 percent) with beds of siltstone (20 percent) up to 0.3 ft thick, modal bed thickness is less than 0.1 ft. Siltstone beds greater than 0.15 ft thick (15 percent) show Ta- Bouma sequences; beds less than 0.1 ft thick (85 percent) show Tc- or Tbc- Bouma sequences; plane laminated siltstone layers less than 1.5 cm thick are very common, these may represent Td rather than Tb Bouma units............................	16.0	2384.5
27. Clayshale as in unit 31 and siltstone beds in a thickening-upward sequence. The abundance of siltstone increases from 10 percent near base of unit to 50 percent at top of unit. Bed thickness also increases upward; maximum bed thickness increases from 0.4 ft near base to 1.0 ft near top of unit; modal bed thickness increases from less than 0.1 ft near base to 0.2 ft near top of unit. Beds greater than 0.3 ft thick predominantly show Ta- Bouma sequences; beds less than 0.15 ft thick show Tc- and Tbc- Bouma sequences.		

	Thickness (feet) Unit	Cum.
Groove molds at 7.3 ft below top of unit trend 263°; possible Zoophycus burrow at 13.5 ft above base of unit. High-angle normal fault with 5 ft of displacement cuts unit 27..............................	31.0	2368.5
26. Clayshale (80 percent) with beds of siltstone (20 percent) up to 1.4 ft thick, predominantly less than 0.4 ft thick, modal bed thickness is 0.15 ft. Clayshale is grayish black (N2), weathers medium dark gray (N4); shows textural lamination and a few discontinuous pinch and swell silt streaks less than 2 mm thick; parting is less than 3 mm thick; soft. Siltstone beds typically have rippled upper surfaces; overall, Tc- Bouma sequences are most common; Tbc- and Ta- Bouma sequences predominate in beds greater than 0.2 ft thick (5 percent); flute mold, 1.6 ft below top of unit trends 276°. Base of unit is above uphill end of a 300 ft long section of guardrail on west side of U.S. Highway 21-52........................	45.0	2337.5
25. Covered; steep gully below U.S. Highway 21-52 on west side; 300 ft long section of guardrail on west side of highway; "Truckers Maximum Safe Speed 25" sign in middle of unit on east side of highway...............	112.5	2292.5

NOTE: Units 17 through 24 are described at outcrop on west side of U.S. Highway 21-52, just uphill of 0.3 mile long section of guardrail, and 0.9 mile south of Bastian.

	Unit	Cum.
24. Clayshale (greater than 95 percent) with minor beds of siltstone (less than 5 percent) less than 0.1 ft thick. Clayshale is grayish black (N2), weathers medium dark gray (N4); fine textural lamination and a few silt laminae less than 0.5 mm thick; parting is 3 mm thick with grayish red (5R4/2) iron stain on parting surfaces............	14.8	2180.0
23. Clayshale as in unit 24 (85 percent) with beds of siltstone (15 percent) up to 0.7 ft thick. Siltstone beds predeominatly show Tb- or Tc- Bouma sequences; 3 beds 0.4 to 0.7 ft thick show Ta- Bouma sequences......	11.2	2165.2

	Thickness (feet) Unit	Cum.
22. Clayshale as in unit 24 (greater than 95 percent) with minor beds of siltstone (less than 5 percent) up to 0.1 ft thick, modal thickness is 1 to 2 cm. Approximately 80 percent of siltstone beds are plane laminated, remainder are cross-laminated....	12.0	2154.0
21. Clayshale as in unit 24 (85 to 90 percent) with beds of siltstone (10 to 15 percent) up to 0.6 ft thick, predominantly less than 0.25 ft thick. Several siltstone beds 0.3 to 0.6 ft thick in upper 5 ft of unit. Siltstone beds less than 0.25 ft thick predominantly show Tb- Bouma sequences; Ta- Bouma sequences predominate in thicker beds..........................	22.0	2142.0
20. Clayshale as in unit 24 (65 percent) with beds of siltstone (35 percent) up to 0.7 ft thick. Variable bed thickness and siltstone beds 0.5 ft thick or greater are distinctive of unit 20. Unit 20 is gradational with overlying, thinner bedded, unit 21. Siltstone beds greater than 0.2 ft thick predominantly show Ta- Bouma sequences; beds 0.1 ft thick and less are predominantly structureless or plane laminated. Small prod molds and hypichnial ridges are common...............	16.2	2120.0
19. Clayshale as in unit 24 (greater than 90 percent) with beds of siltstone (less than 10 percent) up to 0.4 ft thick, predominantly 0.1 ft thick or less. Siltstone beds are predominantly structureless; silt laminae 5 mm to 10 mm thick are common; these laminae are even and structureless..............................	15.3	2103.8
18. Clayshale as in unit 24 (70 to 80 percent) with beds of siltstone (20 to 30 percent) 0.1 to 1.3 ft thick in a thinning-upward sequence. Siltstone abundance decreases upward; modal bed thickness decreases upward from 0.5 to 0.1 ft; Ta- and Tb- Bouma sequences predominate near base of		

	Thickness (feet) Unit	Cum.
unit; Tb-, Tbc-, and Tc- Bouma sequences predominate near top of unit. Siltstone beds have sharp basal contacts and sharp or gradational upper contacts; sole markings are common..................................	26.0	2088.5
17. Clayshale as in unit 24 (greater than 95 percent) with minor beds of siltstone (less than 5 percent) up to 0.15 ft thick. Base of unit 17 is above uphill end of a 0.3 mile long section of guardrail along west side of U.S. Highway 21-52, and across highway from "Truck Escape Ramp" sign.......	12.5	2062.5
16. Covered. Section of guardrail 0.3 mile long along west side of U.S. Highway 21-52 in this interval. Thickness estimated geometrically from map locations of outcrops, strike and dip data, and altitude data obtained with a surveying altimeter accurate to $\pm$ 3 feet..............	835+	2050.0

NOTE: Units 7 through 15 are described at roadcut on west side of U.S. Highway 21-52, 0.5 mile south of Virginia Route 613 and town of Bastian.

15. Mudstone (90 percent) with beds of siltstone (10 percent) up to 0.4 ft thick, predominantly 0.1 to 0.2 ft thick. Mudstone is olive gray (5Y4/1); very silty; horizontal and vertical burrows less than 7 mm wide are very common; some tiny carbonized wood fragments. In the 5 foot interval above the top of unit 15 there are several siltstone beds 0.3 ft to 1.3 ft thick; remainder of outcrop is inaccessible................................	18.0	1215.0
14. Siltstone (70 percent), modal bed thickness is 0.7 ft, with interbeds of clayshale (30 percent), in a thinning-upward sequence. Siltstone is evenly bedded; beds have sharp bases and sharp or gradational tops, and are predominantly structureless; several siltstone beds		

	Thickness (feet) Unit	Cum.
weather a distinctive light brown (5YR5/6). Clayshale is dark gray (N3), weathers medium dark gray (N4); very fine textural lamination; parting is 1 to 3 mm thick; soft. At road level unit 14 is directly across highway from "Truckers Maximum Safe Speed 15" sign..........................	12.5	1197.0
13. Mudstone (85 percent) with beds of siltstone (15 percent) up to 0.3 ft thick, modal bed thickness is 0.1 ft. Mudstone is dark gray (N3), weathers medium dark gray (N4); locally shows 2 to 3 mm thick parting; very few silt laminae less than 1 mm thick; a few horizontal and vertical burrows up to 7 mm wide.....................	14.3	1184.5
12. Mudstone as in unit 13 (60 to 70 percent) with beds of siltstone (30 to 40 percent) 0.2 to 1.0 ft thick; slight thinning-upward. Siltstone beds 0.5 to 1.0 ft thick are distinctive of unit 12; these beds are plane laminated (Tb) or structureless (Ta). At 8.4 ft above base of unit there is a 0.5 ft thick siltstone bed with many 1 to 3 cm long siderite nodules.............	10.0	1170.2
11. Mudstone and minor claystone as in unit 13 (80 to 85 percent) with beds of siltstone (15 to 20 percent) up to 0.7 ft thick, but predominantly 0.1 to 0.4 ft thick, modal bed thickness is 0.2 ft. Siltstone abundance increases to 30 percent at top of unit. Claystone differs from mudstone only in silt content. Siltstone beds are even and persistent; many have sharp bases and gradational tops.........................	91.6	1160.2
10. Mudstone, claystone (10 to 60 percent) and siltstone (30 to 90 percent) in a thickening- and coarsening-upward sequence. Mudstone is as in unit 13. Claystone differs from mudstone only in disseminated silt content. Siltstone abundance ranges from		

	Thickness (feet) Unit	Cum.
30 percent in lower 10 ft of unit to 90 percent in upper 7 ft. Siltstone bed thickness ranges from 0.1 to 0.4 ft in lower 10 ft of unit; and ranges from 0.5 ft to 1.5 ft in upper 7 ft of unit; beds are structureless in upper 7 ft; sole markings are common throughout unit; groove molds 6.8 ft above base of unit trend 234°..............................	24.2	1068.6
9. Claystone (80 to 85 percent) with beds of siltstone (15 to 20 percent) up to 0.4 ft thick, modal bed thickness is 0.2 ft; unit 9 is gradational with unit 8 below; siltstone content is 25 to 30 percent in lower 8 ft of unit. Claystone is dark gray (N3), weathers medium dark gray (N4); very few silt laminae less than 5 mm thick; parting is 1 to 2 mm thick; a few distinct horizontal and short vertical burrows up to 3 mm wide. Siltstone beds commonly show small, low-relief sole markings, mainly groove molds and prod molds.........	14.3	1044.3
8. Claystone as in unit 9 (60 percent) with beds of siltstone (40 percent) up to 1.6 ft thick, modal bed thickness is 0.5 ft. Siltstone beds are predominantly structureless (Ta); sole markings are common; 1.6 ft thick siltstone bed at 2 ft below top of unit with a weathered-out nodule 20 cm long, cavity is filled with dark yellowish orange (10YR6/6) limonitic dust..................	26.6	1030.1
7. Mudstone and clayshale (80 percent) with beds of siltstone (20 percent) up to 0.7 ft thick, predominantly less than 0.2 ft thick; unit 7 is gradational with overlying unit 8; siltstone content of unit 7 increases gradually upward. Mudstone and clayshale are dark gray (N3), weather medium dark gray (N4); finely micaceous; a few distinct horizontal burrows less than 7 mm wide occur in mudstone. Clayshale has faint textural lamination; parting is		

	Thickness (feet) Unit	Cum.
3 mm thick; locally slightly silty. Siltstone is medium gray (N5); beds commonly show Tc- Bouma sequences and rippled top surfaces; horizontal burrows less than 6 mm wide are common on top surfaces of some beds..................................	53.5	1003.5
6. Covered. Thickness estimated geometrically from map location of outcrops, strike and dip data and altitude data measured with a surveying altimeter accurate to $\pm$ 3 ft....	430$\pm$	950.0

NOTE: Unit 5 is described at roadcut along old U.S. Highway 21-52, 0.2 mile east of its junction with the new U.S. Highway 21-52.

5. Clayshale (80 percent) with beds of siltstone (20 percent) up to 0.4 ft thick, modal bed thickness is 0.1 ft. Siltstone abundance ranges up to 40 or 50 percent in a few thin intervals. Shale is of two types; a light olive gray (5Y6/1) shale predominates in lower half of unit, and a grayish black (N2) shale predominates in upper half of unit; minor interbedding of these 2 shale types on a scale of a few centimeters occurs. Light olive gray shale weathers light olive gray (5Y5/2); shows textural lamination, and plane silt laminae up to 3 mm thick; minor color lamination up to 3 mm thick; a few distinct horizontal burrows up to 5 mm wide. Grayish black shale weathers dark gray (N3) to medium gray (N5); shows strong textural lamination and a few silt laminae less than 2 mm thick; minor bioturbation, which weathers yellowish gray (5Y8/1); parting thickness is less than 3 mm. At 56.4 feet above base of unit there is a 0.8 ft thick bentonite bed (sampled); weathers grayish orange (5Y5/7); less resistant than surrounding lithologies and very highly micaceous; mica flakes are silt and sand sized, and have a preferred orientation giving rock a textural lamination. Siltstone beds are sharply defined, persistent, and even; some

	Thickness (feet) Unit	Cum.
beds less than 0.1 ft thick show thickness variations because of rippled top surfaces; Tc- Bouma sequences predominate; a few sole markings, including hypichnial ridges, and groove and bounce molds, trending 228° at 38.5 ft above base of unit; hypichnial ridges are straight, non-branching forms, up to 7 mm wide and generally less than 7 cm long. Small thrust fault with several feet of displacement at 48 feet above base of unit. Top of unit 5 is 40 to 50 feet west of where power lines cross over road...	140.0	520.0
4. Covered. Thickness estimated geometrically from map locations of outcrops, strike and dip data, and altitude data obtained with a surveying altimeter accurate to ± 3 feet..	290±	380.0

NOTE: Units 1 through 3 are described at southwest facing outcrop on northeast side of U.S. Highway 21-52, at junction of U.S. Highway 21-52 and Virginia Route 615 in town of Bastian.

3. Clayshale, medium gray (N5), weathers light olive gray (5Y5/2); shows fine textural lamination; parting is 2 to 5 mm thick; a few horizontal burrows; at top of outcrop shale is more deeply weathered and light olive gray (5Y5/2) on freshest available surface; parting thickness also increases slightly upward............................	12.3	90.0
2. Siltstone (60 percent) in beds 0.1 ft to 3.1 ft thick, modal bed thicknesses of 0.1 and 0.7 ft with interbeds of clayshale (40 percent). Unit 2 was measured and described in bed by bed detail. Siltstone beds greater than 0.5 ft thick comprise 55 percent of unit. Siltstone is medium gray (N5), weathers light olive gray (5Y6/1); micaceous; beds are even, massive, and have flat sharp bases and generally sharp tops; top surfaces of a few beds are rippled; 65 percent of the siltstone beds show Ta- Bouma sequences, 19 percent show Tb- Bouma sequences, 8 percent show		

	Thickness (feet) Unit	Cum.
Tc- Bouma sequences, and 8 percent show Td-Bouma sequences; the unit ABC proximity index is 75 percent; rounded clay galls, typically several cm long, are common as are tiny carbonized wood fragments. Clayshale is medium dark gray (N3) to medium gray (N5), and weathers medium gray (N5) to light gray (N7); shows textural lamination; parting is 2 to 4 mm thick............................	23.2	77.7
Total Brallier Formation..............	3075.8	
Millboro Shale (incomplete):		
1. Clayshale to mudshale, black (N1) at base of unit; becomes lighter in color and slightly upward; by 35 ft above base of unit shale is medium gray (N5); shale shows fine textural lamination throughout unit; Lingula found at 4.5 ft above base of unit; Layer of small calcite and siderite nodules at 32.9 ft above base; pinch and swell pyritic calcite layer 1.5 cm thick at 35.2 ft above base; siderite layers less than 0.1 ft thick occur at 34.0 ft, 39.5 ft, 40.0 ft, 49.3 ft, and 51.4 ft above base of unit. Small flexure of bedding between 35 and 45 ft above base of unit...	54.5	54.5
Total Millboro Shale (incomplete).....	54.5	

SECTION 10

Virginia Highway 16 Section

One of the more nearly complete sections of the Brallier Formation in southwest Virginia, exposed in a series of roadcuts along Virginia Highway 16, in Tazewell County (Tazewell South and Chatham Hill quadrangles). Section is described at many different outcrops because the exposures are discontinuous and as the highway meanders up Little Brushy Mountain it traverses both up and down section. The upper several hundred feet of the Brallier Formation and the "Chemung" Formation are very well exposed. The section begins at stratigraphically lowest exposures of shale, 0.15 mile east of where Virginia Highway 16 crosses over Laurel Fork Creek (453250 meters East, 4096300 meters North, Universal Transverse Mercator grid). Top of the section is 0.15 mile north of the crest of Little Brushy Mountain. Measured and described using Jacob's staff, Abney level, surveying altimeter, and tape by Paul D. Lundegard, September 4, 5, 6, and 7, 1978.

	Thickness (feet) Unit	Cum.
Devonian (incomplete):		
"Chemung" Formation (incomplete):		
60. Siltstone, coarse-grained, and sandstone, very-fine-grained (80 percent) and mudstone (20 percent) in six thickening-upward sequences; each 5 to 10 ft thick; siltstone and sandstone beds are up to 0.2 ft thick in lower part of each sequence where they are generally plane laminated; and 0.6 to 1.0 ft thick at the top of each sequence where they are either plane laminated or show low-angle crossbedding; a few beds are fossiliferous; fossils include crinoid columnals, Spirifer sp. and Buchiola sp. brachiopods; a 0.6 ft thick sandstone bed at 23 ft below top of unit has curving inclined burrows in its upper part; one burrow resembles Cylindrichnus and is 20 cm long. Mudstone is olive gray (5Y4/1). Top of unit 60 is at culvert under road and cluster of four or five small locust trees 0.15 mile of mountain crest..........	50.8	2505.8
59. Siltstone, coarse-grained, and sandstone, very-fine-grained, in three massive beds with possible bed amalgamation. In the up-section direction these beds are 1.7 ft, 4.8 ft, and 2.2 ft thick, respectively;		

		Thickness (feet) Unit	Cum.
	each is medium gray (N5), weathers light olive gray (5Y6/1), shows faint plane lamination, and contains fossiliferous streaks; crinoid columnals are most abundant; other fossils include <u>Camarotoechia</u> sp., and unidentified brachiopod and pelecypod fragments........................	8.7	2455.0
58.	Siltstone, coarse-grained (50 percent), in beds 0.1 to 0.4 ft thick, modal bed thickness is 0.15 ft, with interbeds of mudstone (50 percent). Siltstone beds pinch and swell; some are discontinuous; beds are predominantly plane laminated; a very few imprints of <u>Camarotoechia</u> sp. Mudstone interbeds are dark gray (N3), and weather olive gray (5Y4/1)..................	5.3	2446.3
57.	Siltstone, coarse-grained, a single bed but bed amalgamation is probable; medium gray (N5), weathers light olive gray (5Y6/1); faint plane lamination; several 1 to 2 cm thick fossiliferous streaks very rich in small crinoid columnals; a shale clast or remnant 2 cm thick and 23 cm long occurs locally at probable amalgamation surface. Two imbricate thrust faults, each with 1 to 2 feet of westward displacement cut this bed..........................	1.9	2441.0
56.	Siltstone, coarse-grained, and sandstone, very-fine-grained (80 percent), in beds 0.1 to 0.8 ft thick, modal bed thickness is 0.15 ft, with interbeds of mudshale (20 percent). Individual siltstone and sandstone beds thicken and thin somewhat irregularly and show plane lamination or low-angle crossbedding; some beds are fossiliferous; shale clasts are common in the fossiliferous beds. Fossils are especially abundant in lower 4.0 ft of unit, and include abundant small crinoid columnals, <u>Spirifer</u> sp., <u>Leiorhyncus</u> sp. brachiopods, and <u>Modiola</u> (?), <u>Nucula</u> sp. pelecypods. Mudshale interbeds are dark		

	Description	Thickness (feet) Unit	Cum.
	gray (N4), weather medium gray (N5) to olive gray (5Y4/1), and show weak textural lamination..................................	9.1	2439.1
55.	Siltstone, coarse-grained, essentially a single bed with possible bed amalgamation; some faint plane lamination; a few straight, vertical burrows less than 5 mm wide in upper half of bed..........................	3.3	2430.0
54.	Mudstone (60 percent) with indistinct beds of coarse-grained siltstone (40 percent) less than 0.2 ft thick. Mudstone is olive gray (5Y4/1), very silty, finely micaceous, and has hackly parting. Siltstone beds are medium gray (N5), weather light olive gray (5Y5/2); some beds show plane lamination; siltstone beds are distinguished from mudstone with difficulty....................	11.5	2426.7
53.	Siltstone, coarse-grained, single bed, olive gray (5Y4/1), weathers light olive gray (5Y5/2); massive; structureless........	2.8	2415.2
52.	Siltstone, coarse-grained, in beds 0.15 to 0.5 ft thick with very minor interbeds of mudstone as in unit 54. Siltstone is medium gray (N5), weathers light olive gray (5Y6/1); finely micaceous; beds are either structureless or plane laminated; horizontal burrows are common on the top surfaces of beds; one inclined burrow with longitudinal striae; a few imprints of costate brachiopods..................................	15.0	2412.4
51.	Covered. Probable small high angle fault. Stratigraphic thickness undertain but probably less than 10 feet..................	10.0	2397.4

NOTE: Units 46 through 50 comprise an overall thickening-upward and coarsening-upward sequence.

