

2004

Facies analysis of the Devonian Gordon Stray Sandstone in West Virginia

Patrick S. McBride
West Virginia University

Follow this and additional works at: <https://researchrepository.wvu.edu/etd>

Recommended Citation

McBride, Patrick S., "Facies analysis of the Devonian Gordon Stray Sandstone in West Virginia" (2004).
Graduate Theses, Dissertations, and Problem Reports. 1978.
<https://researchrepository.wvu.edu/etd/1978>

This Thesis is protected by copyright and/or related rights. It has been brought to you by the The Research Repository @ WVU with permission from the rights-holder(s). You are free to use this Thesis in any way that is permitted by the copyright and related rights legislation that applies to your use. For other uses you must obtain permission from the rights-holder(s) directly, unless additional rights are indicated by a Creative Commons license in the record and/ or on the work itself. This Thesis has been accepted for inclusion in WVU Graduate Theses, Dissertations, and Problem Reports collection by an authorized administrator of The Research Repository @ WVU. For more information, please contact researchrepository@mail.wvu.edu.

FACIES ANALYSIS OF THE
DEVONIAN GORDON STRAY SANDSTONE IN WEST VIRGINIA

Patrick S. McBride

Thesis Submitted to the
College of Arts and Sciences
at West Virginia University
in Partial Fulfillment of the Requirements
for the Degree of

Master of Science
in Geology

Richard Smosna, Ph.D., Chair
Thomas Kammer, Ph.D.
David Oldham, Ph.D.

Department of Geology and Geography

Morgantown West Virginia
2004

Keywords: Upper Devonian, Catskill Delta Complex, Gordon Stray Sandstone,
Jacksonburg-Stringtown field
Copyright 2004 Patrick S. McBride

ABSTRACT

FACIES ANALYSIS OF THE DEVONIAN GORDON STRAY SANDSTONE IN WEST VIRGINIA

Patrick S. McBride

Since its discovery in 1895, West Virginia's Jacksonburg-Stringtown field has had a primary production of 20 million barrels of oil (MMBO), with an additional 2 MMBO since 1991 when water flooding began. Based on 10 full-bore cores from Wetzel and Tyler Counties, the reservoir—the Gordon Stray Sandstone—is interpreted to be part of a barrier-island complex, comprising (from bottom to top) lower-shoreface, upper-shoreface, and foreshore sandstone and conglomerate. Tying core interpretations to 123 well logs across the field enables the various facies to be mapped. A north-south thick along the eastern part of the field (20-35 feet thick) reflects aggrading deposition during a slow rise of relative sea level. Conglomerate in the northeast indicates the presence of a feeder stream that supplied coarse sediment to the barrier complex. Facies distributions show that water depth increased seaward (west) and around the southern tip of the barrier island. The major pay zone occurs stratigraphically within the middle of the shoreface facies, a medium-grained, well sorted sandstone with permeabilities of 25-250 milli-darcy (mD). This pay zone may be best developed to the northeast and southeast, compartmentalized by an intervening shaly zone that perhaps accumulated within a minor recess into the barrier. The barrier-island then prograded rapidly westward, laying down a thin sandstone (7-11 feet). Immediately above the barrier-beach facies are washover sandstone and lagoonal mudstone, formed as part of the overall Gordon Stray progradation. Mapping of these

back-barrier facies identifies two washover lobes in the western part of the field, spilling eastward into the lagoon. This map pattern strongly suggests that another thick barrier-island complex exists at some close distance to the west of the Jacksonburg-Stringtown field, a previously unknown exploration target in the Upper Devonian Gordon Stray Sandstone.

TABLE OF CONTENTS

	Page
LIST OF FIGURES	vi
ACKNOWLEDGEMENTS	ix
INTRODUCTION	1
Area of Study	1
Purpose of Study	6
Methodology	6
REGIONAL STRATIGRAPHY	18
Basin Center	21
Slope and Prodelta	21
Delta Front	22
Shoreface and Terrestrial Facies	23
SUBSURFACE SANDSTONES	26
DEPOSITIONAL ENVIRONMENTS	34
Shelf	34
Description	34
Interpretation	34
Lower Shoreface	39
Description	39
Interpretation	40
Upper Shoreface	43
Description	43
Interpretation	46
Foreshore	47
Description	47
Interpretation	48
Washover Fan	51
Description	51
Interpretation	55
Lagoon	58
Description	58
Interpretation	58
INTERPRETATION OF MAPS AND CROSS SECTIONS	61
Structure map	61
Lower Gordon Stray	61
Upper Gordon Stray	72

	Page
Cross sections	76
PRODUCTION AND EXPLORATION	85
CONCLUSIONS	91
REFERENCES	93
APPENDIX – CORE DESCRIPTIONS	96
Ball 18	97
Peter Horner 9	102
Lemasters 0-13	105
Reilly 13	110
J H Dawson	114
J Mills 158-A	116
Lemasters 17	120
Ball 19	123
J Mills 154	127
Thompsons Heirs 8	132

LIST OF FIGURES

Figure	Page
1. Jacksonburg-Stringtown Field, including the Mills extension. From Avary in press.	2
2. Jacksonburg-Stringtown shown in outline. Waterflood area shown in shaded area. Cores identified by well name. Different shading represents production units as defined by PennzEnergy. From Avary, in press.	3
3. Map showing location of the 123 wells used in the present study of the Jacksonburg-Stringtown Field and location of the 10 full-bore cores. Approximate line drawn between the Jacksonburg-Stringtown field and the Mills extension.	5
4. J H Dawson F-14 with Gamma Ray signature	7
5. Lemasters 0-13 Well with Gamma Ray signature	8
6. Ball 19 Well with Gamma Ray signature	9
7. Ball 18 Well with Gamma Ray signature	10
8. Lemasters 17 with Gamma Ray signature	11
9. Thompson Heirs 8 with Gamma Ray signature	12
10. Reilly 13 with Gamma Ray signature	13
11. Peter Horner 9 with Gamma Ray signature	14
12. J Mills 154 with Gamma Ray signature	15
13. J Mills 158-A	16
14. Cross-section of the Acadian clastic wedge, showing the relationship of the Price-Rockwell and Catskill delta complexes. Gordon Stray sandstone of this study is a part of the Venago play of upper Catskill Delta complex. From Boswell et al, 1996.	19
15. Regional lithostratigraphic nomenclature for outcrop and subsurface geology in West Virginia and Pennsylvania. Gordon Stray sandstone of this study is situated within Venago formation of northern West Virginia subsurface. From Boswell et al, 1996.	20
16. East west cross-section showing distribution of Catskill sandstones in the Upper Famennian. Gordon Stray sandstone is subject of present study. From Boswell, 1988.	25
17. Classification of Acadian clastic wedge sandstones by trend relative to depositional strike and paleogeographic position. Sandstones of Gordon interval are classified as S2. From Boswell and Jewell, 1988.	27
18. Thickness of the Gordon interval in West Virginia and Pennsylvania. From Boswell et al, 1996.	30
19. Thickness of the Gordon sandstone. From Boswell and Jewell, 1988.	31
20. Thickness of the Gordon Stray sandstone. From Boswell and Jewell, 1988.	32
21. Full core photo of the Ball 18 well	35
22. Full core photo of the J Mills 154 well	36

23. Full core photo of the Reilly 13 well	37
24. Shelf mudstone with sand ripples and small sand-filled horizontal burrows from the Reilly 13 well. Scale in tenths of inches.	38
25. Lower shoreface sandstone from the J Mills 154 Well (3350'). Core shows fine-grained sandstone with horizontal stratification. Scale in tenths of inches.	41
26. Lower shoreface from the Ball 18 well (3004.5'). Core shows large-scale cross-bedding with shale clasts along the bedding planes. Core plug was taken out of the middle of the core. Scale in tenths of inches.	42
27. Upper shoreface from the Ball 18 core (3001.6'). Core shows medium-grained sandstone with a conglomerate layer at bottom and horizontal stratification. Scale in tenths of inches.	44
28. Upper shoreface from the Lemasters 17 core (2873.3'). Core shows medium- to coarse-grained sandstone with large-scale planar cross-bedding. Scale in tenths of inches.	46
29. Foreshore in the Ball 19 core (3098.5'). Core shows an interbedding of fine-grained sandstone with conglomerate. Small scour surface at base of conglomerate. Scale in tenths of inches.	49
30. Foreshore from the Peter Horner 9 core (2893'). Core shows interbedded conglomerate and medium-grained sandstone with horizontal stratification and small- scale planar cross-bedding. Scale in tenths of inches.	50
31. Washover fans from the J Mills 154 core (3313'). Core shows fine-grained sandstone interbedded with thin shale layers. The sandstone is rippled and shows small-scale planar cross-bedding. Scale in tenths of inches.	53
32. Washover lobe from the Ball 18 core (2979'). Sandstone is medium- to coarse-grained with interbedded shale lenses. Within the sandstone are fragments of brachiopod shells. Burrowing destroyed layering. Scale in tenths of inches.	54
33. Washover channel from the Reilly 13 core. Core shows a sharp contact with the underlying shale and very coarse sandstone interbedded with fine-grained sandstone. Section shows a fining-upward sequence. Scale in tenths of inches.	56
34. Lagoon shale from the Reilly 13 core (2869'). Core shows shale with horizontal sand filled burrows. Interbedded sandstone at top of core. Scale in tenths of inches.	59
35. Structure map of the Jacksonburg-Stringtown field, created on the top of the barrier-island sandstone.	62
36. Gamma-ray log for Tyler 1541 showing placement of picks for the bottom of the barrier-island sandstone, top of the barrier-island sandstone, and top of the Gordon Stray.	63
37. Isopach map of barrier-island sandstone.	65
38. Isopach map of the lower shoreface sandstone, based on ten cores only.	66
39. Isopach Map of the upper shoreface sandstone, based on ten cores only.	67
40. Isopach map of the foreshore sandstone, based on ten cores only.	68
41. Isolith map of Conglomerate. Based on 10 cores only.	70

42. Paleogeographic map of the Gordon Stray sandstone adapted from Figure 20, showing feeder streams, position(s) of barrier island, and the Jacksonburg-Stringtown field. Based on Boswell and Jewell, 1988.	71
43. Isopach map of upper Gordon interval.	74
44. Map of the upper Gordon sandstone. Washover lobes shown in solid black outline.	75
45. Isolith map of the upper Gordon shale.	77
46. Location of cross sections	78
47. EW Cross Section 1	79
48. EW Cross Section 2	80
49. EW Cross Section 3	81
50. EW Cross Section 4	82
51. NS Cross Section 1	83
52. NS Cross Section 2	84
53. Total shale thickness within the lower and upper shoreface, and foreshore facies	87
54. Gordon and Gordon Stray producing wells drilled from 1960 to 2000. From Avary 2001.	88
55. Location of all wells drilled to the Gordon and Gordon Stray from 2000 to 2004 away from the Jacksonburg-Stringtown field drilled to the Gordon. Data from the West Virginia Geologic and Economic Survey.	89

ACKNOWLEDGMENTS

I would like to express my sincerest gratitude to my advisor Dr. Richard Smosna. He has been a source of encouragement and knowledge throughout my career at WVU. Without him this project would not have been completed. Thanks for believing in me. I would also like to express my thanks to Dr. Thomas Kammer and Dr. David Oldham who throughout the project provided me with support and insight.

I would also like to express my thanks and gratitude to the West Virginia Geological and Economic Survey, especially Dr. Dave Matchen and K. Lee Avary for their support, assistance and knowledge.

Most important I would like to thank God for not only the strength and wisdom to finish this project, but for the many blessings He has given me.

“Trust in the LORD with all your heart and lean not on your own understanding; in all your ways acknowledge him, and he will make your paths straight.” Proverbs 3:5,6

INTRODUCTION

Area of Study

The Jacksonburg-Stringtown field (Figure 1), which encompasses 15,386 acres in West Virginia, was discovered in 1895 (Avary, in press). It is located in Wetzel, Tyler, and Doddridge counties along the axis of the Burchfield syncline, between the Arches Fork and Littleton anticlines. The Jacksonburg-Stringtown Field is similar to many oil fields in the state in that oil is trapped along structural lows downdip of gas accumulations (Matchen, in press).

Between 1897 and 1901, over 500 wells were drilled in the field; however, most of them were plugged by 1910. The average well spacing is one well per 13 acres, and the average production life of a well, 20 years. The field has an estimated primary production of 20 MMBO, and the original oil in place is estimated at 88.5 MMBO (Whieldon and Eckard, in Avary, in press).

In 1981 a pilot water-flood project was installed in the Gordon Stray sandstone of the Jacksonburg-Stringtown Field. The project was designed to stimulate 5 wells on a 34-acre section. In the first 4 years, an average of 1300 barrels of oil per acre (BOPA) was recovered. It was not until 1990 that a full-scale water-flood project was begun to increase production. Since that time, more than 100 new wells have been drilled for water injection and 40 new wells have been drilled for production. Over 1,800,000 barrels of oil were produced from January 1991 through February 1999 as a result of the water-flooding (Avary, in press). The study area of this thesis encompasses only the area of the water flooding, although the Jacksonburg-Stringtown field is somewhat larger than the area of active water flooding (Figure 2).

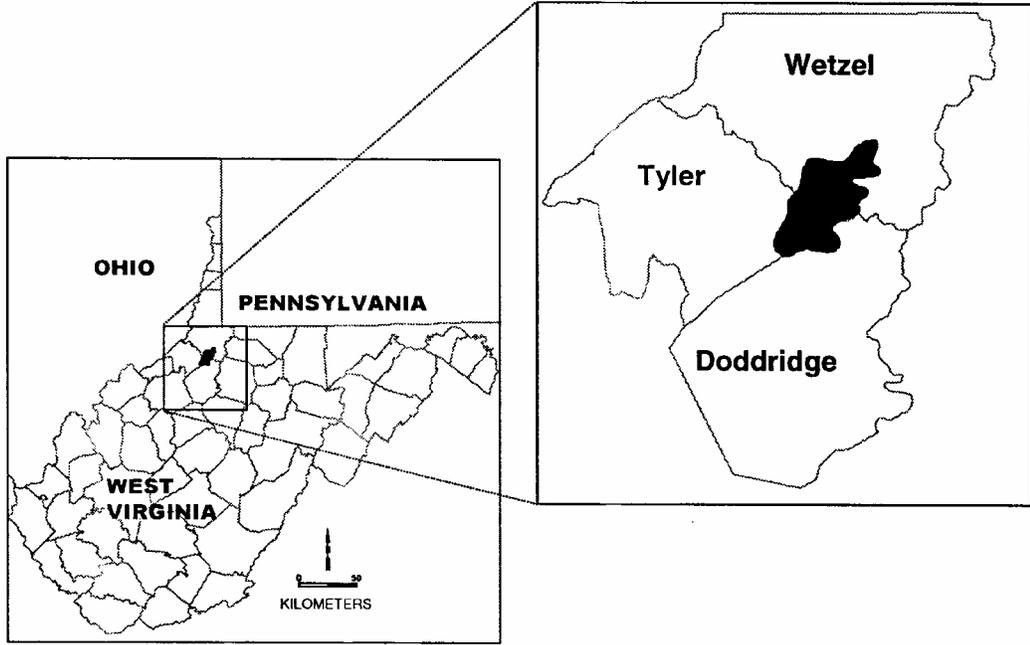


Figure 1. Jacksonburg-Stringtown Field, including the Mills extension. From Avary in press.

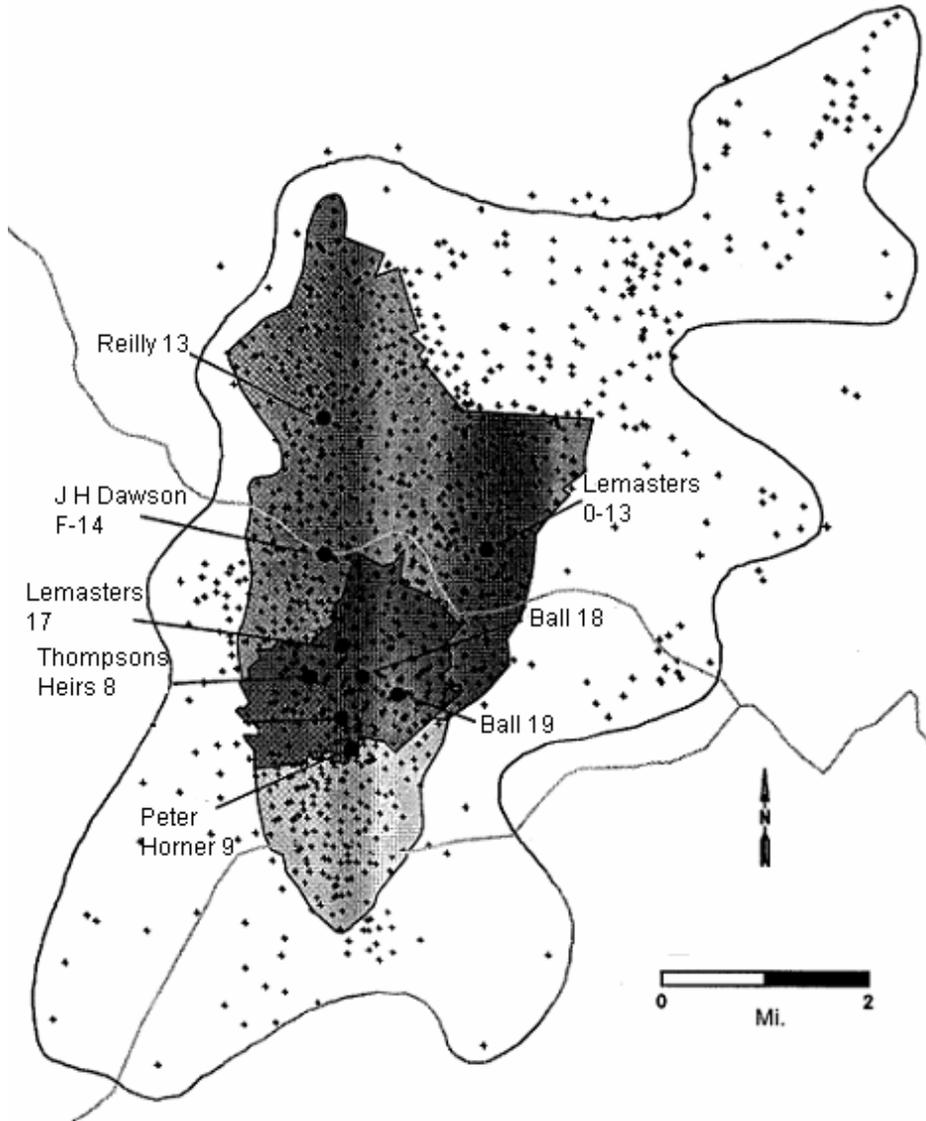


Figure 2. Jacksonburg-Stringtown shown in outline. Waterflood area shown in shaded area. Cores identified by well name. Different shading represents production units as defined by PennzEnergy. From Avary, in press.

To the northeast of the Jacksonburg-Stringtown field is an extension field named Mills (Figure 3). The history of this field is not known in detail. For the purpose of this study, the Mills extension is included as a part of the Jacksonburg-Stringtown field. An approximate line is drawn between the Jacksonburg-Stringtown field and the Mills extension to the northeast.

From the Jacksonburg-Stringtown field, 10 cores and 123 logs were available for study from the West Virginia Geological and Economic Survey (WVGES) (Figure 3).

Purpose of Study

The Jacksonburg-Stringtown field has been in existence for over 100 years; however, no detailed sedimentary study has been conducted on the Gordon Stray sandstone in this field. Work done by the WVGES in 2001 touched on this issue (Hohn, in press), but only general descriptions of lithofacies from six cores were presented and no facies interpretations offered. The primary objective of this thesis is to determine the exact facies and subfacies of the Gordon sandstone within the Jacksonburg-Stringtown Field. It is my hope that this thesis will provide valuable insight into the field for future development and allow better predictions to be made regarding the placement of future exploratory wells.

Methodology

To start this project, 10 cores were described inch-by-inch, paying careful attentions to bedding, texture, fossils and mineral content. A standard grain size comparator was used to determine grain size. While describing the cores, careful attention was also paid to sedimentary structures because such structures can greatly aid in the reconstruction of depositional environments. Upon completion of the core descriptions, stratigraphic columns were drawn for each core (Figures 4-13). The columns are drawn in such a way as to mimic the gamma-ray signature i.e., grain size increases to the left.

After completing the core descriptions and stratigraphic columns, the facies were interpreted. The stratigraphic columns were then compared to the gamma-ray log for that well. The logs matched quite well with the texture as recorded in the stratigraphic column, and individual facies could be identified. Using this correlation of facies to the

Gamma-Ray Curve

J H Dawson F-14 95-1532

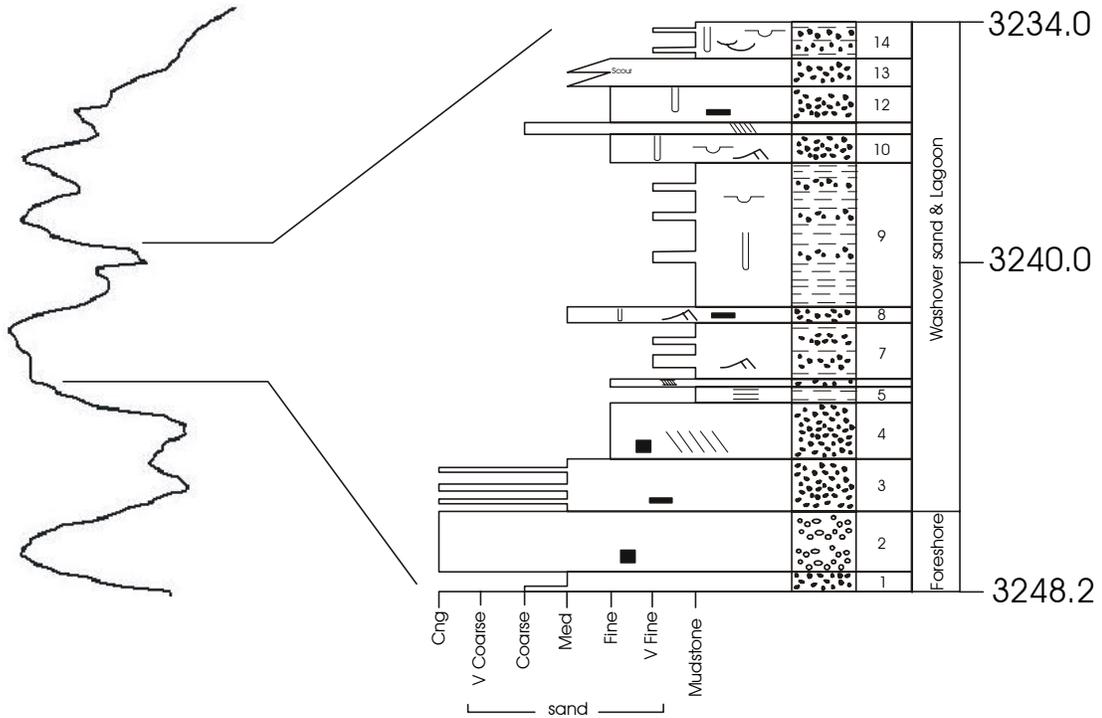


Figure 4. J H Dawson F-14 core with gamma-ray log signature

Key To Symbols applies to Figures 5-13 also.

- | | | | |
|--|-------------------|--|---|
| | Conglomerate | | Graded bedding |
| | Sandstone | | Ripples/ ripple bedding |
| | Shale | | Planar cross-stratification small-scale |
| | Siderite nodules | | Planar cross-stratification large-scale |
| | Quartz Pebble | | Planar stratification |
| | Shale clast | | Trough cross-stratification |
| | Horizontal burrow | | Brachiopods |
| | Vertical burrow | | |

Gamma-Ray Curve

Lemasters 0-13 103-1547

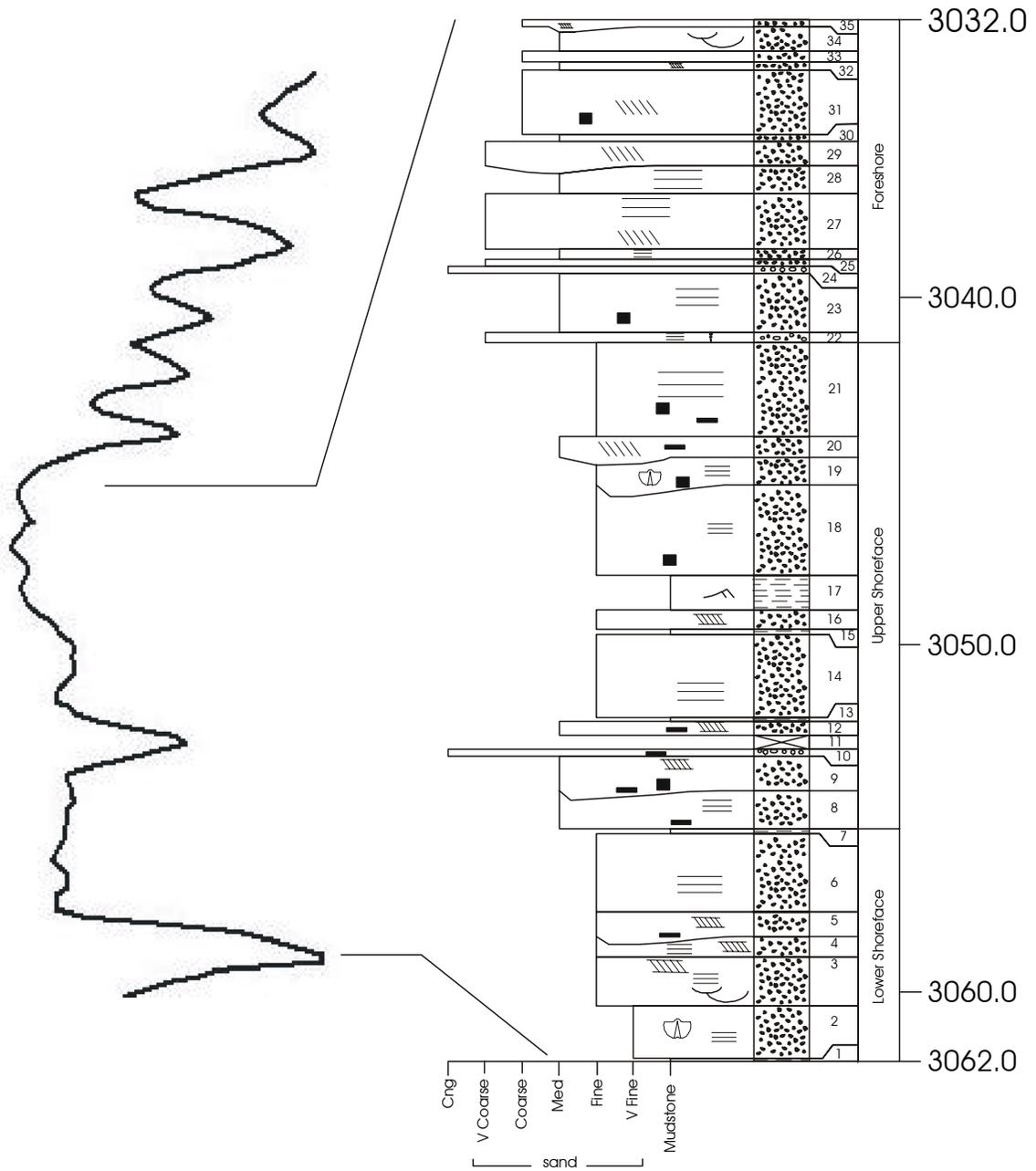


Figure 5. Lemasters 0-13 core with gamma-ray log signature.

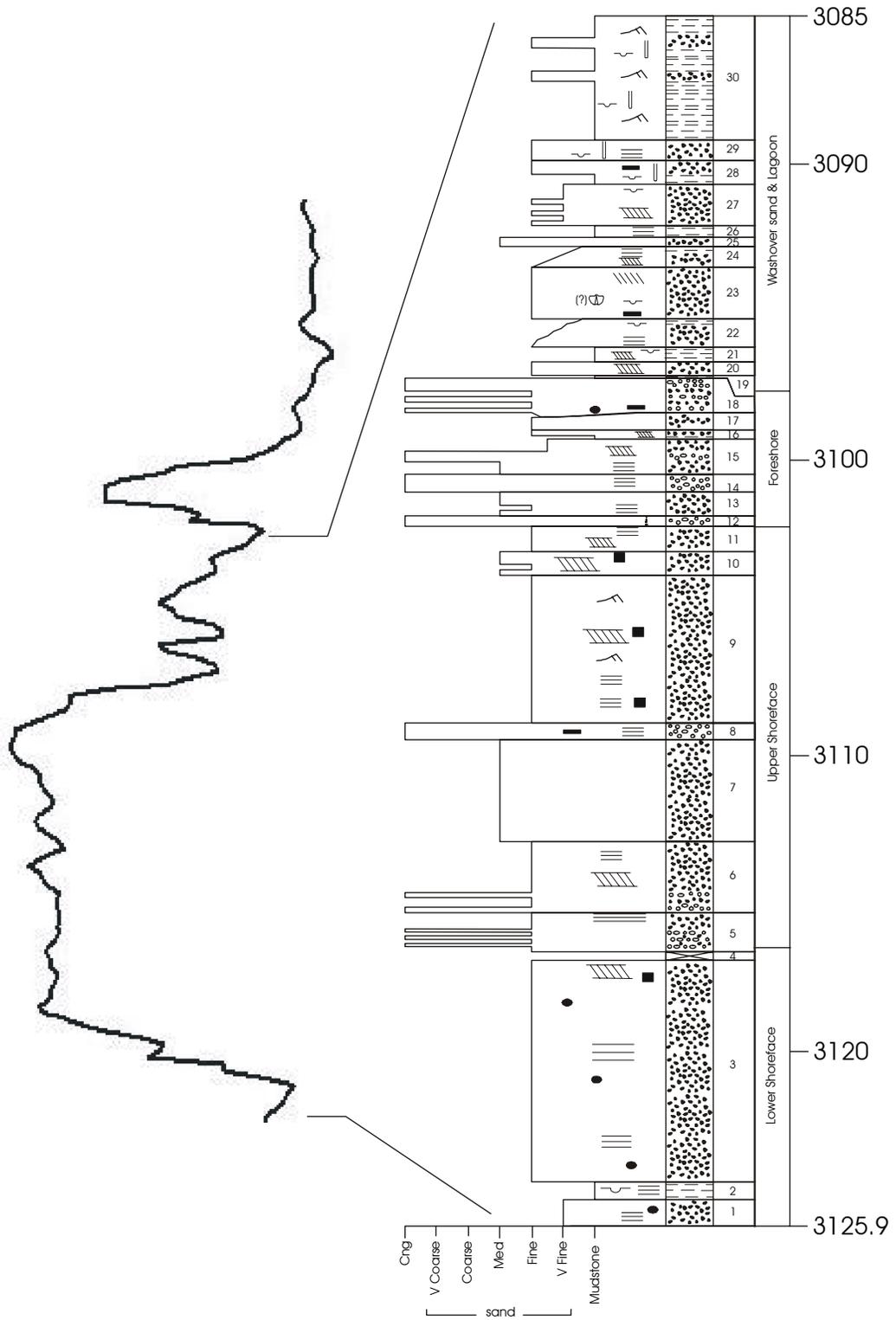


Figure 6. Ball 19 core with gamma-ray log signature.