50. Siltstone, coarse-grained, and sandstone, very-fine-grained, and mudstone in two thickening-upward sequences. Lower

	Thickness (feet) Unit	Cum.
thickening-upward sequence is 16.0 ft thick; upper 4.0 ft consists of fossiliferous, crossbedded sandstone in beds up to 1.3 ft thick, showing incipient ball and pillow structure, and clay chips at base of beds; beds in lower part of this sequence are predominantly less than 0.2 ft thick, with a maximum bed thickness of 0.5 ft. The second thickening-upward sequence is 18.6 ft thick and begins with approximately 70 percent siltstone in beds 0.15 to 0.3 ft thick, bed thickness increases upward with little change in the abundance of siltstone; a 2.1 ft thick coarse-grained siltstone occurs at the top of this sequence; siltstone beds are predominantly plane laminated. Mudstone interbeds are medium dark gray (N4), and weather olive gray (5Y4/1); finely micaceous; part with a hackly edge; commonly show distinct horizontal burrows less than 5 mm wide......	34.6	2387.4
49. Siltstone, coarse-grained, and sandstone, very-fine-grained (80 percent), in beds 0.2 to 0.9 ft thick, modal bed thickness is 0.3 ft, with interbeds of mudstone as in unit 50 (20 percent). Beds of siltstone and sandstone greater than 0.25 ft thick are distinctive of unit 50. Overall thickening-upward sequence; top 6 ft is 90 percent sandstone in beds 0.3 to 0.9 ft thick; beds are generally uneven; plane lamination and low-angle crossbedding are common; top surfaces of some beds show horizontal burrows; a few beds are fossiliferous, especially 0.5 ft thick siltstone at 5.0 ft above base; fossils include <u>Camarotoechia</u> sp. brachiopods and pelecypods (possibly <u>Edmondia</u> sp.)..............................	18.0	2352.8
48. Mudstone as in unit 50 (85 to 90 percent) with beds of siltstone (10 to 15 percent) up to 0.1 ft thick, modal bed thickness is 2 cm. Siltstone beds appear to be predominantly structureless; a few beds show plane lamination or cross-lamination.............	7.5	2334.8

	Thickness (feet) Unit	Cum.
47. Siltstone, coarse-grained, and sandstone, very-fine-grained (70 percent) in beds predominantly 0.15 to 0.6 ft thick, with interbeds of mudstone as in unit 50 (30 percent). Five or 6 siltstone and sandstone beds 0.3 to 0.6 ft thick are distinctive of unit 47. Siltstone and sandstone are medium gray (N5); most beds appear structureless; thickest beds are plane laminated, or show crossbedding in sets up to 0.6 ft thick; some beds pinch and swell. At base of unit there is a 0.6 ft thick, fossiliferous, coarse-grained siltstone bed; fossils concentrated at base of bed include _Camarotoechia_ sp. brachiopods, and _Nucula_ sp., _Buchiola_ sp. pelecypods, and crinoid columnals......................	10.5	2327.3
46. Sandstone, very-fine-grained, and siltstone, coarse-grained (95 percent at base of unit decreasing to 80 percent at top of unit), in beds 0.1 to 0.6 ft thick with interbeds of mudstone as in unit 50 (5 to 20 percent). Sandstone and siltstone are olive gray (5Y4/1); beds generally pinch and swell or are discontinuous; amalgamation of beds is common; sedimentary structures are difficult to observe in lower part of unit, but many beds appear plane laminated or cross-laminated; beds showing low-angle crossbedding in sets 7 to 16 cm thick are common in upper part of unit; vertical burrows with dark gray (N3) clayey fillings penetrate a few beds. Horizontal burrows are very common in mudstone interbeds.......	28.0	2316.8
Total "Chemung" Formation (incomplete).	217.0	

Brallier Formation:

45. Mudstone (75 percent) with beds of coarse-grained siltstone and very-fine-grained sandstone (25 percent) 0.15 to 1.3 ft thick. Mudstone is medium dark gray (N4), weathers olive gray (5Y4/1); finely

	Thickness (feet) Unit	Cum.
micaceous; hackly parting, distinct horizontal burrows less than 5 mm wide are common. Siltstone and sandstone are medium dark gray (N4) to olive gray (5Y4/1), weather light olive gray (5Y5/2); most beds pinch and swell or are discontinuous and show plane lamination or crossbedding in sets greater than 7 cm thick; crossbedding set thickness increases with bed thickness; groups of siltstone and sandstone beds 4.5 and 2.0 ft thick occur at the base of the unit and 14 feet above the base, respectively......................	25.4	2288.3
44. Mudstone as in unit 45 (95+ percent in lower 30 ft of unit, decreases to 90 percent upward) with beds of siltstone to very-fine-grained sandstone (less than 5 percent in lower 30 ft, increases to 10 percent upward) predominantly less than 0.2 ft thick, modal bed thickness is less than 0.1 ft. Mudstone weathers spheroidally along several small high-angle faults with less than 2 ft of displacement; distinct horizontal burrows are common, and tend to weather light brown (5YR5/6); very few imprints of <u>Camarotoechia</u> sp. Siltstone and sandstone are medium gray (N5) to olive gray (5Y4/1); individual beds are of variable thickness or are discontinuous; internal structures are variable; plane laminated, cross-laminated and structureless beds all occur; partings are micaceous...........	44.6	2263.4
43. Deformed zone probably bounded by high angle faults; consists of mudstone as in unit 45 and thin siltstone beds; offset of units 44 and 42 is unknown..............	30.0	2218.8
42. Mudstone as in unit 45 (90 to 95 percent) with interbeds of siltstone (5 to 10 percent) up to 0.15 ft thick, predominantly less than 0.1 ft thick, modal bed thickness is 1 to 1.5 cm. Slight upward increase in		

		Thickness (feet) Unit	Cum.
	the thickness and abundance of siltstone beds. Siltstone beds are only slightly more resistant to weathering than mudstone interbeds..................................	25.0	2188.8
41.	Covered at slight bend in road..............	12.0	2163.8
40.	Mudstone as in unit 45 (85 percent) with beds of siltstone to very-fine-grained sandstone (15 percent) up to 0.25 ft thick, modal bed thickness is less than 0.1 ft. Structures in siltstone and sandstone beds are not easily observed; plane lamination was noted in two beds............	14.6	2151.8
39.	Siltstone, coarse-grained, olive gray (5Y4/1), in poorly defined structureless beds 0.2 to 0.7 ft thick; some amalgamation of beds. Unit 39 forms slight protrusion...	2.9	2137.2
38.	Mudstone as in unit 45 (60 percent) with beds of siltstone and very-fine-grained sandstone (40 percent) up to 0.25 ft thick, modal bed thickness is 0.15 foot. Siltstone and sandstone beds are predominantly structureless; a few beds are cross laminated; a few hypichnial ridges..........	7.5	2134.3
37.	Siltstone, coarse-grained, and sandstone, very-fine-grained (80 percent) in beds less than 0.1 ft to 0.4 ft thick, with interbeds of mudstone as in unit 45 (20 percent). Siltstone and sandstone beds are indistinct; thinnest beds are plane laminated or cross-laminated; other beds are structureless. Unit 37 protrudes over unit 36..............	3.5	2126.8
36.	Mudstone as in unit 45 (85 to 95 percent) with interbeds of siltstone (5 to 15 percent) up to 0.2 ft thick, modal bed thickness is less than 0.1 ft. Several indistinct beds of argillaceous siltstone in lower 7 ft of unit; distinct siltstone beds in remainder of unit show a mixture of Tc-, Tbc-, and Ta-Bouma sequences............................	40.9	2123.3

	Thickness (feet) Unit	Cum.
35. Siltstone, coarse-grained, and sandstone, very-fine-grained, in beds 0.1 to 0.4 ft thick, medium gray (N5); essentially no fine-grained interbeds; sedimentation units are difficult to identify because of common amalgamation of beds; beds less than 0.1 ft thick are predominantly cross-laminated; thicker beds appear structureless or show irregular, discontinuous lamination.	17.6	2082.4
34. Siltstone, very-fine-grained sandstone, and clayshale in an overall thickening- and coarsening-upward sequence, containing 5 smaller megasequences; the upper 2 clearly display coarsening- and thickening-upward trends. Siltstone and sandstone is medium gray (N5); beds are less than 0.1 to 0.3 ft thick; abundance ranges from less than 5 percent in lower 25 ft of unit to nearly 100 percent at top of unit; sole markings, mainly groove molds oriented 242° to 276° are common; Bouma sequences become more complete upward in the unit as a whole and in the upper 2 megasequences where Tbc and Tabc sequences are common; overall, siltstones with Tc- Bouma sequences, flat, sharp bases and rippled top surfaces predominate. Clayshale is dark gray (N3), weathers medium dark gray (N4); shows fine textural lamination; silt laminae less than 1 mm to 1 cm thick are locally common; minor horizontal bioturbation, weathering yellowish gray (5Y8/1); a few 1 to 2 cm thick, pinch and swell siderite layers in lower 25 ft of unit; siderite layers weather moderate brown (5YR4/4) and are structureless. Several small high angle faults with a few feet of displacement......	158.0	2064.8
33. Covered. Stratigraphic thickness estimated geometrically from map location of outcrops, strike and dip data, and altitude data obtained with a surveying altimeter accurate to ± 3 feet................................	46.0	1906.8

	Thickness (feet) Unit	Cum.
32. Clayshale (95 percent) with minor beds of siltstone (5 percent) up to 0.7 ft thick, modal bed thickness is 0.15 ft. Clayshale is brownish black (5YR2/1), weathers medium dark gray (N4); shows weak textural lamination; weathers to 5 to 10 mm thick chips; minor yellowish gray (5Y8/1) horisontal bioturbation. Siltstone beds predominantly show Tc- Bouma sequences and rippled top surfaces......................	90.0	1860.8

NOTE: There are additional exposures of dark shale with minor siltstone interbeds similar to unit 32, both uphill and downhill from outcrop where unit 32 was described. Most of these exposures are repeated section and are folded and faulted. There is probably at least 150 ft of these dark shales with up to 20 percent siltstone in beds predominantly less than 0.3 ft thick, and up to 1.3 ft thick. An accurate thickness estimate is impossible because of structural deformation.

31. Covered. Thickness estimated with Jacob's staff and Abney level........................	50+	1770.8

NOTE: Units 18 through 30 are described along southwestern side of highway in 0.55 mile long straight stretch trending northwest-southeast Units 24 through 30 are generally not well exposed.

30. Claystone (80 percent) with beds of siltstone (20 percent) up to 1.0 ft thick, modal bed thickness is 0.15 ft. Claystone is medium gray (N5), weathers medium light gray (N6) to light gray (N7); strongly bioturbated; up to 100 percent bioturbated in some zones less than 0.5 ft thick; generally 30 to 60 percent bioturbated; burrows are indistinct and horizontal; weathers to subconchoidal chunks. Abrupt dip increase at top of unit. Top of unit is across highway from "Driver Subject to Arrest for Litter Thrown from Vehicle" sign............................	224.0	1720.8
29. Covered....................................	26.0	1496.8
28. Mudstone to claystone (60 percent) with beds of siltstone (40 percent) up to 1.0 ft thick, modal bed thickness is 0.4 ft.		

		Thickness (feet) Unit	Cum.
	Slight decrease in proportion of siltstone upward. Mudstone and claystone are olive gray (5Y4/1) and weather light olive gray (5Y5/2); minor beds of dark gray (N3), bioturbated claystone........................	51.0	1470.8
27.	Mudstone as in unit 28 (95 percent) with minor beds of siltstone (5 percent) up to 0.15 ft thick................................	14.0	1419.8
26.	Mudstone as in unit 28 (70 percent) with beds of siltstone (30 percent) up to 1.8 ft thick, modal bed thickness is 0.2 ft. Siltstone bed thickness increases upward....	22.0	1405.8
25.	Poorly exposed; a few resistant beds of siltstone..................................	33.0	1383.8
24.	Clayshale (45 percent) and claystone (10 percent) with beds of siltstone (45 percent) up to 2.0 ft thick, bed thickness is variable. Clayshale, is olive gray (5Y3/2), weathers light olive gray (5Y5/2) shows textural lamination; silt-free. Claystone occurs in one 4 ft zone, 5 ft above base of unit; shows intense indistinct horizontal bioturbation; unbioturbated portions are medium dark gray (N4), and weather medium gray (N5); bioturbated portions are medium light gray (N6) and weather light gray (N7) to yellowish gray (5Y8/1)......................	30.0	1350.8
23.	Mostly covered with scattered small exposures of bioturbated light olive gray (5Y5/2) claystone, medium dark gray (N4) shale with minor bioturbation, and resistant siltstone beds up to 0.7 ft thick..........	297.2	1320.8
22.	Clayshale, grayish black (N2), weathers dark gray (N3) shows textural lamination; minor bioturbation; bioturbated portions weather yellowish gray (5Y8/1). One siltstone bed 0.8 ft thick in middle of unit......................................	7.8	1023.6

		Thickness (feet) Unit	Cum.
21.	Covered..................................	80.0	1015.8
20.	Siltstone, claystone, and clayshale; a single siltstone bed at base of unit, 0.8 ft thick; overlain by 1.2 ft of yellowish gray (5Y8/1), blocky claystone; in turn overlain by 3.0 ft of shale; shale is brownish black (5YR2/1), weathers medium dark gray (N4); shows textural lamination; minor yellowish gray (5Y8/1) weathering bioturbation.	5.0	935.8
19.	Covered..................................	50.0	930.8
18.	Clayshale and claystone (95 percent) with minor beds of siltstone (5 percent) predominantly less than 0.2 ft thick. Clayshale predominates is lower 35 ft of unit; claystone predominates in upper 65 ft of unit. Clayshale is moderate olive brown (5Y4/4), weathers light olive gray (5Y5/2); shows textural lamination. Claystone is light olive gray (5Y5/2), and weathers light olive gray (5Y6/1).	95.0	880.8

NOTE: Units 10 through 17 are described along east side of the highway between hairpin turn at UTM grid location 453600 m East, 4096200 m North, and sharp turn at UTM grid location 453650 m East, 4095800 m North. In this interval downhill is upsection.

		Unit	Cum.
17.	Mudstone (95 percent) with minor beds of siltstone (5 percent) up to 0.3 ft thick, predominantly less than 0.2 ft thick. Mudstone is olive gray (5Y4/1), weathers light olive gray (5Y5/2); distinct horizontal burrows less than 5 mm wide are common. Siltstone beds show Tc- or Tbc- Bouma sequences. Five ft of section is covered at 12 ft below top of unit. Upper 20 ft of unit 17 may be equivalent to lower 20 ft of unit 18........................	57.0	785.8
16.	Covered..................................	18.0	728.8
15.	Mudstone, olive gray (5Y4/1), weathers light olive gray (5Y5/2); hackly parting; distinct horizontal burrows less than 5 mm wide are common; spheroidal weathering in upper 3.0 ft of unit..................................	13.0	710.8

	Thickness (feet) Unit	Cum.
14. Claystone, weathers light gray (N7); intensely bioturbated; 90 percent bioturbated; indistinct subhorizontal burrows............	4.0	697.8
13. Clayshale, with a few siltstone beds less than 0.2 ft thick. Clayshale is olive gray (5Y4/1), weathers light olive gray (5Y5/2); shows textural lamination; silt-free; minor horizontal bioturbation weathering yellowish gray (5Y8/1); a few distinct horizontal burrows weathering brownish......	34.0	693.8
12. Clayshale, black (N1), weathers grayish black (N2); fine textural lamination; fragments of carbonized wood up to 1.5 cm long are very abundant in lower 2.5 ft; bioturbation weathering yellowish gray (5Y8/1) in upper 2.0 ft. Two siltstone beds 0.3 and 0.2 ft thick, respectively.....	5.0	659.8
11. Mudstone, pale brown (5YR5/2); blocky; a few black flecks of organic matter up to 3 mm long.................................	0.8	654.8
10. Mudstone (80 percent) and clayshale (15 percent) with minor beds of siltstone (5 percent) up to 0.4 ft thick, predominantly less than 0.1 ft thick. Mudstone and shale are moderate olive brown (5Y4/4), and weather light olive gray (5Y5/2); mudstone shows distinct horizontal burrows; clay-shale shows weak textural lamination and is slightly silty; at 16 ft above base of unit there is a 1.0 ft thick zone of mudstone which weathers grayish red (5R4/2) and spheroidally. Flexure of beds at 25 ft above base of unit. In upper 8.0 ft of unit, mudstone is more massive and intensely bioturbated; burrows weather moderate yellowish brown (10YR5/4). Siltstones predominantly show Tc- Bouma sequences.................................	52.0	654.0
9. Covered. Thickness estimated with Jacob's staff and Abney level......................	55.0	602.0

		Thickness (feet) Unit	Cum.
8.	Mudstone (85 percent) and shale (10 percent), with beds of siltstone (5 percent) up to 1.0 ft thick, predominantly less than 0.2 ft thick. Mudstone is olive gray (5Y4/1), weathers light olive gray (5Y5/2); resistant; forms flat, vertical faces; finely micaceous; parting is 5 to 10 mm thick or greater; distinct horizontal burrows up to 4 mm wide are abundant; bioturbation estimated at 30 percent. Shale is dark gray (N3) to black (N1), occurs in intervals up to 6 ft thick, and ranges from clayshale to mudshale; shows weak textural lamination; parting is 3 mm thick; blackish red (5R2/2) iron stain on parting surfaces. Siltstone beds are predominantly cross-laminated and have rippled top surfaces; two amalgamated beds 1.0 ft thick occur at 5 ft above base of unit..................................	152.0	547.0
7.	Covered. With scattered small exposures of olive gray (5Y4/1) clayshale................	70.0	395.0
6.	Clayshale, olive gray (5Y4/1), weathers light olive gray (5Y5/2); shows textural lamination; silt-free; parting is 3 mm thick; a few distinct horizontal burrows. Minor beds of grayish black (N2) clayshale weather medium gray (N5) to dark gray (N3); some bioturbation weathering yellowish gray (5Y8/1); a few tiny black flecks of organic matter. A few siltstone beds less than 0.2 ft thick..............................	18.0	325.0
5.	Covered with scattered float of siltstone plates and grayish black (N1) shale as in unit 6..................................	202.0	307.0
4.	Clayshale, grayish black (N2), as in unit 6. Claystone occurs where bioturbation is intense..................................	22.0	105.0
3.	Covered with scattered, small exposures of grayish black (N2) shale as in unit 6.......	31.0	83.0

	Thickness (feet) Unit	Cum.
2. Claystone and minor clayshale with a very few siltstone beds less than 0.1 ft thick. Claystone is dark gray (N3), weathers medium gray (N5) to light olive gray (5Y5/2); bioturbated; bioturbated portions weather yellowish gray (5Y8/1); very finely micaceous; silt-free. Clayshale is same color as claystone; shows textural lamination and lacks significant bioturbation. Siltstone beds are cross-laminated, and have rippled top surfaces................	7.0	52.0
Total Brallier Formation..............	2243.8	
Millboro Shale (incomplete):		
1. Claystone and minor clayshale. Claystone is dark gray (N3), weathers medium gray (N5) to light olive gray (5Y5/2); minor bioturbation, weathering yellowish gray (5Y8/1); finely micaceous. Clayshale is same color as claystone; shows textural lamination and lacks significant bioturbation............................	45.0	45.0
Total Millboro Shale (incomplete)......	45.0	

SECTION 11

Broadford Section

Section of lower Brallier Formation, Millboro Shale, and complete section of Huntersville Chert exposed in roadcuts along Virginia Route 91 near its junction with Virginia Route 601, Broadford quadrangle, Tazewell County, Virginia (440000 meters East, 4089600 meters North, Universal Transverse Mercator grid). Base of section is 0.5 mile north of junction of Virginia Routes 91 and 601, at sharp bend in road. Top of section is 0.25 mile south of junction of Virginia Routes 91 and 601. Section measured, described and sampled using Jacob's staff, Abney level, surveying altimeter, and tape by Paul D. Lundegard, March 29 and 30, 1978.

Devonian (incomplete):

Brallier Formation (incomplete):

		Thickness (feet) Unit	Cum.
18.	Mudstone (95 percent) with beds of siltstone (5 percent) 1 cm to 0.6 ft thick, modal bed thickness is 0.1 ft. Mudstone is olive gray (5Y4/1); shows hackly, subconchoidal parting 4 to 8 mm thick; hard and brittle. Siltstone is light olive gray (5Y6/1); beds highly weathered; some beds are indistinct from surrounding mudstone; 90 percent of beds show Tc- Bouma sequences; beds with rippled top surfaces are very common. At base of unit there is a 1.0 ft thick bed of claystone; moderate olive brown (5Y4/4), weathers light olive gray, parting is 5 to 10 mm thick................	71.0	1453.0
17.	Covered. No indication of resistant beds...	93.0	1382.0
16.	Claystone and minor clayshale; both are dark gray (N3) to olive gray (5Y4/1), and weather medium dark gray (N4) to light olive gray (5Y6/1); color becomes more olive gray upward; minor yellowish gray (5Y8/1) weathering horizontal bioturbation; parting is 2 to 7 mm thick; some slickenslides on bedding planes; clayshale shows faint textural lamination. Unit 16 is across road from "Maximum Safe Speed 20" sign..................................	20.0	1289.0
15.	Mudstone (90 percent) with beds of siltstone (10 percent) up to 0.6 ft thick, modal bed thickness 0.1 ft. Mudstone is olive gray (5Y4/1), weathers light olive gray (5Y5/2); micaceous; hackly parting 3 to 7 mm thick. Siltstone beds are predominantly cross-laminated; some beds are indistinct from surrounding mudstone..................	41.0	1269.0
14.	Covered. No indication of resistant beds...	11.0	1228.0
13.	Mudstone as in unit 15 (95 percent) with beds of siltstone (5 percent) up to 0.6 ft thick, modal bed thickness is 0.1 ft. Mudstone is most silty in middle of unit which forms slight protrusion. Siltstone		

		Thickness (feet) Unit	Cum.
	is olive gray (5Y3/2); beds are predominantly cross-laminated; 0.1 ft thick bed at 24 ft below top of unit is calcareous and weathers dark yellowish brown (10YR4/2). Calcareous nodule layer 0.1 ft thick at 26.5 ft above base of unit................................	69.0	1217.0
12.	Covered. No indication of resistant beds...	10.0	1148.0
11.	Mudstone as in unit 15. Silty nodule layer 0.1 ft thick at base of unit; weathers light brown (5YR5/6)........................	15.0	1138.0
10.	Mudstone as in unit 15 with a very few indistinct siltstone layers less than 1 cm thick and one siltstone bed 0.3 ft thick in middle of unit...........................	21.0	1123.0
9.	Covered. No indication of resistant beds...	18.0	1102.0
8.	Mudstone as in unit 15 with several siltstone beds up to 0.2 ft thick. Some fairly distinct horizontal burrows in mudstone. Middle of unit is across road from telephone pole................................	32.0	1084.0

NOTE: Units 6 and 7 are described in shale pit approximately 300 ft south of junction of Virginia Routes 91 and 601.

7.	Mudstone as in unit 15 (90 percent) with beds of siltstone (10 percent) up to 0.3 ft thick. Some horizontal burrows in mudstone..................................	16.4	1052.0
6.	Claystone, olive gray (5Y4/1), weathers light olive gray (5Y6/1); slightly silty; finely micaceous; parting is 2 to 5 mm thick. Two beds of grayish black (N2) shale; a 0.3 ft thick bed at 7.6 ft above base of unit and a 0.8 ft thick bed at top of unit; both beds weather to a slight recess and show textural lamination; the upper bed also has a few silt laminae about 1 mm thick, immediately beneath this bed is 0.3 ft of highly bioturbated medium		

	Thickness (feet) Unit	Cum.
dark gray (N4) mudstone. Two siltstone beds 0.3 and 0.9 ft thick occur at 2.0 and 8.8 ft above base of unit, respectively; the lower siltstone bed is cross-laminated..	23.6	1035.6
5. Covered. Offset to exposures along Virginia Route 91, 0.25 mile north of its junction with Virginia Route 601, at sharp bend in road. Scattered exposures of dark gray (N3) clayshale and olive gray (5Y4/1) claystone. Thickness estimated from map locations and altitudes of outcrops and strike and dip data. Altitudes measured with surveying altimeter accurate to ± 3 feet................................	330+	1012.0
Total Brallier Formation (incomplete)..	771.0	

Millboro Shale:

	Unit	Cum.
4. Claystone, olive black (5Y2/1) to grayish black (N2), weathers medium gray (N5) to dark yellowish orange (10YR6/6); medium to strong bioturbation; bioturbated parts weather yellowish gray (5Y8/1); indistinct burrows are less than 2 mm wide and horizontal; some 2 to 3 mm thick yellowish gray biolaminae and streaks; faint textural lamination where bioturbation is less intense; bioturbation decreases in upper 3 ft; parting is 5 to 10 mm thick and hackly....................................	17.0	682.0
3. Clayshale, grayish black (N2), weathers medium dark gray (N4), with a grayish red (5R4/2) iron stain on parting surfaces in lower 12 ft of unit; shows textural lamination throughout; parting is 2 to 5 mm thick in lower 30 ft and 5 to 10 mm thick in upper 26 ft of unit; phosphate (?) nodule layer 0.1 ft thick at 21.0 ft above base of unit; moderate reddish brown (10R4/6) layer of sticky clay 5 mm thick at 30.0 ft above base of unit................................	56.0	665.0

	Thickness (feet) Unit	Cum.
2. Covered. Thickness estimated from map locations of outcrops, strike and dip data, and altitude data obtained with a surveying altimeter accurate to ± 3 feet.............	565+	609.0
Total Millboro Shale..................	638.0	

Huntersville Chert:

1. Limestone, weathers medium gray (N5) to dark gray (N3); very cherty; highly fossiliferous; contains corals and brachiopods; beds are 0.2 ft to 7.5 ft thick; modal bed thickness is 0.7 ft; two glaconitic siltstone to very-fine-grained sandstone beds 0.2 and 0.4 ft thick occur at 8 ft above base of unit; limestone from 22.5 to 25.0 ft above base of unit is also glauconitic; covered zone 4.5 ft thick at 16.5 ft above base of unit.........	44.0	44.0
Total Huntersville Chert................	44.0	

SECTION 12

Marion Section

Incomplete section of Brallier Formation including a siltstone bundle exposed in roadcuts along west side of Virginia Route 16, 0.4 mile south of Hungry Mother Lake dam, and 3.5 miles north of Marion, beneath high voltage power lines, Smyth County, Marion quadrangle, Virginia (452950 meters East, 4080100 meters North, Universal Transverse Mercator grid). Section is in lower one-third of Brallier Formation, beds are overturned slightly to the northwest. Section measured, described, and sampled using Jacob's staff, Abney level, and tape by Paul D. Lundegard, March 27, 1978.

Devonian (incomplete):	Thickness (feet)	
Brallier Formation (incomplete):	Unit	Cum.
6. Mudstone, olive gray (5Y4/1); indistinct horizontal burrows, hackly parting 2 to 5 mm thick.................................	13.9	144.4

	Thickness (feet) Unit	Cum.
5. Siltstone (75 percent) in beds up to 5.0 ft thick, modal bed thickness is 0.1 to 0.25 ft, 40 percent of beds are greater than 0.35 ft thick, interbeds are clayshale (25 percent). Unit 5 was measured and described in bed by bed detail. Siltstone is medium gray (N5), weathers light olive gray (5Y5/2); micaceous; evenly bedded; 59 percent of beds show Ta- Bouma sequences, 30 percent show Tb- Bouma sequences, and 11 percent show Tc- Bouma sequences; the unit ABC proximity index (Walker, 1967) is 74 percent; abundant sole markings with a mean trend of 266° include flute molds load casted flute molds, groove molds, ridge and furrow structure; hypichnial ridges resembling Paleophycus are very common; these trace fossils are 6 to 10 cm long, 8 to 10 mm wide and their ends taper into the bed; other sedimentary features include clay galls up to 20 cm in length concentrated near the base of beds, size grading, and tiny black wood fragments. Clayshale is dark gray (N3) to olive gray (5Y4/1), weathers medium gray (N5) to light olive gray (5Y5/2); shows textural lamination; finely micaceous; a few tiny black wood fragments; parting is 2 to 5 mm thick. Several very small high angle faults....................................	44.7	130.5
4. Clayshale, dark gray (N3), weathers medium dark gray (N4); shows textural lamination; parting is 2 to 3 mm thick. Two siltstone beds each 0.15 ft thick; one bed 4.4 ft below top of unit has sinusoidal lamination; the other bed at 15.6 ft below top of unit is plane laminated.........................	27.8	85.8
3. Clayshale (70 percent) with beds of siltstone (30 percent) 0.1 to 0.35 ft thick, modal bed thickness is 0.1 ft. Unit 3 was measured and described in bed by bed detail. Clay-shale is dark gray (N3), weathers medium gray (N5); shows textural lamination;		

	Thickness (feet) Unit	Cum.
locally slightly silty; parting is 2 to 5 mm thick; brittle. Siltstone is medium gray (N5); 7 percent of beds (one bed) show Tab- Bouma sequences, 71 percent show Tb- Bouma sequences, 11 percent show Tc- Bouma sequences, unit ABC proximity index (Walker, 1967) is 38 percent; abundant groove molds trending 288° to 308°; 0.1 ft thick siderite layer at base of unit........	7.5	58.0
2. Clayshale as in unit 3, with a few beds of siltstone (1 percent) up to 0.4 ft thick, modal bed thickness is 0.1 ft. Seventy-five percent of the siltstone beds are cross-laminated; groove mold at 10 ft below top of unit trends 266°.........................	38.6	50.5
1. Siltstone (75 percent) in beds 0.2 ft to 2.0 ft thick, with interbeds of clayshale as in unit 3 (25 percent). Siltstone beds are all somewhat fractured; two beds contain shale clasts................................	11.9	11.9
Total Brallier Formation (incomplete)..	144.4	

SECTION 13

Richlands Section

Complete section of Cloyd Conglomerate Member of Price Formation and incomplete section of Brallier Formation. Only the uppermost Brallier Formation is exposed. Section exposed in ditch and hillside along old U.S. Highway 460, 0.4 mile west of Richlands High School, across highway from small brick utility shed, Tazewell County, Richlands quadrangle (430450 East, 4105200 North, Universal Transverse Mercator grid). Section measured and described with Jacob's staff, Abney level, and tape by Paul D. Lundegard, September 8, 1978.

	Thickness (feet) Unit	Cum.
Mississippian (incomplete):		
Price Formation (incomplete):		
Cloyd Conglomerate Member:		
8. Sandstone, fine- to medium-grained; medium to thickly bedded; massive; quartz pebbles; crossbedding......................	23.0	116.1
Total Cloyd Conglomerate Member........	23.0	
Devonian (incomplete):		
Brallier Formation (incomplete):		
7. Clayshale, dark gray (N3), weathers medium dark gray (N4); shows textural lamination; a few silt laminae less than 5 mm thick; grayish red (5R4/2) iron stain on parting surfaces. A few cross-laminated siltstones up to 0.1 ft thick..........................	12.0	93.1
6. Siltstone, a single bed, dark gray (N3), argillaceous, resistant; consists of alternating medium gray (N5) silt laminae and streaks, and darker, more argillaceous siltstone; parting is 1 to 3 cm thick in lower 1.3 ft; middle 0.6 ft weathers to a recess.................................	3.8	81.1
5. Mudstone, to mudshale with weak textural lamination; both are dark gray (N3); hackly parting is 2 to 5 mm thick; grayish red (5R4/2) iron stain on parting surfaces. A few 1 to 2 cm thick siltstone beds; plane laminated or low angle cross-lamination.....	6.0	77.3
4. Siltstone as in unit 6; weak irregular parting 1 to 3 cm thick; grayish red (5R4/2) iron stain on parting surface.......	2.3	71.3
3. Mudshale, dark gray (N3), weathers medium gray (N5); shows textural lamination; silt laminae and streaks 5 to 10 mm thick are common; some are internally plane laminated or cross-laminated; parting is 3 to 5 mm thick; grayish red (5R4/2) iron stain on parting surfaces. A few siltstone beds up to 0.2 ft thick but predominantly less		

	Thickness (feet) Unit	Cum.
than 0.1 ft thick; slightly more numerous upward; sole marking noted on one bed. Upper half of unit is poorly exposed........	36.0	69.0
2. Clayshale (95 percent) with minor beds of siltstone (5 percent) up to 0.5 ft thick, modal bed thickness is 2 cm. Siltstone decreases in abundance towards middle of unit from both top and bottom. Clayshale is dark gray (N3), weathers medium gray (N5); shows textural lamination; silt laminae and streaks 0.5 to 7 mm thick are common; minor indistinct horizontal bioturbation; bioturbated zones yellowish gray (5Y8/1). Siltstone is micaceous; beds show Tc- and Tbc- Bouma sequences; 0.5 ft thick bed at 23 ft above base of unit contains abundant Lingula. Small, high angle fault of unknown displacement at base of unit next to culvert under highway..	30.0	33.0
1. Siltstone (85 percent) in beds 0.1 to 0.4 ft thick with interbeds of mudshale (15 percent). Siltstone is medium gray (N5); micaceous; beds are plane laminated or cross-laminated. Mudshale is dark gray (N3), weathers medium gray (N5); shows textural lamination........................	3.0	3.0
Total Brallier Formation (incomplete)..	93.1	

SECTION 14

Haytersl Gap Section

Incomplete section of Brallier Formation exposed in roadcuts along Virginia Highway 80 and Virginia Route 689, Washington County, Hayters Gap quadrangle, Virginia. Base of section is in shale pit next to house along Virginia Route 689, 0.2 mile west of its intersection with Virginia Highway 80 (416800 meters East, 4077000 meters North, Universal Transverse Mercator grid). Top of section is at roadcut along Virginia Highway 80, 0.15 mile south of where it crosses Wolf Creek (417250 meters East, 4076400 meters North, Universal Transverse Mercator grid). Section measured, described, and sampled using Jacob's staff, Abney level, and tape by Paul D. Lundegard, March 31, 1978.

Devonian (incomplete):	Thickness (feet) Unit	Cum.
Brallier Formation (incomplete):		
34. Mudstone (60 percent) and claystone (40 percent) with a few beds of siltstone predominantly less than 0.1 ft thick. Mudstone predominates in lower 2.5 ft of unit, claystone in upper 20 ft. Mudstone is dark gray (N3) to grayish black (N2), weathers medium dark gray (N4); parting is 5 to 10 mm thick; parting surfaces are smooth; scattered silt laminae 1 to 3 mm thick. Claystone is olive gray (5Y4/1), weathers light olive gray (5Y5/2); parting is 5 to 10 mm thick; partings are even to subconchoidal. Siltstone bed 0.2 ft thick at top of unit has groove mold trending 279°.	4.5	881.8
33. Siltstone, coarse-grained, and sandstone, very-fine-grained (75 percent), in beds 0.1 to 0.7 ft thick, modal bed thickness is 0.25 ft, with interbeds of mudstone (25 percent) less than 0.2 ft thick. Siltstone and sandstone are olive gray (5Y4/1) to medium gray (N5); abundance is constant throughout unit; several beds are plane laminated. Mudstone is olive gray (5Y4/1) to dark gray (N3), weathers light olive gray (5Y6/1)...............................	18.1	877.3
32. Sandstone, very-fine-grained, single bed, medium gray (N5) to medium light gray (N6); even bedded; Ta- Bouma sequence, abundant		

	Thickness (feet) Unit	Cum.
groove molds with a mean trend of 278°......	1.4	859.2
31. Claystone to mudstone (80 to 90 percent) with beds of siltstone (10 to 20 percent) less than 0.2 ft thick. Siltstone bed thickness and abundance increase upward. Claystone and mudstone are olive gray (5Y4/1) to black (N1), weather light olive gray (5Y5/2) to medium gray (N5); parting is 4 to 6 mm thick.........................	7.5	857.8
30. Siltstone (85 percent) in beds 0.2 to 0.3 ft thick with interbeds of clayshale (15 percent) predominantly less than 0.1 ft thick. Siltstone is evenly bedded; Ta- and Tb- Bouma sequences predominate. Clayshale is dark gray (N3); shows textural lamination; very slightly silty; parting is 2 to 5 mm thick.................................	3.0	850.3
29. Clayshale as in unit 30 with several beds of siltstone less than 0.1 ft thick...........	1.6	847.3
28. Siltstone (90 percent) in beds 0.2 to 0.7 ft thick, with interbeds of clayshale as in unit 30 (10 percent) less than 0.1 ft thick. Siltstone is evenly bedded; 3 beds show Tb or Tbc Bouma sequences; 3 beds show Tc Bouma sequences............................	2.0	845.7
27. Clayshale as in unit 30 (60 percent) with beds of siltstone (40 percent) 1 cm to 0.25 ft thick in a coarsening and thickening-upward sequence. Siltstone is medium gray (N5); micaceous; Tc- Bouma sequences predominate; groove molds on 0.25 ft thick bed at top of unit trend 274°..............	2.0	843.7
26. Siltstone (80 percent) in 5 beds 0.1 ft to 1.2 ft thick, with interbeds of clayshale as in unit 30. Two 1.2 ft thick siltstone beds are distinctive of unit 26. Siltstone is evenly bedded; micaceous; 4 of the 5 beds show Ta- Bouma sequences..............	3.8	841.7

	Thickness (feet) Unit	Cum.
25. Clayshale (80 percent) with beds of siltstone (20 percent) 1 cm to 0.25 ft thick. Clayshale is dark gray (N3), weathers medium gray (N5) to light olive gray (5Y6/1); shows textural lamination; silt-free; parting is 2 mm thick......................	3.4	837.9
24. Sandstone, very-fine-grained, and siltstone, coarse-grained (95 percent), in uniformly thick beds up to 2.4 ft thick, separated by shale partings or thin shale interbeds (5 percent). Modal sandstone and siltstone bed thickness is 0.4 to 0.6 ft; 50 percent of beds are greater than 0.5 ft thick. Sandstone and siltstone are medium gray (N5); micaceous; evenly bedded; 80 percent of beds show Ta- Bouma sequences, 20 percent show Tb- Bouma sequences; content grading; load casts; 0.5 ft thick bed at 7.4 ft above base of unit has flute molds trending 267°..............................	13.7	834.5
23. Clayshale (75 percent) with beds of siltstone (25 percent) less than 0.1 ft to 0.6 ft thick. Clayshale is dark gray (N3); shows textural lamination; a few silt laminae less than 1 mm thick; locally slightly silty; parting is 2 to 5 mm thick. Siltstone is medium gray (N5); evenly bedded; abundant sole markings with a mean trend of 273°..	8.7	823.0
22. Siltstone, single bed, even, Tb- Bouma sequence, abundant flute and groove molds with a mean trend of 278°..................	0.8	812.1
21. Mudshale (70 percent) with beds of siltstone to very-fine-grained sandstone (30 percent) less than 0.4 ft thick. Abundance and bed thickness of siltstone and sandstone decrease upward. Mudshale is black (N1), weathers medium dark gray (N4); shows textural lamination; parting is 2 mm thick; brittle. Siltstone and sandstone are medium gray (N5); 75 percent of beds show Tb-		