Gamma-Ray Curve

Ball 18 95-1125

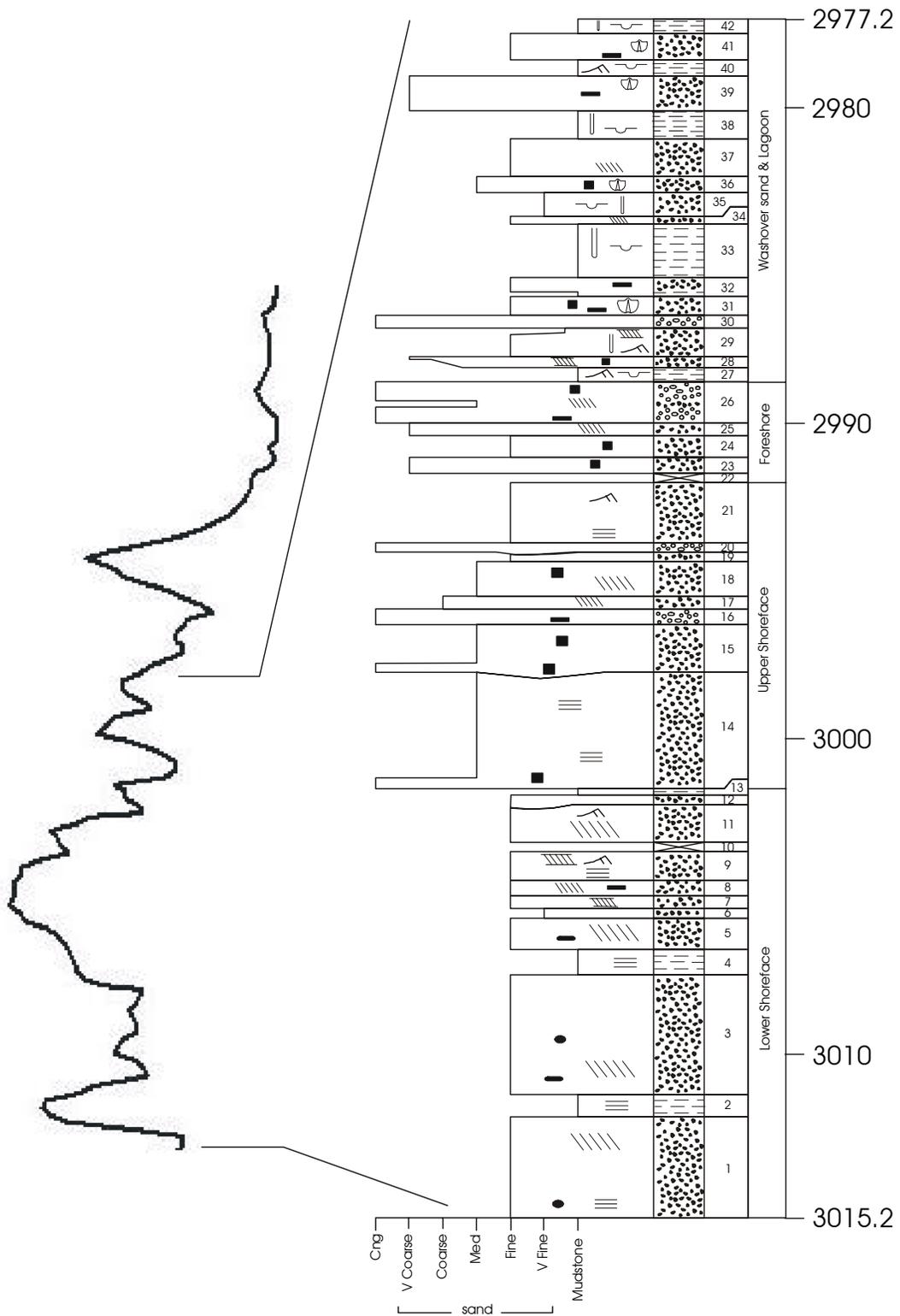


Figure 7. Ball 18 core with gamma-ray log signature.

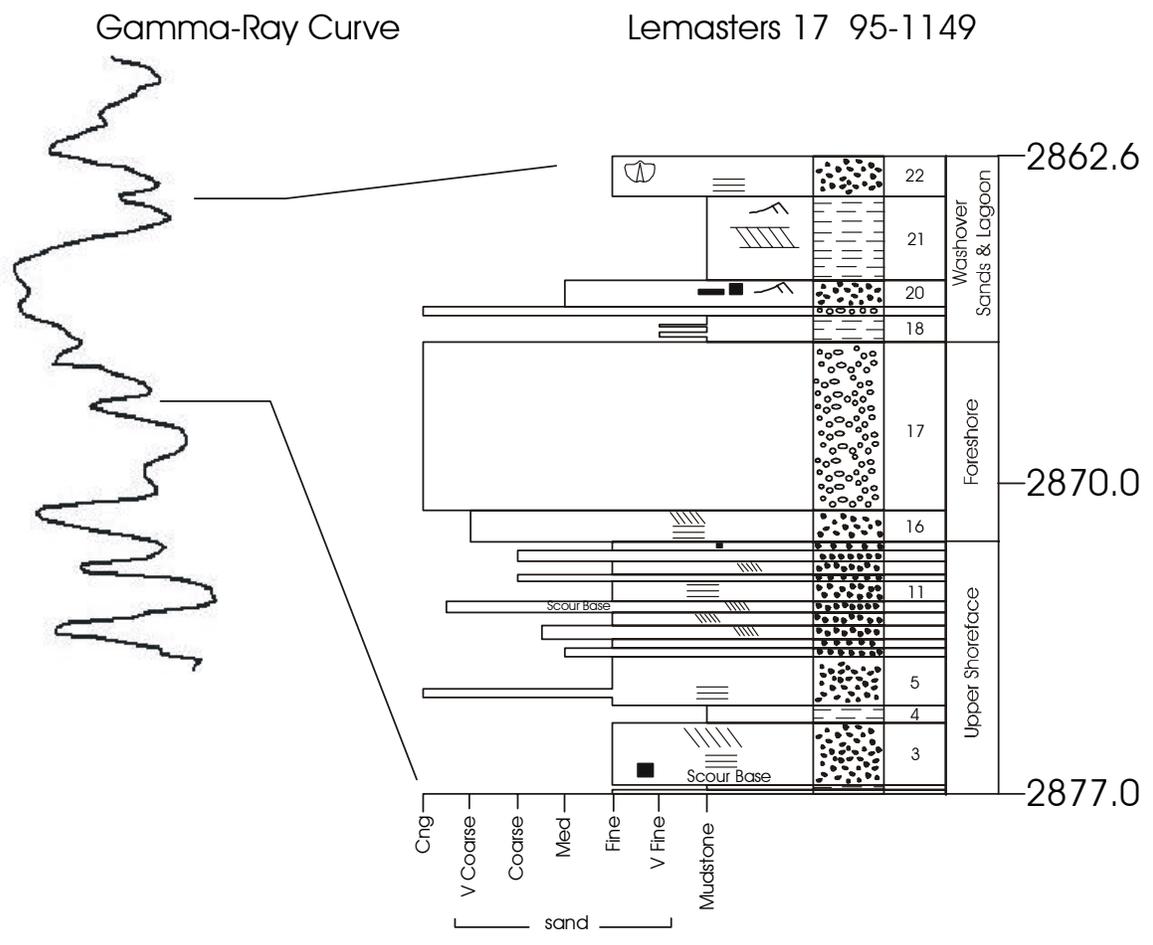


Figure 8. Lemasters 17 core with gamma-ray log signature.

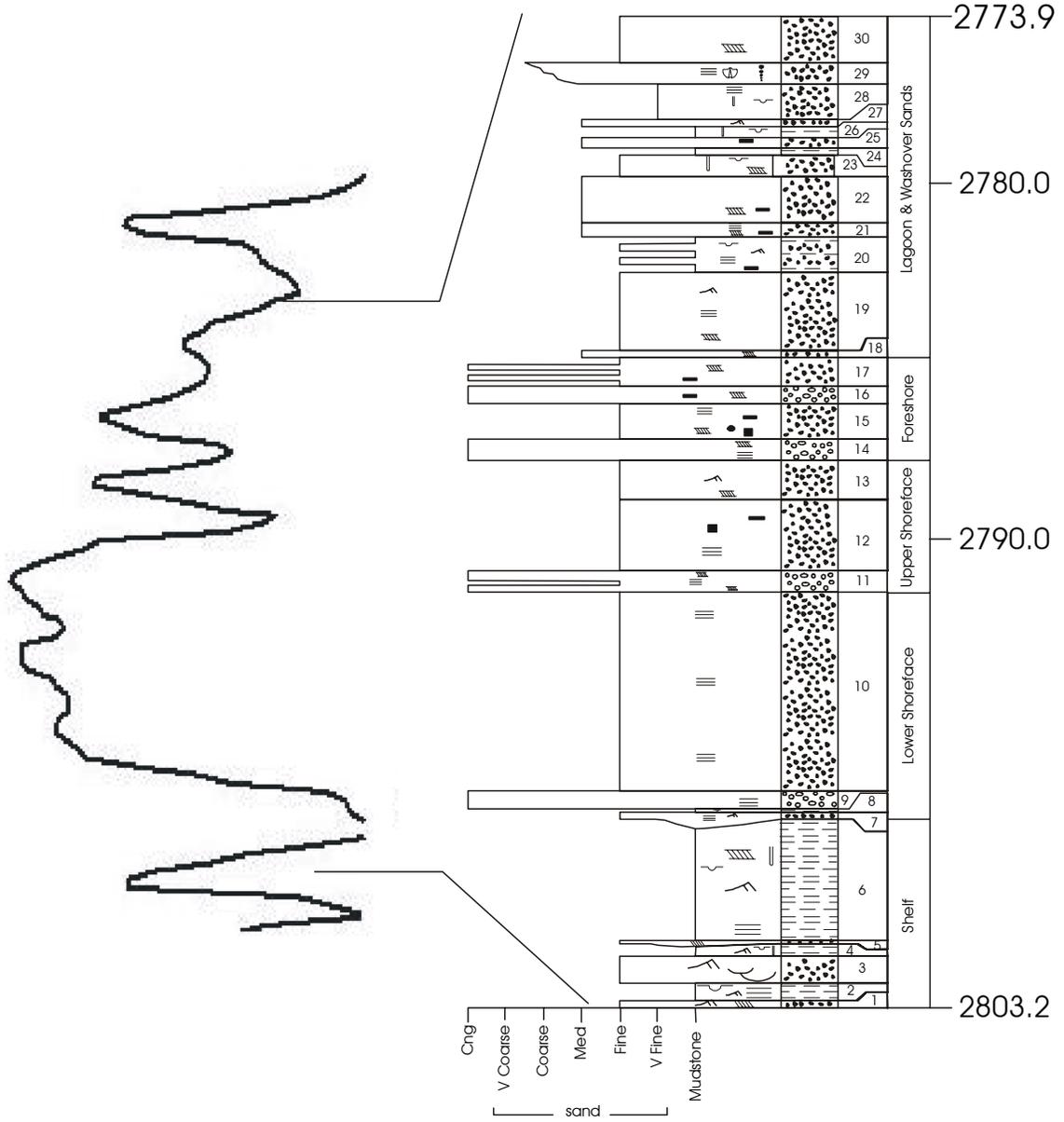


Figure 9. Thompson Heirs 8 core with gamma-ray log signature.

Gamma-Ray Curve

Reilly 13 103-1315

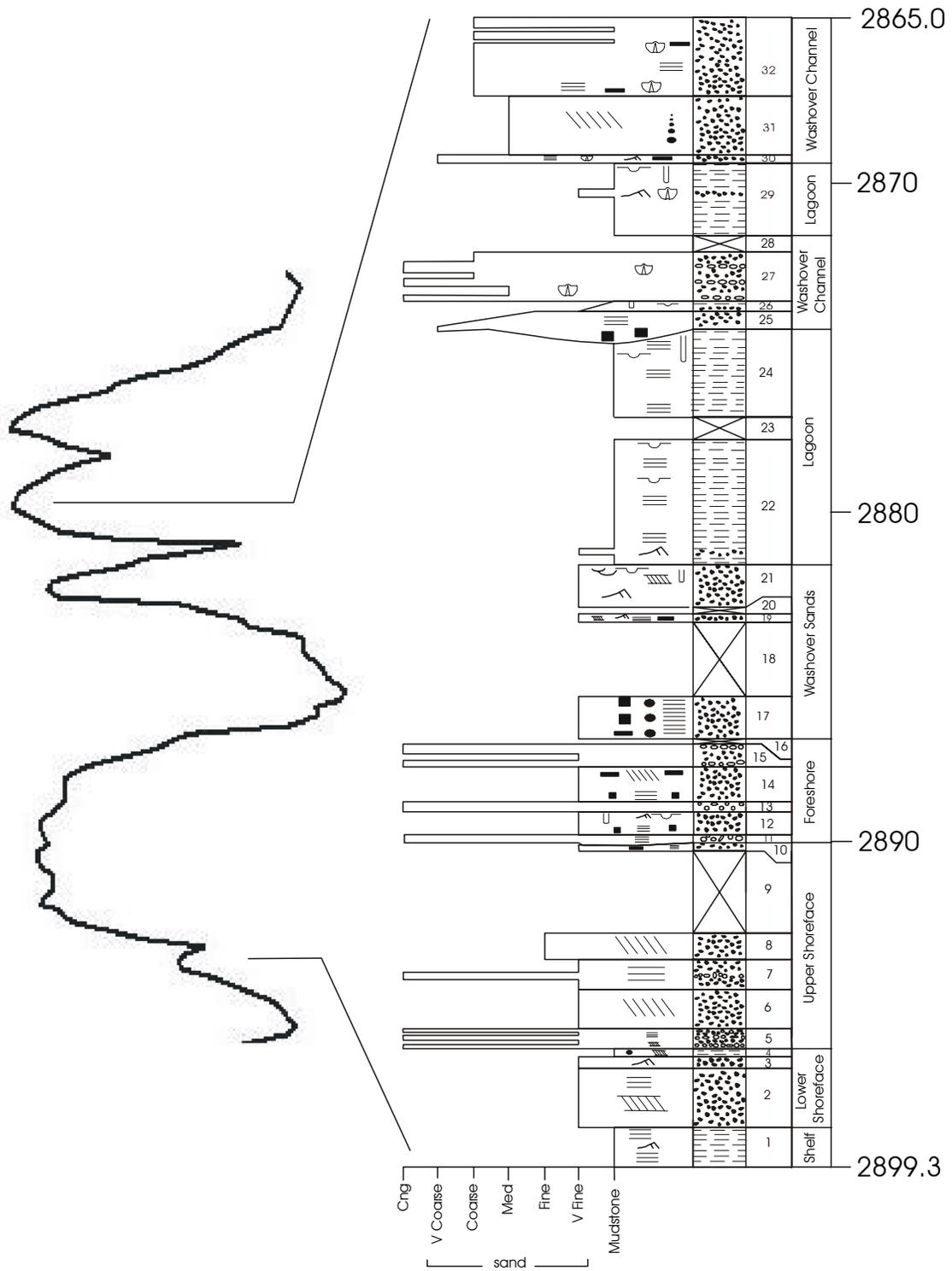


Figure 10. Reilly 13 core with gamma-ray log signature.

Gamma-Ray Curve

Peter Horner 9 95-741

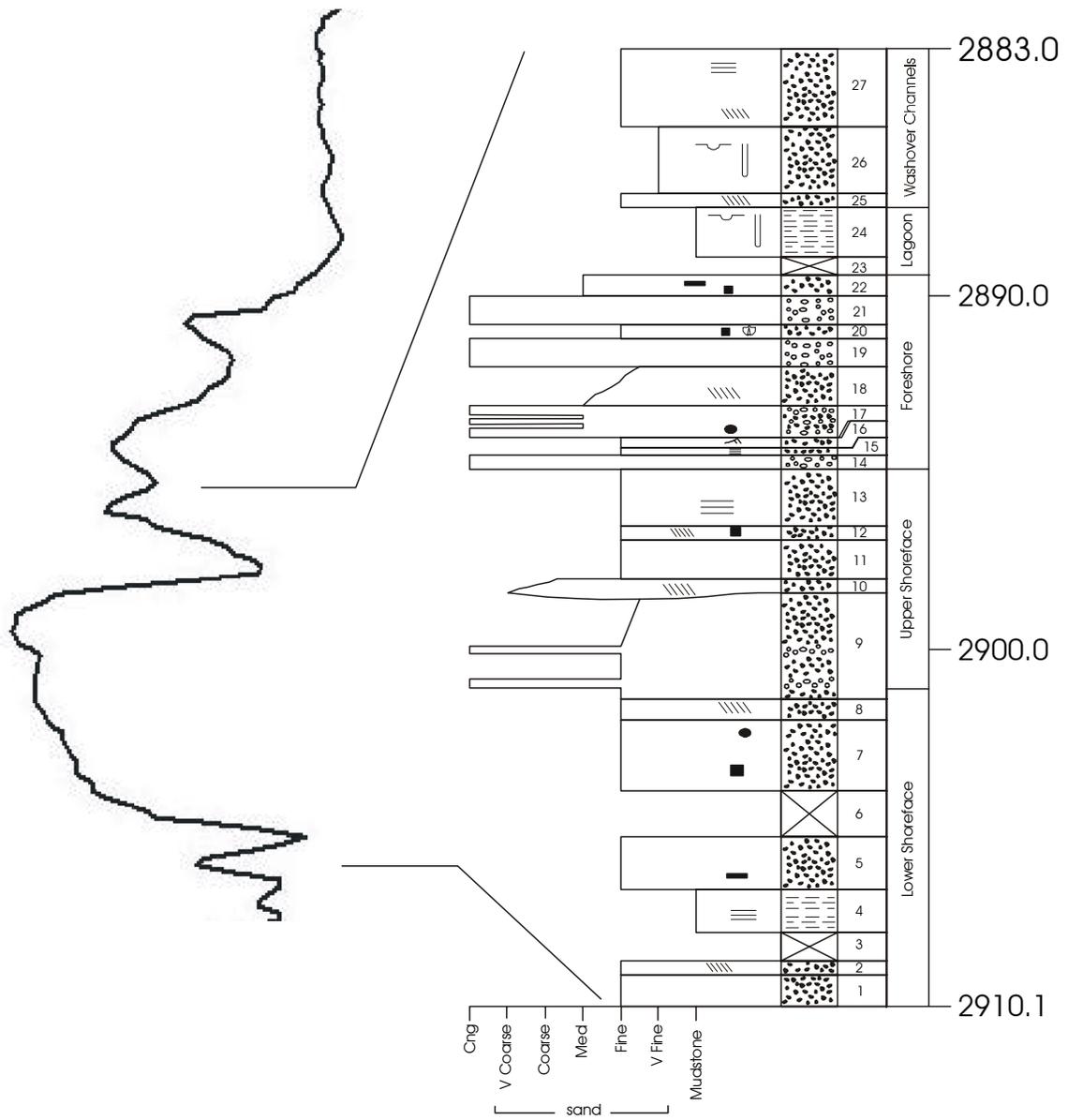


Figure 11. Peter Horner 9 core with gamma-ray log signature.

Gamma-Ray Curve

J Mills 154

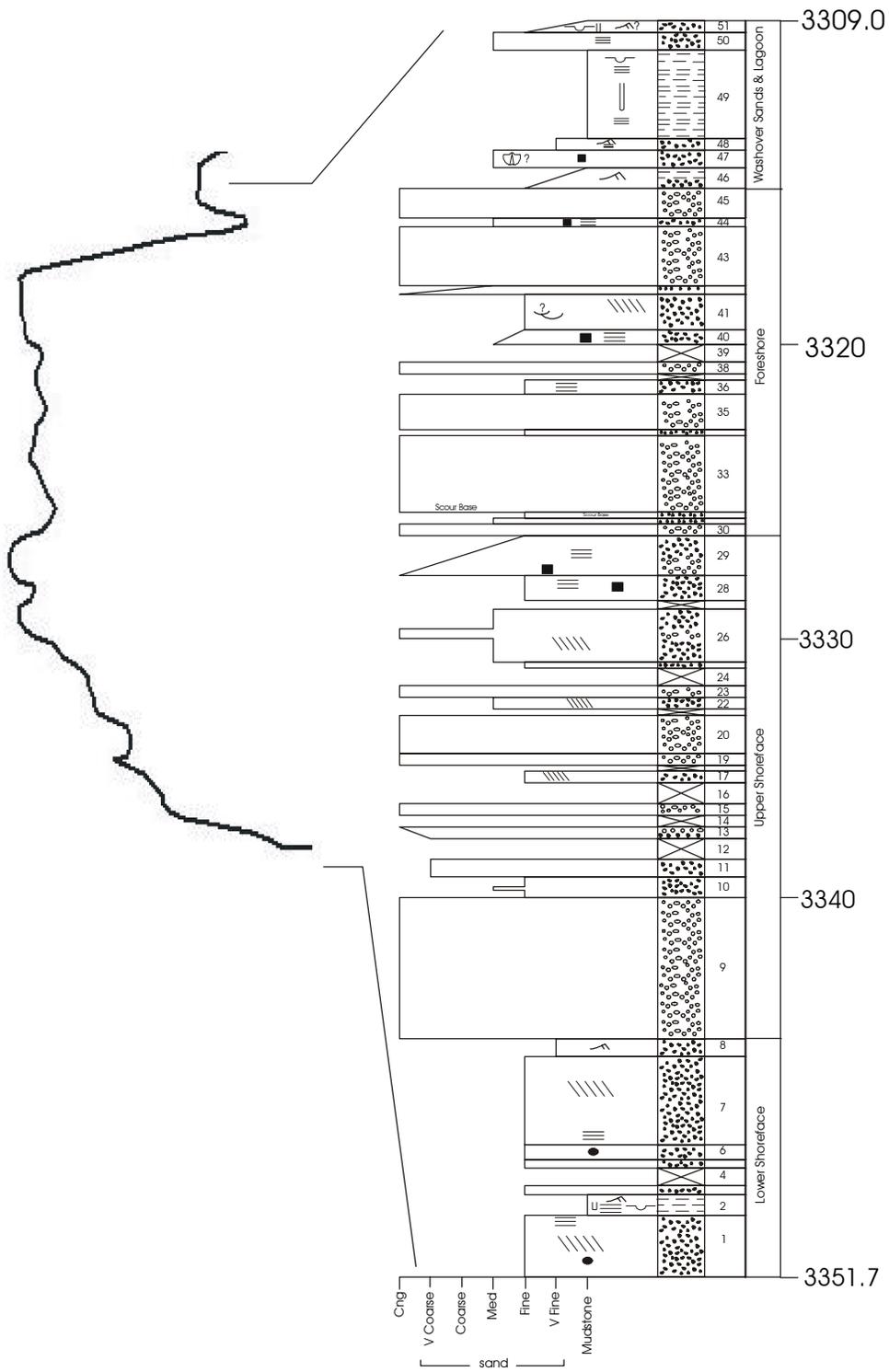


Figure 12. J Mills 154 core with gamma-ray signature.

J Mills 158 - A

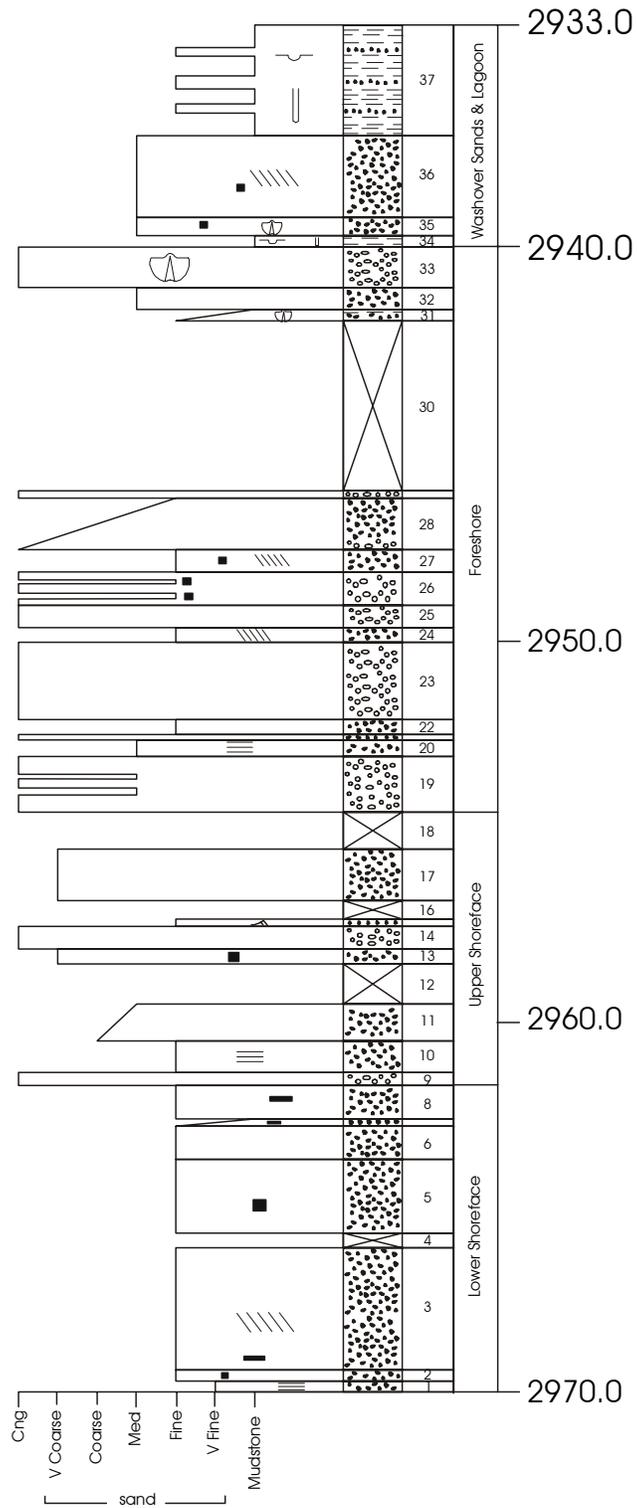


Figure 13. J Mills 158-A core. No gamma-ray log available.

gamma-ray curve, the remaining 113 logs were analyzed and facies were picked throughout the field, using cross-section in GeoGraphix. Once the facies were identified on all well logs, four east-west (dip) and two north-south (strike) cross sections were made. Subsurface maps showing the structure (on the top of the barrier-island sandstone), thickness of the lower Stray, thickness of the upper Stray, thickness of sandstone in the upper Stray, and thickness of the shale in the upper Stray were constructed to show the distribution of the several facies throughout the field.

REGIONAL STRATIGRAPHY

During the Devonian period, the Laurussian continent was beginning to assemble from Baltica (western Europe), Armorica (France and Spain), and Laurentia (North America), leading to the Acadian orogeny. The Appalachian area at this time was strongly influenced by a tropical climate with a wide range of rainfall (Woodrow, 1985). To the west of the newly raised Acadian mountains were several river systems that coalesced into a large prograding alluvial plain (Dennison, 1985). These river systems were responsible for deposition of a large amount of sediment into the Catskill Sea that would eventually make up the Catskill delta complex of New York, Pennsylvania, and West Virginia. The Devonian Catskill delta complex in conjunction with the Upper Devonian-Lower Mississippian Price-Rockwell delta complex comprise the Acadian clastic wedge (Figure 14) (Boswell and Donaldson, 1988; Kammer and Bjerstedt, 1988).

The Catskill delta complex is composed of marine, transitional, and terrestrial clastic rocks (Boswell and Donaldson, 1988). In West Virginia, the delta complex is represented by (from bottom to top) the Marcellus Shale or Millboro Shale, Brallier Formation, Greenland Gap Group, and Hampshire Formation. In Pennsylvania, the Marcellus Formation, Hamilton Group, Brallier Formation, Scherr and Foreknobs Formations (Lock Haven Formation), and Hampshire Group or Catskill Formation represent the delta complex (Boswell and Donaldson, 1988). In general, each formation represents a different facies. Figure 15 shows the subsurface stratigraphy across Pennsylvania and West Virginia and how it relates to the outcrop.

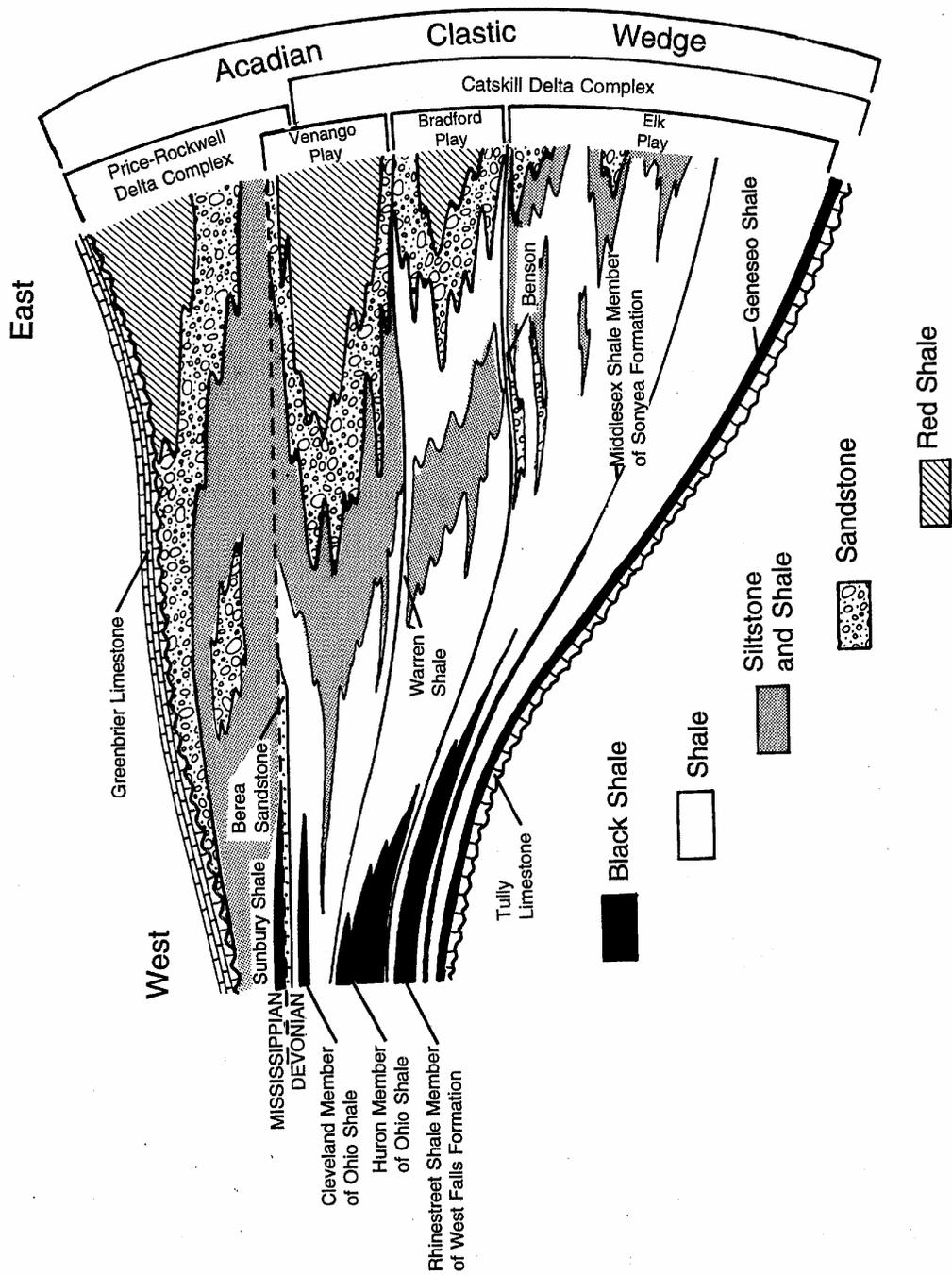


Figure 14. Cross-section of the Acadian clastic wedge, showing the relationship of the Price-Rockwell and Catskill delta complexes. Gordon Stray sandstone of this study is a part of the Venago play of upper Catskill Delta complex. From Boswell et al, 1996.

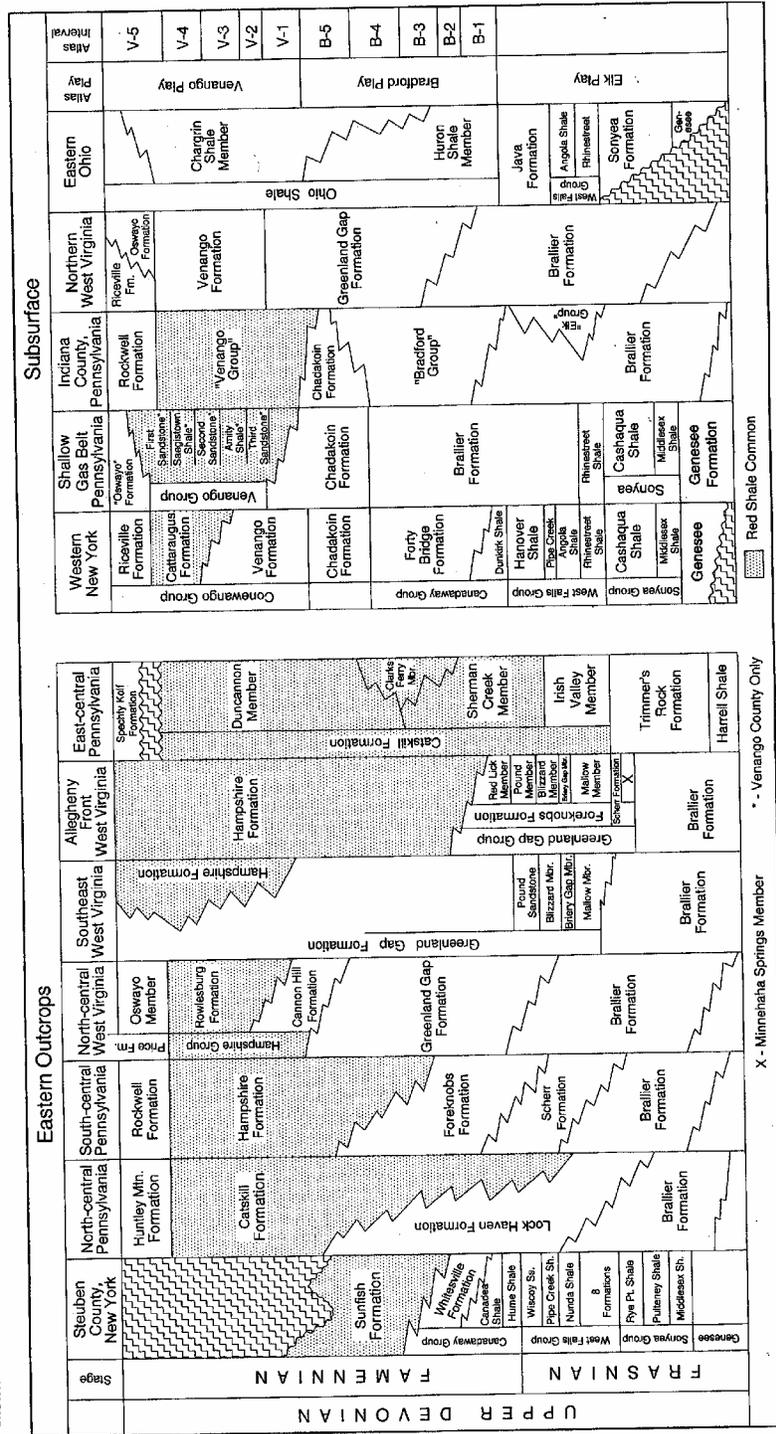


Figure 15. Regional lithostratigraphic nomenclature for outcrop and subsurface geology in West Virginia and Pennsylvania. Gordon Stray sandstone of this study is situated within Venango formation of northern West Virginia subsurface. From Boswell et al, 1996.

Basin Center

The basin center is identified in the rock record by black shale (Millboro and Marcellus Shales), which marks the onset of clastic deposition of the Catskill delta (Woodrow et al, 1988). These black shales are interpreted to have formed in anaerobic conditions at depths ranging from 100 to 200 m (Ettensohn, 1985). As indicated by chemical and petrographic analyses, organic matter constitutes 15 to 20 percent of the dark shales (Ettensohn, 1985). Much of this organic matter is thought to have come from the shallow sea where solar radiation and possibly equatorial upwelling greatly increased plankton productivity (Ettensohn, 1985). Another source for the organic matter was the nearby landmass. The humid climate was conducive for plant growth, and streams carried the plant material to the sea (Ettensohn, 1985). The stratigraphic distribution of these black shales represents times of sea-level rise (Dennison, 1985). During a transgression, the epicontinental sea flooded the shelf, estuarine, and flood-plain environments. Such transgressions were quite common in the sequences preserved by the Catskill delta (Ettensohn, 1985).

Slope and Prodelta Environment

The slope and prodelta environments are preserved in the rock record by the Brallier Formation. Five separate facies have been described within the Brallier Formation; from the bottom to top they are as follows: basinal, lobe-margin, interlobe-slope, turbidite-slope, and delta-front (Lundegard et al, 1985). Each facies grades upward into the next, and overall they grade into the overlying Greenland Gap Group.

The basinal facies is composed primarily of black shale with minor siltstone turbidites and local silty laminae (Lundegard et al, 1985). The lobe-margin, or the area

around the margins of the delta lobes, is located near the distal edge of the slope and consists of bioturbated claystone and shale with abundant silty laminae. The silty laminae are individually graded with sharp lower contacts, load casts, and gradational upper contacts,. Based on these features, the silty laminae are interpreted as distal turbidite flows (Lundegard et al, 1985). The interlobe-slope, or the area between delta lobes, is located on the slope and comprises bioturbated mudstone with a few thin turbidite siltstone beds showing Bouma sequences. Thin-bedded siltstone beds with Bouma sequences make up the turbidite-slope facies of the Brallier Formation. Most of the turbidites that occur in the Brallier Formation occur within this fourth facies. The last facies is identified as the delta-front, which is characterized by thick siltstone beds with lenticular bedding, low-angle trough cross-bedding, and abundant and diverse marine fossils (Lundegard et al, 1985).

Delta-Front Environment

The Greenland Gap Group, or the Scherr and Foreknobs Formations, makes up the Catskill delta-front facies. Results of storm and wave activity can be observed throughout the section, and these processes were responsible for shaping the shallow shelf (Boswell and Donaldson, 1988). The Greenland Gap Formation is generally distinguished from the underlying Brallier Formation by its slightly coarser-grained texture (Boswell, 1988). The coarser-grained texture plus storm and wave activity document the more nearshore position. In the subsurface, the Greenland Gap Group has been informally divided into seven stratigraphic intervals: Bradford, Lower Balltown, Middle Balltown, Upper Balltown, Speechley, Warren, and upper Greenland Gap (Boswell, 1988).

The Bradford interval is a distinctive marker bed throughout much of West Virginia. This interval is predominantly siltstone, tabular, and approximately 30 m thick (Boswell, 1988). The lower half of the unit has a coarsening-upward sequence, whereas the upper half tends to show a fining-upward sequence. The Lower Balltown interval is characterized by shaly siltstone that separates the coarser Bradford siltstone below from coarser strata above. The Middle Balltown interval is marked by siltstone with only minor shale layers; however, toward the west the unit fines, becoming mostly shale (Boswell, 1988). Two prominent shale marker beds characterize the Upper Balltown interval, whereas the main body is rich in siltstone and sandstone. The Speechley interval, with a siltstone texture, is significantly finer-grained than the intervals that bound it. The Warren interval marks the initiation of the final major progradation of the Catskill delta complex. This interval is approximately 60 m thick and is marked by a package of massive siltstones. A heterogeneous sequence of interbedded shale, siltstone and minor sandstone characterizes the upper Greenland Gap interval (Boswell, 1988).

Shoreface and Terrestrial Facies

The Hampshire Formation is recognized as the red portion of the Catskill delta complex and characterizes the subaerial sections of the delta (Boswell and Donaldson, 1988). The red color in the rocks is evidence for oxidation that must have occurred above sea level. The lower boundary of the Hampshire is not clear; however, many workers have placed the boundary above the highest bed that contains marine fossils (Boswell, 1988). To help with the lower-boundary problem, Boswell (1988) divided the Hampshire Group into two units: a lower unit rich in sandstone, bearing marine fauna and

known as the Cannon Hill Formation, and an upper nonmarine unit, rich in red mudstone and named the Rowlesburg Formation.

Sandstones of the Cannon Hill Formation are typically tabular, flat-bottomed, quartz-rich and interbedded with red, green and gray shale (Boswell, 1988). Some of these sandstones contain marine fossils that are indicative of a nearshore-marine setting. Other sandstones are white to light-gray and contain white quartz-pebble conglomerate, indicating a high-energy setting (Harper and Laughrey, 1987). Sandstone of the Cannon Hill Formation have been classified by the informal terminology of well drillers, including two progradational packages, known as the Elizabeth and Bayard, and one overlying sandstone package named the Fifth (Figure 16) (Boswell, 1988).

The Rowlesburg Formation is defined on the bottom by contact with the Fourth sandstone interval (Figure 16) and on top by the highest red shale (Boswell, 1988). The Rowlesburg may contain appreciable intervals of sandstone; these often have a fining-upward sequence and are highly lenticular (Boswell, 1988). The red color of the rocks indicates terrestrial deposition, which is also indicated by mud cracks and coarser-grained sandstone.

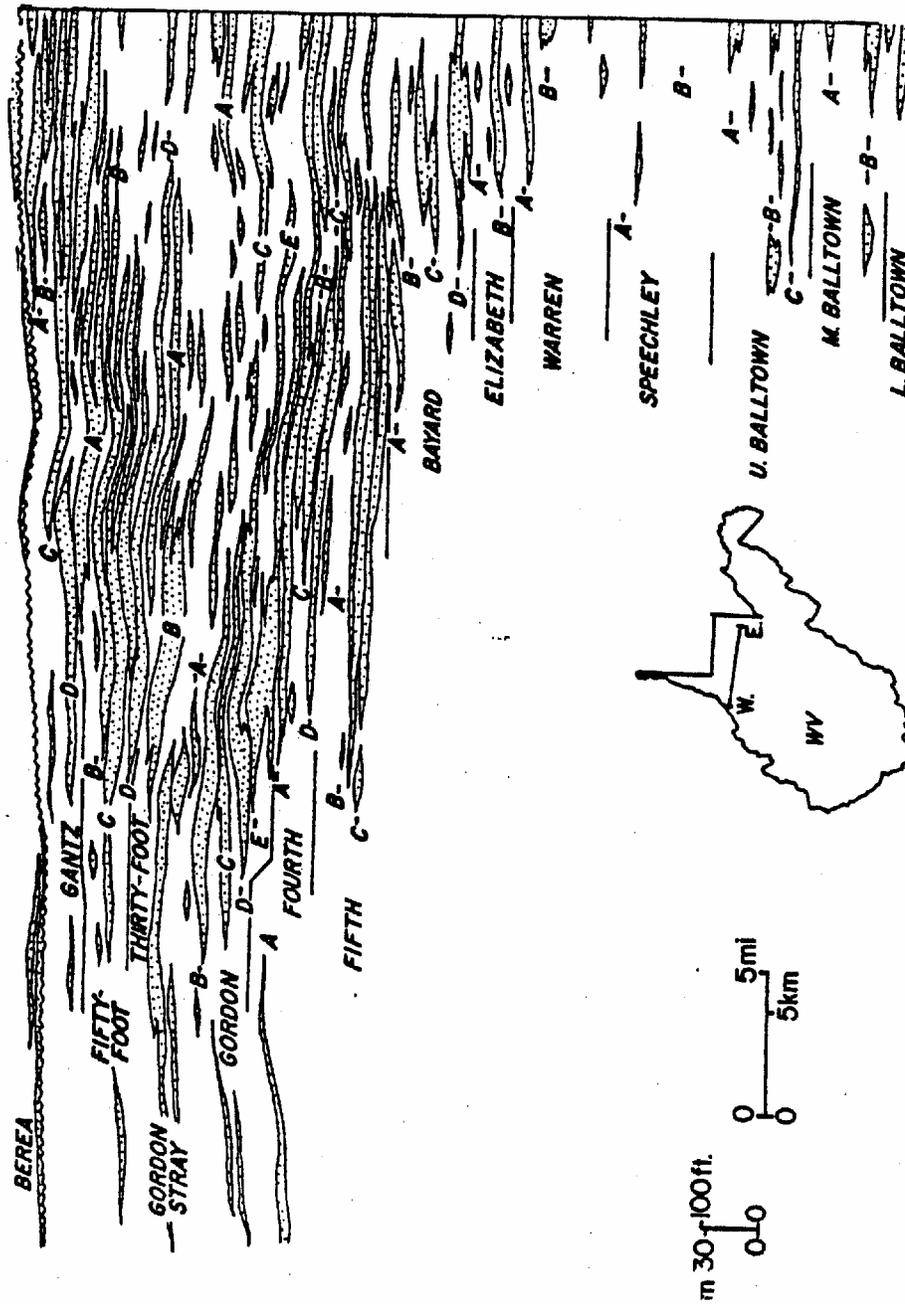


Figure 16. East west cross-section showing distribution of Catskill sandstones in the Upper Famennian. Gordon Stray sandstone is subject of present study. From Boswell, 1988.

SUBSURFACE SANDSTONES

The Catskill delta has long been associated with the thick wedge of clastic red beds (Boswell, 1988). This name, however, is misleading in that it brings to mind only the red rocks that dominate outcrops along the eastern margin of the basin (Boswell, 1988). The diachronous nature of these units makes traditional lithostratigraphic terminology difficult on a regional basis; therefore, an informal terminology has been developed by petroleum geologists (Boswell and Donaldson, 1988). In the subsurface, thick sequences of nonred marine strata are typical. In West Virginia and southern Pennsylvania, these marine rocks are thought to be part of the distal pinch-out of the Hampshire Formation (Boswell et al, 1996). The uppermost stratigraphic section of the Catskill can be divided further into packages of sandstone approximately 200 feet thick, which represent small cycles of transgression and regression (Boswell and Jewell, 1988). Collectively, these sandstone packages are known to the local geologists as the Venango Formation (Figure 15). The Venango petroleum play lies within this sedimentary complex and has accounted for much of the oil and gas produced from northern West Virginia and western Pennsylvania (Harper and Laughrey, 1987).

The sandstone packages include the Balltown, Warren, Elizabeth, Bayard, Fifth, Fourth, Gordon, Thirty-foot, Fifty-foot, Gantz, Berea-Riddlesburg, Lower Weir, Middle Weir and Upper Weir (Figure 16) (Boswell and Jewell, 1988). Boswell (1988) has compiled a series of isopach maps of the subsurface sandstones that indicate the sand-dispersal patterns. These patterns are suggestive of specific depositional environments. The sandstones are interpreted based on the trend of the thickest sandstone occurrence and the paleogeographic position of that trend (Figure 17). Boswell and Jewell (1988)

labeled sandstones, which are aligned parallel to the depositional strike of the basin margin (commonly north-south) as type S sandstones and sandstones which parallel the paleoslope (commonly east-west) as type D sandstones. These classifications are suffixed by “1” if the sandstone is interpreted to have formed in terrestrial environments, “2” if along the shoreline, “3” if in shallow shelf environments, and “4” if in deeper-water submarine fans (Figure 4).

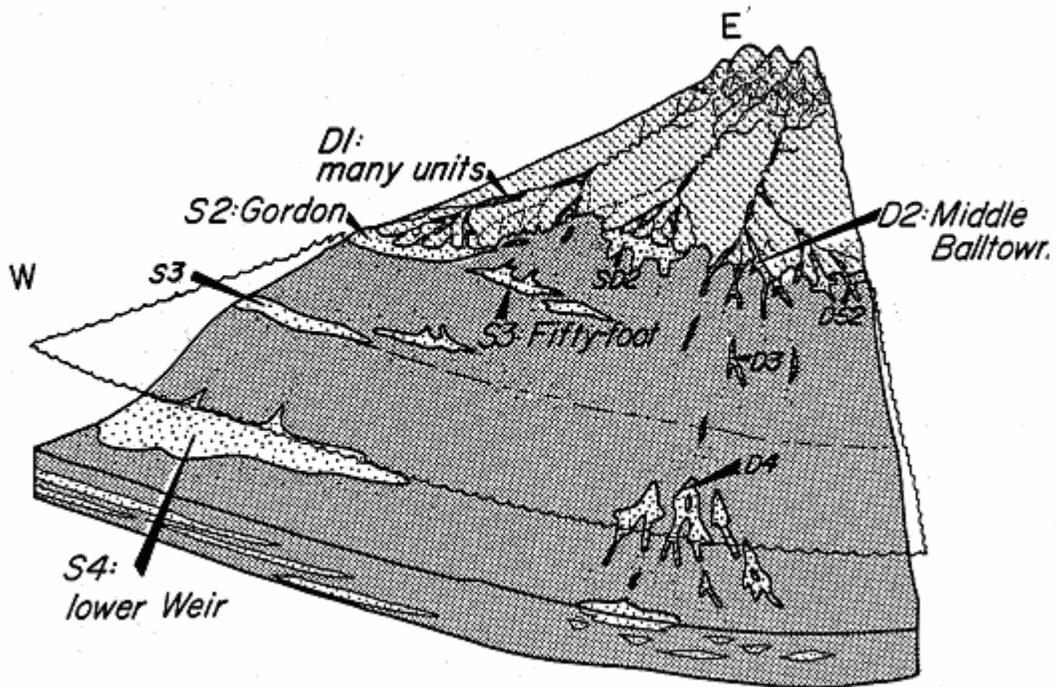


Figure 17. Classification of Acadian clastic wedge sandstones by trend relative to depositional strike and paleogeographic position. Sandstones of Gordon interval are classified as S2. From Boswell and Jewell, 1988.

Type D1 sandstones, which represent distributary and fluvial-channel deposits, are present on every map; however, these trends are discontinuous, thin, and narrow. Type D2 sandstones are common in the Balltown and Speechley intervals of the delta complex, representing a digitate shoreline, most likely extended distributary channels (Boswell and Jewell, 1988). The Warren through the Fourth sandstones are interpreted to be type DS2 and SD2. The dominant sandstone trends in these intervals are interpreted to have formed along shorelines with lobate morphologies. These units indicate brackish-marine and nonmarine sandstones encased in red, green and gray shale (flood-plain deposits) characterized by roots and paleosol development. Type S2 sandstones are most common in the Gordon sandstones (Boswell, 1988); they are interpreted to have formed along a straight, wave-dominated shoreline (Boswell and Jewell, 1988). The Fifty-foot sandstones are classified as type S3 sandstones, having a map trend similar to that of the Gordon and Warren sandstones. However, because eastern outcrop equivalents are gray siltstone and shale containing a brackish-marine fauna, they are interpreted to be deposited as an offshore sand bar. Type S4 sandstones comprise the Weir sandstones which represent deep-water submarine-fan deposits.

The Gordon sandstone interval contains the S2 type sandstone of Boswell and Jewell (1988) and has been interpreted as a beach/barrier-island deposit on the basis of isopach maps (Figure 18). The Gordon, however, does not outcrop and all interpretation must be done from well logs and cores. The Gordon interval is often subdivided into the Gordon (Figure 19) and the Gordon Stray (Figure 20). The Gordon Stray occurs higher in the section and displays a pattern that mimics the distribution of the entire Gordon interval (Matchen, in press). In Pennsylvania, the Gordon Stray has also been called

Third Stray, Campbells Run, and Gray (Harper and Laughrey, 1987). The Gordon Stray sandstone is typically an erratic rider sandstone above the Gordon; however, in places, the Gordon Stray exceeds the Gordon in thickness and reservoir quality (Harper and Laughrey, 1987).

The sandstones of the Gordon interval, as described by Harper and Laughrey (1987), vary from white or pink to light gray or brown. They are also fine to coarse-grained, having scattered conglomeratic lenses; they may be highly porous and permeable or have very low porosity and permeability. The conglomeratic zones are composed of flattened elliptical or ovoid quartz pebbles up to two centimeters in diameter.

Matchen (2001), in his work on the Jacksonburg-Stringtown oil field in Wetzel, Tyler, and Doddridge counties of West Virginia, has identified five lithofacies that are stacked into three parasequences. The lithofacies include a featureless sandstone, laminated sandstone, conglomeratic sandstone, shale, and heterolithic bioturbated sandstone. The thickest shale beds are commonly present in the lowest part of the Gordon Stray interval; they are dark gray and laminated with thin bands of siderite locally (Matchen, in press). The featureless sandstone is very-fine- to fine-grained, very well sorted, and contains few recognizable sedimentary structures. The laminated sandstone is fine- to very-fine-grained, very well sorted, and contains a wide variety of sedimentary structures including horizontal lamination and low-angle cross-bedding. Gravel-sized clasts within a fine- to very-fine-grained sand is characteristic of the conglomeratic sandstone. The texture varies from sand-supported to clast-supported. Scour surfaces are common, and other sedimentary structures include low-angle bidirectional and

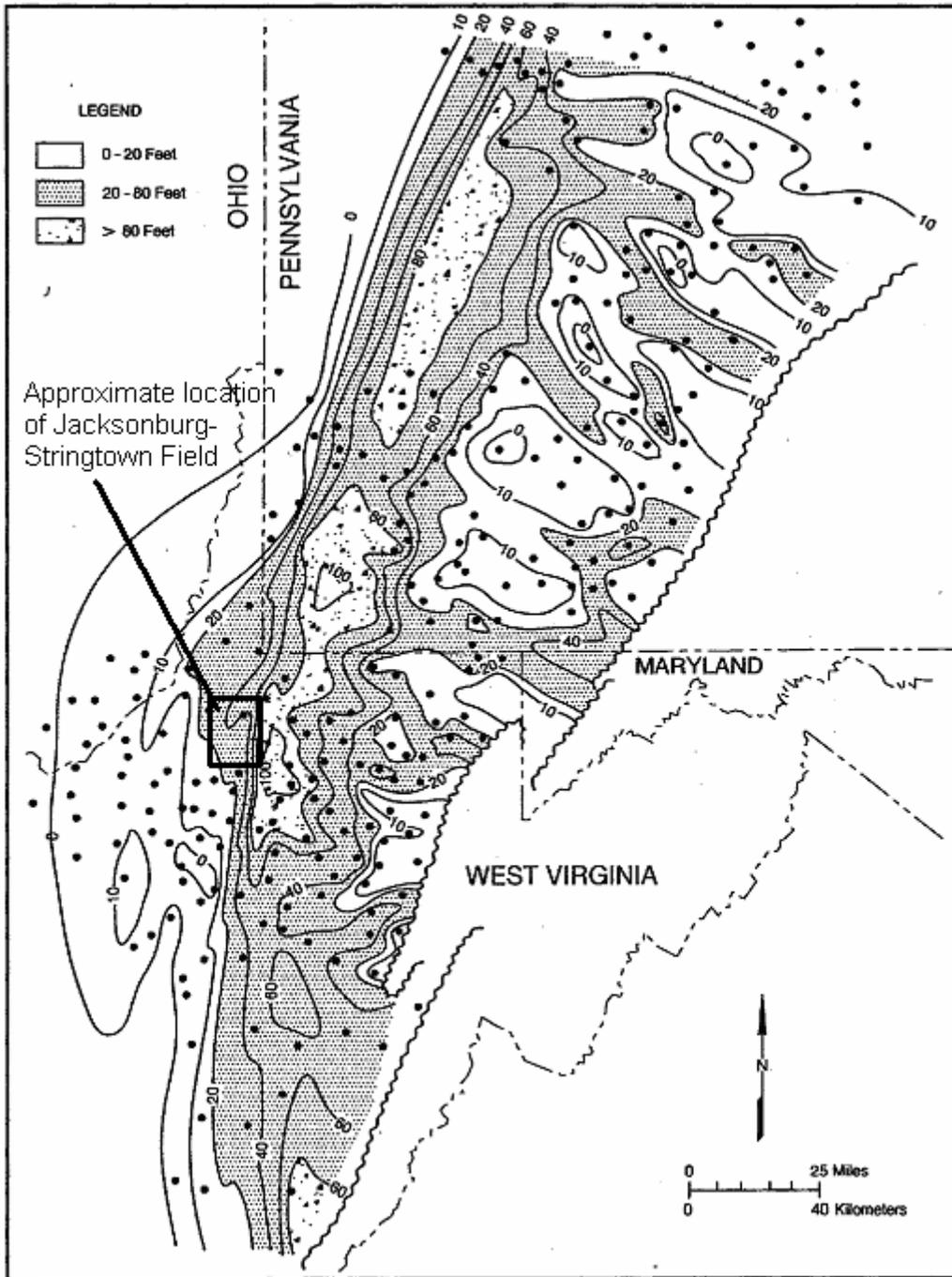


Figure 18. Thickness of the Gordon interval in West Virginia and Pennsylvania. From Boswell et al, 1996.

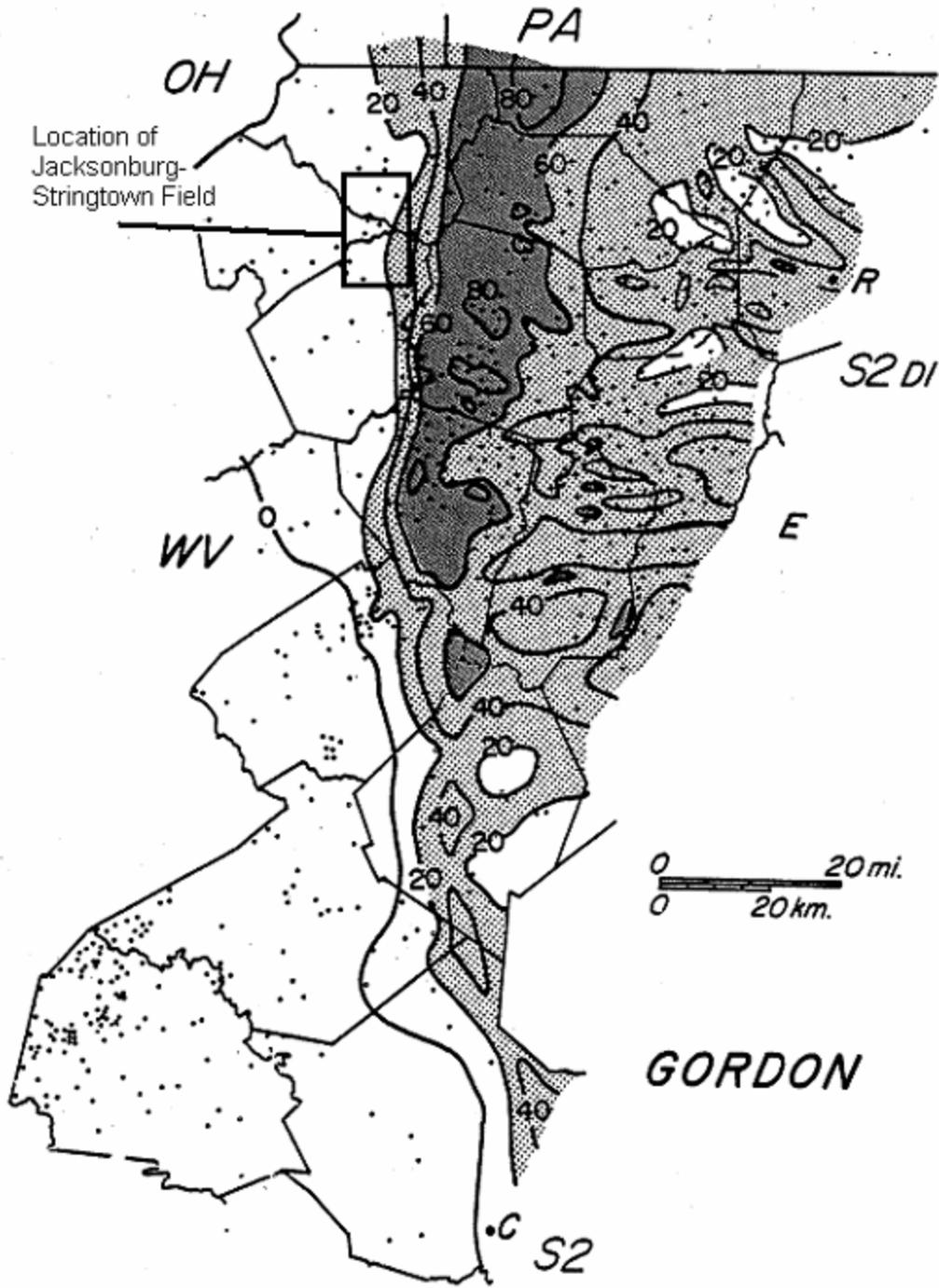


Figure 19. Thickness of the Gordon sandstone. From Boswell and Jewell, 1988.