	Thickness (feet) Unit	Cum.
Bouma sequences; sole markings at base of unit have a mean trend of 274°..............	10.5	811.3
20. Clayshale (85 percent) with beds of siltstone (15 percent) up to 0.3 ft thick, predominantly less than 0.15 ft thick. Siltstone increases in abundance upward to 50 percent in upper 4.0 ft of unit. Clayshale is black (N1), weathers medium dark gray (N4) shows textural lamination; silt laminae less than 1 mm thick; parting is 2 mm thick; grayish red (10R4/2) iron stain on parting surfaces; brittle. Siltstone is medium gray (N5)..................................	8.5	800.8
19. Siltstone and very-fine-grained sandstone (90 percent) in beds up to 1.4 ft thick, predominantly 0.3 to 0.6 ft thick, with thin interbeds of clayshale (10 percent) predominantly less than 0.2 ft thick. Siltstone and sandstone are evenly bedded; base of beds are flat and sharp; top of beds are gradational; groove molds 3.4 ft below top of unit trend 250°. Clayshale is grayish black (N2) to medium dark gray (N4), weathers medium dark gray (N4); shows textural lamination; silt laminae up to 1 mm thick are common.........................	12.3	792.3
18. Clayshale (80 percent) with 5 beds of siltstone (20 percent) less than 0.1 ft thick. Clayshale is grayish black (N2), weathers medium dark gray (N4); shows textural lamination; a few silt laminae less than 1 mm thick near base of unit; parting is 2 mm thick. Siltstone beds are all cross-laminated.................................	1.4	780.0
17. Sandstone, very-fine-grained, and siltstone (80 percent), in beds up to 1.1 ft thick, predominantly 0.1 to 0.6 ft thick, with interbeds of mudshale (20 percent). Sandstone and siltstone are medium gray (N5); 55 percent of beds show Tb- Bouma sequences, remainder show Tc- Bouma sequences. Mudshale		

	Thickness (feet) Unit	Cum.
is medium dark gray (N4); shows textural lamination, parting is 2 to 5 mm thick......	5.7	778.6
16. Siltstone in 2 or more amalgamated beds; siltstone is medium gray (N5). Lowest bed is 0.8 ft thick, shows Tbc Bouma sequence, and is graded. Upper bed is 2.9 ft thick, shows Tab Bouma sequence, is graded, and is possibly 2 amalgamated beds..............	3.7	772.9
15. Siltstone and very-fine-grained sandstone (70 percent) in beds 0.1 to 0.7 ft thick, with interbeds of clayshale (30 percent). Sixty percent of siltstone and sandstone beds show Tb- Bouma sequences; ripple crests at 1.4 ft below top of unit trend 300°-120° with current towards southwest; ball and pillow structure at 1.8 ft above base of unit. Clayshale is medium dark gray (N4); shows textural lamination; silt-free; parting is 5 to 10 mm thick.................	4.3	769.2
14. Siltstone, coarse-grained, single bed, Tabc Bouma sequence, rippled top surface....	1.9	764.9
13. Claystone (60 percent) with beds of siltstone (40 percent) up to 0.4 ft thick, predominantly 0.1 to 0.2 ft thick. Claystone is olive gray (5Y4/1), weathers medium gray (N5); parting is 3 to 5 mm thick. Siltstone is medium gray (N5); 90 percent of beds show Tc- Bouma sequences.........................	3.2	763.0
12. Covered....................................	480 ±	759.9

NOTE: Units 7 through 11 are described at exposure on north side of Virginia Route 689, 200 ft west of church at junction of Virginia Routes 689 and 80.

	Thickness (feet) Unit	Cum.
11. Mudstone, olive gray (5Y4/1); hackly parting 5 to 10 mm thick, some distinct horizontal burrows 3 to 5 mm wide...........	3.5	279.8

	Thickness (feet) Unit	Cum.
10. Siltstone, coarse-grained, single even bed, base is sharp, Tab Bouma sequence, groove molds trending 245° and 254° , calcitic..................................	0.7	276.3
9. Claystone, highly weathered, light gray (N7), irregular parting is greater than 10 mm thick, blackish red (5R2/2) iron stain on parting surfaces, probably strongly bioturbated........................	1.7	275.6
8. Mudstone with several beds of siltstone 1 to 3 cm thick. Mudstone is medium dark gray (N4), weathers medium gray (N5); very silty; hackly parting is 5 to 10 mm thick; brittle. Siltstone is medium gray (N5); beds are plane laminated; one calcitic bed, 0.2 ft thick at 3.0 ft above base, weathers pale brown (5YR5/2)................	6.0	273.9
7. Mudstone with 3 or 4 beds of siltstone, 0.1 to 0.6 ft thick. Mudstone is dark gray (N3), weathers medium gray (N5); hackly parting is greater than 7 mm thick, grayish red (5R4/2) iron stain on parting surfaces; brittle. Siltstone is medium gray (N5), calcitic; 0.6 ft thick bed, 3.1 ft below top of unit, overlies a 0.5 ft thick bed of dark gray (N3) fissile shale with textural lamination................................	8.0	267.9

NOTE: Unit 6 is described along crest of northwest trending ridge, beginning behind church at junction of Virginia Routes 80 and 689, and continuing northwest towards shale pit on north side of Virginia Route 689, 0.2 mile from same junction.

6. Mudstone and claystone; scattered exposures; approximately 50 percent of unit is well exposed, remainder is inferred to be of similar lithology from examination of float chips and absence of resistant beds. Mudstone and claystone are olive gray (5Y4/1), weather light olive gray (5Y5/2); finely micaceous; a few indistinct horizontal burrows, parting is 2 to 10 mm thick;

	Thickness (feet) Unit	Cum.
brittle; some float chips of dark gray (N3) shale in 5 ft interval 35 ft below top of unit; 0.4 ft thick siltstone bed at 61 ft below top of unit, bed is laminated and has flute and groove molds......................	148.0	259.9
5. Covered..................................	79.8	111.9
Total Brallier Formation (incomplete)..	849.7	

Millboro Shale (incomplete):

NOTE: Units 1 through 4 are described at shale pit above Virginia Route 689, 0.2 mile west of its intersection with Virginia Route 80. A small reverse fault dips 55° to the southeast and repeats units 2, 3, and 4. Units 1 through 4 are described on lower block of fault. Exposures are very fresh.

	Unit	Cum.
4. Claystone (90 percent) and clayshale (10 percent). Claystone is dark gray (N3), weathers medium dark gray (N4); subconchoidal bedding fracture; weathers to small angular chips. Two beds of black (N1) clayshale, each 0.4 ft thick at 1.8 and 6.3 ft above base of unit show textural lamination and are more resistant than claystone. Indistinct siltstone bed, 0.2 ft thick, at base of unit, weathers yellowish gray (5Y8/1); plane laminated or cross-laminated; alternating silty and clayey laminae. Several beds of light-weight, yellowish gray (5Y8/1) weathering clay (?), 0.1 to 0.2 ft thick; possibly highly weathered siderite layers or bentonites................................	8.4	32.1
3. Interbedded clayshale (60 percent) and claystone (40 percent). Clayshale is black (N1), weathers grayish black (N2); shows textural lamination; more resistant than claystone beds; parting is 5 to 10 mm thick. Claystone weathers medium light gray (N6); parting is greater than 10 mm thick....................................	4.0	23.7

	Thickness (feet) Unit	Cum.
2. Claystone, dark gray (N3), weathers to medium dark gray (N4) subconchoidal chips 10 mm thick..............................	9.5	19.7
1. Interbedded clayshale (60 percent) and claystone (40 percent). Clayshale and claystone as in unit 3. Several silt laminae 1 to 10 mm thick in claystone in upper 1.5 ft of unit. Black clayshale beds are 0.5 ft to 2.2 ft thick, and more resistant than claystone. Gray claystone beds are 0.5 to 0.8 ft thick...............	10.2	10.2
Total Millboro Formation (incomplete).	32.1	

SECTION 15

Holston Gap Section

Incomplete section of Broadford Sandstone Member and Ceres Member of Price Formation (following the usage of Bartlett, 1974) exposed in roadcut along north side of U.S. Highway 19-58, 0.15 mile west of "Arco" station, Washington County, Brumley quadrangle, Virginia (403500 meters East, 4070550 meters North, Universal Transverse Mercator Grid). Bedding strikes 65 degrees northeast and dips 31 degrees southeast. Section measured and described using Jacob's staff, Abney level, and tape by Paul D. Lundegard. September 9, 1978.

Mississippian (incomplete):

Price Formation (incomplete):

Broadford Sandstone Member (incomplete):

3. Sandstone, medium to thick bedded, virtually no fine grained interbeds, some crossbedding, basal bed is 2.0 ft thick and in sharp contact with unit 2. Unit 3 was not described in detail.....	100±	154.4
Total Broadford Sandstone Member (incomplete)	100±	

Ceres Member (incomplete):

2. Mudstone (65 percent) with approximately 8 beds

		Thickness (feet) Unit	Cum.
	of fine- to very-fine-grained sandstone(35 percent) 0.2 to 0.6 ft thick. Thickness and abundance of sandstone beds increase upward. Mudstone is dark gray (N3), weathers medium dark gray (N4); micaceous; parting is 3 to 6 mm thick, blackish red (5R2/2) iron stain on parting surfaces; shows weak textural lamination in places; a few irregular silt laminae and streaks. Sandstone is light gray (N7); micaceous; most beds show Ta- or Tb- Bouma sequences; probable amalgamation of some beds; several beds have bounce or groove molds trending 215° to 239°; irregular beds 1 cm thick are common; these are possibly burrowed..	8.4	54.4
1.	Mudstone as in unit 2 (90 to 98 percent) with beds of fine- to very-fine-grained sandstone (2 to 10 percent) 1 cm to 0.15 ft thick. Thickness and abundance of sandstone beds increase upward. Irregular sand laminae up to 1 cm thick are common in mudstone. Sandstone is light gray (N7); micaceous; beds greater than 0.1 ft thick predominantly show Tb- Bouma sequences; many beds less than 0.1 ft thick have irregular top and bottom contacts, and irregular disturbed lamination; organic and current formed sole markings are common; prod and bounce molds trend 239° at 21.4 ft above base of unit............................	46.0	46.0
	Total Ceres Member........................	54.4	
	Total Price Formation (incomplete)........	154.4	

SECTION 16

Robinette Gap Section

Incomplete section of Brallier Formation exposed along Virginia Route 856 in Robinette Gap, 0.3 mile south of Virginia Route 802, Washington County, Wallace quadrangle, Virginia (389650 meters East, 4066000 meters North, Universal Transverse Mercator Grid). Bedding strikes 65 degrees northeast and dips 34 degrees southeast. At Wooten Gap, 1.6 miles to the northeast, Bartlett and Webb (1971, p. 66-67) identified "Chemung" fossils below the Cloyd Conglomerate Member of the Price Formation, in the interval here called Brallier Formation. Section measured and described using Jacob's staff, Abney level, and tape by Paul D. Lundegard, September 9, 1978.

	Thickness (feet) Unit	Cum.
Mississippian (incomplete):		
Price Formation (incomplete):		
4. Cloyd Conglomerate Member; not described...	27.4	60.9
Devonian (incomplete):		
Brallier Formation (incomplete):		
3. Mudshale to mudstone (80 percent) with beds of siltstone (20 percent, increases to 80 percent in upper 3.2 ft of unit) less than 0.1 to 0.5 ft thick. Mudshale and mudstone are dark gray (N3), weather medium gray (N5); mudshale shows weak textural lamination. Siltstone is medium gray (N5); a few beds weather pale red (10R6/2) and are probably sideritic; beds have flat, sharp bases and undulatory top surfaces; several beds show plane lamination at base which becomes undulatory upward; one bed shows cross-bedding. Unit 3 is in slightly gradational contact with the overlying Cloyd Conglomerate..............................	22.0	40.0
2. Mudstone, dark gray (N3), weathers pale brown (5YR5/2); very silty; forms a resistant protrusion. At base of unit there is a 0.4 ft thick bed of ferruginous, coarse-grained sandstone with quartz pebbles up to 10 mm in diameter...........	6.5	18.0

	Thickness (feet) Unit	Cum.
1. Mudstone to mudshale, dark gray (N3), weather medium dark gray (N4); brittle; mudshale shows weak textural lamination; a few indistinct siltstone beds 1 to 2 cm thick; 11 structureless siderite nodule layers less than 0.2 ft thick occur in lower 10 ft of unit, these weather light brown (5YR5/6) to grayish red (5R4/2)...........................	11.5	11.5
Total Brallier Formation (incomplete).	40.0	

SECTION 17

Hilton's Section

Upper part of Brallier Formation, "Chemung" Formation (?), and Cloyd Conglomerate Member of the Price Formation (following the usage of Bartlett, 1974) exposed in roadcuts and in shale pit near Hiltons, Scott County, Hilton quadrangle, Virginia. Base of section is in shale pit, south side of U.S. Highway 421, across from "Clark's Food Market" and "Shell" station (368800 meters East, 4057150 meters North, Universal Transverse Mercator Grid). Units 1 through 5 are described in this shale pit. Units 7 through 13 are described at roadcuts along Virginia Route 709, paralleling Hilton Creek, in Hilton Gap. Top of section is 600 ft northwest of the junction of Virginia Route 709 and U.S. Highway 421 (369450 meters East, 4056850 meters North, Universal Transverse Mercator Grid). Section measured, described, and sampled using Jacob's staff, Abney level, surveying altimeter, and tape by Paul D. Lundegard, September 9, 1978.

	Thickness (feet) Unit	Cum.
Mississippian (incomplete):		
Price Formation (incomplete):		
Cloyd Conglomerate Member:		
13. Sandstone, fine- to very-fine-grained (95 percent) in beds 0.1 to 1.5 ft thick with minor interbeds of clayshale (5 percent) less than 0.1 ft thick. Sandstone is dark gray (N3); beds pinch and swell or are discontinuous; low angle crossbedding. Clayshale is dark gray (N3); shows textural lamination.......	12.3	647.3
Total Cloyd Conglomerate Member.......	12.3	
Total Price Formation (incomplete)....	12.3	
Devonian (incomplete):		
"Chemung" Formation (?):		
12. Sandstone, very-fine-grained (60 percent) in beds 0.1 to 0.4 ft thick, with interbeds of mudstone (40 percent). Sandstone is medium gray (N5); beds pinch and swell or are discontinuous; beds show predominantly plane and undulatory lamination; cross-lamination at tops of beds; a few sole markings; groove mold trends 270°; 0.4 ft thick bed at base of unit is strongly bioturbated; individual burrows up to 1 cm wide. Mudstone is dark gray (N3), silt laminae up to 5 mm thick are locally common; yellowish gray (5Y8/1) biolamination and streaks up to 3 mm thick. Siderite nodule layers up to 0.1 ft thick occur at 1.6 ft, 2.5 ft, and 10.0 ft above base of unit; nodules have concentric structure and weather light brown (5YR5/6).	13.0	635.0
Total "Chemung" Formation (?).........	13.0	

Brallier Formation (incomplete):	Thickness (feet) Unit	Cum.
11. Mudstone, dark gray (N3) weathers medium gray (N5) to olive gray (5Y4/1); grouped and individual silt laminae up to 5 mm thick are common, especially in middle 10 ft of unit; yellowish gray (5Y8/1) biolamination and streaks up to 3 mm thick, more abundant in middle 10 ft of unit where bioturbation reaches 20 to 40 percent. Plane laminated siltstone bed 0.1 ft thick at 5 ft above base of unit; two 0.25 ft thick siltstone beds in upper 2.0 ft of unit; pinch and swell to discontinuous; show cross-lamination and fine groove molds. Siderite nodules 5 ft below top of unit......................	28.0	622.0
10. Mudstone (90 percent) with beds of siltstone (10 percent) up to 0.25 ft thick, modal bed thickness 0.2 ft. Mudstone is dark gray (N3), weathers olive gray (5Y4/1); parting is 5 mm thick. Siltstone is dark gray (N3); beds have sharp, flat bases; show Tb or Tbc Bouma sequences; some beds show rippled top surfaces. Unit 10 forms resistant protrusion from outcrop..........	8.5	594.0
9. Clayshale with a few beds of siltstone (1 percent) up to 0.1 ft thick. Clayshale is dark gray (N3) to olive gray (5Y4/1), weathers light olive gray (5Y6/1) to olive gray (5Y4/1); shows textural lamination; silt laminae less than 1 mm thick are common; minor yellowish gray (5Y8/1) bioturbation occurring as diffuse reworked zones and biolaminae and streaks up to 1 mm thick; silt laminae and bioturbated portions are dark yellowish orange (10YR6/6) on fresh surfaces; parting is 3 to 5 mm thick. Siltstone beds show Tbc and Tc Bouma sequences, and rippled top surfaces; 8 to 10 siltstone beds in lower 10 ft of unit. Six siderite nodule layers up to 0.1 ft thick occur in upper 7 ft of unit; nodules weather grayish red (5R5/2).........................	45.5	585.5
8. Covered....................................	100.0	540.0

	Thickness (feet) Unit	Cum.
7. Clayshale as in unit 9 with a few beds of siltstone and very-fine-grained sandstone (1 percent) less than 0.1 ft thick. Siltstone and sandstone beds show Tc Bouma sequences and rippled top surfaces. Siderite nodule 2 cm thick at 21.5 ft above base of unit weathers light brown (5YR5/6). Base of unit is opposite cinder block building next to white house........................	40.0	440.0
6. Covered. Thickness estimated geometrically from map location of outcrops, strike and dip data and altitude data obtained with a surveying altimeter accurate to $\pm$ 3 feet. Offset to shale pit above U.S. Highway 421 across from "Clark's Food Market" and "Shell station"............................	140.0	400.0
5. Clayshale to mudshale, olive gray (5Y4/1) to dark gray (N3), weathers light olive gray (5Y5/2); shows textural lamination; silt laminae up to 2 mm thick are common and comprise 30 percent of several intervals 0.2 ft to 1.2 ft thick and 50 percent of one 5 ft thick interval 50 ft below top of unit; weakly bioturbated in upper 60 ft of unit; diffuse yellowish gray (5Y8/1) burrow mottling, biolamination and streaks up to 3 mm thick...........................	112.0	260.0
4. Claystone and shale as in unit 5. Claystone is olive gray (5Y4/1) to dark gray (N3), weathers light olive gray (5Y5/2); 10 to 80 percent bioturbation as in unit 5; thin layers up to 2 cm thick are completely bioturbated; silt laminae up to 1 mm thick are very common; 5 siderite layers and nodule layers 1 to 2 cm thick in middle of unit.................................	50.0	145.0
3. Clayshale, olive gray (5Y4/1) to dark gray (N3) weathers light olive gray (5Y5/2); shows textural lamination; a few silt laminae up to 1 mm thick; very minor yellowish gray (5Y8/1) bioturbation as in		

	Thickness (feet) Unit	Cum.
unit 5. Eleven siderite layers and nodule layers 1 to 2 cm thick; nodules weather light brown (5YR5/6) to pale reddish brown (10R5/2)............................	34.0	98.0
2. Clayshale as in unit 3 with more abundant bioturbation; bioturbation reaches 10 percent; biolaminae 1 to 5 mm thick are common; many are slightly silty. Several highly weathered siderite layers 1 cm thick in middle of unit....................	20.0	64.0
1. Clayshale, medium dark gray (N4) to olive gray (5Y4/1), weathers medium light gray (N6) to light olive gray (5Y6/1); shows textural lamination; silt laminae up to 2 mm thick are common, and tend to occur in groups. Several siderite layers and nodule layers, 1 to 2 cm thick in lower half of unit; some are highly weathered to a dark yellowish orange (10YR6/6) punky material and form recesses in outcrop..................................	44.0	44.0
Brallier Formation (incomplete)........	622.0	

SECTION 18

Nottingham Section

Incomplete section of Brallier Formation exposed in shale pit on southeast side of U.S. Highway 421-58, 0.1 mile northwest of "Flanary's Grocery", and 0.7 mile northeast of Virginia Route 614, Scott County, Gate City quadrangle, Virginia (365200 meters East, 4055750 meters North, Universal Transverse Mercator Grid system). Section is of the upper part of the Brallier Formation at the tip of a tongue-like topographic ridge extending northwest from Pine Ridge. Pine Ridge is formed by Mississippian sandstones of the Price Formation. Section measured and described using Jacob's staff, Abney level, and tape by Paul D. Lundegard, July 18, 1978.