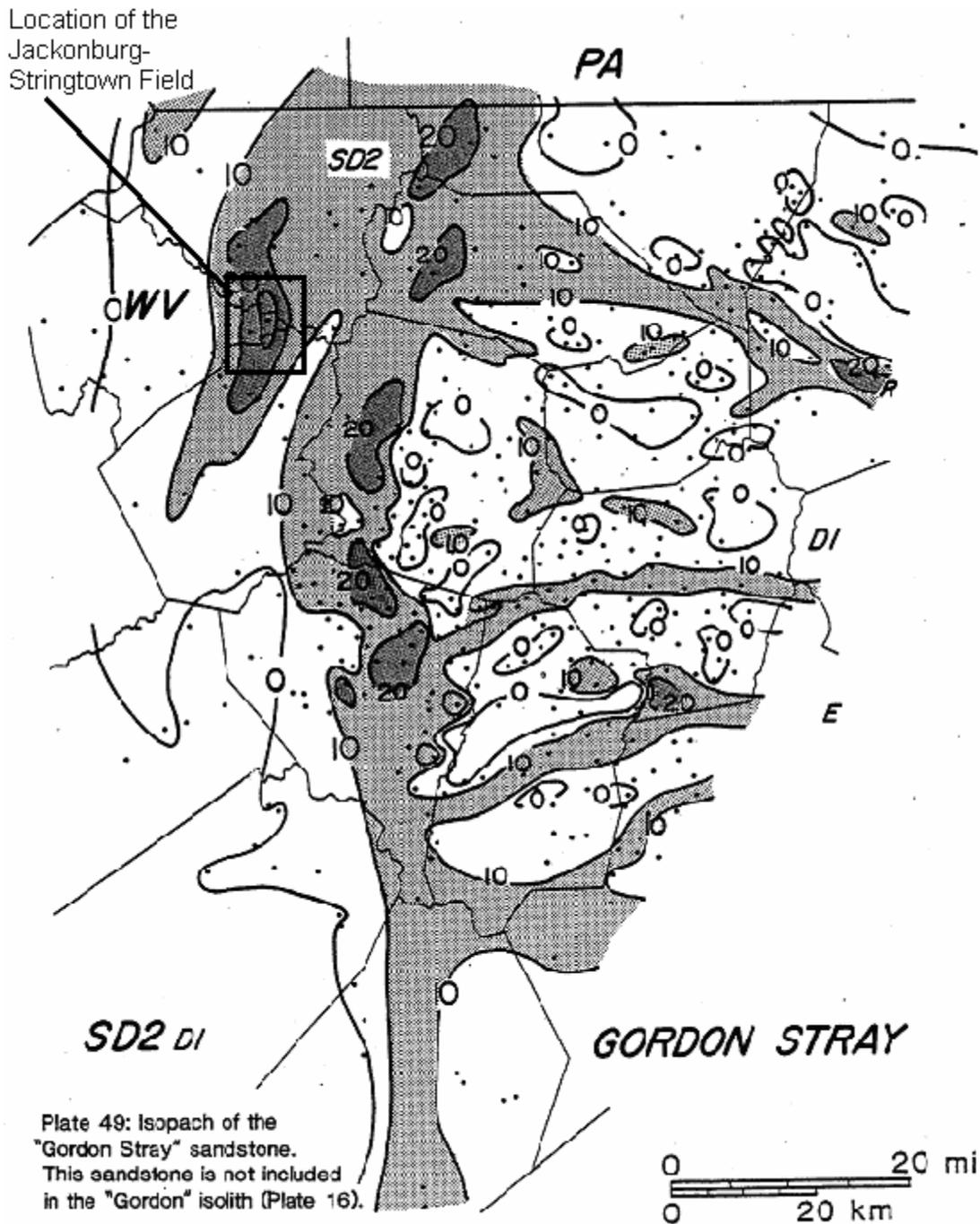


Figure 20. Thickness of the Gordon Stray sandstone. From Boswell and Jewell, 1988.

unidirectional cross- bedding, high-angle cross-bedding, inverse grading, rare ripple bedding, and occasional brachiopods, bivalves, and echinoderms. The heterolithic bioturbated lithofacies is present at the top of the Gordon Stray in all the cores of the Jacksonburg-Stringtown field. This section was deposited as interbedded sandstone and shale, but extensive bioturbation resulted in a mixture of rock types within the Gordon Stray. Matchen (2001) recognized three parasequences within the Gordon Stray, each with a coarsening-upward regressive pattern.

In the same study of the Jacksonburg-Stringtown field, McDowell (2001) found that primary porosity of the Gordon Stray sandstone is intergranular, whereas secondary porosity occurs as molds of dissolved or partially dissolved potassium feldspars. The cement in the Gordon Stray consisted of clay, calcite, silica, and siderite; however, the nature of the cement changes between different areas of the field depending on depth of burial and diagenesis of the clays and feldspars.

DEPOSITIONAL ENVIRONMENTS

Based on ten full bore cores in the Jacksonburg-Stringtown field (Figure 3, with graphic logs shown on Figures 4-13), depositional facies were determined based on bedding, texture, fossils, and mineral content. Figures 21-23 show three full-core photos with most of the facies described here.

Shelf

Description

The shelf facies is present in two of the cores, the Reilly 13 and the Thompsons Heirs 8. The shelf facies is predominantly shale in both cores; however, in the Thompsons Heirs 8 core there are interbedded fine-grained sandstones near the bottom. The Reilly 13 core has no sandstone interbeds; however, the gamma-ray curve shows evidence of sandstone down-section. The sandstones are thin and are composed of well-rounded grains. Internally, sedimentary structures include trough cross-bedding, ripple marks, and large-scale planar cross-bedding (Figure 24).

The shale is silty in places and is bioturbated in the Thompsons Heirs 8 core. In both cores the shale has horizontal stratification and ripple marks in more silty zones. The Thompsons Heirs 8 core also has small-scale planar cross-bedding.

Interpretation

The shelf environment starts at mean fair-weather wave base and extends seaward (Walker and Plint 1992). Reading (1996) identified a transition zone between mean fair-weather wave base and mean storm wave base. In this transition zone, deposition is dominated by alternating storm and fair-weather conditions. Deposition includes



Figure 21. Full core photo of the Ball 18 well.



Figure 22. Full core photo of the J Mills 154 well.



Figure 23. Full core photo of the Reilly 13 well.



Figure 24. Shelf mudstone with sand ripples and small sand-filled horizontal burrows from the Reilly 13 well. Scale in tenths of inches.

interbedded coarse sand and fine sand that represents storm and fair-weather conditions respectively. Farther seaward the grains become much finer, even muddy.

The sandstones of the Gordon Stray sandstone are thin and are composed of well-rounded grains. Internally, sedimentary structures include trough cross-bedding, ripple marks, and large-scale planar cross-bedding. These interbeds show evidence for an increase in current energy, most likely during storms. The shale is horizontally stratified, silty in places, and locally bioturbated. Shale is representative of fair-weather conditions. In the shelf environment the burrowing and grazing activities of organisms generally destroyed most sedimentary structures. However, Walker and Plint (1992) noted that in environments where conditions were inhospitable (lack of oxygen, food, etc.) to benthonic organisms, the primary sedimentary structures include horizontal stratifications.

Lower Shoreface

Description

The lower-shoreface facies is present in eight of the cored wells (Ball 18, Ball 19, Peter Horner 9, Reilly 13, J Mills 158 A, J Mills 154, Lemasters 0-13, and Thompson Heirs 8); however, it is complete only in the Thompsons Heirs 8 well. The other seven cores terminate above the base of the lower shoreface. Based on gamma-ray-log interpretation, though, it appears that all of the cores end at or very close to the bottom of this facies. The average thickness is 7.6 feet with a minimum of 2.4 feet in the Reilly 13 and a maximum of 13.6 feet in the Ball 18.

The lower shoreface is composed of tan sandstone that is predominantly fine-grained (Figures 25 and 26). This sandstone is well sorted and well rounded, but in the

Thompson Heirs 8 core there is a basal layer of quartz pebbles, rock fragments, and mud clasts up to 5 mm in size. Some laminated shale partings also occur in this facies.

The bedding is thin to medium (4-30 cm in thickness) and the basal contact in the Thompsons Heirs 8 well is erosional. The sandstone exhibits small- and large-scale planar cross-bedding, trough cross-bedding and ripple marks. Horizontal stratification occurs mainly toward the bottom of the lower shoreface.

Only one brachiopod shell was observed in the Lemasters 0-13 core, but horizontal and vertical burrows are present within the shale partings.

Interpretation

The shoreface begins on the shelf at the fair-weather wave base and extends landward to the mean low tide level (Reading, 1996). McCubbin (1981) stated that the lower shoreface is generally composed of fine sand, and the seaward boundary is marked by the appearance of very fine sediments, eventually grading into mud. According to Reading (1996) and McCubbin (1981), the lower shoreface is separated from the upper shoreface on the basis of grain size. The lower shoreface tends to have finer-grained material, whereas the upper shoreface tends to be coarser.

The basal contact in the Thompsons Heirs 8 well is erosional and contains a layer of conglomerate. The erosional contact indicates the energy level increased drastically and cut into the underlying shelf mud. Along with the erosional contact, the conglomerates suggest storm currents. Stratification is horizontal towards the bottom of the lower shoreface sandstone. According to McCubbin (1981), the bottom of the lower



Figure 25. Lower shoreface sandstone from the J Mills 154 Well (3350'). Core shows fine-grained sandstone with horizontal stratification. Scale in tenths of inches.

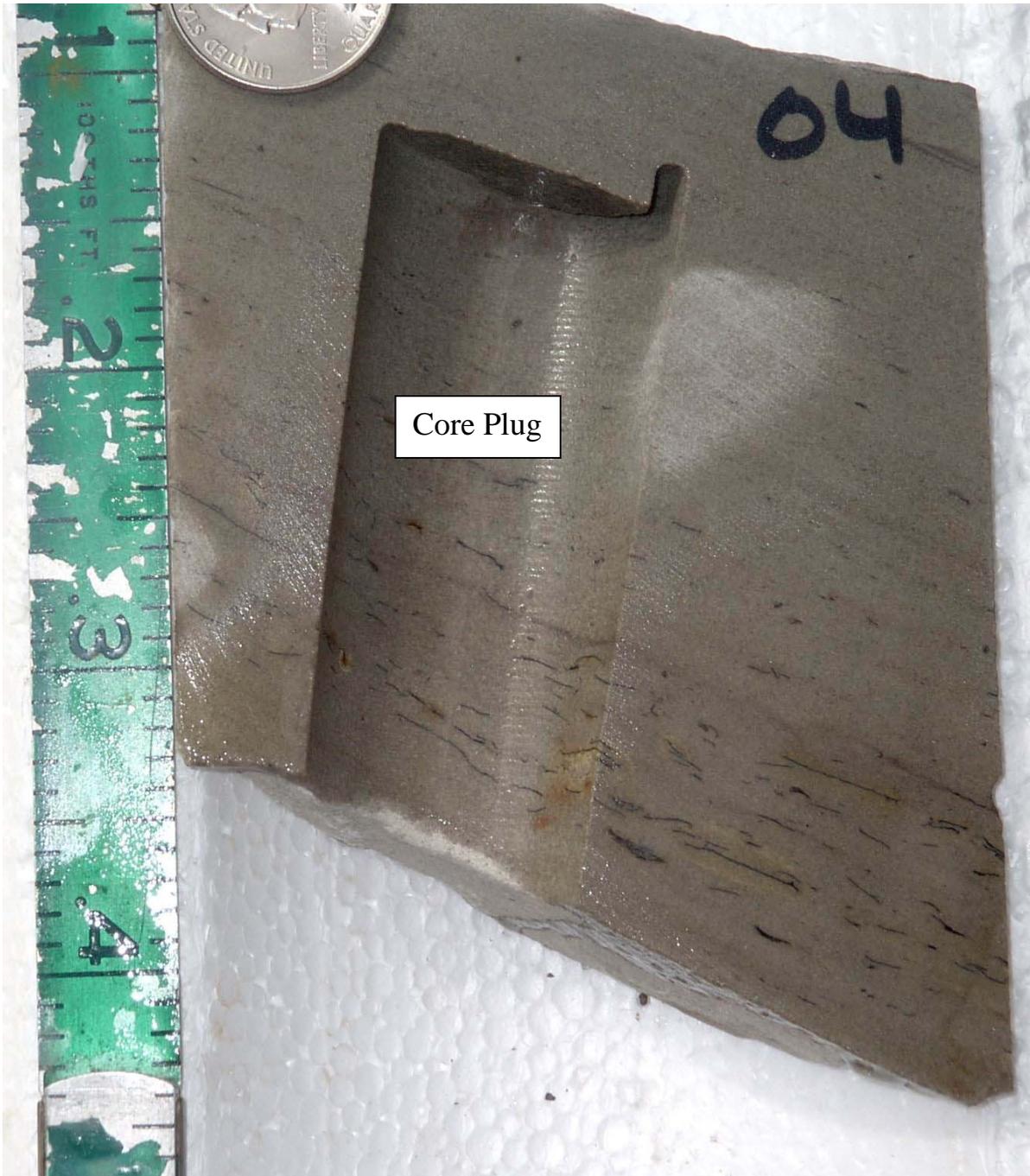


Figure 26. Lower shoreface from the Ball 18 well (3004.5'). Core shows large-scale cross-bedding with shale clasts along the bedding planes. Core plug was taken out of the middle of the core. Scale in tenths of inches.

shoreface is composed of mostly planar and nearly horizontal stratification, indicating a no-flow regime. Up-section, the sandstone exhibits small-scale and large-scale planar cross-bedding, trough cross-bedding and ripple marks (lower flow regime), which show an increase in the energy level landward and into shallower water.

Upper Shoreface

Description

The upper shoreface is present in all of the cored wells except the J H Dawson F-14, which apparently was not cored deep enough. The upper shoreface averages 9.1 feet thick with a minimum thickness of 4.2 feet in the Thompsons Heirs 8 and a maximum of 15.4 feet in the J Mills 154 well.

Sandstone from this facies has an average grain size of medium sand. The color ranges from tan to light gray with most beds being a tanish/brown color. Grains are well rounded and well sorted throughout, but there are scattered quartz pebbles and mud clasts in the sandstone.

The sandstone is thin to medium bedded and shows large- and small-scale cross-bedding, horizontal stratification, and ripple marks. In the lower part of this facies, in most of the cores, the sandstone is featureless, as described also by Matchen (2001). In the Peter Horner 9 and the Lemasters 17 cores, the sandstone contains several scour surfaces with rip-up clasts. Rare shale beds occur within the upper shoreface (much fewer than the lower shoreface), and sand ripples within the shale produce a lenticular bedding.

Fossils include rare brachiopod shells (Lemasters 0-13). Burrowing of any kind is absent within this facies (Figures 27 & 28).

Interpretation

Reading (1996) and Davis (1994) generalized that shoreface sandstones are principally composed of well rounded sand and gravel. Moreover, Reading (1996) and McCubbin (1981) stated that the grains of the upper shoreface would be coarser than those of the lower shoreface. This coarser size is because the upper section of the shoreface is comparatively steep (about 1:10) and is dominated by wave-driven flow associated with shoaling waves and to a lesser extent rip currents. In contrast, the lower section is practically flat (about 1:200) and is dominated by tidal currents and storm-induced flows (Reading, 1996). Physically, the shoreface serves as a transition zone between offshore/shelf processes and the nearshore/barrier-island processes.

Sedimentary details on the shoreface are determined primarily by the specific hydrodynamic regime. For example, in a high-energy environment, biogenic structures are not well developed and have a low preservation potential, whereas in a low-energy setting biogenic reworking may be so thorough that the sediment becomes homogenous. Shorefaces of mixed energy are characterized by a distinctive facies which reflects a repeated alteration between storm and fair-weather processes (Reading, 1996). The Gordon Stray sandstone shows large- and small-scale cross-bedding, horizontal stratification, and ripple marks. Hartley et al (1999) noted that sedimentary structures associated with the shoreface generally include planar laminae that are horizontal to slightly inclined bounding surfaces separating sets of climbing, tabular, and occasional

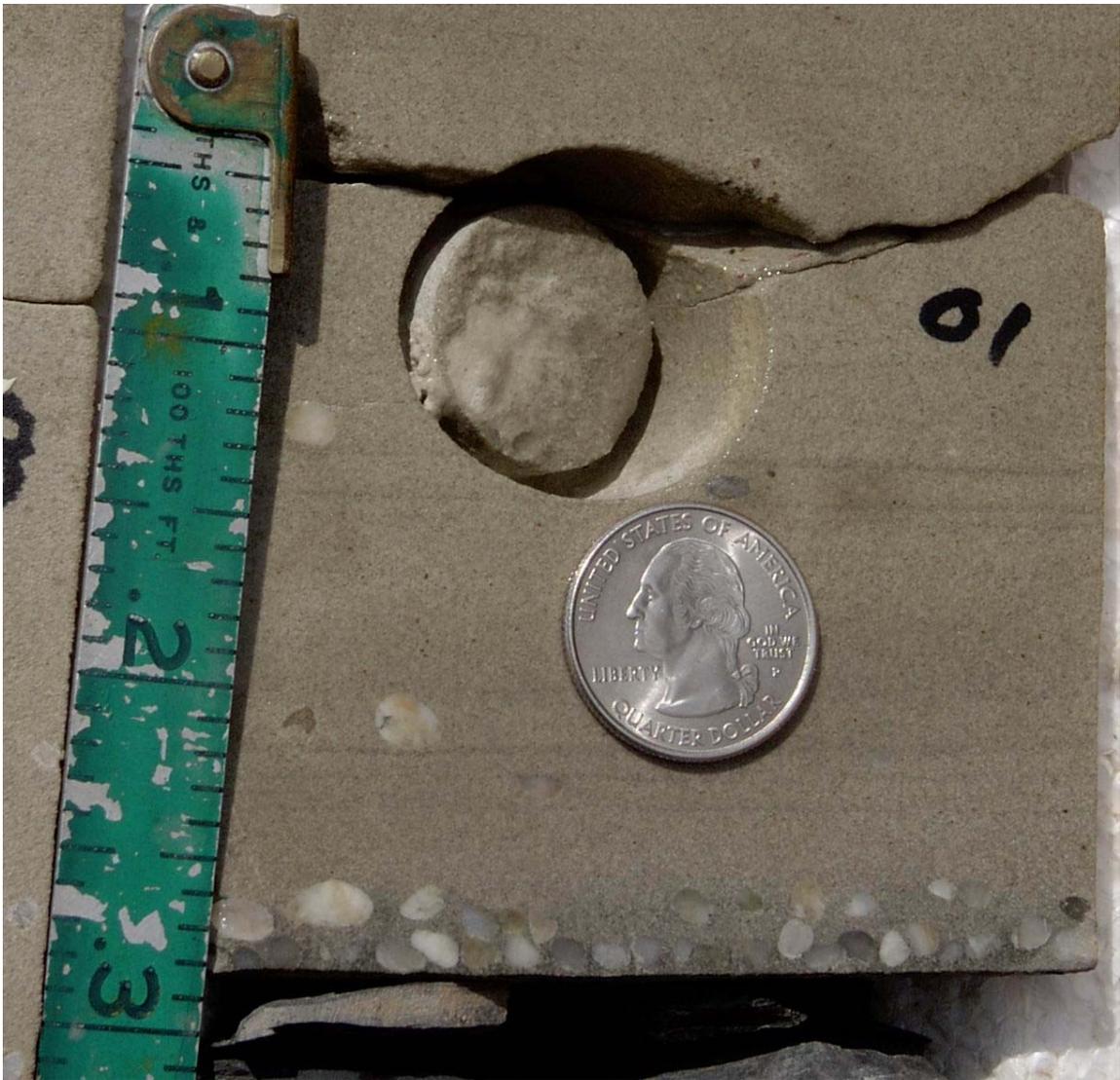


Figure 27. Upper shoreface from the Ball 18 core (3001.6'). Core shows medium-grained sandstone with a conglomerate layer at bottom and horizontal stratification. Scale in tenths of inches.



Figure 28. Upper shoreface from the Lemasters 17 core (2873.3'). Core shows medium- to coarse-grained sandstone with large-scale planar cross-bedding. Scale in tenths of inches.

trough cross-bedding. In the modern record, medium- to large-scale cross-bedding is common along with high-angle trough cross-bedding, which occur due to migration of dunes or mega-ripples (McCubbin, 1981). Reading (1996) stated that the cross-bedding is mainly small-scale. In the Peter Horner 9 and the Lemasters 17 cores, the sandstone contains several scour surfaces with rip-up clasts. According to McCubbin (1981), the upper shoreface can show cycles of erosion and deposition that relate to changing wave conditions.

Fossils include marine body fossils. Burrowing of any kind is absent within this facies. The high energy was not ideal for animals that burrow because the substrate was not stable.

Foreshore

Description

The foreshore is present in every core except the J H Dawson 4-14 well, which was not cored deep enough. The average thickness for the foreshore is 6.4 feet with a minimum of 2.8 feet (Ball 18) and a maximum of 15.2 feet (J Mills 158-A).

The foreshore is mainly composed of medium-grained sandstone and conglomerate. However, the Lemasters 17 core contains a thin shale layer with fine-grained sandstone lenses near the top of the foreshore, and the Reilly 13 has a few very fine sandstone beds. Bedding is thin to medium. The grains are well-rounded quartz and rock fragments, and they are well sorted for the most part with the exception of quartz pebbles and a few mud clasts near the base. All the units have a light tan color, and there is some evidence of iron staining, especially where siderite nodules are common.

Within the conglomerate, the average pebble size is approximately 5 mm with some of the clasts reaching up to 2.0 cm. The matrix is fine- to medium-grained sandstone. Conglomerate beds are distributed throughout this facies.

Sedimentary structures in the conglomerate are often difficult to identify, but the sandstone displays large-scale planar cross-bedding, trough cross-bedding, horizontal stratification, and small-scale planar cross-bedding in all of the cores except the J H Dawson F-14 core. Two cores (Reilly 13 and J Mills 154) show an erosional base near the bottom of this facies.

Fossils are rare although brachiopod shells are present in the Peter Horner 9 and the J Mills 158-A well. In the Reilly 13 core horizontal and vertical burrows are present in the fine-grained sandstone beds. (Figure 29 & 30)

Interpretation

The foreshore environment lies directly landward of the shoreface environment, between the high-tide and low-tide lines. The hydrodynamic processes here are controlled primarily by wave action in the swash zone although low-gradient or mesotidal beaches may also experience surf-zone processes (Reading, 1996). Due to the high energy within this facies, the foreshore is composed mainly of medium-grained sandstone and conglomerate. Reading (1996) noted that the average grain size in a foreshore environment is fine to medium sand; however, Davis (1994) and McCubbin (1981) noted that the grain size within any environment is highly variable, depending on the local conditions. The Lemasters 17 core contains a thin shale layer with fine-grained sandstone lenses near the top of the foreshore, and the Reilly 13 has a few very fine



Figure 29. Foreshore in the Ball 19 core (3098.5'). Core shows an interbedding of fine-grained sandstone with conglomerate. Small scour surface at base of conglomerate. Scale in tenths of inches.



Figure 30. Foreshore from the Peter Horner 9 core (2893'). Core shows interbedded conglomerate and medium-grained sandstone with horizontal stratification and small-scale planar cross-bedding. Scale in tenths of inches.

sandstone beds. DeCelles (1987) explains the segregation of fine and coarse material as a characteristic of storm and fair-weather conditions. During storms, coarse material is carried from the beach by storm-enhanced rip currents. During fair weather conditions, the coarse material is again driven landward, depositing finer grains on the beach eventually being covered by coarser grained material.

Under normal swash-zone conditions, surface bed forms are those of the upper-flow regime, principally horizontal stratification. The upper-flow conditions are due to the foreshore having a relatively steep face, as compared to the shoreface, resulting in the backwash of the waves accelerating due to gravity. Sedimentary structures in the Gordon Stray conglomerate are often difficult to identify, but the sandstone displays large-scale planar cross-bedding, trough cross-bedding, horizontal stratification, and small-scale planar cross-bedding in the Ball 19 core. Reading (1996) reports that the most common structures of a foreshore environment are parallel lamination and small-scale ripple bedding, and Davis (1994) reports ripples, large-scale planar and large-scale trough cross-bedding, and planar bedding conditions may be present. Two cores (Reilly 13 and J Mills 154) show an erosional surface with quartz pebbles and mud clasts near the base of this facies, which was created as the sediment of the upper shoreface was exposed to the higher-energy conditions of the foreshore. Marine fossils are present in this facies.

Washover Fan

Description

Above the foreshore, the cores and the gamma-ray log show that the facies drastically change, becoming finer-grained. The washover fan, as a package, ranges in

thickness in the cores from 0 feet in the Lemasters 0-13 to approximately 10 feet in the Ball 19 cores.

Throughout all the cores, individual washover lobes are composed of silty, fine- to medium-grained sandstone interbedded with silty shale. The sandstone is gray or tan in color, well sorted, and well rounded. The sandstone is, for the most part, thinly bedded and generally shows a sharp contact with the overlying and underlying units. Typical thickness of the sandstone beds ranges from a few inches up to a foot. At the base of the unit, there are mud clasts ripped up from the underlying shale beds. This facies shows a fining-upward texture in all of the cores except the Ball 18 well. Within the sandstone there are large- and small-scale planar cross-bedding, ripple marks, and horizontal stratification. Horizontal stratification and occasional ripples dominate the shale. Brachiopod shells are present in this facies of all cores, along with horizontal and vertical burrowing. The burrows occur primarily in the shales, but they are sand filled. (Figures 31 & 32)

Washover channels are identified only in the Reilly 13 and the Peter Horner 9 cores. The sandstone is fine- to medium-grained, well rounded, and well sorted with occasional quartz pebbles and mud clasts, especially near the base. Sandstone beds are generally thin to medium bedded, with a typical thickness of a few inches to a foot. The base of the channel has a scour surface cutting a few inches into the underlying lagoonal sediments. Throughout the facies, large-scale planar cross-bedding, ripple marks, and horizontal stratification are present. The ripples tend to be draped with a very thin (<1mm) shale parting. Fossils in the washover channels are similar to those of the



Figure 31. Washover fans from the J Mills 154 core (3313'). Core shows fine-grained sandstone interbedded with thin shale layers. The sandstone is rippled and shows small-scale planar cross-bedding. Scale in tenths of inches.

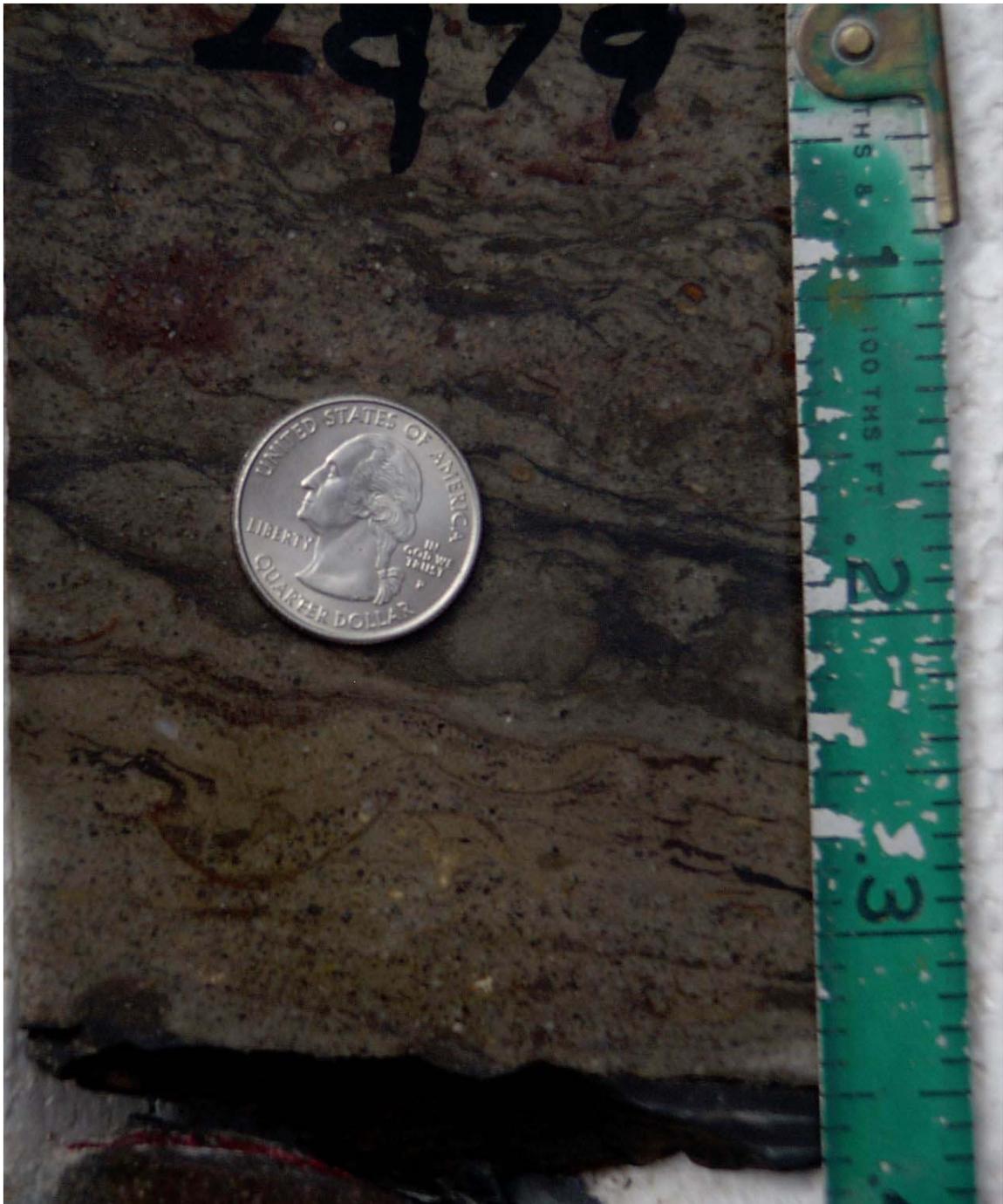


Figure 32. Washover lobe from the Ball 18 core (2979'). Sandstone is medium- to coarse-grained with interbedded shale lenses. Within the sandstone are fragments of brachiopod shells. Burrowing destroyed layering. Scale in tenths of inches.

washover lobes: brachiopods shells and horizontal and vertical burrows. However, there seem to be less burrowing but more body fossils (Figure 33).

Interpretation

Generally dunes act as a barrier to the ocean; however, during powerful storms the elevated water can sometimes breach or top low dunes. Storm water takes the path of least resistance and may follow a meandering path through saddles between the dunes. Waves erode much of the dune sediment as they travel landward, depositing a widespread sand layer (lobe) landward of the dunes and extending into the lagoon. These deposits collectively constitute the washover fan, and as the name implies it is shaped like a large fan in a map view. The washover fans can be semi-circular, sheet-like or tabular bodies up to a few hundred meters in width and oriented normal to the shoreline (Walker and Plint, 1992). Each deposit tends to be fairly thin, on the order of a few centimeters; however, multiple washover events can lead to an overall deposit of several meters thick. Due to the dissimilarities in each washover fan, they cannot be correlated from exposure to exposure (Friis et al, 1998). The upper few centimeters of the deposit may be highly bioturbated or vegetated with a developing soil. Interfan areas are covered by thick deposits of mud or mud and sand (Friis et al, 1998).