Devonian (incomplete):	Thickness (feet)	
Brallier Formation (incomplete):	Unit	Cum.
1. Claystone to clayshale, both are olive gray (5Y4/1) to dark gray (N3), and weather light gray (N7) to grayish orange (10YR7/4); a few silt laminae up to 1 mm thick; weakly to strongly bioturbated; bioturbation averages approximately 20 percent; clayshale shows textural lamination and is less bioturbated than claystone; bioturbation is horizontal; individual burrows are generally not recognizable; bioturbated zones weather yellowish gray (5Y8/1); some completely reworked zones up to 0.15 ft thick; abundant biolamination and streaks. No beds of siltstone...........	165.0	
Total Brallier Formation (incomplete)....	165.0	

SECTION 19

Cowan Gap Section

The Price Formation, including the Greendale and Ceres Members (following the usage of Bartlett, 1974) is exposed in railroad cuts about fifty yards west of where Virginia Route 636 passes under the railroad tracks, Scott County, Church Hill quadrangle, Virginia (348900 meters East, 4053900 meters North, Universal Transverse Mercator Grid). Section measured and described using Jacob's staff, Abney level, and tape by Paul D. Lundegard, September 9, 1978.

Mississippian (incomplete):	Thickness (feet)	
Price Formation (incomplete):	Unit	Cum.
Greendale Member (incomplete):		
10. Sandstone, thick bedded, massive. Not measured or described in detail.		
9. Sandstone, very-fine-grained (80 percent, but difficult to estimate), in beds less than 0.1 ft to 0.25 ft thick with interbeds of mudstone (20 percent). Sandstone and mudstone are difficult to distinguish because there is little weathering difference between them. Sandstone is medium gray		

	Thickness (feet) Unit	Cum.
(N5); beds are pinch and swell or discontinuous; parallel laminated or with slightly disturbed lamination. Mudstone is dark gray (N3) and very silty............	1.6	78.5
8. Sandstone, very-fine-grained, single bed, medium gray (N5), plane laminated, massive..	1.6	76.9
Total Greendale Member (incomplete)....	3.2	
Ceres Member (incomplete):		
7. Mudstone to non-bedded argillaceous siltstone (70 percent) with distinct beds of coarse-grained, to very-fine-grained sandstone (30 percent) up to 0.1 ft thick. Mudstone and nonbedded siltstone are dark gray (N3). Siltstone and sandstone beds are predominantly plane laminated or have irregular horizontal lamination. Siderite nodule layer, 0.1 ft thick, in middle of unit............................	5.3	75.3
6. Sandstone, very-fine-grained, two massive beds separated by a shale parting; lower bed is 2.5 ft thick and medium dark gray (N4); upper bed is 0.8 ft thick and medium light gray (N6)..........................	3.3	70.0
5. Mudshale, to mudstone; both are dark gray (N3) parting is 3 to 6 mm thick; blackish red (5R2/2) iron stain on parting surfaces; rare silt laminae less than 1 mm thick. Mudshale shows weak textural lamination. Siderite nodules up to 1.6 ft in long dimension are scattered throughout unit. One 0.1 ft thick, plane laminated siltstone bed, 1.0 ft below top of unit.............	9.7	66.7
4. Sandstone, very-fine-grained, in beds 0.1 to 0.4 ft thick, sideritic, plane laminated or with slightly disturbed horizontal lamination. Minor dark gray (N3) mudshale in lower half		

	Thickness (feet) Unit	Cum.
of unit. At top of unit there is a 0.9 ft thick, ferruginous, fine-to coarse-grained sandstone with abundant quartz pebbles, capped by a 0.1 ft thick undulatory siderite layer..........................	4.6	57.0
3. Mudshale to mudstone, dark gray (N3), some silt laminae less than 1 mm thick; mudshale shows textural lamination; many uneven siltstone beds (10 percent), 1 to 3 cm thick, with irregular lamination.....	1.4	52.4
2. Siltstone, coarse-grained, 2 or 3 beds, each of variable thickness, medium dark gray (N4); lowermost bed is 0.7 ft thick and shows low-angle cross bedding. Minor mudshale interbeds.......................	1.2	51.0
1. Clayshale to mudshale (greater than 90 percent) with minor beds of siltstone to very-fine-grained sandstone (less than 10 percent) up to 0.15 ft thick. Abundance of siltstone and sandstone decreases upward from less than 5 percent in lower 15 ft to 10 percent in upper 10 ft. Shale is olive gray (5Y4/1); silt content increases upward; shows textural lamination; a few silt laminae less than 1 mm thick; parting is 3 to 5 mm thick; very minor yellowish gray (5Y8/1) bioturbation. Siltstone and sandstone are medium gray (N5); in lower 15 ft beds are less than 0.1 ft thick and predominantly plane laminated; in upper 10 ft beds are pinch and swell to discontinuous, and some beds show plane lamination which becomes undulatory upward. Siderite nodule layers less than 0.1 ft thick occur at 15, 18, 38.5, and 42 ft above base of unit....	49.8	49.8
Total Ceres Member (incomplete)......	52.4	
Total Price Formation (incomplete)...	78.5	

SECTION 20

Little War Gap Section

Nearly complete section of gray silty shale unit of Chattanooga Shale in roadcuts on the west side of Tennessee Highway 70, Hawkins County, Camelot quadrangle, Tennessee, (318550 meters East, 4040500 meters North, Universal Transverse Mercator Grid). Exposures are of low knobs in Poor Valley across highway from Klepper Chapel. Section begins at farm gate next to barn and continues to the south. Top of section is about 30 feet north of curve warning sign. Highway is oblique to the strike of bedding. Measured, described and sampled using Jacob's staff, Abney level, and tape by Paul D. Lundegard on July 17, 1978, and its radioactivity profile measured using scintillometer by Paul D. Lundegard and Greg Hinterlong, November 10, 1978.

Devonian:	Thickness (feet) Unit	Cum.
Chattanooga Shale (incomplete):		
11. Mudshale and nonbedded siltstone. Mudshale is dark gray (N3), weathers medium gray (N5), shows textural lamination; thin silt laminae less than 1 mm thick are common; platy parting 2 to 10 mm thick with a modal thickness of 5 mm. Non-bedded siltstone is plane laminated and very similar to the mudshale but has a greater silt content. Unit becomes less silty upward. Upper three fourths of unit are more deeply weathered and freshest color is olive gray (5Y4/1), weathered color is yellowish gray (5Y7/2). Top of unit is 30 ft north of curve warning sign..........	85.0	400.0
10. Siltstone, medium gray (N5), nonbedded, platy, plane laminated, individual laminae are less than 1 mm thick and even; parting is 3 to 10 mm thick and even. Unit 10 forms crest of knob............................	13.5	315.0
9. Mudshale, dark gray (N3), weathers medium gray (N5), shows textural lamination; silt laminae less than 1 mm thick are very common; even, plane laminated silt layers less than 5 mm thick are also common, parting is 3 mm thick and even............................	13.5	301.5

	Thickness (feet) Unit	Cum.
8. Clayshale with 28 or more sideritic siltstone layers 1 to 2.5 cm thick. Clayshale is dark gray (N3), weathers medium gray (N5), shows faint textural lamination; generally non-silty; a few silt laminae less than 1 mm thick; parting is 3 to 5 mm thick. Sideritic siltstone layers are dark yellowish brown (10YR4/1), weather dark yellowish orange (10YR6/6), structureless; beds commonly of variable thickness and difficult to trace laterally. At road level, top of unit 8 is directly below crest of knob........................	58.4	288.0
7. Mudshale, dark gray (N3), weathers medium light gray (N6) to light olive gray (5Y6/1); shows textural lamination and variable amounts of even silt laminae less than 1 mm thick; disseminated silt content increases upward and shale becomes harder and more brittle; parting is 5 to 10 mm thick. There is gentle folding of the beds in this unit. Base of unit is at beginning of long, continuous exposure of low knob....	99.6	229.6
6. Covered..................................	44.4	130.0
5. Clayshale, deeply weathered, pale yellowish brown (10YR6/2) to pale brown (5YR5/2), weathers light olive gray (5Y6/1); finely micaceous; shows faint textural lamination; a few silt laminae less than 1 mm thick; faint moderate brown (5YR4/4) color lamination associated with some silt laminae; minor disseminated silt; parting is 1.5 to 3.0 cm thick.....................	5.6	85.6
4. Covered..................................	9.0	80.0
3. Clayshale as in unit 5; upper 2.0 ft of unit is mudshale with abundant even silt laminae less than 1 mm thick; minor amounts of bioturbation. Unit 3 is described in ditch along northwest side of road...............	16.0	71.0

	Thickness (feet) Unit	Cum.
2. Covered..................................	50.0	55.0
1. Mudshale to clayshale, as in unit 5.......	5.0	5.0
Total Chattanooga Shale (incomplete).	390.0	

SECTION 21

Flat Gap Section

Nearly complete section of gray silty shale unit of Chattanooga Shale exposed in roadcut along east side of Tennessee Route 31, 4.3 miles north of its junction with U.S. Highway 11-W, Lee Valley quadrangle, Hawkins County, Tennessee (300700 meters East, 4030450 meters North, Universal Transverse Mercator Grid). Base of section is 75 ft south of where culvert passes under road. Provo, Kepferle, and Potter (1977, p. 46) described the Chattanooga Shale at this locality, and Hasson (1972) described the Mississippian Grainger Formation and uppermost Chattanooga Shale. Section measured, described, and sampled using Jacob's staff, Abney level, and tape by Paul D. Lundegard, July 12 and 13, 1978, and its radioactivity profile measured using scintillometer by Paul D. Lundegard and Greg Hinterlong, November 11, 1978.

Mississippian (incomplete):

Grainger Formation (incomplete):

Basal siltstone member; not measured or described.

Devonian (incomplete):

Chattanooga Shale (incomplete):

21. Clayshale (95 percent) with beds of siltstone (5 percent) up to 0.2 ft thick. Siltstone increase in abundance upward. Clayshale is dark gray (N3), weathers medium gray (N5) to medium light gray (N6); shows textural lamination; parting is 2 to 5 mm thick; a few siderite (?) nodules weathering light brown (5YR5/6). Siltstone is medium light gray (N6), weathers light gray (N7) light

	Thickness (feet) Unit	Cum.
brown (5YR5/6) iron stain in places; micaceous; tiny specks of dark organic matter; beds have sharp basal contacts and slightly gradational top contacts; Tab Bouma sequences; a few sole markings in upper 15 ft of unit. Provo, Kepferle, and Potter (1977, p. 47) measured flute molds in this unit trending 244^{o}, with blunt ends toward east......................	92.1	575.3
20. Covered....................................	43.0	483.2
19. Clayshale, brownish black (5YR2/1) to black (N1), weathers medium dark gray (N4); shows textural lamination; slightly silty; parting is 5 to 10 mm thick. Unit 19 is described in creek bed 15 ft northeast of culvert under road.....................................	6.0	440.2
18. Covered....................................	94.0	434.2
17. Siltstone, light olive gray (5Y6/1), weathers medium gray (N5) to light olive gray (5Y6/1); some light brown (5YR5/6) iron stain on surface; non-bedded and generally shows no lamination; strongly bioturbated; parting is irregular and 5 to 10 mm thick...	10.4	340.2
16. Covered....................................	67.5	329.7

NOTE: Units 1 through 15 comprise an overall thickening- and coarsening-upward sequence.

15. Sandstone, fine-grained, to siltstone, medium light gray (N6) to dark gray (N3); indistinctly bedded; sedimentation units are not recognizable; structureless or having black, clayey laminae or streaks which are uneven, and discontinuous; highly bioturbated with distinct curving and branching horizontal burrows less than 5 mm wide observable on some parting surfaces; these burrows resemble Scalarituba but lack the transverse scaliform ridges of that genus; irregular, bumpy partings, 1 to		

	Thickness (feet) Unit	Cum.
5 cm thick; bedding strikes 68 degrees northeast, and dips 56 degrees southeast into fault plane at top of unit............	27.0	262.2
14. Sandstone, very-fine-grained, and siltstone, medium light gray (N6) to dark gray (N3); indistinctly bedded as in unit 13 but more massive; the most prominent and persistent partings are spaced 1 to 3 ft apart with spacing increasing upward in unit; parting surfaces are irregular and bumpy with up to 5 mm of relief; some disturbed lamination consisting of alternating gray silt or sand and black clayey or organic material on the scale of 1 to 2 mm; scattered streaks of dark clayey material common in more massive upper half of unit; blebs and lenses of clean silt (endichnia?) about 5 mm wide are common; highly bioturbated throughout...................................	36.8	235.2
13. Siltstone, medium gray (N5); similar to units 14 and 15 but with thinner parting 1 cm thick; shows even plane lamination 1 to 3 mm thick, and discontinuous, uneven wavy lamination probably disturbed by horizontal burrowing; horizontal burrows 5 mm wide are visible on parting surfaces...	10.9	198.4
12. Disturbed zone; high angle reverse fault; highly fractured and contorted siltstone beds and mudshale..........................	5.0	187.5
11. Claystone and mudstone; both are light olive gray (5Y5/2); some yellowish gray (5Y8/1) horizontal burrows; a few silt laminae less than 2 mm thick; a few siltstone beds 2 cm thick with uneven, wavy laminae. Unit 11 becomes siltier upward and siltstone beds become more abundant.......................	24.7	182.5
10. Mudshale (70 percent) with indistinct beds of siltstone 1 cm to 1.1 ft thick in a thinning-upward sequence. Mudshale is dark gray (N3); shows textural lamination.		

	Thickness (feet) Unit	Cum.
Siltstone is medium dark gray (N4); beds have irregular, wavy, uneven laminae of silt and clay; rare cross lamination in thinner beds; horizontal burrows are very common....................................	17.4	157.8

NOTE: Units 1 through 9 comprise an overall thickening- and coarsening-upward sequence.

9. Siltstone (75 percent) in distinct beds up to 2.4 ft thick with interbeds of clayshale or non-bedded siltstone (25 percent). Unit 9 shows an overall thinning-upward and is composed of two separate thinning-upward sequences. Lower thinning-upward sequence is about 20 ft thick and has a modal bed thickness of 0.6 ft. Upper thinning-upward sequence is about 11 ft thick and has a modal bed thickness of less than 0.2 ft. Distinct siltstone beds are medium gray (N5); evenly bedded, sharp basal contacts and sharp or slightly gradational upper contacts; top-truncated Bouma sequences and amalgamation of beds are common in lower 14 ft of unit; 90 percent of beds greater than 0.2 ft thick show Ta- Bouma sequences; Tc- Bouma sequences predominate in beds less than 0.2 ft thick; unit ABC proximity index (Walker, 1967) is 54 percent; a few shale clasts and sole markings, fine groove molds trend 264^{o} at 14 ft above base of unit. Clayshale is dark gray (N3); shows textural lamination; very slightly silty; parting is 2 mm thick. Non-bedded siltstone is dark gray (N3); laminated, platy and less resistant than distinct siltstone beds; lamination consists of alternating layers of gray silt and black clay and organic matter; parting is 5 mm thick....................................	31.2	140.4
8. Siltstone, non-bedded, platy; dark gray (N3); consists of alternating plane to wavy gray silt laminae and black laminae of clay and organic matter on the scale of 1 to 5 mm.		

	Description	Thickness (feet) Unit	Cum.
	Some distinct beds of siltstone to very-fine-grained sandstone, 1 to 2 cm thick, expressed as ribs on outcrop; these layers pinch and swell and have wavy, disrupted lamination or cross-lamination. Horizontal burrows (silt filled endichnia) less than 5 mm wide are very common..................	3.3	109.2
7.	Sandstone, very-fine-grained, in four distinct beds, 0.4 to 1.4 ft thick; interbedded with platy, non-bedded siltstone as in unit 8. Sandstone beds show Ta- Bouma sequences; lowermost sandstone bed has a rippled top surface........................	4.7	105.9
6.	Siltstone, non-bedded, platy, as in unit 8..	5.0	101.2
5.	Siltstone in four distinct beds, 0.8 to 1.4 ft thick with little or no shale interbeds. Siltstone beds show Ta-, or Tb- Bouma sequences; shale clasts, and amalgamation of beds is common; one bed is discontinuous, beds are otherwise very even and persistent.............................	4.4	96.2
4.	Siltstone (approximately 60 percent) with interbeds of clayshale (40 percent). Siltstone is dark gray (N3); bedding is indistinct; sedimentation units are difficult to identify; alternating laminae of gray silt and black organic-rich clay less than 1 to 3 mm thick; many laminae are wavy or disrupted; silt-filled endichnia are common. Clayshale is dark gray (N3), parting is 2 mm thick; very little disseminated silt.....	8.1	91.8
3.	Siltstone; non-bedded, platy. A resistant unit with sharp break in slope at base. Siltstone is grayish black (N2) and consists of alternating laminae of medium dark gray silt and black organic-rich clayey laminae 1 to 2 mm thick; many distinct siltstone layers less than 2 cm thick give outcrop a ribbed appearance where grouped; some siltstone layers pinch and swell and are laminated or cross-laminated...............	14.9	83.7

	Thickness (feet) Unit	Cum.
2. Mudshale; consists of alternating laminae of black (N1) organic-rich clay (40 to 70 percent) and medium gray (N5) silt (30 to 60 percent). Silt laminae are 2 to 15 mm thick and give outcrop a ribbed appearance; become thicker and more numerous upward; predominantly even and continuous but pinch and swell layers and silt blebs are common; thicker silt layers are internally laminated; a few horizontal silt-filled burrows. Foerstia was found in middle of unit..........................	14.8	68.8
1. Clayshale to mudshale; coarsening upward; moderate brown (5YR4/4) in lower half of unit, grayish black (N2) to olive black (5Y2/1) in upper half of unit; more deeply weathered in lower half of unit where weathered color is pale yellowish brown (10YR6/2) to grayish orange (10YR7/4); in upper half of unit shale weathers medium light gray (N6) to medium dark gray (N4) with a blackish red (5R2/2) iron stain on parting surfaces. Shale shows textural lamination; silt laminae and streaks less than 1 mm to 3 mm thick are common and become thicker and more abundant upward; black shreds of organic matter are common; parting is 2 to 5 mm thick.................	54.0	54.0
Total Chattanooga Shale (incomplete)...	575.3	

SECTION 22

U.S. Highway 25 Section

Complete section of gray silty shale unit of Chattanooga Shale exposed on east-facing slope of Poor Valley Ridge and in roadcuts along U.S. Highway 25E in Grainger County, Bean Station quadrangle, Tennessee (290300 meters East, 4025700 meters North, Universal Transverse Mercator Grid). Units 1 through 9 are described on east-facing slope of Poor Valley Ridge across U.S. Highway 25E and Annex Creek from "Mobil" Station. Units 10 through 12 are described at roadcuts along U.S. Highway 25E beginning apporximately 500 ft south of "Mobil" station. Section Measured, described, and sampled using Jacob's staff, Abney level, and tape by Paul D. Lundegard, July 15 and 16, 1978, and its radioactibity profile measured with scintillometer by Paul D. Lundegard and Greg Hinterlong, November 9 and 10, 1978.

	Thickness (feet) Unit	Cum.
Mississippian (incomplete):		
Basal siltstone member of Grainger Formation;		
not measured or described.		
Devonian (incomplete):		
Chattanooga Shale (incomplete):		
12. Clayshale, grayish black (N2) to black (N1), weathers dark gray (N3) to medium dark gray (N4); shows textural lamination; parting is 2 to 4 mm thick. A few thin siltstone beds, 0.1 to 0.3 ft thick in upper part of unit. Upper contact is gradational with Grainger Formation. Unit 12 was not described in detail; exposed across highway from small white house.......	119.0	453.3
11. Covered....................................	150 ±	334.3
10. Claystone, light olive gray (5Y6/1), moderate reddish brown (10R4/6) varigations where weathered; silt-free; brownish black (5YR2/1) fragments of organic matter are common; sticky when wet; weathers to irregular chunks................................	16.0	184.3

NOTE: Units 1 through 9 are described on east-facing hillside of Poor Valley Ridge, across highway and Annex Creek from "Mobil" station. Unit 9 forms the crest of Poor Valley Ridge, and was correlated with the massive sandstone beds exposed along U.S. Highway 25 beneath unit 10 by Jacob's staff and Abney level.

	Thickness (feet) Unit	Cum.
9. Sandstone, very-fine-grained, light gray (N7) to yellowish gray (5Y8/1); irregular partings a few tenths of ft apart; a few distinct massive beds up to 2.6 ft thick; beds show disturbed irregular lamination, or wavy uneven laminae, streaks, and blebs or are structureless; lamination consists of alternating gray sand or silt layers and darker clayey layers. Lower 10 ft of unit 9 forms a vertical face and overhangs unit 8. Unit 9 forms crest of Poor Valley Ridge..............................	53.0	168.3
8. Clayshale to mudshale with a few beds of siltstone and very-fine-grained sandstone, predominantly less than 0.1 ft thick. Shale is grayish black (N2); shows textural lamination; abundant silt laminae are medium dark gray and less than 1 mm to 1 cm thick; the abundance of silt laminae increases abruptly from about 10 percent to 60 percent at 5 ft above base of unit then gradually diminishes upward to less than 5 percent near top of unit. In this siltier zone silt laminae have a modal thickness of 4 to 5 mm; uneven pinch and swell layers and lenses predominate; a few silt laminae are internally plane laminated or cross-laminated; some horizontal burrows. A few distinct siltstone beds less than 0.1 ft thick occur between 2 and 5 ft above base of unit; beds pinch and swell; lamination consists of alternating gray and black, irregular, wavy laminae; distinct siltstone bed, 0.3 ft thick, at 1.7 ft above base of unit is very even and persistent; shows sharp base and slightly gradational top; Tab Bouma sequence; parting lineation trending 263° - 083°; immediately below this bed is a non-		

	Thickness (feet) Unit	Cum.
resistant bed of medium light gray (N6) claystone, 0.5 ft thick....................	22.3	115.3
7. Covered..................................	21.0	93.0
6. Siltstone, coarse-grained, to sandstone, very-fine-grained; poorly bedded; irregular partings 1 to 3 cm thick; wavy to discontinuous laminae of alternating gray silt or sand and black clayey material; a few distinct horizontal burrows.................	25.5	72.0
5. Mudshale, grayish black (N2); shows textural lamination; laminae and streaks of silt up to 3 mm thick are abundant..................	4.5	46.5
4. Interlaminated siltstone (60 percent) and mudshale (40 percent). Siltstone laminae, streaks, and blebs are medium gray (N5); 1 mm to 5 mm thick. Mudshale laminae are grayish black (N2); show textural lamination. Parting thickness ranges from 2 mm in shaly parts of unit, to 1 cm in silty parts.	5.0	42.0
3. Claystone, olive gray (5Y4/1), weathers light olive gray (5Y6/1); non-resistant; shows some faint textural lamination; parting is subconchoidal, subparallel with bedding and 5 to 7 mm thick.......................	8.0	37.0
2. Mudshale with up to 5 percent siltstone beds less than 0.1 ft thick. Mudshale is black (N1); silt laminae, streaks, and blebs less than 3 mm thick are abundant and become more numerous upward; some textural lamination; parting is 2 to 5 mm thick; Foerstia found in lower 10 ft of unit. Siltstone is medium gray (N5); increases in abundance upward; somewhat irregular clayey laminae and cross laminae; a few hypichnial ridges; a few beds weather light brown (5YR5/6) and are probably sideritic. Upper 19 ft of unit forms nearly vertical face......................	22.0	29.0

	Thickness (feet) Unit	Cum.
1. Clayshale to claystone; both are medium dark gray (N4) to light olive gray (5Y6/1); slightly silty; minor yellowish gray (5Y8/1) weathering horizontal bioturbation; parting is 3 mm thick; clayshale shows textural lamination..................................	7.0	7.0
Total Chattanooga Shale (incomplete)....	401.0	

SECTION 23

Rock Haven Section

Nearly complete section of gray silty shale unit of Chattanooga Shale exposed in roadcuts along old U.S. Highway 25E about 1.1 miles northwest of its intersection with U.S. Highway 11W in the Avondale quadrangle, Grainger County, Tennessee (285800 meters East, 4044200 meters North, Universal Transverse Mercator Grid). Section begins behind trailer home at community of Rock Haven, and continues southeast to where power lines cross over road. Section measured, described, and sampled using Jacob's staff, Abney level, and tape by Paul D. Lundegard, July 15, 1978, and its radioactivity profile measured using scintillometer by Paul D. Lundegard and Greg Hinterlong, November 9, 1978.

Mississippian (incomplete):

Basal siltstone member of Grainger Formation:

Not measured or described. Exposed in roadcut, 200 ft southeast of where utility lines cross over road.

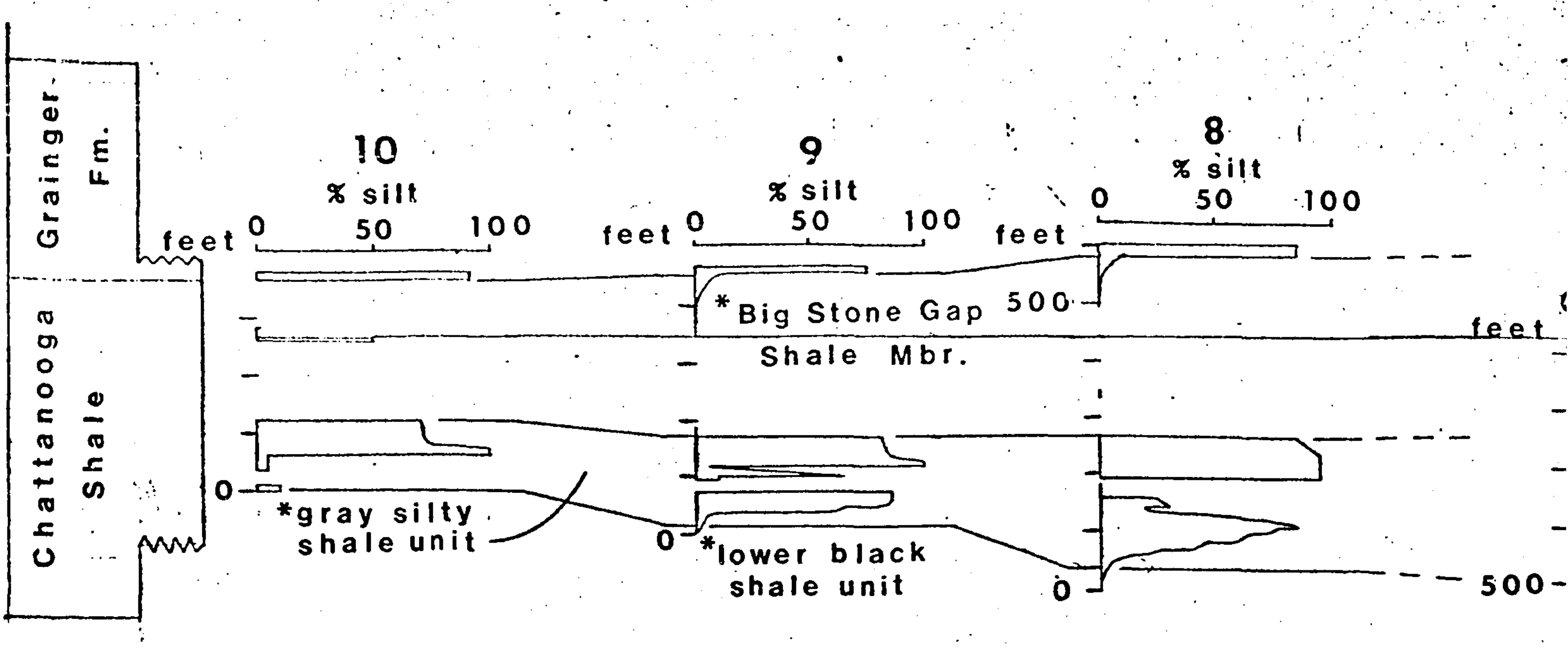
Devonial (incomplete):

Chattanooga Shale (incomplete):

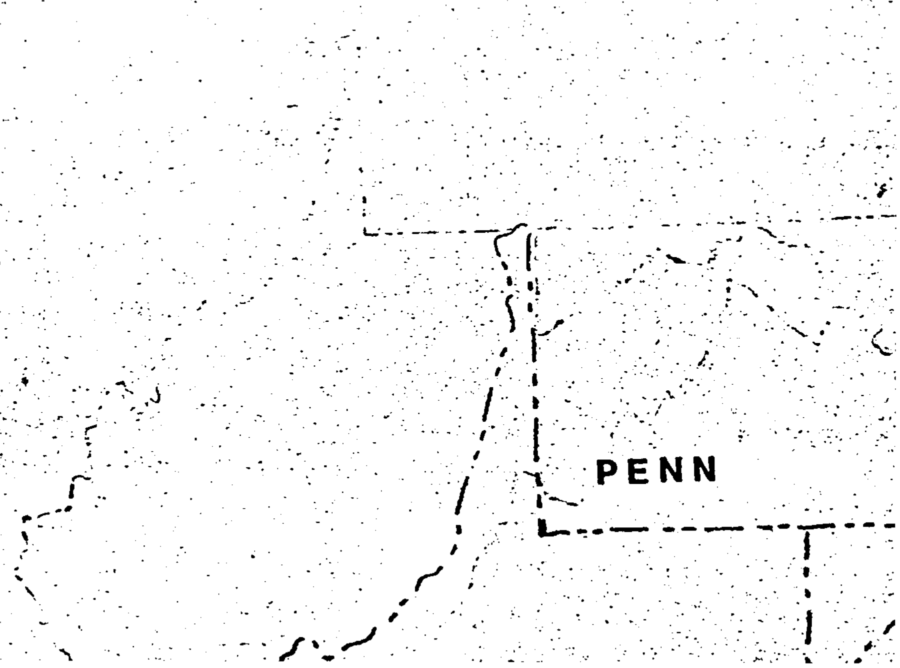
	Unit	Cum.
13. Covered....................................	85.0	371.8
12. Clayshale, black (N1), weathers dark gray (N3); shows textural lamination; silt-free; parting is 2 to 3 mm thick; soft. Unit 12 is exposed beneath utility lines on the western flank of the ridge formed by the Grainger Formation.................	20.0	286.8

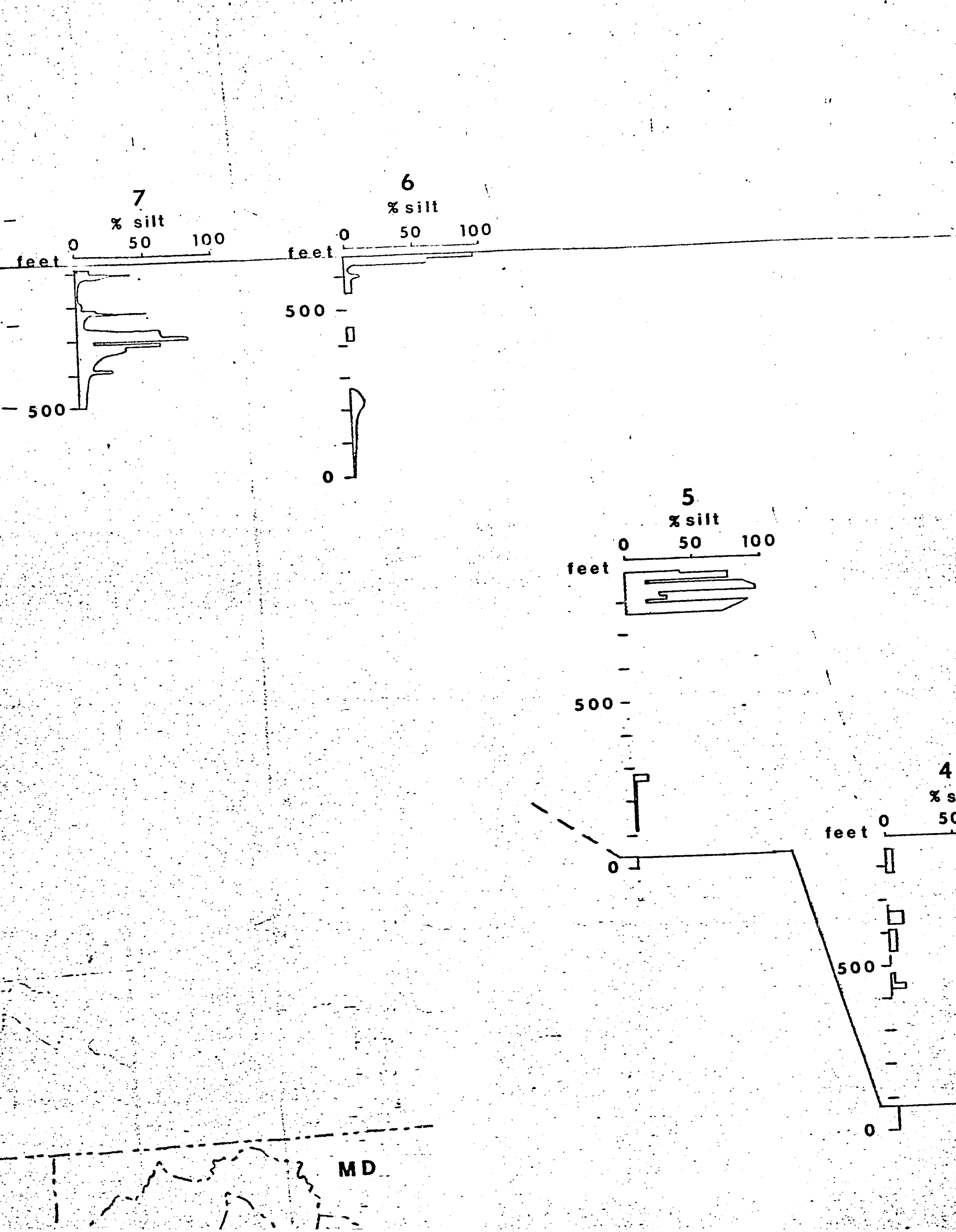
	Thickness (feet) Unit	Cum.
11. Sandstone, very-fine-grained (50 percent), in beds 2 cm to 0.25 ft thick, with interbeds of clayshale (50 percent). Sandstone is pale yellowish brown (10YR6/2); structureless or with faint, discontinuous laminae. Clayshale is dark gray (N3), weathers medium dark gray (N4); shows textural lamination..........................	5.0	266.8
10. Covered. Scattered exposures of indistinctly bedded dark gray sandstone and very silty, dark gray shale............................	135.0	261.8
9. Sandstone, fine-grained, in six fairly distinct beds; medium gray (N5) to medium dark gray (N4); structureless or with wavy, irregular lamination and randomly oriented black wisps of clayey material; some horizontal bioturbation....................	5.5	126.8
8. Poorly exposed; sandy black (N1) shale, and platy, argillaceous sandstone with discontinuous, wavy laminae......................	3.9	121.3
7. Sandstone, fine-grained, dark gray (N3); beds are 0.2 to 1.5 ft thick and generally indistinct and poorly defined; structureless or with irregular wavy and discontinuous laminae and streaks; sedimentation units are difficult to recognize. Interbeds are less resistant argillaceous sandstone and sandy shale with irregular parting 3 mm to 5 cm thick; wavy, discontinuous laminae and streaks of sand and clay; some distinct horizontal burrows. Fault with 2 ft of displacement at base of unit...............	38.9	117.4
6. Sandstone, fine-grained, resistant, fractured, light gray (N6) to light brownish gray (5YR6/1), weathers grayish orange (10YR7/4); partings are 0.3 to 1.0 ft apart, uneven and subparallel to master bedding but commonly truncate each other; beds are structureless; sedimentation units are not identifiable.......................	7.1	78.5

	Thickness (feet) Unit	Cum.
5. Sandstone, very-fine-grained, dark gray (N3); indistinct bedding units are defined by the more persistent partings; the parting surfaces are very bumpy, largely because of abundant endichnial burrows less than 5 mm wide; major bedding units have disturbed, wavy lamination and irregular non-persistent partings 1 to 2 cm thick....................	8.4	71.4
4. Mudshale with a few beds of siltstone 1 to 2 cm thick. Mudshale is black (N1); silt is dominantly as even, parallel laminae less than 1 mm to 5 mm thick; up to 20 megascopic laminae per centimeter; some silt-filled horizontal burrows; parting is platy and 2 to 5 mm thick; brittle. Siltstone is dark gray (N3); cross-laminated or showing wavy, discontinuous laminae. Unit 4 is described at vertical outcrop about 40 ft off road, and hidden by underbrush..................................	26.5	63.0
3. Covered.....................................	19.0	36.5
NOTE: Units 1 and 2 are described at outcrop behind trailer home.		
2. Claystone, light olive gray (5Y5/2) weathered; abundant yellowish gray (5Y8/1) to light olive gray (5Y6/1) weathering bioturbation; burrows are horizontal; individual burrows are less than 3 mm wide; approximately 60 percent bioturbation; small brown woody fragments are abundant................................	5.0	17.5
1. Mudshale, black (N1), weathers dark gray (N3); plane and wavy silt laminae 1 to 2 mm thick and lensoid silt blebs up to 1 cm wide are common; parting is even and 3 to 5 mm thick; weathers to brittle plates; a few pinch and swell siltstone layers up to 2 cm thick show disturbed lamination. Foerstia was found in upper 4 ft of unit. Unit 1 forms subvertical face...............	12.5	12.5
Total Chattanooga Shale (incomplete)...	371.8	



*Oliver and others [1969]