Washover lobes of the Gordon Stray sandstone are composed of silty, fine- to medium-grained sandstone interbedded with silty shale. They tend to have an erosional base overlain by a lag deposit, mud clasts ripped up from the underlying shale bed. The sandstone is thinly bedded and shows a fining-upward signature above the basal lag. Sedimentary structures in the washover lobes include horizontal stratification, sub-parallel laminations, and medium-scale landward-dipping cross-bedding (Reading, 1996).



Figure 33. Washover channel from the Reilly 13 core. Core shows a sharp contact with the underlying shale and very coarse sandstone interbedded with fine-grained sandstone. Section shows a fining-upward sequence. Scale in tenths of inches.

Within the Gordon Stray sandstone there are large- and small-scale planar cross-bedding, ripple marks, and horizontal stratification. Horizontal stratification develops by sheetflow under upper-flow-regime conditions (Davis, 1994). The large-scale planar cross-bedding of the Gordon Stray sandstone formed as foresets spilled into the lagoon behind the barrier island. Also common are ripples draped with mud, which represent the changing of current strength (Davis, 1994). When the currents were high, during times of washover events, sand was deposited. During times of low current, or during normal lagoonal conditions, mud layers formed.

Brachiopod shells are present in all of the cores, along with horizontal and vertical burrowing. The burrows tend to be dominantly in the shale, but they are sand-filled. Reading (1996) noted that washover sand may be bioturbated shortly after deposition, while the sediment is still soft, allowing for the sediment to mix.

Washover-channel deposits are quite similar to washover fans in that during high-energy events, i.e. storms, the elevated water can sometimes breach or top the dunes. Washover channels however, cut down farther into sediment of the barrier island, even to a depth below sea level. The base of the Gordon Stray channels has a scour surface cutting into the underlying lagoonal sediments; a basal erosion surface covered by a lag deposit. Near the bottom of the facies, large-scale planar cross-bedding is noted, which, according to Walker and Plint (1992), represents a deep-channel facies. Overlying this are ripple marks and horizontal stratification. The ripples tend to be draped with a very thin (<1mm) shale parting, whereas the cross-bedding is present only in the sandstone. Ripples and horizontal stratification are sedimentary structures that can be associated with a shallow-channel facies (Walker and Plint, 1992).

Fossils in the washover channels are similar to those of the washover lobes. There seems to be less burrowing due to the mobility of the sand, but more body fossils, which were concentrated by storm currents.

Lagoon

Description

The lagoon facies is composed of shale with interbedded washover sandstones. The shales of this facies range in thickness from 0 feet in the Lemasters 0-13 core to 10 feet in the Reilly 13 core.

The shale is a dark gray color with an occasional tan hue near the interbedded sandstone. The shale is locally silty. Throughout this facies, the sedimentary structures include horizontal stratification with occasional ripple marks near the sandier/siltier beds.

This facies is very bioturbated with horizontal and vertical, sand-filled burrows. (Figure 34).

Interpretation

The lagoon is an extremely variable, shallow-water, low-energy environment located behind the barrier-island. By definition, lagoons are wet basins formed by barriers separating the sea from the land (Oertel et al, 1992). The variability is due in part to the prevailing climate and tidal settings (Reading, 1996). Lagoons in a tidal setting commonly have complicated bathymetry produced by extensive channels, tidal flats, and marshes. In contrast lagoons in a wave-dominated setting are initially deep open-water environments (Oertel et al, 1992). In a tidal-dominated setting, specifically a



Figure 34. Lagoon shale from the Reilly 13 core (2869'). Core shows shale with horizontal sand filled burrows. Interbedded sandstone at top of core. Scale in tenths of inches.

microtidal setting, the water may experience abnormally high salinities because the water body has limited contact with the open sea. However, a lagoon in a mesotidal setting has salinity values that are more normal as open seawater can freely enter the lagoon via tidal inlets.

According to Friis et al (1998), sediment in a lagoon is commonly black mud with a variable sand content. Alternating layers of sand, mud, silt, and peat also characterize many lagoonal sequences. In humid climates, organic matter such as plant debris is common. Much of the sand that makes its way into the lagoon is brought in by washover events associated with high-water storms, and the depositional rate is dependent on the frequency of storm events.

The Gordon Stray lagoon facies is composed of dark shale with interbedded washover sandstone. The shale is locally silty. Throughout this facies, the dominant sedimentary structure is horizontal stratification with occasional ripple marks in the sandier/siltier beds. Sandstones in the lagoon most likely represent the distal section of washover lobes; they are of a finer grain size and are not as thick. Silt and fine sand laminations and ripple marks were produced by slight water agitation by the wind. Lagoon environments are known for extremely high rates of bioturbation, and much of the sediment is homogeneous sandy mud (Friis et al, 1998). Where bioturbation was absent, sedimentary structures such as horizontal lamination and soft-sediment deformation were preserved. The Gordon Stray lagoonal facies is very bioturbated with horizontal and vertical sand filled burrows; there were no body fossils identified within this facies.

INTERPRETATION OF MAPS AND CROSS SECTIONS

For this project, several maps were constructed in order to characterize the facies within the Jacksonburg-Stringtown field. Also included are a structure map and six cross sections, two north-south (strike) and 4 east-west (dip).

Structure Map

The structure map indicates sub-sea elevation on the top of the barrier-island sandstone (Figure 35). The map is shaded so that the darker sections represent lower areas of the field. The structure is relatively simple, consisting of a few highs and lows. The structure map created by Matchen (2001), which uses the top of the Gordon Stray interval as a datum, shows an east-west trending fault across the southern end of the field. The fault is believed to have a displacement of approximately 30 feet (Matchen, in press). My map, based on the subsurface data in Figure 35, has similar trends to the map created by Matchen, such as a northeast-southwest trend in the middle of the area and east-west trend to the north of the field. The northeast-southwest trend is related to the Burchfield Syncline that runs northeast-southwest through that area of the state.

Lower Gordon Stray

By comparing the 10 cores to their gamma-ray logs, the well log signature of the barrier-island facies can be identified and traced across the field. Three stratigraphic picks were made for each well: the bottom of the barrier-island sandstone, the top of the barrier-island sandstone, and the top of the Gordon Stray interval. The Gordon Stray top was picked at the first sandstone kick above the barrier-island sandstone (Figure 36). Once the top and bottom of the barrier-island facies were selected for all wells, an isopach map was constructed for the sandstone across the field.

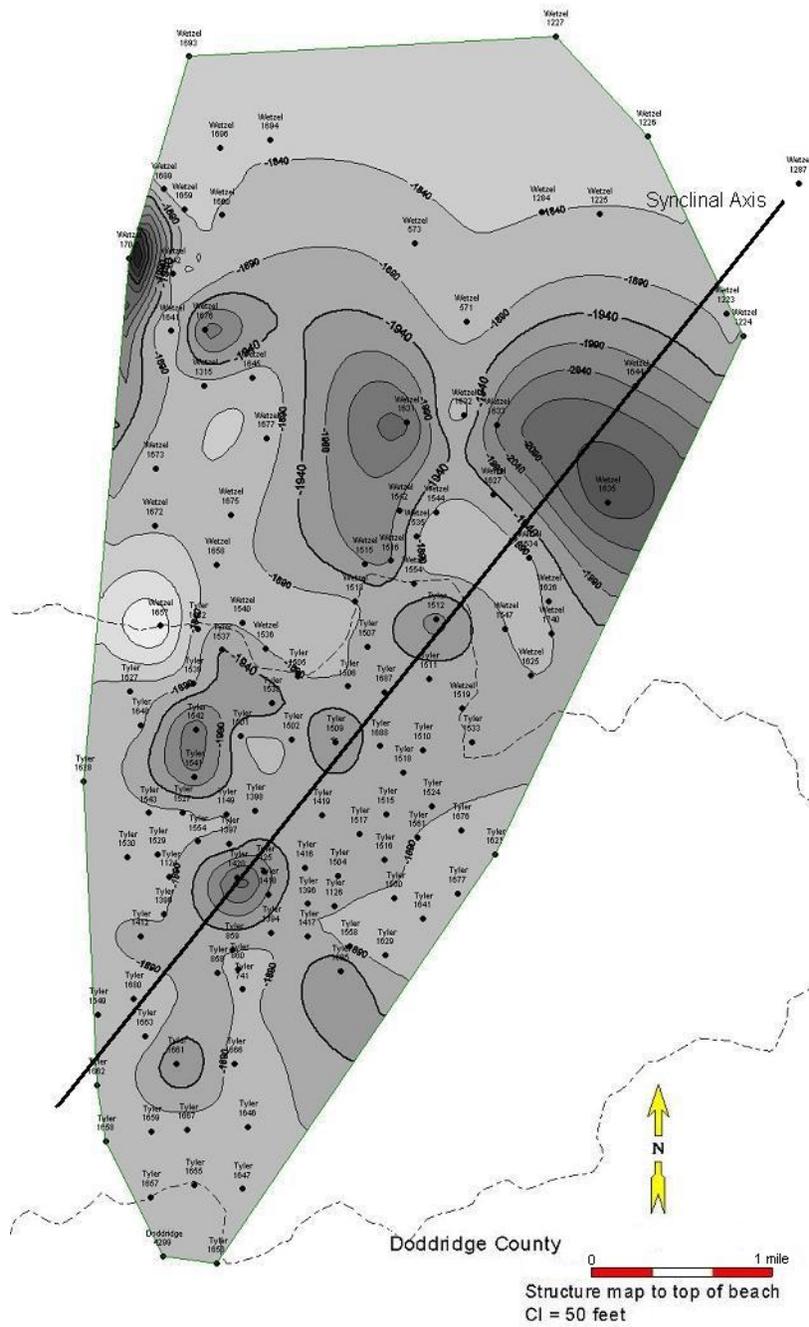


Figure 35. Structure map of the Jacksonburg-Stringtown field, created on the top of the barrier-island sandstone.

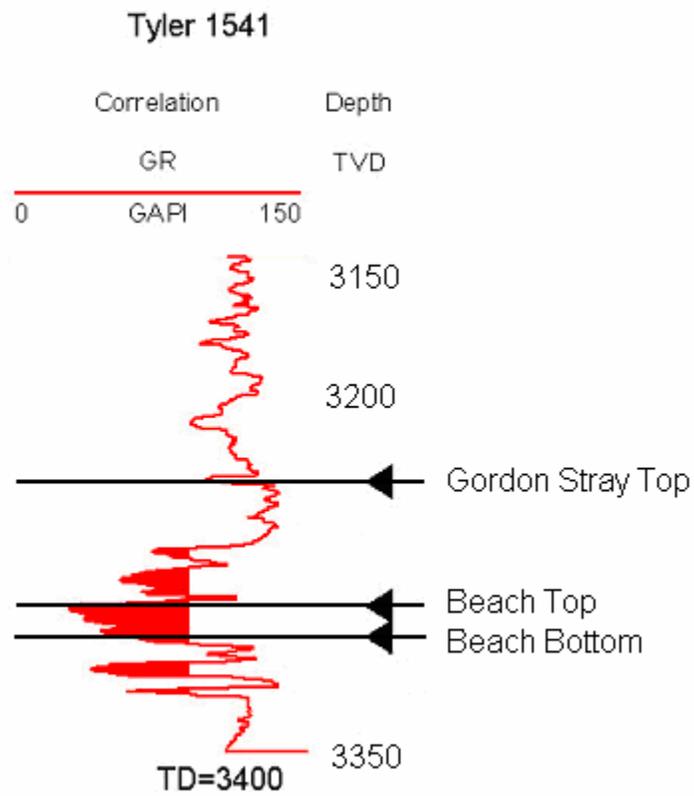


Figure 36. Gamma-ray log for Tyler 1541 showing placement of picks for the bottom of the barrier-island sandstone, top of the barrier-island sandstone, and top of the Gordon Stray.

The isopach map (Figure 37) shows that the thickest section of the barrier-island sandstone (greater than 20 feet) has a general north-south trend along the eastern edge of the field. The isopach map by Boswell (1988) shows a similar thickness of the Gordon Stray in the area of the Jacksonburg-Stringtown field, but with less detail (Figure 20). The isopach map created for this project also shows the sandstone to thin towards the south and west.

Barrier-island subfacies (lower shoreface, upper shoreface, and foreshore) identified from the 10 cores show that not only does the barrier-island sandstone thin towards the south, but water depth must have been generally deeper to the south as well (Figures 38-40). The lower shoreface sandstone is thickest in areas of generally deeper water (south), whereas the foreshore sandstone is thickest in areas of generally shallower water (north). This distribution of facies is the case during time of aggradation. Hardie (1986) noted that (in carbonate environments) during times of a slow sea-level rise, with a sedimentation rate that keeps up with sea-level rise, the supratidal deposits are thickest landward and subtidal deposits are thickest seaward. The same is observed with the Gordon Stray sandstone. A steady sea-level rise, coupled with high sedimentation rate, allowed the barrier island to aggrade, accumulating the thickest foreshore deposits landward and the thickest shoreface deposits seaward. The three isopach maps collectively show a northern shift of facies thickness from the lower shoreface to upper shoreface to the foreshore.

On the large-scale isopach map created by Boswell, the Gordon Stray sandstone in the Jacksonburg-Stringtown field appears to mark the southern end of an elongate barrier island that extended at least 40 miles north in West Virginia and into

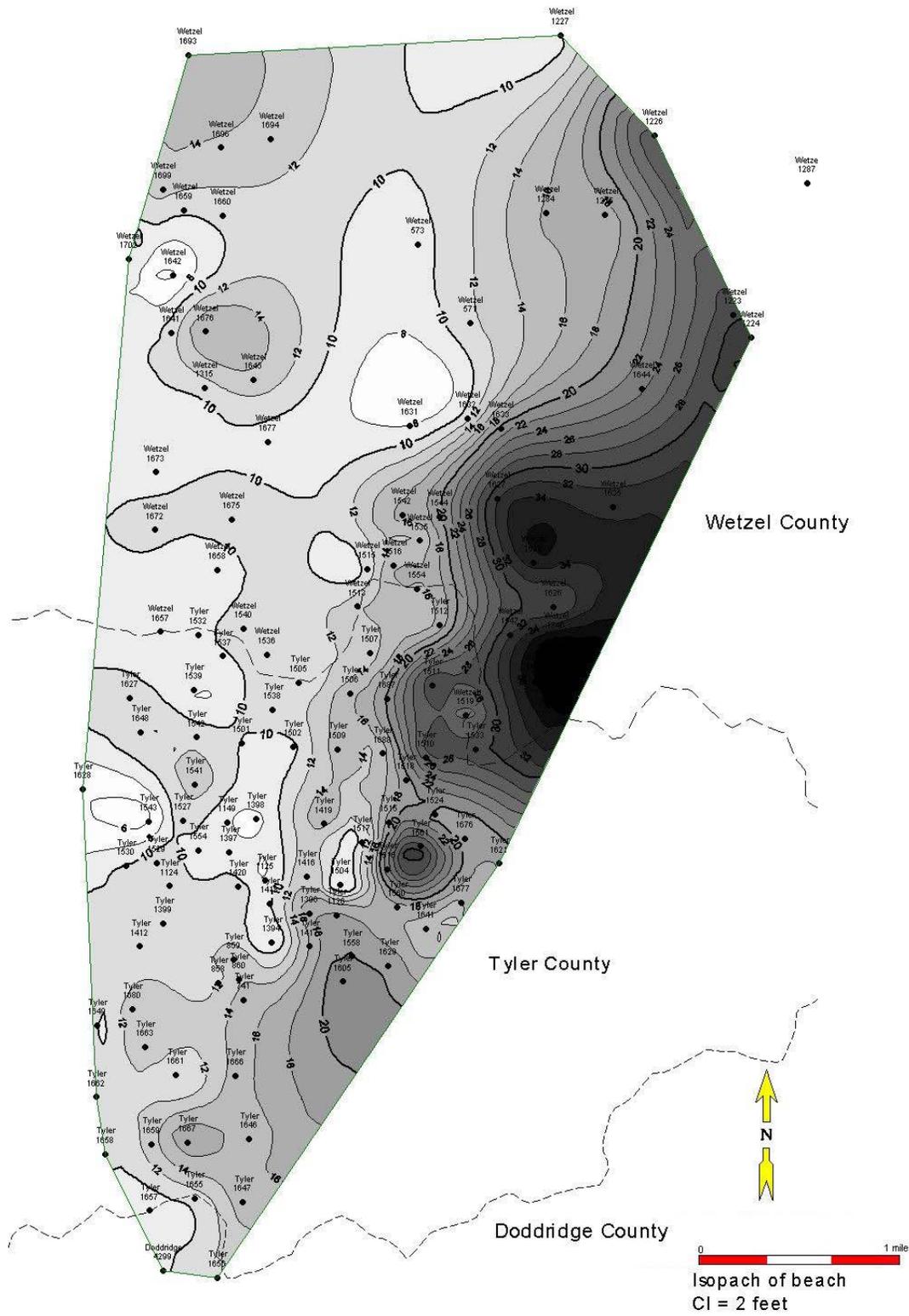


Figure 37. Isopach map of barrier-island sandstone.

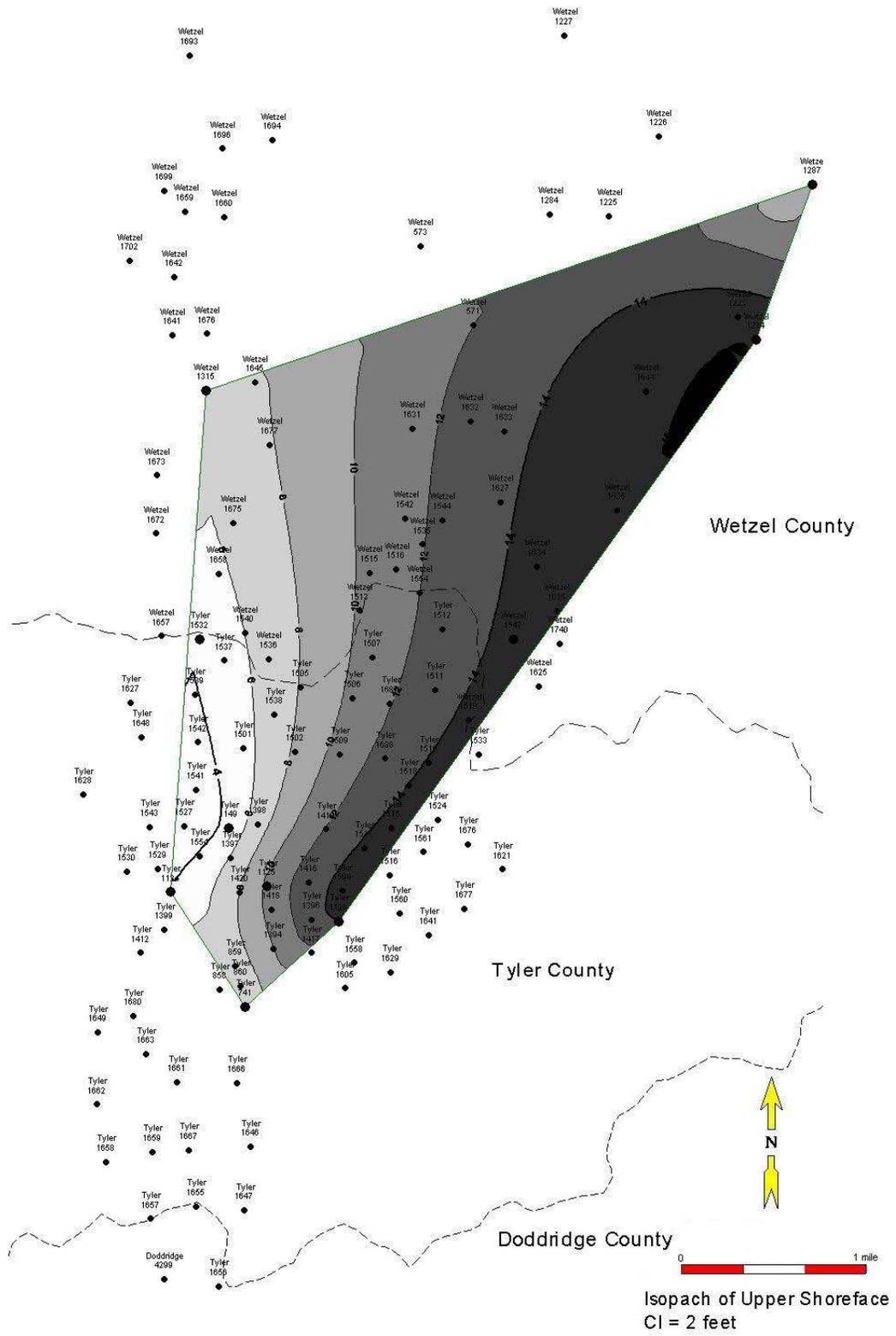


Figure 39. Isopach Map of the upper shoreface sandstone, based on ten cores only.

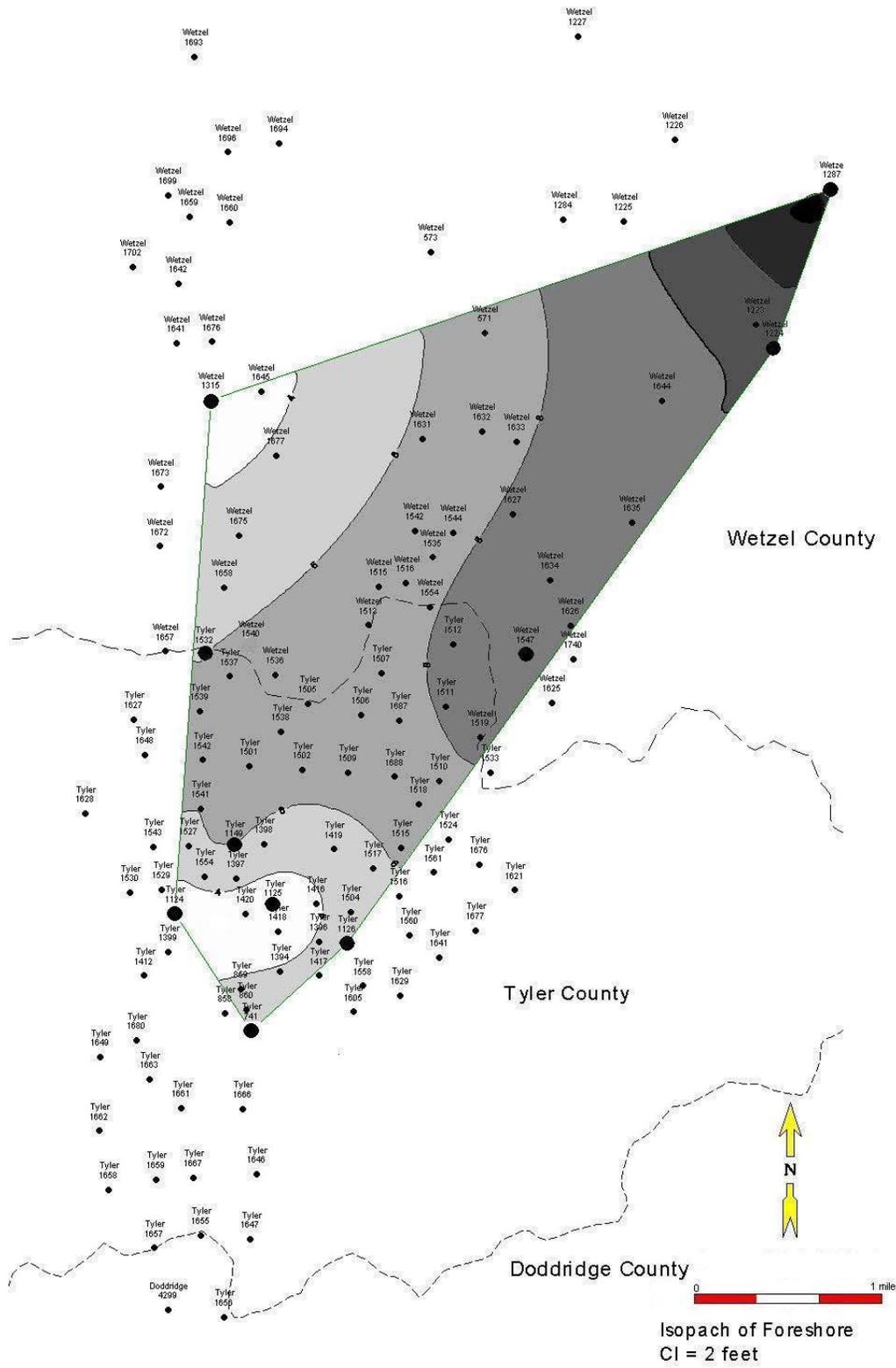


Figure 40. Isopach map of the foreshore sandstone, based on ten cores only.

Pennsylvania. The longshore current responsible for building this barrier island appears to have flowed in a southern direction. Another piece of evidence for a south-flowing longshore current is the isolith map of total conglomerate. For this map, the total thickness of conglomerate in the ten cores were summed as a net thickness (Figure 41). The isolith map shows that the conglomerate is thickest (8-15 feet) in the northeast section of the field and thins to the southwest. The conglomerate is thought to have entered the study area from a stream located just north of the Jacksonburg-Stringtown field. According to Boswell (1988), there is a westerly-directed linear sandstone thick that represents a fluvial system. The sandstone trend ends in Marion County, with the stream mouth entering into Wetzel County (due north of the Jacksonburg-Stringtown field) (Figure 42). Tectonic uplift of the newly forming Acadian mountains supplied coarse clasts of quartz and rock fragments that were transported westward by fluvial systems such as this.

The supply of coarse sediment to the area was a fluvial system north of the field. Barrier-island sediment aggraded more quickly in the north due to a high sediment influx, and the topography built up to sea level. The slow increase in relative sea level created additional accommodation space, and the foreshore sandstone accumulated a significant thickness. Most of the coarse sediment entering the area accumulated in the northern part of the field close to its source; hence, the sedimentation rate decreased to the south. Accommodation space there was not filled as rapidly, and water depth in general was somewhat deeper. Again, isopach maps of the lower-shoreface, upper -shoreface, and foreshore facies show a northern thickening of the foreshore and a southern thickening of the lower shoreface.

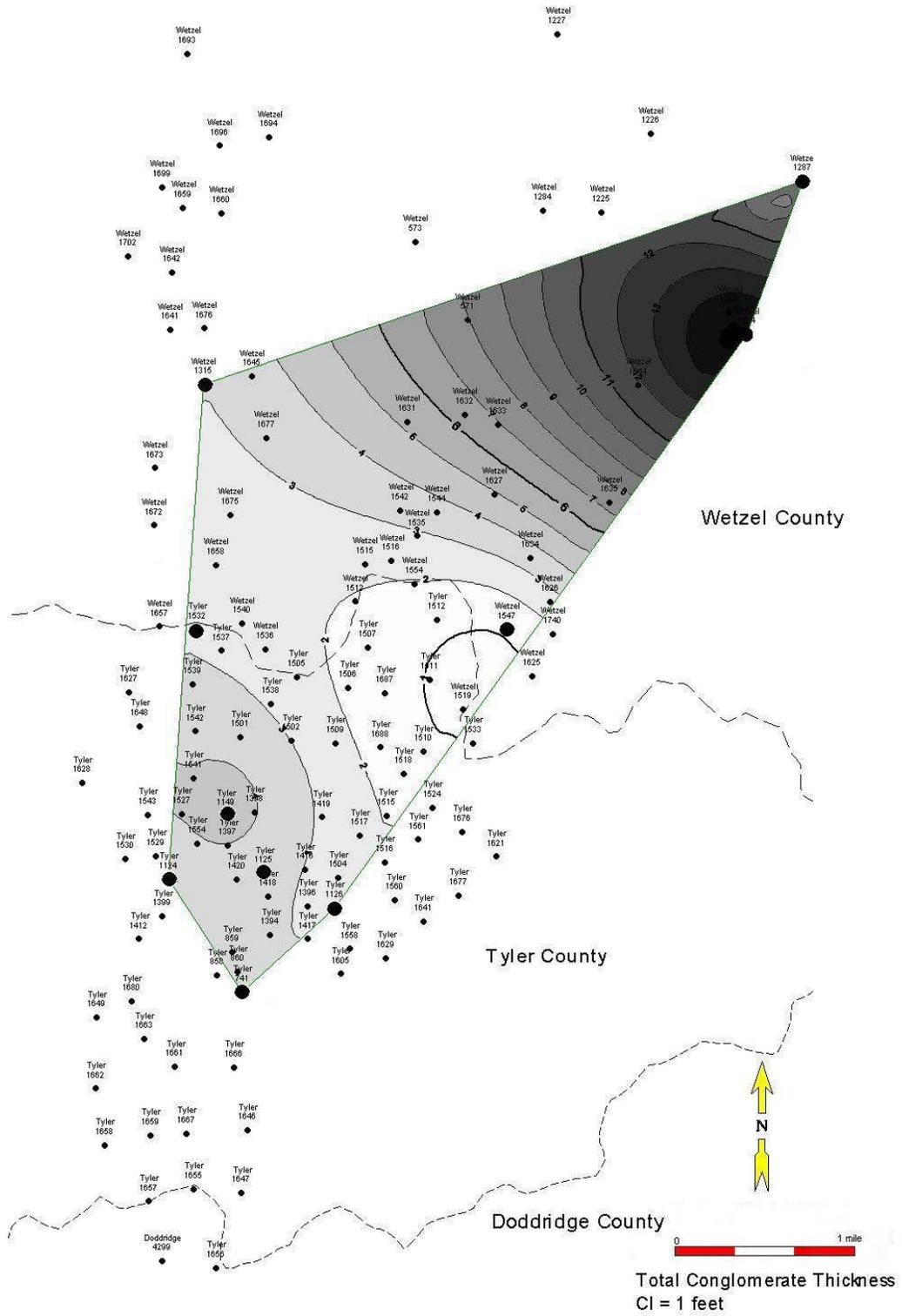


Figure 41. Isolith map of Conglomerate. Based on 10 cores only.