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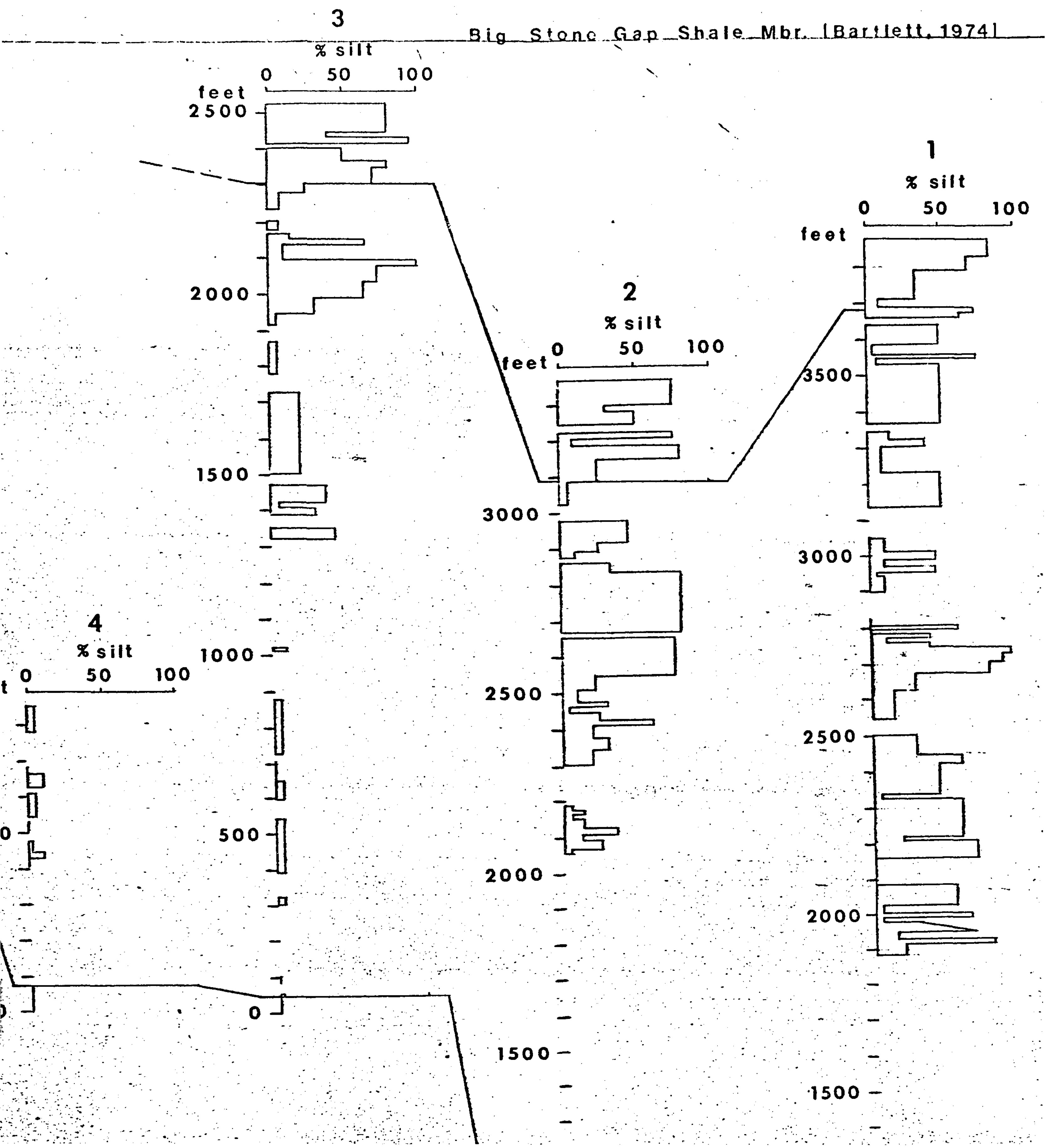

Big Stone Gap Shale Mbr. [Bartlett, 1974]
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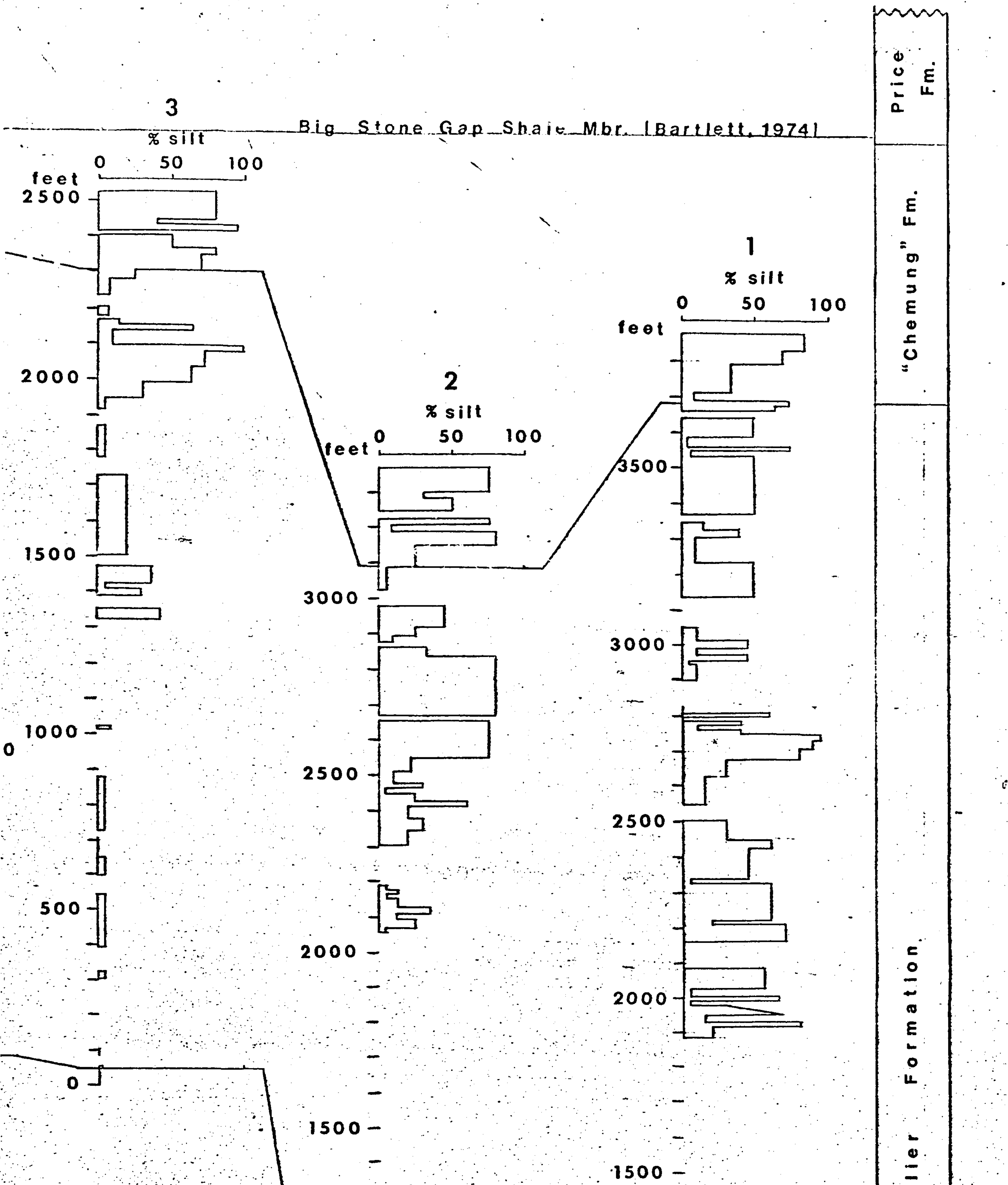
PLATE 1



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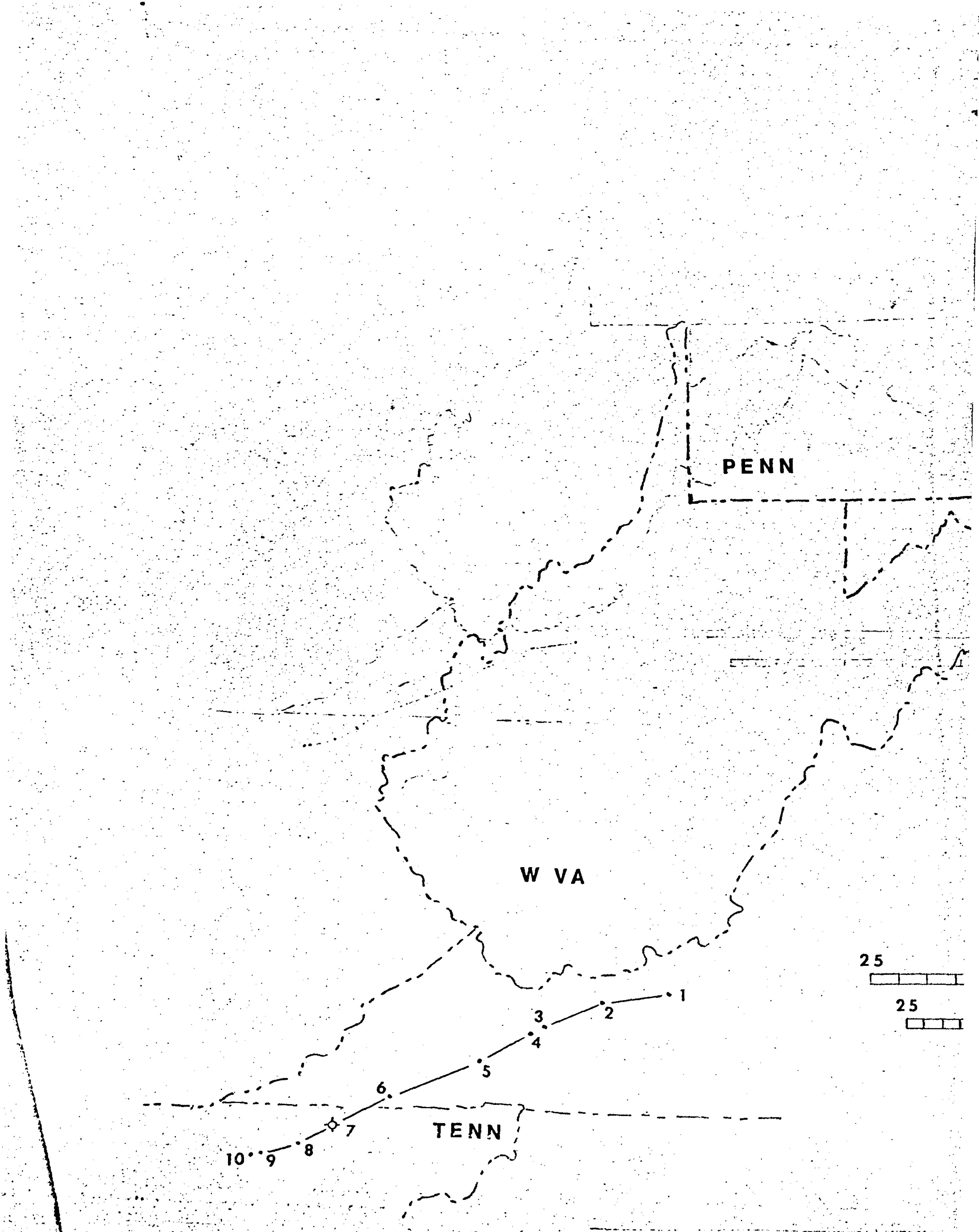
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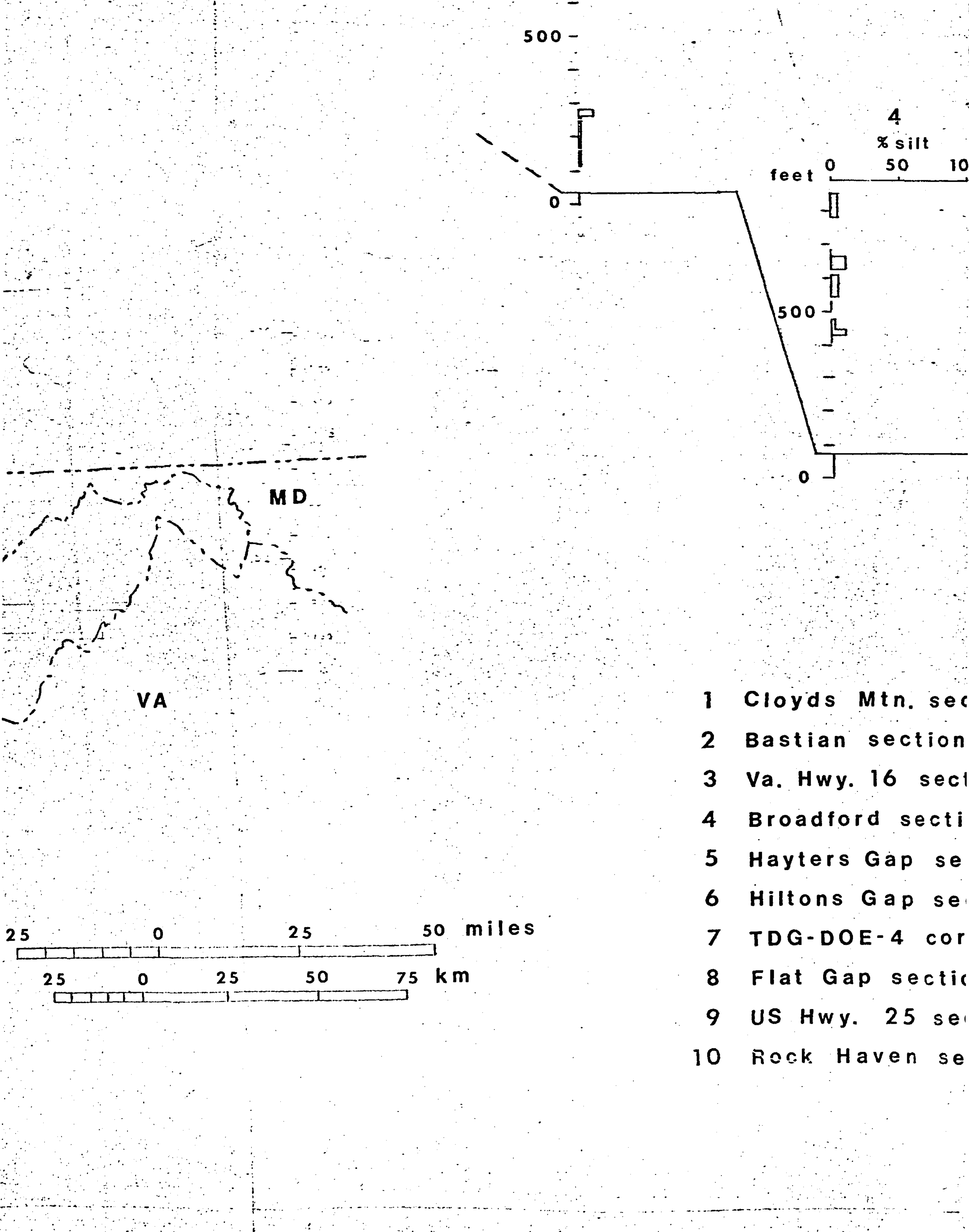
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7 TDG-DOE-4 cor
8 Flat Gap sectio
9 US Hwy. 25 se
10 Rock Haven se
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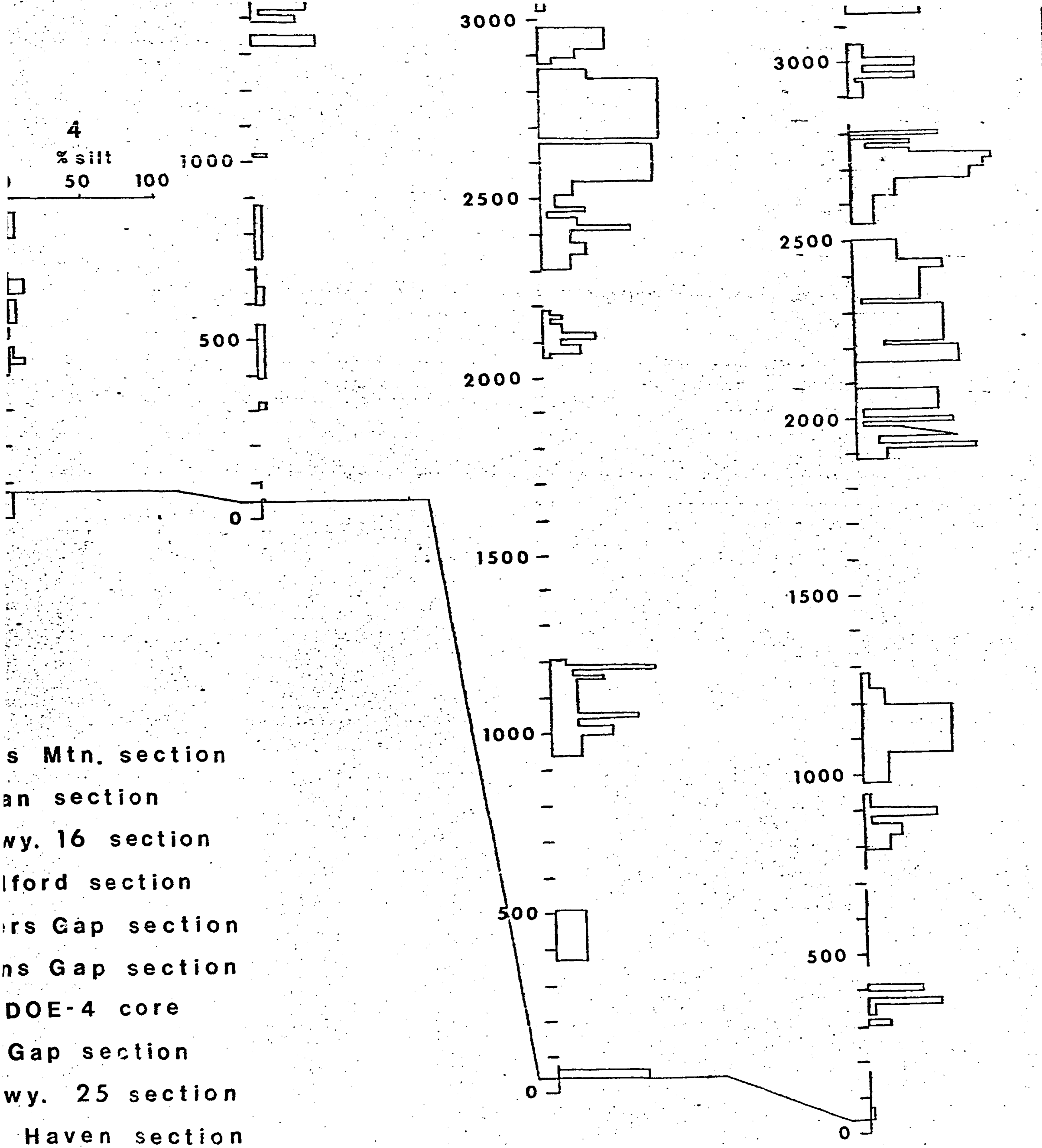
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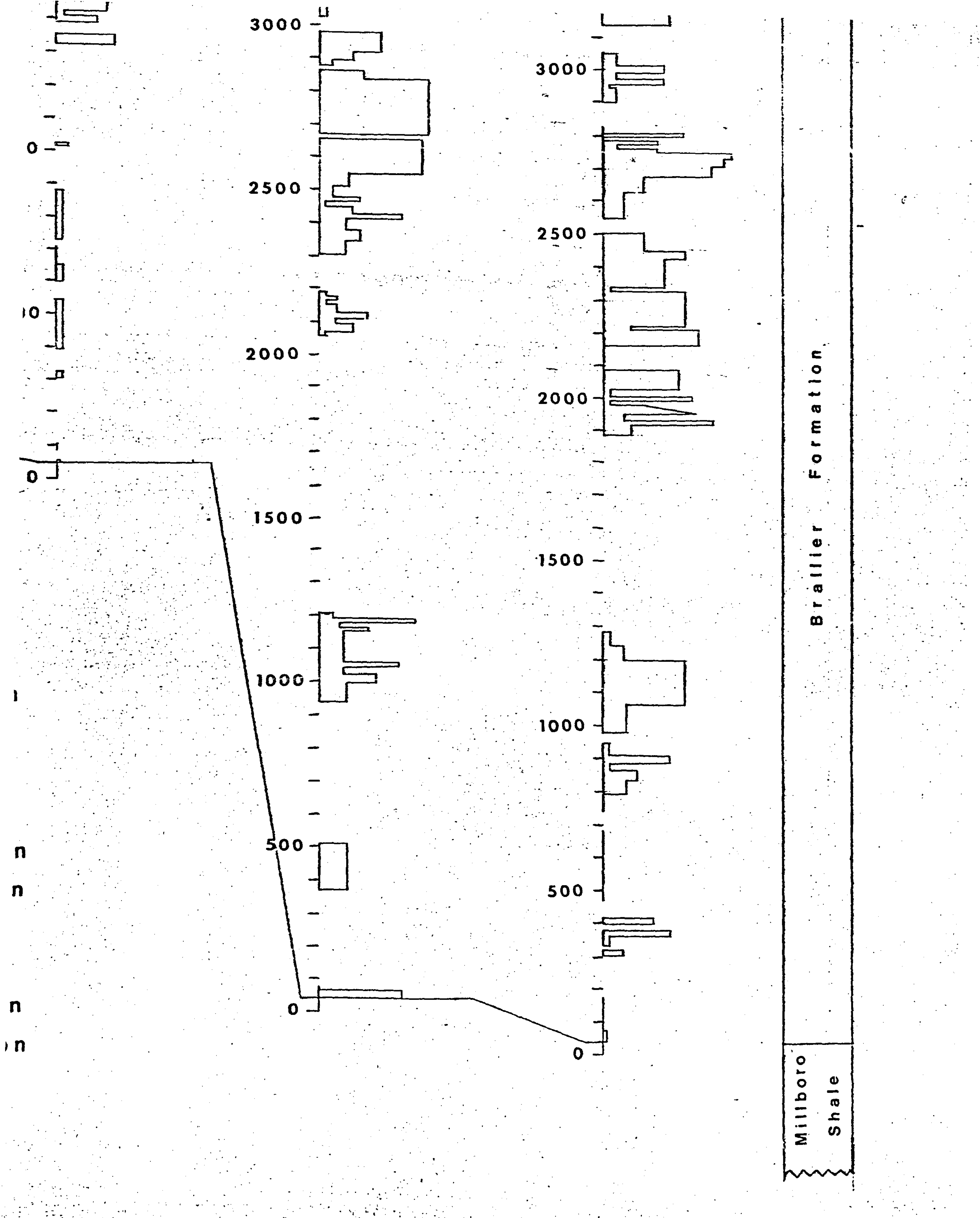
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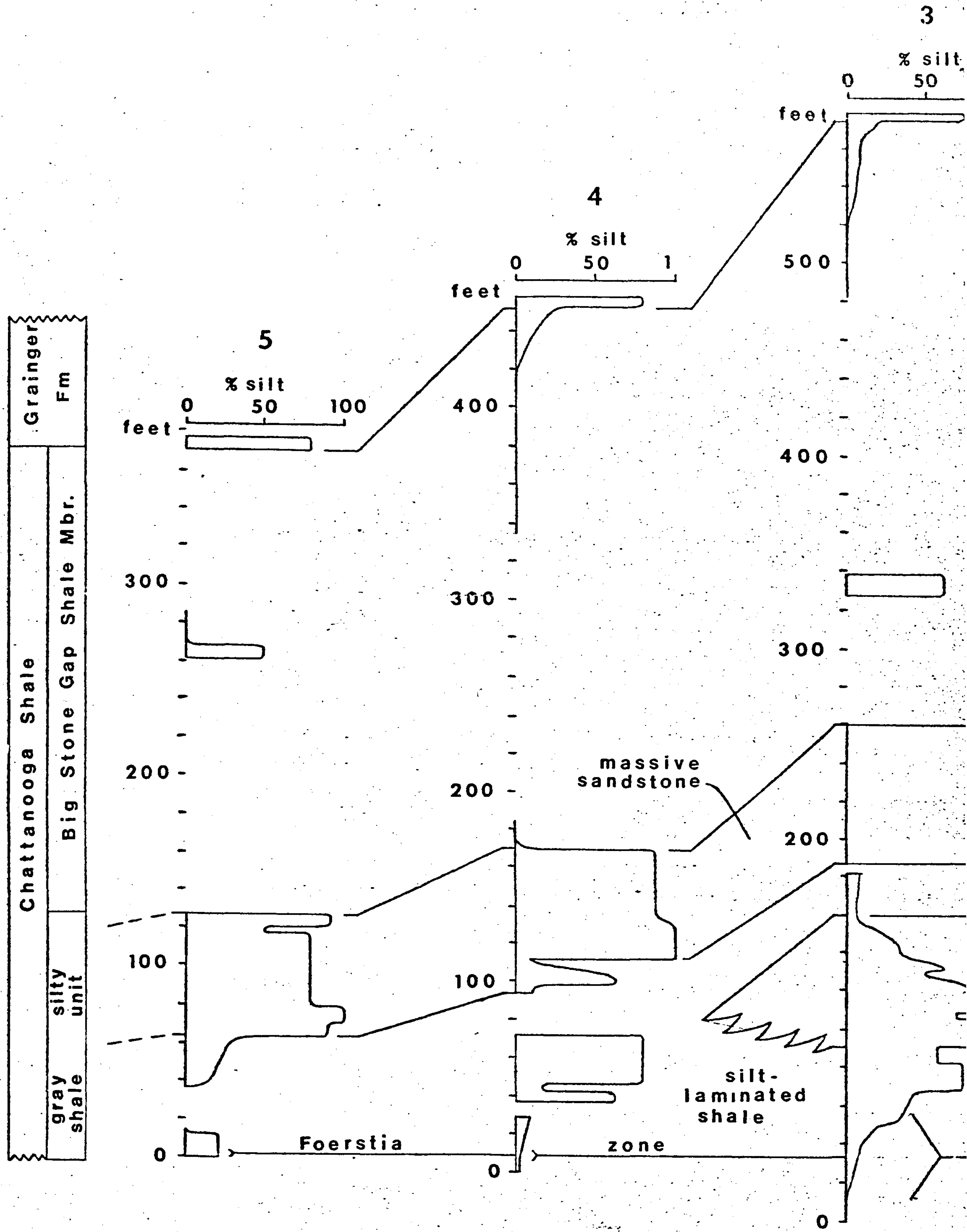
Brallier Formation
Millboro Shale