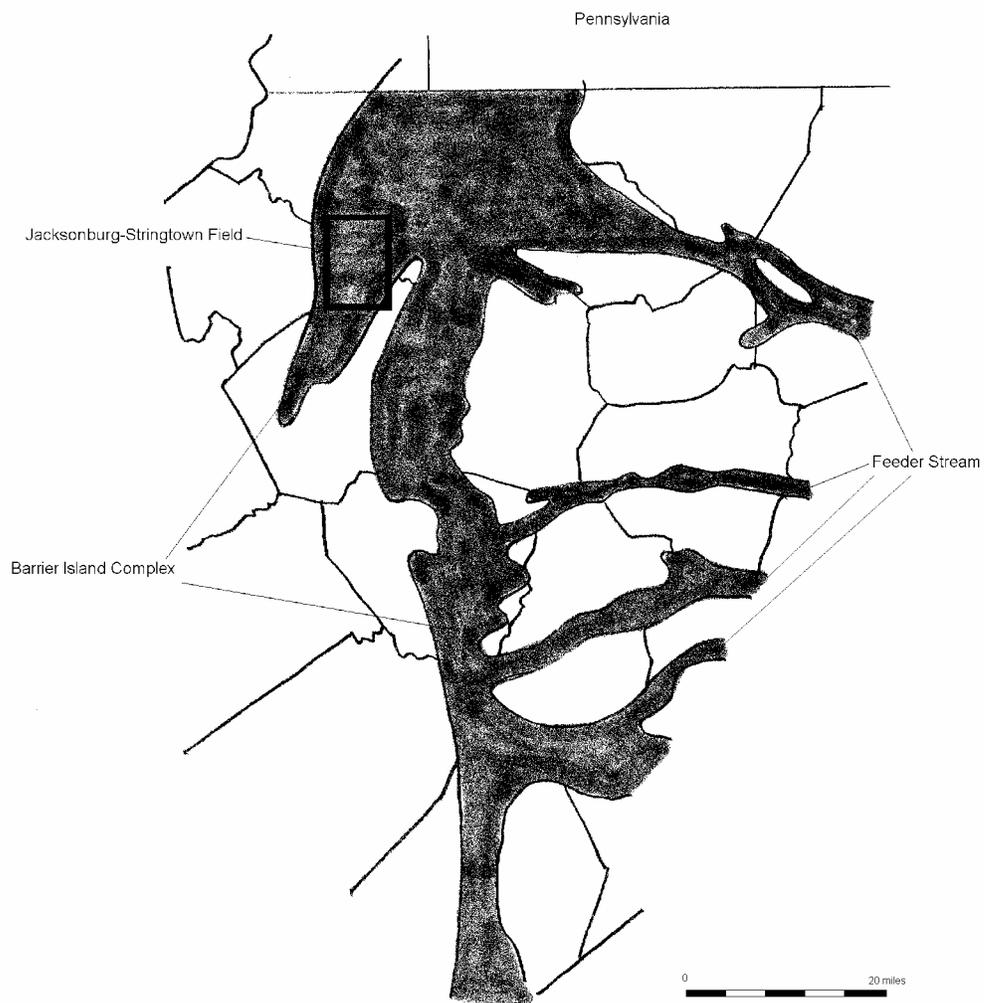


Figure 42. Paleogeographic map of the Gordon Stray sandstone adapted from Figure 20, showing feeder streams, position(s) of barrier island, and the Jacksonburg-Stringtown field. Based on Boswell and Jewell, 1988.

Upper Gordon Stray

As defined earlier, the upper Gordon Stray includes the strata above the barrier-island sandstone and below the first major sandstone kick on the gamma-ray log. The thickness of this interval across the field remains relatively constant around 50-60 feet thick (Figure 43). In the northern area of the field, however, the upper interval reaches a thickness of over 75 feet. The map is shaded so that thicker areas are shown as a dark gray whereas the thinner areas are lighter.

The upper Gordon Stray is divided into sandstone and shale based on a value of 90 GAPI units on the gamma-ray log. Rock with a reading greater than 90 is assumed to be shale, and rock less than 90, sandstone. The sandstone thickness ranges up to 30 feet thick (maximum). The areas of thickest sandstone are to the west, and the sandstone thins towards the east. The sandstone has a lobate geometry and appears to be washover sands from another barrier island farther to the west. There are two lobes present on the map with 20-30 feet of sandstone (see Figure 44). Previously, however, it was thought that the barrier-island sandstone of the Jacksonburg-Stringtown field was the westernmost sandstone of the Gordon Stray (Bowell 1988; Matchen 2001).

To the west, the barrier island pinches out. The barrier island that formed in the eastern Jacksonburg-Stringtown field was apparently stationary for a time allowing a thick accumulation of sediment to build. It was previously thought that this was a seaward pinch-out of the facies. However, maps shown here show that there was a rapid progradation of the barrier-island to another stable position to the west. The barrier island jumped quickly seaward (to the west), depositing only a thin sheet of sand across the western part of the field. The barrier island stopped prograding to the west of the

Jacksonburg-Stringtown field and, presumably, built up in thickness to the point where washover lobes were forming behind it. On Boswell's (1988) map, there is an earlier barrier-island to the east of the Jacksonburg-Stringtown field. This shows that the beach was obviously prograding to the west.

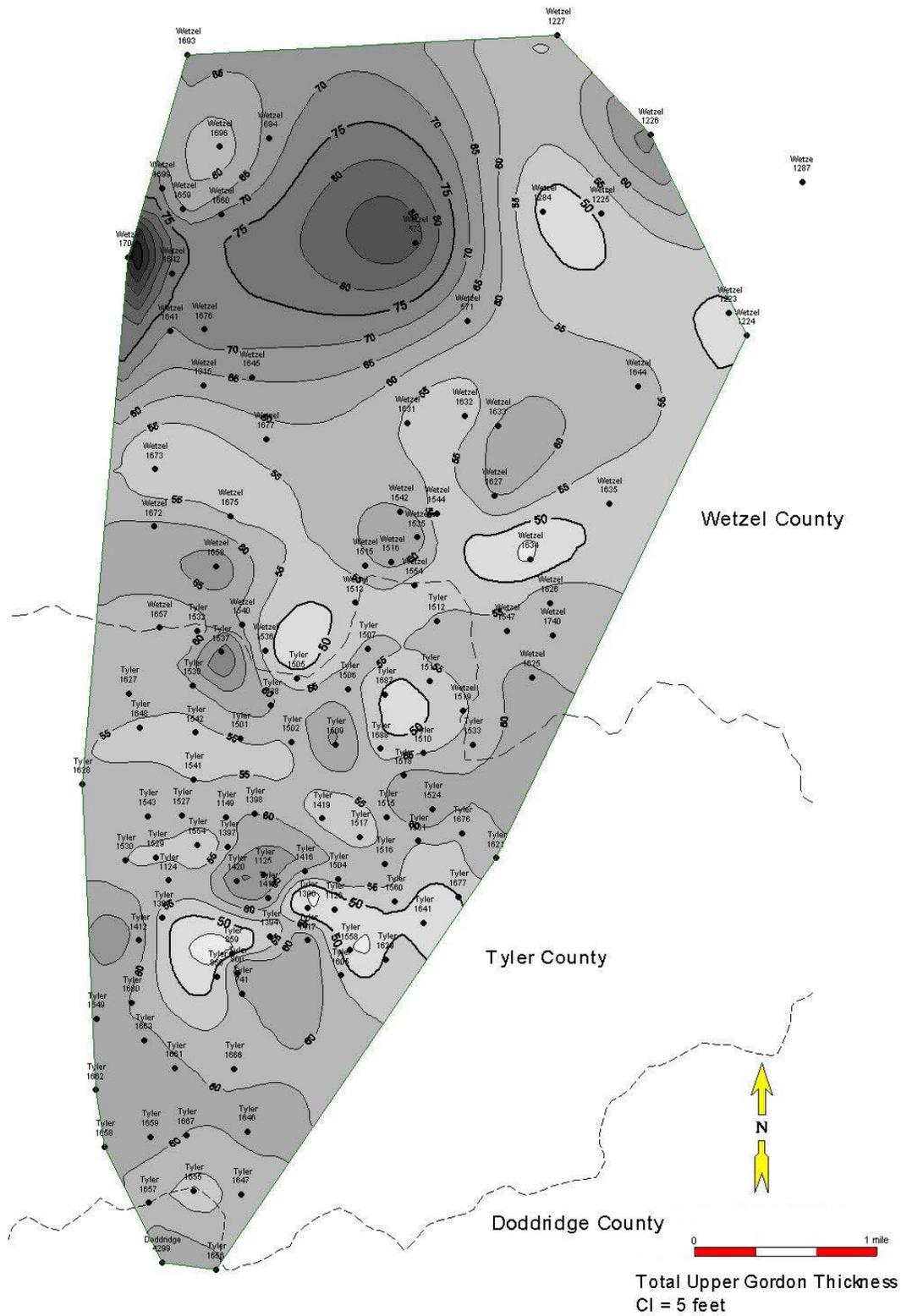


Figure 43. Isopach map of upper Gordon interval.

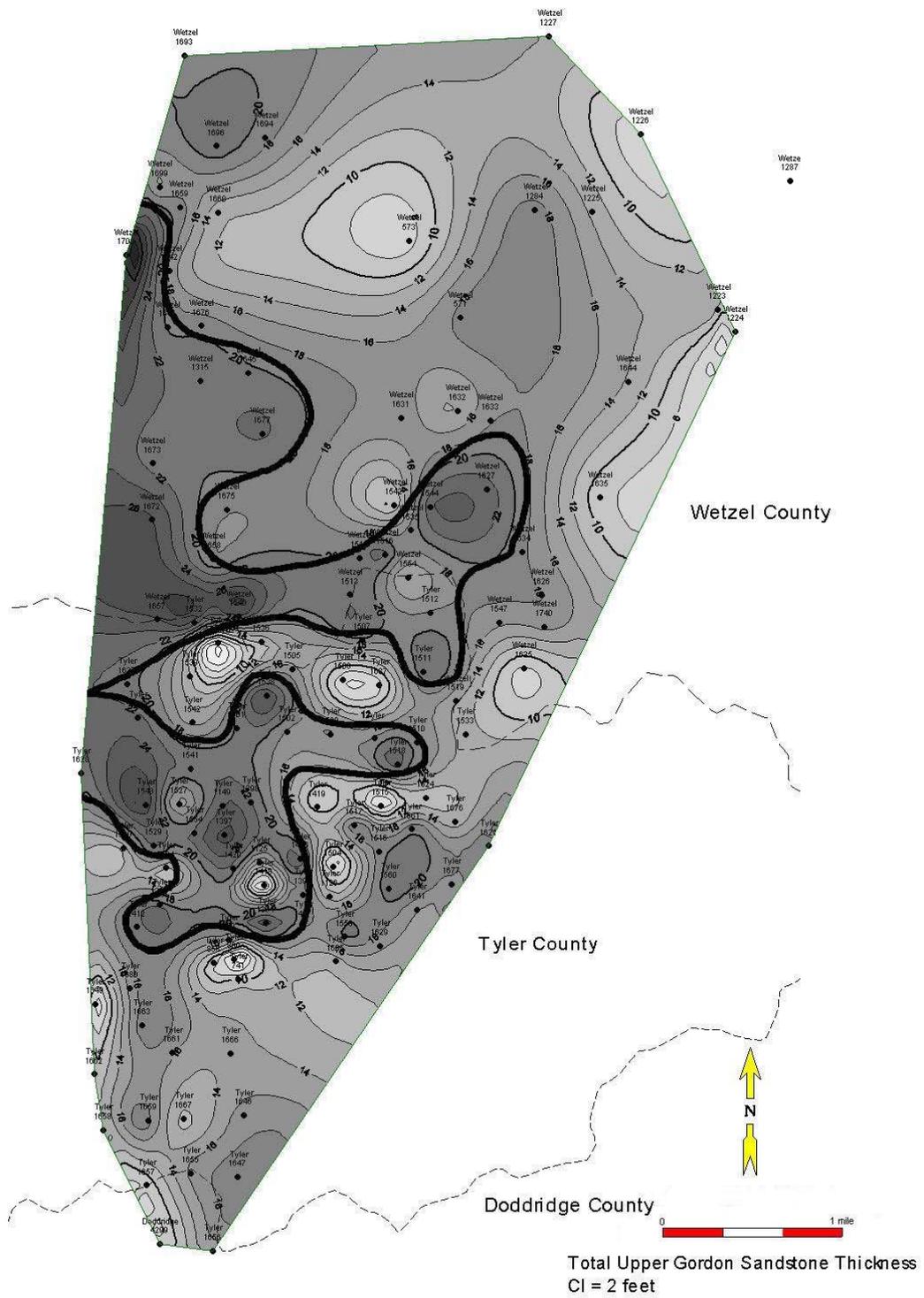


Figure 44. Map of the upper Gordon sandstone. Washover lobes shown in solid black outline.

The isolith map of the upper Gordon Stray shale shows the net thickness of shale within this unit (Figure 45). The shale in this unit represents the lagoonal environment to the east of the proposed barrier island. The shale is thickest (>50 feet) to the north, south, and east, wherever the sandstone lobes are absent.

Cross Sections

Six cross sections were constructed throughout the field (Figure 46), four east-west (dip) and two north-south (strike) (Figures 47-52). As expected, the east-west cross sections show a thinning of the barrier-island sandstone to the west. The north-south 1 cross section maintains a fairly constant barrier-island thickness, whereas the north-south 2 cross sections show the barrier-island thicken and thin, eventually thinning towards the southern end of the field.

On the east-west cross sections, the washover sands can be seen above the barrier-island sand that is on the bottom. To the west, these sandstones thicken and become more dominant, whereas to the east, the lagoonal shales thicken. Below the barrier-island sandstone on the bottom is a series of sandstones that were not cored. Matchen (2001) mentions these sandstones as part of his C zone, which constituted the lowest of his parasequences. That interpretation was based on log-signature alone, again because the cores did not penetrate to this interval.

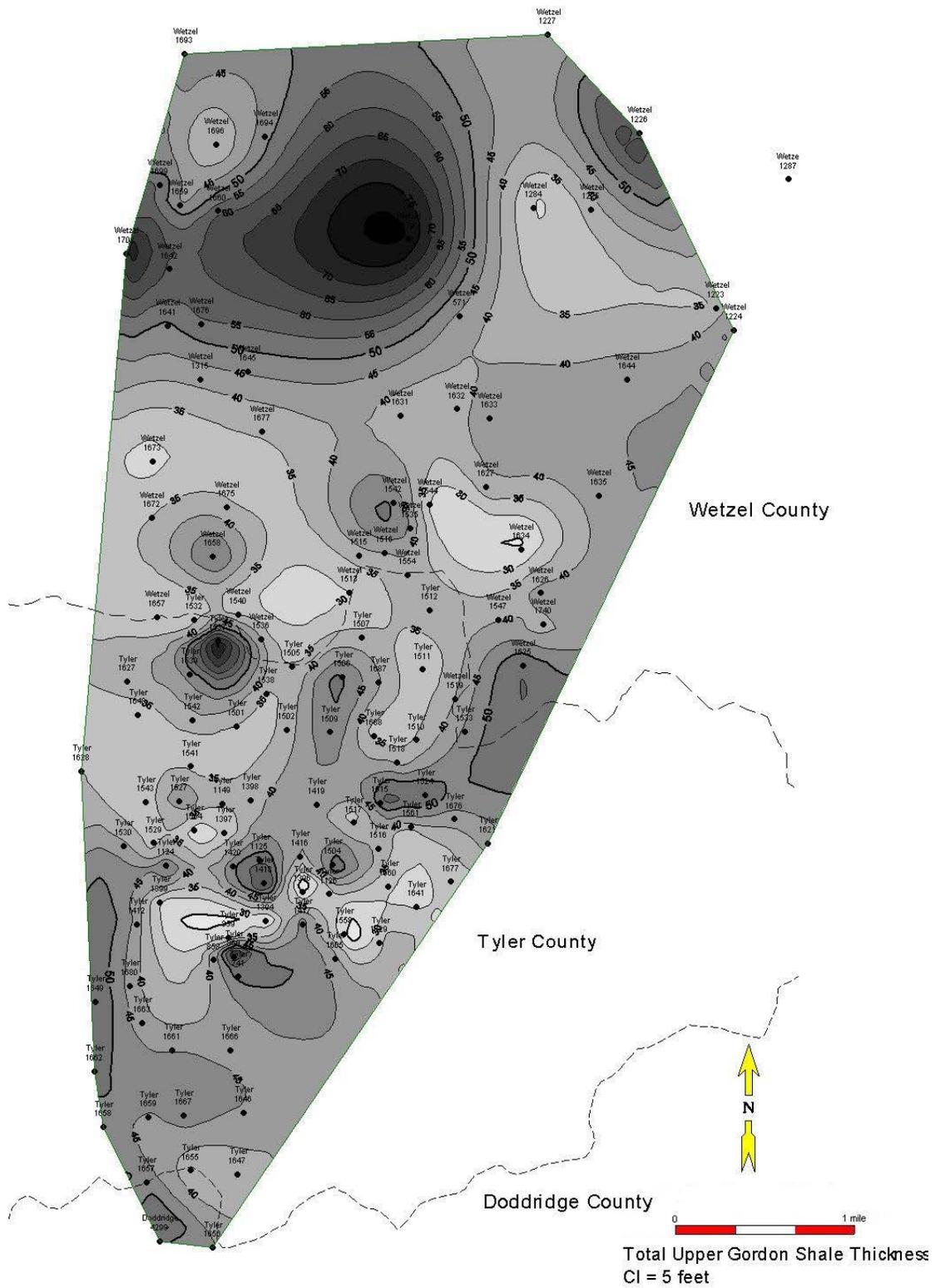


Figure 45. Isolith map of the upper Gordon shale.

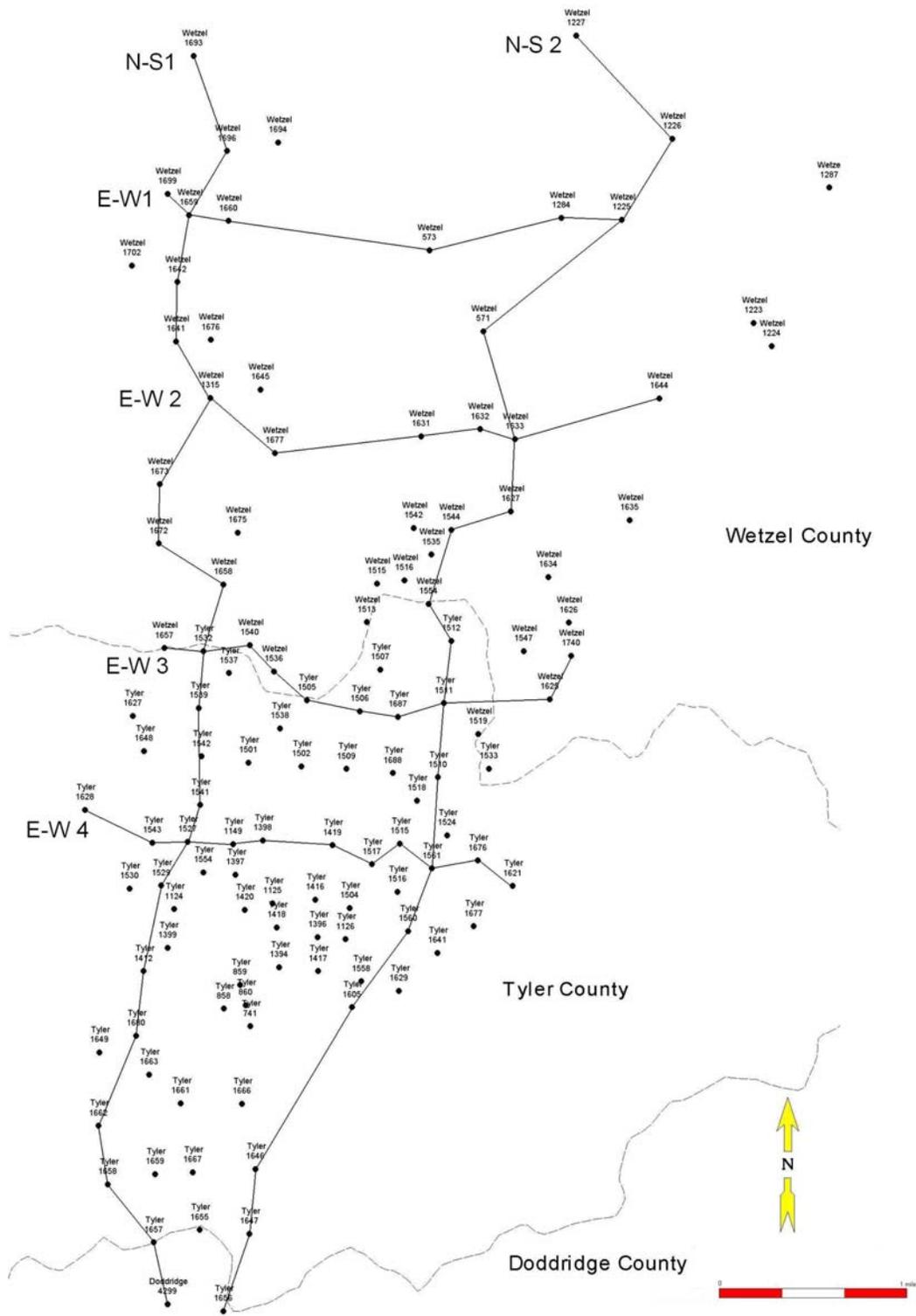


Figure 46. Location of cross sections.

E

E-W 1

W

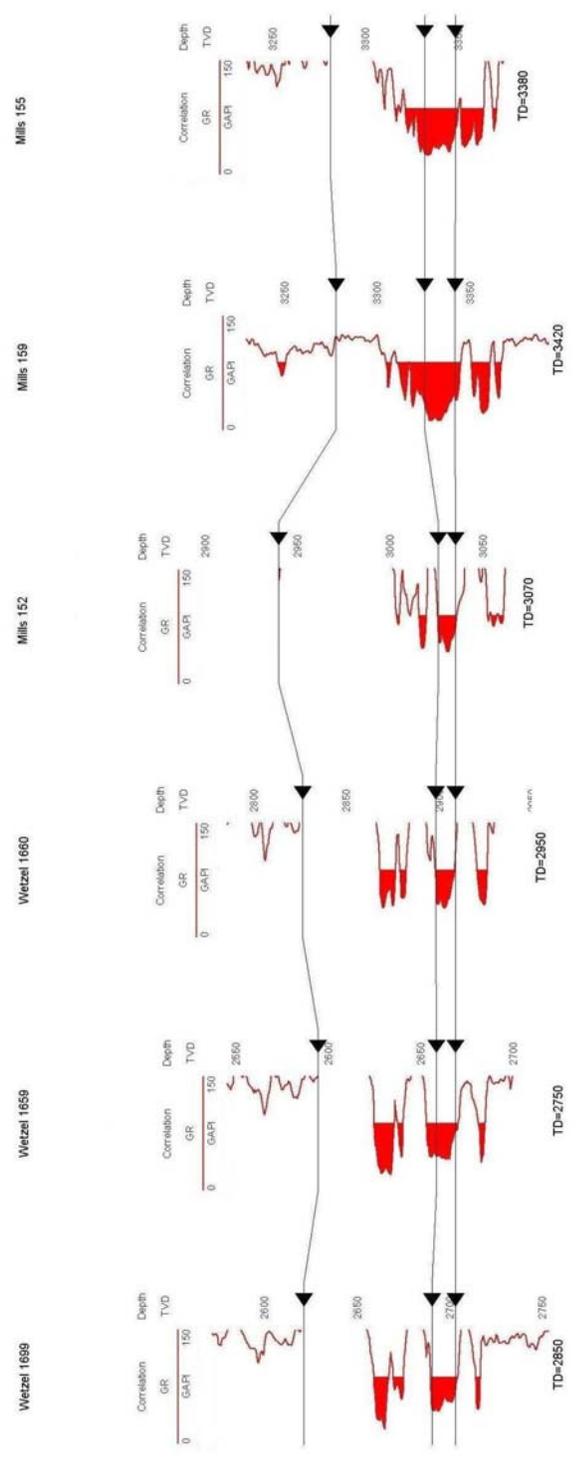


Figure 47. EW cross section 1.

E

E-W 2

W

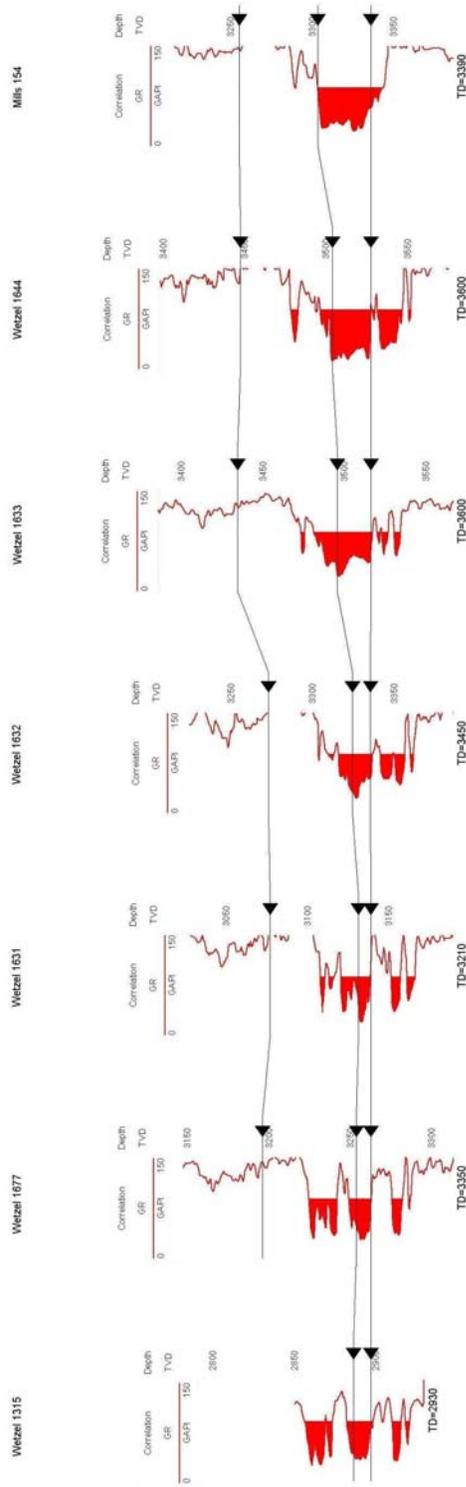


Figure 48. EW cross section 2.

E

W

E-W 3

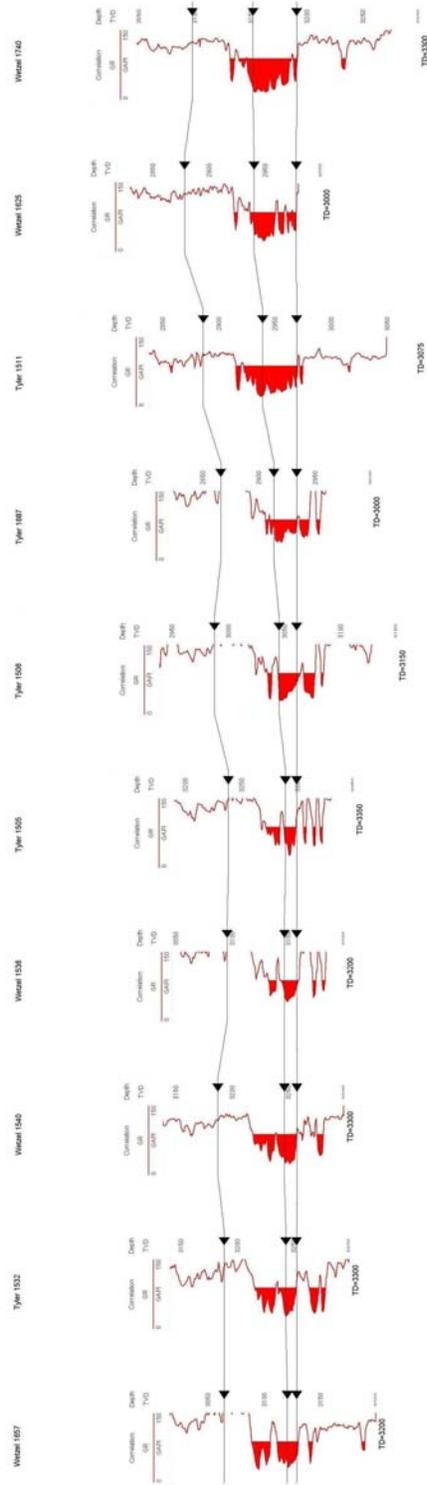


Figure 49. EW cross section 3.

E

W

E-W 4

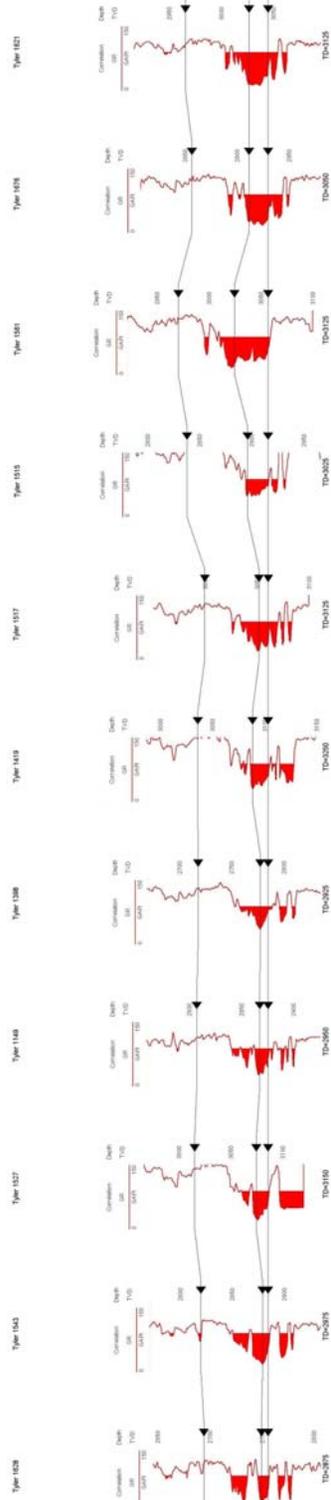


Figure 50. EW cross section 4.

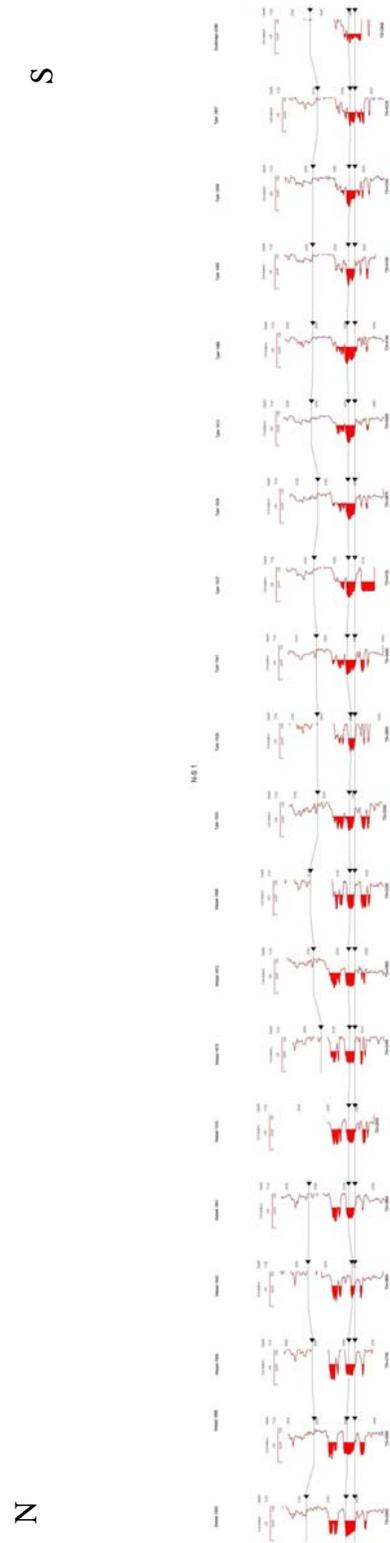


Figure 51. NS cross section 1.