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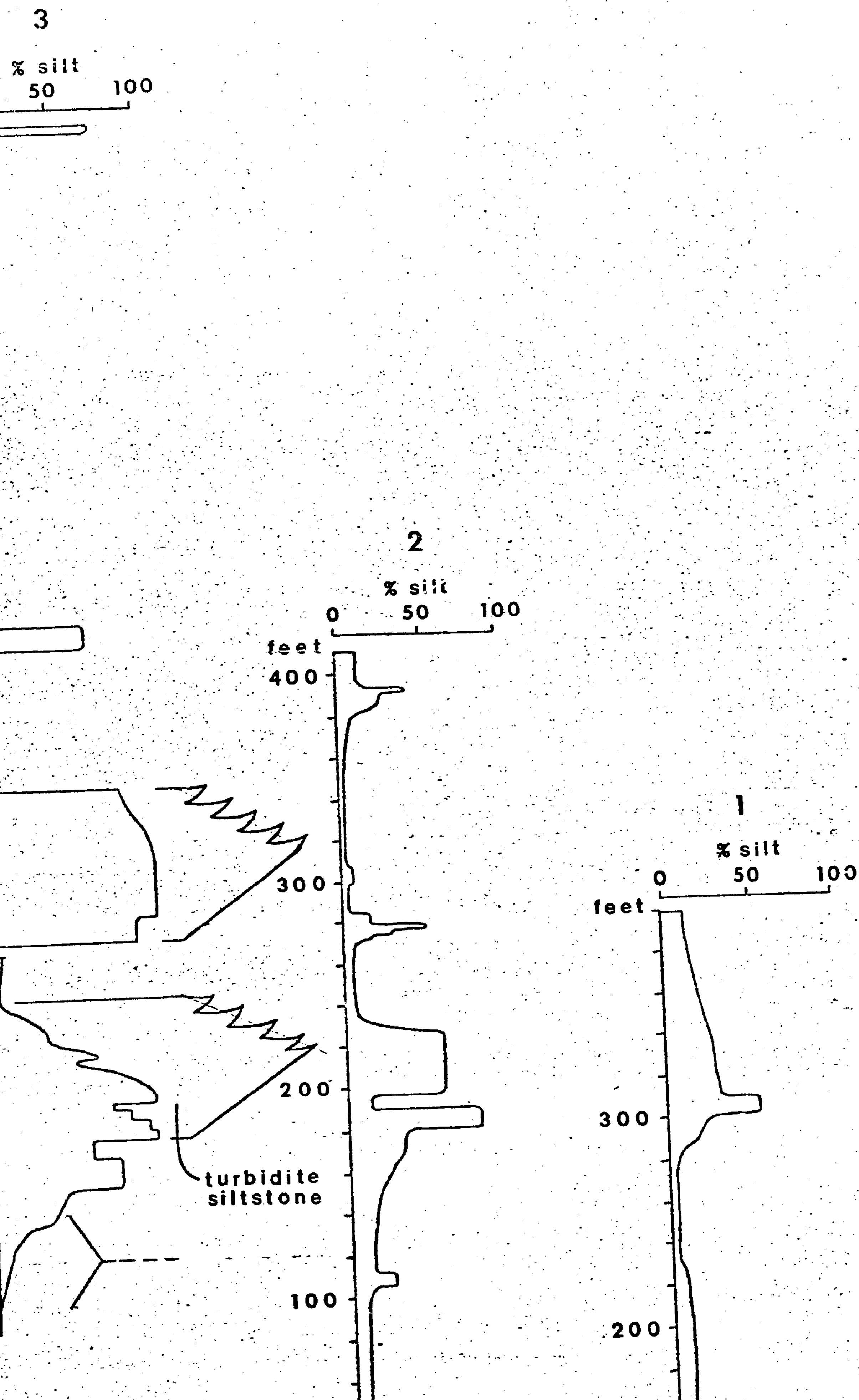
Grainger Fm
Chattanooga Shale
Big Stone Gap Shale Mbr.
silty unit
gray shale
massive sandstone
silt-laminated shale
Foerstia
zone

PLATE 2



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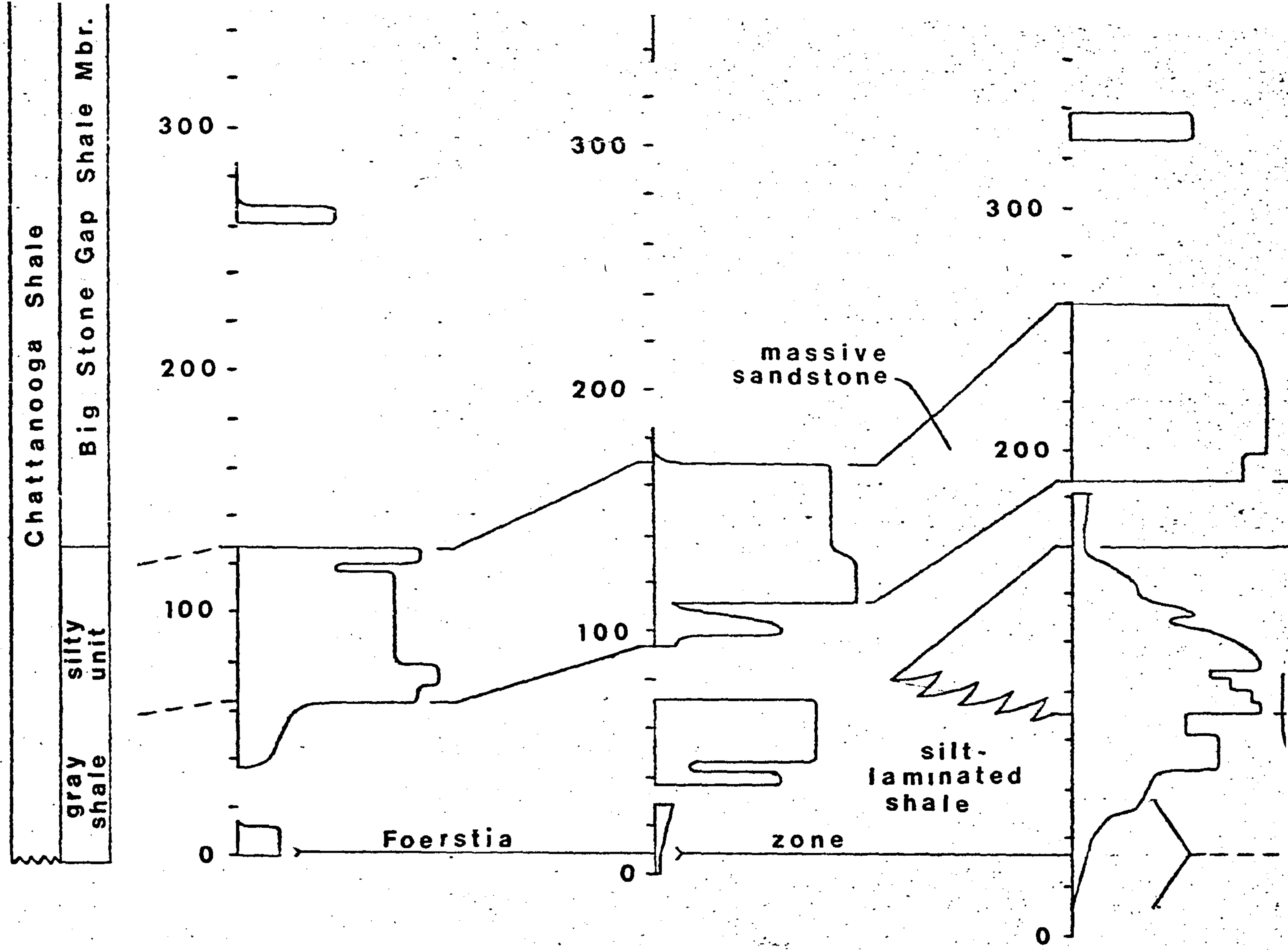

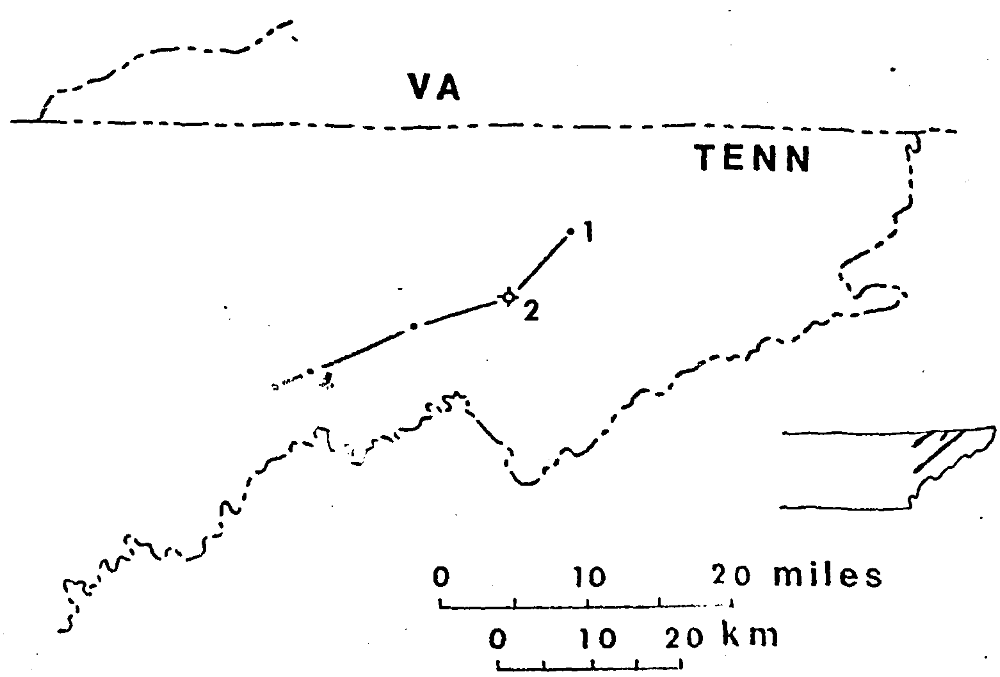

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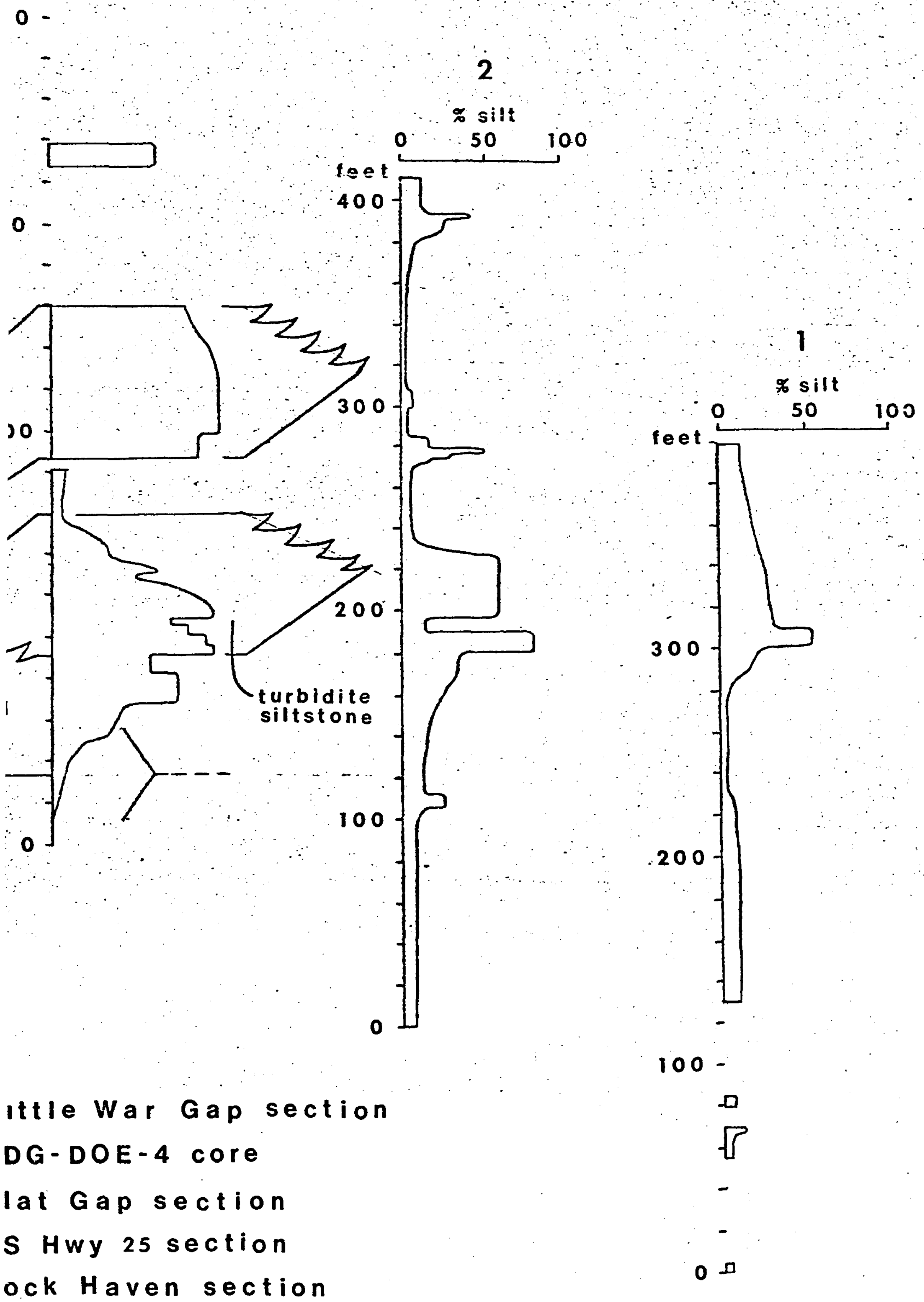
5 Rock Haven s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ock Haven section