S

N

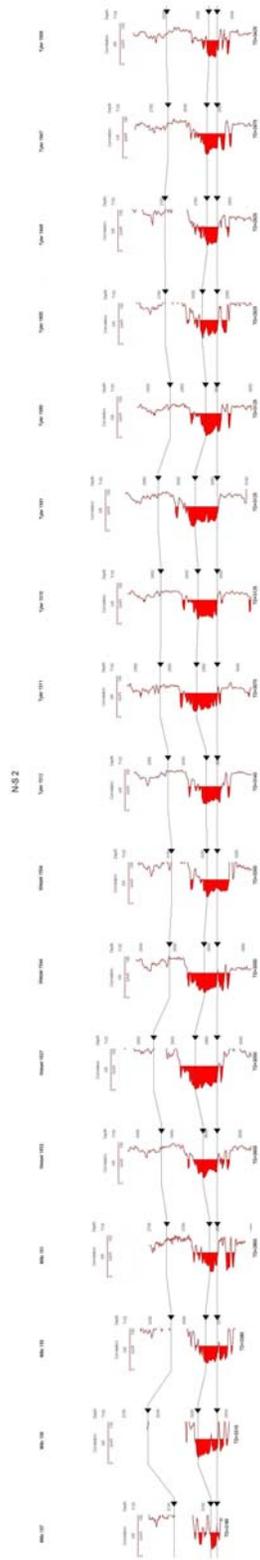


Figure 52. NS cross section 2.

PRODUCTION AND EXPLORATION

The highest levels of production come from the middle section of the barrier-island sandstone, specifically the lower upper shoreface and the upper lower shoreface. The sandstones of this facies are fine- to medium-grained, well sorted, well rounded, and have good porosity and permeability. The Ball 18 and Peter Horner 9 wells show permeabilities up to 250 mD within the upper- and lower-shoreface sandstones (McDowell, in press). This is the zone that Matchen (2001) named the featureless sandstone unit (Fss). The Fss is known to have the highest levels of production, due to the fact that the completion intervals are within this zone. In this zone, and log porosity has been measured up to 25% and permeabilities have been measured up to 250 mD (Aminian et al, in press a&b). The conglomerate and coarse-grained sandstone of the upper upper shoreface and the foreshore tend to have more cement and therefore a lower porosity and permeability (McDowell, in press). The finer-grained sandstone of the lower lower shoreface and the washover lobes may have a high porosity; however, either the pore space is too small or there is not enough interconnectedness of pore space to allow for the free flow of hydrocarbons.

Matchen (2001) divided the Gordon Stray into three parasequences throughout the Jacksonburg-Stringtown field. Parasequence A of Matchen approximately matches the foreshore and upper shoreface sandstones of my study. Parasequence B approximately matches the lower shoreface and shelf facies of my study. Parasequence C is interpreted on well logs alone; no core data was available of this interval. Matchen (2001) then identified reservoir sandstones within each parasequence and mapped this distribution. In the west portion of the field, where the barrier island sandstone is relatively thick, the

reservoir seems to be in parasequence A, that is, the upper shoreface sandstone. In the eastern portion of the field, where the barrier island sandstone is thicker, the reservoir seems to be in parasequence B, that is, the lower shoreface sandstone. Except for a small area where the reservoir rock is in parasequence C, that is, shelf sandstone.

Production differences across the field may be due, in part, to compartmentalization of this reservoir caused by shale interbeds (Figure 53). Figure 53 shows the total shale thickness within the shoreface and foreshore of the Gordon Stray barrier-island facies the map shows an area of relatively thick shale in the east central part of the field. The reason for the shale's presence is not known. Perhaps this area of thick shale may have accumulated within a minor recess into the barrier-island (although, there is no evidence to substantiate that claim). This shaly zone may cause the drastic permeability change within the overall system, compartmentalizing the field. Areas north and south of this shaly zone tend to have better reservoir rocks with barrier island sandstone (Matchen, in press).

To date, no wells have been drilled to the Gordon Stray sandstone directly west of the Jacksonburg-Stringtown field (Figures 54 and 55). Figure 55 shows all wells away from Jacksonburg-Stringtown field that produce from either the Gordon or the Gordon Stray and were drilled between 2000 and 2004. The well data was acquired from the West Virginia Geologic and Economic Survey. This map was made to extend the data presented in Figure 54. Because of the lack of data to the west of the field, and westward thinning of the Gordon Stray sandstone within the field, it was previously assumed that the Gordon Stray in the Jacksonburg-Stringtown field was the most westerly sandstone of the Acadian clastic wedge (Boswell 1988, Matchen 2001, Avery 2001). However, new

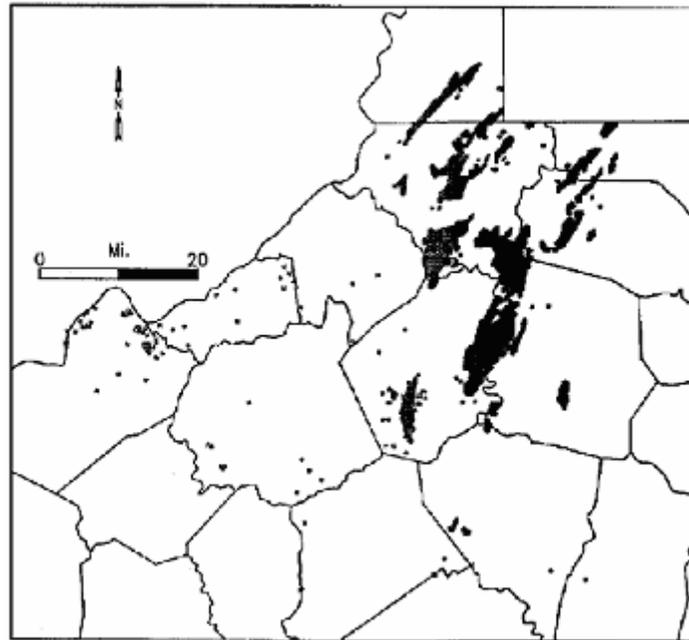


Figure 54. Gordon and Gordon Stray producing wells drilled from 1960 to 2000.
From Avary 2001.

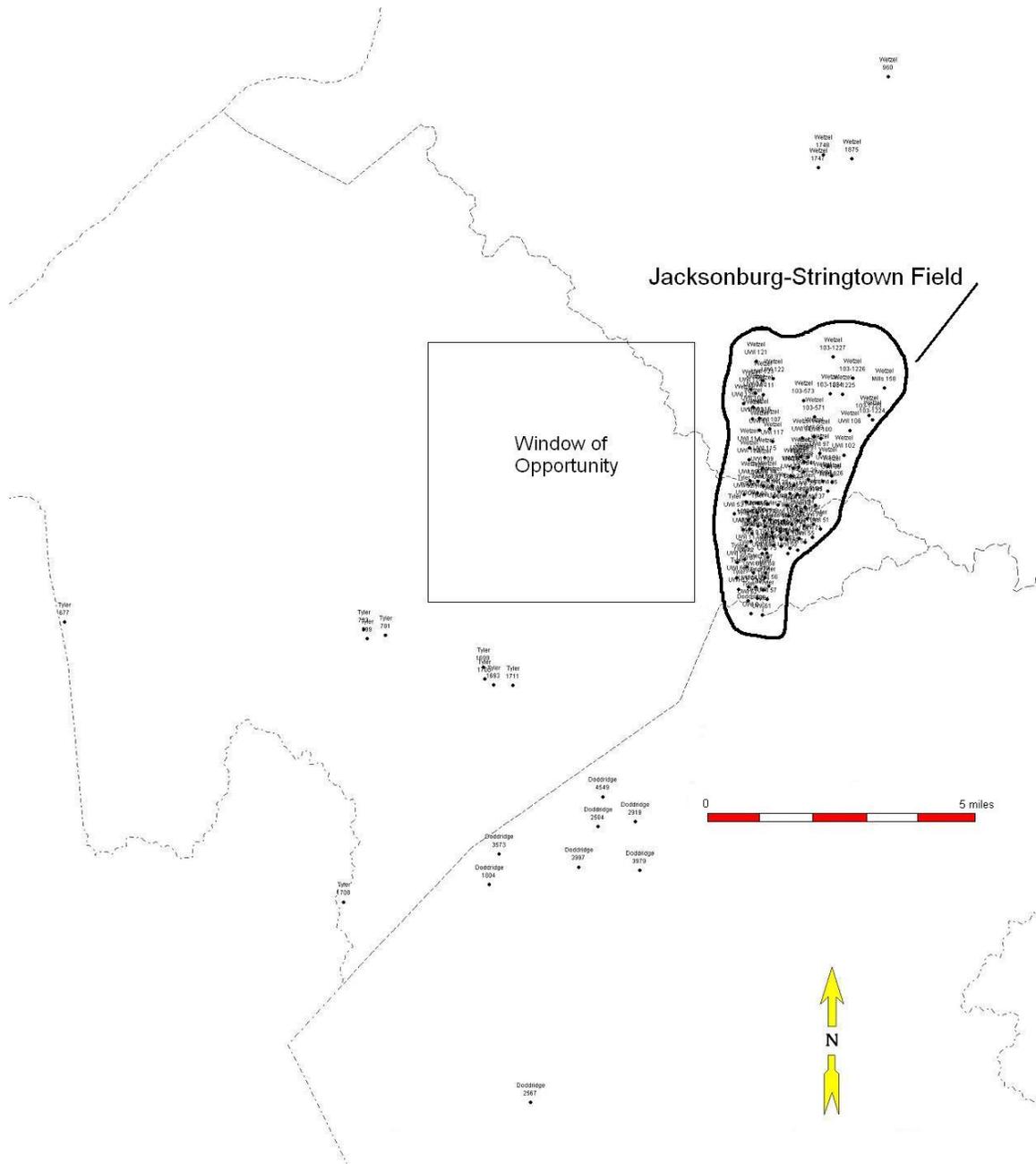


Figure 55. Location of all wells drilled to the Gordon and Gordon Stray from 2000 to 2004 away from the Jacksonville-Stringtown field drilled to the Gordon. Data from the West Virginia Geologic and Economic Survey.

data and maps presented here show the possibility of another barrier-island sandstone farther to the west, which can potentially be an area for future hydrocarbon exploration. This area is labeled as the “window of opportunity” on Figure 55. A westward progradational jump of 10 miles would be consistent with earlier Gordon Stray progradation, assuming a progradational jump similar to earlier distances (Avary, in press).

CONCLUSIONS

The Gordon Stray sandstone has long been known as a reservoir rock in the Appalachian basin. However, facies studies on the Gordon Stray in the subsurface have yet to be conducted. The purpose of this study was to determine the exact depositional environment of the Gordon Stray sandstone in the Jacksonburg-Stringtown field of West Virginia. This goal was accomplished by careful examination of 10 3-inch full bore cores, 123 well logs, and the interpretation of maps and cross sections constructed from this data.

The Gordon Stray sandstone of the Jacksonburg-Stringtown field is composed of conglomerate, sandstone, and shale which represent related facies of a barrier-island complex. Based on the sedimentary structures, texture, fossils, and vertical changes seen within the ten cores, it is concluded that the barrier-island complex was composed of six different facies: shelf, lower shoreface, upper shoreface, foreshore, lagoon, and washover fans. During deposition of the barrier-island sandstone, there was a slow steady rise in relative sea level and a sediment influx rate that equaled the rate of sea-level rise, causing aggrading sedimentation.

The Jacksonburg-Stringtown field was previously thought to represent the farthest progradation of the Gordon Stray. However, maps shown here suggest that the barrier-island complex jumped farther to the west (basinward) depositing little sediment during the rapid progradation. Once the barrier-island was established to the west, however, the system aggraded again to a point where washover sandstones from the beach were deposited in the lagoon behind. These washover sands in the cores of the Jacksonburg-

Stringtown field are the main evidence for another barrier-island system to have existed basinward of the Jacksonburg-Stringtown field.

The Gordon Stray has produced in the Jacksonburg-Stringtown field for 100+ years. To date, there have been few, if any, wells drilled directly west of the field. This area, I believe, should be looked at from an exploration standpoint, as it could contain a barrier-island system similar to the one seen in the Jacksonburg-Stringtown field.

REFERENCES CITED

Aminian, K., Thomas, Benjamin., Oyerkun, Ademula., Bilgesu, H.I., Ameri, S., in press. Application of Artificial Neural Networks to Reservoir Characterization *in* Petroleum geology and reservoir characterization of the Upper Devonian Gordon sandstone, Jacksonburg-Stringtown oil field, Northwestern West Virginia. West Virginia Geologic and Economic Survey, Publication B-45, p. 66-95.

Aminian, K., Thomas, Benjamin., Oyerkun, Ademula., Bilgesu, H.I., Ameri, S., in press. Permeability Distribution Prediction *in* Petroleum geology and reservoir characterization of the Upper Devonian Gordon sandstone, Jacksonburg-Stringtown oil field, Northwestern West Virginia. West Virginia Geologic and Economic Survey, Publication B-45, p. 66-95.

Avary, K.L., in press. Discovery and Development *in* Petroleum geology and reservoir characterization of the Upper Devonian Gordon sandstone, Jacksonburg-Stringtown oil field, Northwestern West Virginia. West Virginia Geologic and Economic Survey, Publication B-45, p. 11-23.

Kammer, T.W., and Bjerstedt, T.W., 1988. Genetic stratigraphy and depositional systems of the Upper Devonian-Lower Mississippian Price-Rockwell delta complex in the central Appalachians. USA: *Sedimentary Geology*, v. 54, p 265-301.

Boswell, R.M., 1988. Basin analysis of the Acadian clastic wedge in Northern West Virginia and adjacent areas, Ph. D. Dissertation, pp. 12-90. WVU Morgantown, WV.

Boswell, R. M., and Donaldson, A. C., 1988. Depositional architecture of the Catskill delta complex; central Appalachian basin, U.S., *in* Canadian Society of Petroleum Geologists Memoir 14, pp. 65-84.

Boswell, R.M., Heim, L.R., Wrightstone, G.R., and Donaldson, A.C., 1996. Play Dvs: Upper Devonian Venango sandstones and siltstones *in* Roen, J.B. and Walker, B.J. (Eds), *The Atlas of Major Appalachian Gas Plays*, Publication V-25, West Virginia Geological and Economic Survey, Morgantown, WV. Pp. 63-69.

Boswell, R.M. and Jewell, G.A., 1988. Atlas of Upper Devonian/Lower Mississippian sandstones of the subsurface of West Virginia. Circular C-43. West Virginia Geological and Economic Survey, Morgantown, WV pp. 144.

Davis, R. A., 1994, Barrier-island systems – a geologic overview, *in* Davis, R. A., ed., *Geology of Holocene barrier-island systems*: Springer – Verlag, Berlin, p. 1-46.

DeCelles, Peter G., 1987. Variable preservation of middle Tertiary, Coarse-grained, nearshore to outer-shelf storm deposits in southern California. *Journal of Sedimentary Petrology*. pp. 250-264.

- Dennison, J.M., 1985. Catskill Delta shallow marine strata, *in* The Catskill Delta: Geological Society of America, Sp. Paper 201 pp. 91-105.
- Ettensohn, F.R., 1985, Controls on development of Catskill Delta complex basin-facies, *in* The Catskill Delta: Geological Society of America, Sp. Paper 201 pp. 65-77.
- Friis, Henrik, Millelsen, Jorgen, and Sandersen, Peter, 1998, Depositional environment of the Vejle Fjord Formation of the Upper Oligocene-lower Miocene of Denmark; a barrier-island/barrier-protected depositional complex: *Sedimentary Geology*, v. 117, no. 3-4, p. 221-244.
- Hardie, Lawrence A., 1986. Stratigraphic models for carbonate tidal-flat deposition. v. 81 *Colorado school of Mines quarterly*. pp. 59-74.
- Harper, J. A., and Laughrey, C. D., 1987. Geology of the oil and gas fields of southwestern Pennsylvania. Pennsylvania Geologic Survey, Mineral Resource Report 87, p. 27-35.
- Hartley, Adrian J., and Jolley, Elizabeth J., 1999, Unusual coarse clastic, wave-dominated shoreface deposits, Pliocene to Middle Pleistocene, Northern Chile: Implications for coastal facies analysis: *Journal of Sedimentary Research*, v. 69, p. 105 – 114.
- Hohn, M., in press. Introduction *in* Petroleum geology and reservoir characterization of the Upper Devonian Gordon sandstone, Jacksonburg-Stringtown oil field, Northwestern West Virginia. West Virginia Geologic and Economic Survey, Publication B-45, p. 4-10.
- Lundegard, P.D., Samuels, N.D., Pryor, W.A., 1985. Upper Devonian turbidite sequence, central and southern Appalachian basin: Contrasts with submarine fan deposits, *in* The Catskill Delta: Geological Society of America, Sp. Paper 201 pp. 107-121.
- Matchen, D., in press, Regional and Local Geology. *in* Petroleum geology and reservoir characterization of the Upper Devonian Gordon sandstone, Jacksonburg-Stringtown oil field, Northwestern West Virginia. West Virginia Geologic and Economic Survey, Publication B-45, p. 24-42.
- McCubbin, D.G., 1981. Barrier-Island and strand-plain facies. *American Association of Petroleum Geologists*. pp 247-278.
- McDowell, R., Petrology and Petrophysics, 2001. *in* Petroleum geology and reservoir characterization of the Upper Devonian Gordon sandstone, Jacksonburg-Stringtown oil field, Northwestern West Virginia. West Virginia Geologic and Economic Survey, Publication B-45, p. 43-46.

Oertel, George F., Kraft, J. Chris, Kearney, Michael S., and Woo, H. J., 1992, A rational theory for barrier-lagoon development: SEPM Special Publication no. 48, p. 77 – 87.

Reading, H.G., 1996. Sedimentary Environments: Processes, Facies and Stratigraphy. 3rd edition. pp 154-231.

Walker, R. G., and Plint, A. G., 1992, Wave and storm dominated shallow marine systems, *in* Walker, R. G. and James, N. P., eds., Facies models, response to sea level change: Geotext 1, Geological Association of Canada, p. 219 – 238.

Woodrow, D. L., 1985. Paleogeography, paleoclimate, and sedimentary processes of the Late Devonian Catskill Delta, *in* The Catskill Delta: Geological Society of America, Sp. Paper 201 pp. 51- 63.

Woodrow, D.L., Dennison, J.M., Ettensohn, F.R., Sevon, W.T., and Kerchgasser, W.T., 1988. Middle and Upper Devonian stratigraphy and paleogeography of the central and southern Appalachians and eastern midcontinent, USA *in* Canadian Society of Petroleum Geologists Memoir 14, pp. 277-299.

APPENDIX

CORE DESCRIPTIONS

Ball 18

Unit 1

3015.2-3012.0 (3.2')

SANDSTONE, fine-grained, well-rounded, quartz, scattered siderite nodules

LARGE-SCALE LOW-ANGLE PLANAR CROSS BEDDING at top

HORIZONTAL STRATIFICATION at bottom

Unit 2

3012.0-3011.3 (.7')

SHALE, dark gray

HORIZONTAL STRATIFICATION

Unit 3

3011.3-3007.5 (3.8')

SANDSTONE, fine-grained, well-rounded, quartz, few siderite nodules, scattered shale clasts

LARGE-SCALE LOW-ANGLE PLANAR CROSS BEDDING

Unit 4

3007.5-3006.7 (.8')

SHALE, dark gray, silty/sandy

HORIZONTAL STRATIFICATION

Unit 5

3006.7-3005.7 (1.0')

SANDSTONE, fine-grained, well-rounded, quartz, shale clasts throughout

LARGE-SCALE LOW-ANGLE PLANAR CROSS BEDDING

Unit 6

3005.7-3005.4 (.3')

SHALE/SANDSTONE, wavy bedding

Unit 7

3005.4-3005.0 (.4')

SANDSTONE, fine-grained, well-rounded, quartz

HORIZONTAL STRATIFICATION, SMALL-SCALE LOW-ANGLE PLANAR CROSS BEDDING

Unit 8

3005.0-3004.5 (.5')

SANDSTONE, fine-grained, shale clasts throughout

LARGE-SCALE HIGH ANGLE PLANAR CROSS BEDDING

Unit 9

3004.5-3003.6 (.9')

SANDSTONE, fine-grained, few shale clasts, shale lenses near top
HORIZONTAL STRATIFICATION near bottom, RIPPLES and SMALL-SCALE LOW
ANGLE PLANAR CROSS BEDDING

Unit 10

3003.6-3003.3 (.3')
MISSING

Unit 11

3003.3-3002.1 (1.2')
SS, fine-grained, few scattered thin shale layers
LARGE-SCALE LOW-ANGLE PLANAR CROSS BEDDS, RIPPLES near top

Unit 12

3002.1-3001.8 (.3')
SANDSTONE, fine-grained
Scour base

Unit 13

3001.8-3001.6 (.2')
SHALE, dark gray
HORIZONTAL STRATIFICATION, HORIZONTAL BURROWS

Unit 14

3001.6-2997.9 (3.6')
SANDSTONE, upper fine-grained, conglomerate at bottom, scattered quartz pebbles
throughout
HORIZONTAL STRATIFICATION

Unit 15

2997.9-2996.4 (1.5')
SANDSTONE, upper fine-grained, CONGLOMERATE at base, few thin
CONGLOMERATE layers
Scour base

Unit 16

2996.4-2995.9 (.5')
CONGLOMERATE, average size is .5 cm, shale clasts throughout

Unit 17

2995.9-2995.5 (.4')
SANDSTONE, coarse-grained, well-rounded, quartz, few quartz pebbles
LARGE-SCALE LOW-ANGLE PLANAR CROSS BEDDING

Unit 18

2995.5-2994.4 (1.1')

SANDSTONE, medium-grained, well-rounded, quartz grains, few scattered quartz pebbles
LOW ANGLE PLANAR CROSS BEDS

Unit 19

2994.4-2994.1 (.3')
SANDSTONE, fine-grained, few quartz pebbles

Unit 20

2994.1-2993.8 (.3')
SANDSTONE, Conglomerate and coarse-grained
Scour base

Unit 21

2993.8-2991.9 (1.9')
SANDSTONE, fine-grained, few quartz pebbles
Faint HORIZONTAL STRATIFICATION at bottom, RIPPLES at top

Unit 22

2991.9-2991.6 (.3')
MISSING

Unit 23

2991.6-2991.1 (.5')
SANDSTONE, coarse-grained, few quartz pebbles

Unit 24

2991.1-2990.4 (.7')
SANDSTONE, fine-grained, few conglomerate layers
Top is .1' of shale/sandstone wavy bedding

Unit 25

2990.4-2990.0 (.4')
SANDSTONE, coarse-grained, few quartz pebbles
Large-scale low angle planar cross bedding

Unit 26

2990.0-2988.7 (1.3')
CONGLOMERATE with .2' medium-grained sandstone in middle
CONGLOMERATE has few shale clasts with an average clast size of 5mm
Sandstone has large scale low angle planar cross bedding

Unit 27

2988.7-2988.25 (.45')
SHALE, occasional thin fine-grained sandstone lenses
RIPPLES in sandstone, HORIZONTAL BURROWS

Unit 28

2988.25-2987.9 (.35')

SANDSTONE, fine- to coarse-grained, few quartz pebbles
SMALL-SCALE LOW-ANGLE PLANAR CROSS BEDS**Unit 29**

2987.9-2987.0 (.9')

SANDSTONE, fine-grained with few thin shale lenses, few medium-grained sandstone layers, grading into shale on top
VERTICAL BURROWS, RIPPLES, SMALL-SCALE LOW-ANGLE PLANAR CROSS BEDDING**Unit 30**

2987.0-2986.6 (.4')

CONGLOMERATE with one small fine-grained sandstone layer
Matrix is fine-grained sandstones**Unit 31**

2986.6-2986.0 (.6')

SANDSTONE, fine-grained, few shale clasts throughout, one coarse-grained sandstone layer in middle
Brachiopod shells throughout**Unit 32**

2986.6-2985.4 (.6')

Shale and fine-grained sandstone
Scour base**Unit 33**

2985.4-2983.7 (1.7')

SHALE with very fine-grained sandstone lenses
HORIZONTAL and VERTICAL BURROWS, highly burrowed**Unit 34**

2983.7-2983.45 (.25')

SANDSTONE, fine-grained
LARGE-SCALE LOW-ANGLE PLANAR CROSS BEDDING, VERTICAL and HORIZONTAL BURROWS**Unit 35**

2983.45-2982.7 (.75')

SHALE and very fine sandstone
HORIZONTAL and VERTICAL BURROWS, highly burrowed

Unit 36

2982.7-2982.2 (.5')

SANDSTONE, medium-grained, quartz pebbles

Brachiopod shells

Unit 37

2982.2-2981.0 (1.2')

SANDSTONE, fine-grained, quartz

LARGE-SCALE LOW-ANGLE PLANAR CROSS BEDDING

Unit 38

2981.0-2980.1 (.9')

SHALE, few very fine-grained sandstone lenses

VERTICAL and HORIZONTAL BURROWS, very burrowed

Unit 39

2980.1-2979.0 (1.1')

SANDSTONE, coarse-grained with one thin (<1") shale layer near bottom, shale clasts throughout

Brachiopod shells at top (?)

Unit 40

2979.0-2978.5 (.5')

SHALE

RIPPLES near bottom, HORIZONTAL BURROWS

Unit 41

2978.5-2977.65 (.85')

SANDSTONE, fine-grained, shale clasts throughout

Brachiopod shells

Unit 42

2977.65-2977.2 (.45')

SHALE, dark gray

HORIZONTAL and VERTICAL BURROWS

Peter Horner 9

Unit 1

2910.1-2909.2 (.9')

SANDSTONE, fine-grained quartz

Unit 2

2909.2-2908.8 (.4')

SANDSTONE, fine-grained quartz

LARGE-SCALE LOW-ANGLE PLANAR CROSS BEDDING

Unit 3

2908.8-2908.0 (.8')

MISSING

Unit 4

2908.0-2906.8 (1.2')

SHALE, dark gray

HORIZONTAL STRATIFICATION

Unit 5

2906.8-2905.3 (1.5')

SANDSTONE, fine-grained, quartz, few shale clasts

Unit 6

2905.3-2904.0 (1.3')

MISSING

Unit 7

2904.0-2902.0 (2.0')

SANDSTONE, fine-grained, quartz, few quartz pebbles, one siderite nodule

Ripple bed in middle of unit

Unit 8

2902.0-2901.4 (.6')

SANDSTONE, fine-grained quartz, rare quartz pebbles

LARGE-SCALE LOW-ANGLE PLANAR CROSS BEDDING

Unit 9

2901.4-2898.4 (3.0')

SANDSTONE, fine-grained, scattered thin quartz conglomerate layers

Unit 10

2898.4-2898.0 (.4')

SANDSTONE, medium-grained, coarse grained at very bottom, scour base

LARGE-SCALE LOW-ANGLE PLANAR CROSS BEDDING

Unit 11

2898.0-2896.9 (1.1')

SANDSTONE, fine-grained

Unit 12

2896.9-2896.5 (.4')

SANDSTONE, fine-grained, four conglomerate layers throughout

LARGE-SCALE LOW-ANGLE PLANAR CROSS BEDDING

Unit 13

2896.5-2894.9 (1.6')

SANDSTONE, fine-grained

Faint HORIZONTAL STRATIFICATION

Unit 14

2894.9-2894.5 (.4')

CONGLOMERATE in fine-grained matrix, average clast size is 4mm

Unit 15

2894.5-2894.3 (.2')

SANDSTONE, fine-grained, quartz, few quartz pebbles

Faint HORIZONTAL STRATIFICATION

Unit 16

2894.3-2894.0 (.3')

SANDSTONE, fine-grained, quartz

RIPPLES

Unit 17

2894.0-2893.1 (.9')

Alternating layers of medium-grained SANDSTONE and CONGLOMERATE, few siderite nodules throughout

Unit 18

2893.1-2892.0 (1.1')

CONGLOMERATE → medium-grained sandstone, fining upward bed, quartz

LARGE-SCALE LOW-ANGLE PLANAR CROSS BEDDING

Unit 19

2892.0-2891.2 (.8')

CONGLOMERATE → coarse-grained sandstone, fining upward bed, largest clast is 1.5 cm

Unit 20

2891.2-2890.8 (.4')

SANDSTONE, fine-grained, quartz pebbles near top
Brachiopod shells, squeezed shale structures

Unit 21

2890.8-2890.0 (.8')

CONGLOMERATE, matrix is coarse-grained sandstone
Thin coarse-grained sandstone layer near top

Unit 22

2890.0-2889.4 (.6')

SANDSTONE, medium-grained quartz, few shale clasts, few quartz pebbles

Unit 23

2889.4-2888.9 (.5')

MISSING

Unit 24

2888.9-2887.5 (1.4')

SHALE

HORIZONTAL STRATIFICATION at bottom, top is HORIZONTALLY and
VERTICALLY BURROWED

Unit 25

2887.5-2887.1 (.4')

SANDSTONE, fine-grained

LARGE-SCALE LOW-ANGLE PLANAR CROSS BEDDING

Unit 26

2887.1-2885.2 (1.9')

SHALE, with very fine-grained sandstone layers, wavy bedding

Highly burrowed with VERTICAL and HORIZONTAL BURROWS

Unit 27

2885.2-2883.0 (2.2')

SANDSTONE, fine-grained, LARGE-SCALE LOW-ANGLE PLANAR CROSS
BEDDING near bottom, top is HORIZONTAL STRATIFICATION

Lemasters 0-13

Unit 1

3062.0-3061.9 (.1')

SHALE, dark gray

HORIZONTAL STRATIFICATION

Unit 2

3061.9-3060.4 (1.5')

SANDSTONE, very fine-grained, dark mineral laminations along bedding planes

HORIZONTAL STRATIFICATION, one brachiopod shell

Unit 3

3060.4-3059.0 (1.4')

SANDSTONE, fine-grained, dark mineral laminations along bedding planes

SMALL-SCALE HIGH-ANGLE PLANAR CROSS BEDS, TROUGH CROSS BEDS,

HORIZONTAL STRATIFICATION in middle of section

Unit 4

3059.0-3058.4 (.6)

SANDSTONE, fine-grained,

HORIZONTAL STRATIFICATION near bottom, SMALL-SCALE LOW-ANGLE

PLANAR CROSS BEDS near top

Unit 5

3058.4-3057.7 (.7')

SANDSTONE, fine-grained

Scour base, shale rip up clasts, SMALL-SCALE LOW-ANGLE PLANAR CROSS

BEDS

Unit 6

3057.7-3055.45 (2.25')

SANDSTONE, fine-grained

Faint HORIZONTAL STRATIFICATION

Unit 7

3055.45-3055.3 (.15')

SHALE, dark gray, very fine-grained sandstone lenses within, wavy bedding

RIPPLES in sand

Unit 8

3055.3-3054.2 (1.1')

SANDSTONE, upper fine-grained, shale clasts at bottom

Very faint HORIZONTAL STRATIFICATION at bottom

Unit 9

3054.2-3053.2 (1.0')

SANDSTONE, upper fine-grained, shale clasts at bottom, few scattered quartz pebbles
Scour base, SMALL-SCALE LOW-ANGLE PLANAR CROSS BEDS

Unit 10

3053.2-3053.0 (.2')

CONGLOMERATE, average size .4 cm, matrix is fine-grained sandstone, shale clasts
throughout

Unit 11

3053.0-3052.6 (.4')

MISSING

Unit 12

3052.6-3052.2 (.4')

SANDSTONE, medium-grained, shale clasts throughout
SMALL-SCALE LOW-ANGLE PLANAR CROSS BEDS

Unit 13

3052.2-3052.1 (.1')

SHALE, with few sandstone RIPPLES within it

Unit 14

3052.1-3049.7 (2.4')

SANDSTONE, fine-grained, quartz
Faint HORIZONTAL STRATIFICATION

Unit 15

3049.7-3049.55 (.15')

SHALE
HORIZONTAL STRATIFICATION

Unit 16

3049.55-3049.0 (.55')

SANDSTONE, fine-grained
Small scale low angle planar cross beds

Unit 17

3049.0-3048.0 (1.0')

SHALE, with few fine-grained sandstone lenses
RIPPLES in sandstone

Unit 18

3048.0-3045.4 (2.6')

SANDSTONE, fine-grained, one thin CONGLOMERATE layer at bottom, few scattered quartz pebbles in middle
Faint HORIZONTAL STRATIFICATION throughout

Unit 19

3045.4-3044.6 (.8')

SANDSTONE, fine-grained, quartz pebbles in middle
Scour base with medium-grained sandstone directly above the scour, faint
HORIZONTAL STRATIFICATION

Unit 20

3044.6-3044.0 (.6')

SANDSTONE, upper fine-grained, .05" CONGLOMERATE layer in middle, shale clasts throughout
Scour base with medium-grained sandstone at scour, LARGE-SCALE LOW-ANGLE
PLANAR CROSS BEDDING

Unit 21

3044.0-3041.3 (2.7')

SANDSTONE, fine-grained, few shale clasts at bottom, few quartz pebbles near top, dark minerals along bedding plane
HORIZONTAL STRATIFICATION throughout

Unit 22

3041.3-3041.0 (.3')

CONGLOMERATE, matrix is medium-grained sandstone, coarse-grained sandstone layers
HORIZONTAL STRATIFICATION

Unit 23

3041.0-3039.3 (1.7')

SANDSTONE, medium-grained, few quartz pebbles at bottom and top
HORIZONTAL STRATIFICATION

Unit 24

3039.3-3039.1 (.2')

CONGLOMERATE, average clast size is .8cm, matrix is very coarse-grained sandstone

Unit 25

3039.1-3038.9 (.2')

SANDSTONE, coarse-grained, some shale clasts
HORIZONTAL STRATIFICATION

Unit 26

3038.9-3038.6 (.3')

SANDSTONE, medium-grained, shale clasts throughout

Faint HORIZONTAL STRATIFICATION

Unit 27

3038.6-3037.0 (1.6')

SANDSTONE, very coarse-grained, scattered quartz pebbles throughout
Scour base, HORIZONTAL STRATIFICATION in middle, large-scale low angle planar
cross bedding and LARGE-SCALE HIGH-ANGLE PLANAR CROSS BEDDING

Unit 28

3037.0-3036.2 (.8')

SANDSTONE, medium-grained, few coarse-grained layers in middle, very thin shale
layer at top
HORIZONTAL STRATIFICATION in middle

Unit 29

3036.2-3035.5 (.7')

SANDSTONE, coarse-grained, scattered quartz pebbles
LARGE-SCALE LOW-ANGLE PLANAR CROSS BEDS, scour base

Unit 30

3035.5-3035.3 (.2')

SANDSTONE, medium-grained, quartz pebbles
SMALL-SCALE HIGH-ANGLE PLANAR CROSS BEDS

Unit 31

3035.3-3033.45 (1.85')

SANDSTONE, coarse-grained, one thin CONGLOMERATE layer, few scattered quartz
pebbles
LARGE-SCALE LOW-ANGLE PLANAR CROSS BEDS

Unit 32

3033.45-3033.2 (.25')

SANDSTONE, medium-grained
SMALL-SCALE LOW-ANGLE PLANAR CROSS BEDS

Unit 33

3033.2-3032.9 (.3)

SANDSTONE, coarse-grained

Unit 34

3032.9-3032.2 (.7')

SANDSTONE, medium-grained, one thin CONGLOMERATE layer in middle
LARGE-SCALE HIGH-ANGLE and TROUGH CROSS BEDS

Unit 35

3032.2-3032.0 (.2')

SANDSTONE, coarse-grained, fining upward
Scour base, SMALL-SCALE LOW-ANGLE PLANAR CROSS BEDS

Reilly 13

Unit 1

2899.3-2898.1 (1.2')

SHALE with very fine-grained sandstone, wavy bedding
HORIZONTAL STRATIFICATION in shale, rippled in sandstone, VERTICAL and
HORIZONTAL BURROWS throughout

Unit 2

2898.1-2896.3 (1.8')

SANDSTONE, very fine-grained
Faint LARGE-SCALE LOW-ANGLE PLANAR CROSS BEDS, becoming
HORIZONTAL towards top

Unit 3

2896.3-2895.95 (.35')

SANDSTONE, very fine-grained, shale clasts on basal surface
Scour base, SMALL-SCALE LOW-ANGLE PLANAR CROSS BEDS, RIPPLES

Unit 4

2895.95-2895.7 (.25')

SHALE and very fine-grained sandstone, wavy bedding, siderite nodules
SMALL-SCALE LOW-ANGLE PLANAR CROSS BEDS, RIPPLES, top has
HORIZONTAL STRATIFICATION

Unit 5

2895.7-2895.1 (.6)

SANDSTONE and CONGLOMERATE interbedded
CONGLOMERATE has average clast size of 6mm, quartz pebbles, matrix is very fine-
grained sandstone
SANDSTONE is very fine-grained

Unit 6

2895.1-2893.9 (1.2')

SANDSTONE, very fine-grained, few scattered quartz pebbles
Faint large-scale low angle planar cross bedding

Unit 7

2893.9-2893.0 (.9')

SANDSTONE and CONGLOMERATE interbedded
CONGLOMERATE has average clast size of 4mm, quartz pebbles, concentrated in
middle of unit, horizontal layers
SANDSTONE, very fine-grained, faint HORIZONTAL STRATIFICATION

Unit 8

2893.0-2892.2 (.8')

SANDSTONE fine-grained, few scattered quartz pebbles
Very faint large-scale low angle planar cross bedding

Unit 9

2892.2-2889.7 (2.5')

MISSING

Unit 10

2889.7-2889.45 (.25')

SANDSTONE, very fine-grained, few scattered shale clasts

Faint HORIZONTAL STRATIFICATION

Unit 11

2889.45-2889.2 (.25')

CONGLOMERATE, matrix is very fine-grained sandstone, average clast size is 7mm, quartz pebbles

HORIZONTAL STRATIFICATION, slight imbrication parallel to bedding

Unit 12

2889.2-2888.5 (.7')

SANDSTONE, very fine-grained sandstone, quartz, occasional thin layers of quartz pebbles, few scattered quartz pebbles

HORIZONTAL STRATIFICATION towards bottom, RIPPLES at top, mostly

VERTICAL BURROWS near top few HORIZONTAL BURROWS

Unit 13

2888.5-2888.2 (.3')

CONGLOMERATE, well rounded quartz pebbles, average size is 6mm, matrix is fine-grained sand, poor cementation,

Unit 14

2888.2-2887.15 (1.05)

SANDSTONE, very fine-grained, quartz, few scattered quartz pebbles (more concentrated towards bottom), shale clasts increase vertically as quartz clasts decrease

HORIZONTAL STRATIFICATION near bottom, top half has large-scale low angle planar cross bedding

Unit 15

2887.15-2886.45 (.7)

CONGLOMERATE with interbedded sandstone

CONGLOMERATE has well-rounded quartz pebbles, 4mm in size, matrix is very fine-grained

SANDSTONE is very fine-grained

Unit 16

2886.45-2886.3 (.15)

MISSING

Unit 17

2886.3-2885.0 (1.3')

SANDSTONE, very fine-grained, thin quartz pebble layers throughout, shale clasts throughout, siderite nodules

LARGE-SCALE LOW-ANGLE PLANAR CROSS BEDS, HORIZONTAL STRATIFICATION towards top

Unit 18

2885.0-2882.75 (2.25')

MISSING

Unit 19

2882.75-2882.5 (.25')

SANDSTONE, very fine-grained, dark mineral laminations

HORIZONTAL STRATIFICATION at bottom, SMALL-SCALE LOW-ANGLE PLANAR CROSS BEDS and RIPPLES at top

Unit 20

2882.5-2882.3 (.2')

MISSING

Unit 21

2882.3-2881.0 (1.3')

SANDSTONE, very fine-grained

RIPPLES and small-scale low angle planar cross bedding at bottom, HORIZONTAL STRATIFICATION in middle and towards top, very top has small bed (.1') of RIPPLES and a small bed (.1') of VERTICAL and HORIZONTAL BURROWS

Unit 22

2881.0-2877.2 (2.8')

SHALE and interbedded very fine-grained sandstone

HORIZONTAL STRATIFICATION, few scattered HORIZONTAL BURROWS

Unit 23

2877.2-2876.5 (.7')

MISSING

Unit 24

2876.5-2873.85 (2.65')

SHALE

HORIZONTAL STRATIFICATION towards bottom, highly burrowed (horizontal and vertical) towards top

Unit 25

2873.85-2873.3 (.55')

SANDSTONE, fine-grained with very coarse-grained layers at bottom (.10'), few scattered quartz pebbles throughout
HORIZONTAL STRATIFICATION towards bottom, layers thinning towards top

Unit 26

2873.3-2873.0 (.3')

SHALE with interbedded medium- and fine-grained sandstone
HORIZONTAL STRATIFICATION, burrowed towards top (horizontal and vertical)

Unit 27

2873.0-2871.5 (1.5')

SANDSTONE interbedded with CONGLOMERATE
Sandstone is medium- and coarse-grained
CONGLOMERATE is in a medium- and coarse-grained sandstone matrix, average clast size is 8mm
Brachiopod shells throughout

Unit 28

2871.5-2871.0 (.5')

MISSING

Unit 29

2871.0-2868.8 (2.2')

SHALE, sandy, very fine-grained sandstone
Sandstone is rippled rest of section is horizontally and vertically burrowed

Unit 30

2868.8-2868.55 (.25')

SANDSTONE, coarse-grained, shale clasts throughout
Rippled at very bottom, HORIZONTAL STRATIFICATION the rest of the way

Unit 31

2868.55-2867.0 (1.55')

SANDSTONE, medium-grained with few thin CONGLOMERATE layers
Large-scale low angle planar cross bedding

Unit 32

2867.0-2865.0 (2.0')

SANDSTONE, coarse-grained, shale clasts
HORIZONTAL STRATIFICATION

J H Dawson F-14

Unit 1

3248.2-3247.7 (.5')

SANDSTONE, medium-grained, coarse-grained at bottom

HORIZONTAL STRATIFICATION and large-scale low angle planar cross bedding

Unit 2

3247.7-3246.2 (1.5')

CONGLOMERATE in coarse-grained matrix, quartz pebbles, upper section is grain supported

Unit 3

3246.2-3244.9 (1.3')

SANDSTONE and CONGLOMERATE interbedded, medium-grained sandstone with five CONGLOMERATE layers, few shale clasts throughout

Trough cross bedding

Unit 4

3244.9-3243.5 (1.4')

SANDSTONE, fine-grained, quartz pebbles near bottom

Large-scale low angle planar cross bedding

Unit 5

3243.5-3243.1 (.4')

SHALE

HORIZONTAL STRATIFICATION

Unit 6

3243.1-3242.9 (.2)

SANDSTONE, fine-grained

Small scale RIPPLES

Unit 7

3242.9-3241.5 (1.4')

SHALE with thin layers of fine-grained SANDSTONE, lenticular bedding

Starved RIPPLES in the SANDSTONE

Unit 8

3241.5-3241.1 (.4')

SANDSTONE, medium-grained, shale clasts throughout

VERTICAL BURROWS at bottom, rippled above

Unit 9

3241.1-3237.5 (3.6')

SHALE and very fine-grained SANDSTONE, lenticular bedding

VERTICAL and HORIZONTAL BURROWS

Unit 10

3237.5-3236.8 (.7')

SANDSTONE, fine-grained

VERTICAL and HORIZONTAL BURROW, small-scale RIPPLES

Unit 11

3236.8-3236.5 (.3')

SANDSTONE, coarse-grained, few quartz pebbles

Large-scale low angle planar cross beds

Unit 12

3236.5-3235.6 (.9')

SANDSTONE, fine-grained, shale clasts throughout

Top has VERTICAL BURROW

Unit 13

3235.6-3234.9 (.7')

SANDSTONE, medium-grained → fine-grained, 2 FUS

Scour base separating the two FUS's

Unit 14

3234.9-3234.0 (.9')

SHALE with fine-grained SANDSTONE interbedded

Trough cross beds, HORIZONTAL and VERTICAL BURROW

J Mills 158-A

Unit 1

2970.0-2969.7 (.3')
SANDSTONE, very fine-grained
HORIZONTAL STRATIFICATION

Unit 2

2969.7-2969.4 (.3')
SANDSTONE fine-grained, pebbly near bottom, and few scattered throughout unit

Unit 3

2969.4-2966.1 (3.3')
SANDSTONE, fine-grained, few scattered SHALE clasts throughout
LARGE-SCALE LOW-ANGLE PLANAR CROSS BEDDING

Unit 4

2966.1-2965.7 (.4')
MISSING

Unit 5

2965.7-2963.7 (2.0')
SANDSTONE, fine-grained, pebbly average size 3mm

Unit 6

2963.7-2962.8 (.9')
SANDSTONE, fine-grained

Unit 7

2962.8-2962.6 (.2')
SANDSTONE, fine-grained, shale clasts, SHALE at top, pebbles throughout

Unit 8

2962.6-2961.7 (.9')
SANDSTONE, fine-grained, SHALE clasts throughout

Unit 9

2961.7-2961.35 (.35')
CONGLOMERATE in fine-grained SANDSTONE matrix, average size is 3mm

Unit 10

2961.35-2960.5 (.85')
SANDSTONE, fine-grained, pebbly
HORIZONTAL STRATIFICATION

Unit 11

2960.5-2959.5 (1.0')
SANDSTONE, coarse-grained, pebbly, medium-grained at very top

Unit 12

2959.5-2958.4 (1.1')
MISSING

Unit 13

2958.4-2958.0 (.4')
SANDSTONE very coarse-grained, pebbly

Unit 14

2958.0-2957.4 (.6')
CONGLOMERATE in coarse-grained SANDSTONE matrix average clast is 4mm

Unit 15

2957.4-2957.2 (.2')
SANDSTONE, fine-grained
RIPPLES

Unit 16

2957.2-2956.7 (.5)
MISSING

Unit 17

2956.7-2955.3 (1.4')
SANDSTONE, very coarse-grained, pebbly

Unit 18

2955.3-2954.3 (1.0')
MISSING

Unit 19

2945.3-2952.8 (1.5')
CONGLOMERATE interbedded with medium- and coarse-grained SANDSTONE

Unit 20

2952.8-2952.35 (.45')
SHALE and fine-grained SANDSTONE interbedded
HORIZONTAL STRATIFICATION in SANDSTONE

Unit 21

2952.35-2952.2 (.15')
CONGLOMERATE

Unit 22

2952.2-2951.8
SANDSTONE, fine-grained

Unit 23

2951.8-2949.7 (2.1')
CONGLOMERATE in coarse-grained SANDSTONE matrix average clast size 5mm

Unit 24

2949.7-2949.3 (.4')
SANDSTONE, fine-grained, pebbly
LARGE-SCALE LOW-ANGLE PLANAR CROSS BEDDING

Unit 25

2949.3-2948.7 (.6')
CONGLOMERATE, quartz pebbles in medium- and coarse-grained matrix

Unit 26

2948.7-2947.8 (.9')
SANDSTONE, fine-grained with very thin interbedded CONGLOMERATE layers,
CONGLOMERATE matrix is medium-grained

Unit 27

2948.7-2947.2 (.6')
SANDSTONE, fine-grained, few scattered quartz pebbles
LARGE-SCALE LOW-ANGLE PLANAR CROSS BEDDING

Unit 28

2947.2-2945.8 (1.4')
CONGLOMERATE → fine-grained SANDSTONE, FUS, CONGLOMERATE matrix is
fine-grained

Unit 29

2945.8-2945.6 (.2')
CONGLOMERATE in fine-grained matrix, 1 cm is largest clast

Unit 30

2945.6-2941.0 (4.6')
MISSING

Unit 31

2941.0-2940.7 (.3')
SANDSTONE, fine-grained → SHALE, SANDSTONE is pebbly
Brachiopod shells

Unit 32

2940.7-2940.1 (.6')

SANDSTONE, medium-grained, pebbly

Unit 33

2940.1-2939.0 (1.1')

CONGLOMERATE interbedded with very thin fine-grained SANDSTONE layers
towards top

Brachiopods in SANDSTONE

Unit 34

2939.0-2938.7 (.3')

SHALE

HORIZONTAL and VERTICAL BURROW

Unit 35

2938.7-2938.2 (.5')

SANDSTONE, medium-grained, pebbly

Brachiopod shells

Unit 36

2938.2-2936.0 (2.2')

SANDSTONE, alternating fine- and medium-grained, scattered quartz pebbles

LARGE-SCALE LOW-ANGLE PLANAR CROSS BEDDING

Unit 37

2936.0-2933.0 (3.0')

SHALE with fine-grained SANDSTONE layers

VERTICAL and HORIZONTAL BURROW, highly bioturbated, burrows are sand filled

Lemasters 17

Unit 1

2877.0-2876.9 (.1')

SANDSTONE, fine-grained

Small-scale low angle planar cross beds

Unit 2

2876.9-2876.8 (.1')

SHALE

Unit 3

2876.8-2875.4 (1.4')

SANDSTONE, fine-grained, quartz pebbles at bottom, scour base, few shale lenses

HORIZONTAL STRATIFICATION at bottom, LARGE-SCALE LOW-ANGLE

PLANAR CROSS BEDDING above HORIZONTAL STRATIFICATION

Unit 4

2875.4-2875.0 (.4')

SHALE

Unit 5

2875.0-2873.9 (1.1')

SANDSTONE, fine-grained, one very thin CONGLOMERATE layer

HORIZONTAL STRATIFICATION

Unit 6

2873.9-2873.7 (.2')

SANDSTONE, medium-grained, scour base

Unit 7

2873.7-2873.5 (.2')

SANDSTONE, fine-grained

Small-scale low angle planar cross bedding

Unit 8

2873.5-2873.2 (.3')

SANDSTONE and CONGLOMERATE interbedded

SANDSTONE is medium-grained

LARGE-SCALE LOW-ANGLE PLANAR CROSS BEDDING

Unit 9

2873.2-2872.9 (.3')

SANDSTONE, fine-grained

LARGE-SCALE LOW-ANGLE PLANAR CROSS BEDDING

Unit 10

2972.9-2872.65 (.25')

SANDSTONE and CONGLOMERATE interbedded, scour base
SANDSTONE is coarse-grained, LARGE-SCALE LOW-ANGLE PLANAR CROSS
BEDDING

Unit 11

2872.65-2872.2 (.45')

SANDSTONE, fine-grained
HORIZONTAL STRATIFICATION

Unit 12

2872.2-2872.05 (.15')

SANDSTONE, coarse-grained

Unit 13

2872.05-2871.75 (.3')

SANDSTONE, fine-grained
LARGE-SCALE LOW-ANGLE PLANAR CROSS BEDDING

Unit 14

2871.75-2871.5 (.25')

SANDSTONE, coarse-grained
LARGE-SCALE HIGH-ANGLE PLANAR CROSSBEDS

Unit 15

2871.5-2871.3 (.2')

SANDSTONE, fine-grained, scattered quartz pebbles
LARGE-SCALE LOW-ANGLE PLANAR CROSS BEDDING

Unit 16

2871.3-2870.6 (.7')

SANDSTONE, very coarse-grained
HORIZONTAL STRATIFICATION at bottom, LARGE-SCALE LOW-ANGLE
PLANAR CROSS BEDDING above HORIZONTAL STRATIFICATION

Unit 17

2870.6-2866.8 (3.8')

CONGLOMERATE in very coarse-grained sandstone matrix

Unit 18

2866.8-2866.2 (.6')

SHALE with SANDSTONE interbeds

Unit 19

2866.2-2866.0 (.2')

CONGLOMERATE in fine-grained matrix, few shale clasts throughout

Unit 20

2866.0-2865.4 (.6')

SANDSTONE, medium-grained, some quartz pebbles at top, few shale clasts at top
RIPPLES at top

Unit 21

2865.4-2863.5 (1.9')

SHALE with SANDSTONE interbeds

SANDSTONE has ripple marks and LARGE-SCALE LOW-ANGLE PLANAR CROSS
BEDDING

Unit 22

2863.5-2862.6 (.9')

SANDSTONE, fine-grained

RIPPLES and HORIZONTAL STRATIFICATION at bottom, brachiopods at top

Ball 19

Unit 1

3125.9-3125.0 (.9')

SANDSTONE, very fine-grained, few shale clasts

HORIZONTAL STRATIFICATION

Unit 2

3125.0-3124.4 (.6')

SH with few fine-grained SANDSTONE layers, lenticular bedding

Unit 3

3124.4-3116.92 (7.48')

SANDSTONE, fine-grained, siderite nodules, few quartz pebbles

HORIZONTAL STRATIFICATION

Unit 4

3116.92-3116.62 (.3')

MISSING

Unit 5

3116.62-3115.3 (1.32')

SANDSTONE, fine-grained, few thin CONGLOMERATE layers

Three scour surfaces throughout

HORIZONTAL STRATIFICATION near top, bottom is LARGE-SCALE LOW-ANGLE
PLANAR CROSS BEDS

Unit 6

3115.3-3112.9 (2.4')

SANDSTONE, fine-grained, few CONGLOMERATE layers near bottom

Small-scale low-angle planar cross bedding at bottom HORIZONTAL
STRATIFICATION above

Unit 7

3112.9-3109.45 (3.45')

SANDSTONE, fine-grained, few quartz pebbles near top, few shale clasts towards
bottom

Unit 8

3109.45-3108.9 (.55')

CONGLOMERATE, sharp basal contact, shale clasts throughout very coarse-grained
SANDSTONE at top

Faint HORIZONTAL STRATIFICATION throughout

Unit 9

3108.9-3103.9 (5.0')

SANDSTONE, fine-grained with few medium-grained sections throughout, scattered quartz pebbles
Ripple marks, LARGE-SCALE LOW-ANGLE PLANAR CROSS BEDS, faint
HORIZONTAL STRATIFICATION at bottom

Unit 10

3103.9-3103.1 (.8')
SANDSTONE, fine- and medium-grained
Large-scale trough cross bedding

Unit 11

3103.1-3102.25 (.85')
SANDSTONE, fine-grained
LARGE-SCALE LOW-ANGLE PLANAR CROSS BEDS

Unit 12

3102.25-3101.9 (.35')
SANDSTONE, coarse-grained, 3 FUS in unit

Unit 13

3101.9-3101.1 (.8')
SANDSTONE, medium- and coarse-grained
HORIZONTAL STRATIFICATION

Unit 14

3101.1-3100.5 (.6')
CONGLOMERATE, interbeds of fine-grained SANDSTONE
HORIZONTAL STRATIFICATION

Unit 15

3100.5-3099.3 (1.2')
SANDSTONE, fine-grained with coarse- and medium-grained interbeds
HORIZONTAL STRATIFICATION and LARGE-SCALE LOW-ANGLE PLANAR
CROSS BEDS

Unit 16

3099.3-3099.0 (.3')
SANDSTONE, fine-grained
LARGE-SCALE LOW-ANGLE PLANAR CROSS BEDS

Unit 17

3099.0-3098.4 (.6')
SANDSTONE, fine-grained

Unit 18

3098.4-3097.25 (1.15')

CONGLOMERATE with interbeds of fine-grained SANDSTONE

Unit 19

3097.25-3097.15 (.1')

SANDSTONE, very fine-grained

Unit 20

3097.15-3096.7 (.45')

SANDSTONE, fine-grained, shale clasts near bottom

Small-scale low-angle planar cross bedding

Unit 21

3096.7-3096.2 (.5')

SANDSTONE, very fine-grained, shale clasts throughout

Top is highly burrowed, middle has LARGE-SCALE LOW-ANGLE PLANAR CROSS BEDS

Unit 22

3096.2-3095.25 (.95')

SANDSTONE fine-grained, grading into SHALE

Bottom has HORIZONTAL STRATIFICATION, top is burrowed

Unit 23

3095.25-3093.5 (1.75')

SANDSTONE, fine-grained, shale clasts near bottom

HORIZONTAL STRATIFICATION near bottom, LARGE-SCALE LOW-ANGLE PLANAR CROSS BEDS in middle, LARGE-SCALE TROUGH CROSS BEDDING

Unit 24

3093.5-3092.8 (.7')

SANDSTONE, very fine-grained

Top has HORIZONTAL STRATIFICATION, bottom is LARGE-SCALE LOW-ANGLE PLANAR CROSS BEDS

Unit 25

3092.8-3092.5 (.3')

SANDSTONE, medium-grained

Unit 26

3092.5-3092.1 (.4')

SHALE with interbeds of very fine-grained SANDSTONE

HORIZONTAL STRATIFICATION

Unit 27

3092.1-3090.7 (1.4')

SANDSTONE, medium- and fine-grained, few thin SHALE layers

LARGE-SCALE LOW-ANGLE PLANAR CROSS BEDS, few HB

Unit 28

3090.7-3089.9 (.8')

SANDSTONE, very fine-grained

VERTICAL AND HORIZONTAL BURROWS

Unit 29

3089.9-3089.2 (.7')

SANDSTONE, fine-grained, few shale layers, flaser bedding

HORIZONTAL STRATIFICATION, BURROWS

Unit 30

3089.2-3085.0 (4.2')

SHALE and SANDSTONE, very fine-grained and fine-grained, wavy bedding

RIPPLES and LARGE-SCALE LOW-ANGLE PLANAR CROSS BEDS in

SANDSTONE, SHALE is highly burrowed

J Mills 154

Unit 1

3351.7-3349.6 (2.1')

SANDSTONE, fine-grained, few siderite nodules

LARGE-SCALE LOW-ANGLE PLANAR CROSS BEDDING, HORIZONTAL STRATIFICATION at top

Unit 2

3349.6-3348.9 (.7)

SHALE with few very fine-grained sandstone layers

HORIZONTAL STRATIFICATION at bottom, RIPPLES in sand

Unit 3

3348.9-3348.6 (.3')

SANDSTONE, fine-grained

Unit 4

3348.6-3348.0 (.6')

MISSING

Unit 5

3348.0-3347.7 (.3')

SANDSTONE, fine-grained

Unit 6

3347.7-3347.2 (.5')

SANDSTONE, fine-grained, pebbly, siderite nodules, on SHALE parting in middle

Unit 7

3347.2-3344.2 (3.0')

SANDSTONE, fine-grained

HORIZONTAL STRATIFICATION at bottom, LARGE-SCALE LOW-ANGLE PLANAR CROSS BEDDING at top, very thin SHALE parting at very top

Unit 8

3344.2-3343.6 (.6')

SANDSTONE, very fine-grained

RIPPLES

Unit 9

3343.6-3338.8 (4.8')

CONGLOMERATE, 10 FUS throughout, becoming matrix supported towards top

Unit 10

3338.8-3338.1 (.7')

SANDSTONE, fine- and medium-grained, mostly fine-grained
HORIZONTAL STRATIFICATION at top

Unit 11

3338.1-3337.5 (.6')

SANDSTONE very coarse-grained, large quartz pebbles (3 cm)

Unit 12

3337.5-3336.8 (.7')

MISSING

Unit 13

3336.8-3336.4 (.4')

SANDSTONE and CONGLOMERATE interbedded, 2 CUS's

Unit 14

3336.4-3336.0 (.4')

MISSING

Unit 15

3336.0-3335.6 (.4')

CONGLOMERATE, coarse-grained matrix, matrix supported

Unit 16

3335.6-3334.9 (.7')

MISSING

Unit 17

3334.9-3334.5 (.4')

SANDSTONE, fine-grained

LARGE-SCALE LOW-ANGLE PLANAR CROSS BEDDING

Unit 18

3334.5-3334.3 (.2')

MISSING

Unit 19

3334.3-3333.9 (.5')

CONGLOMERATE, very coarse-sandstone matrix, matrix supported

Unit 20

3333.9-3332.6 (1.3')

CONGLOMERATE in fine-grained sandstone matrix

Unit 21

3332.6-3332.4 (.2')

MISSING

Unit 22

3332.4-3332.0 (.4')

SANDSTONE, medium-grained

LARGE-SCALE LOW-ANGLE PLANAR CROSS BEDDING

Unit 23

3332.0-3331.6 (.4')

CONGLOMERATE in medium-grained sandstone matrix

Unit 24

3331.6-3331.0 (.6')

MISSING

Unit 25

3331.0-3330.8 (.2')

SANDSTONE, fine-grained

Unit 26

3330.8-3329.0 (1.8')

SANDSTONE, medium-grained, pebbly

LARGE-SCALE LOW-ANGLE PLANAR CROSS BEDDING

Unit 27

3329.0-3328.7 (.3')

MISSING

Unit 28

3328.7-3327.85 (.85')

SANDSTONE, fine-grained, pebbly

HORIZONTAL STRATIFICATION near bottom

Unit 29

3327.85-3326.5 (1.35')

SANDSTONE, fine- and coarse-grained interbedded, FUS's, more pebbly near bottom

HORIZONTAL STRATIFICATION

Unit 30

3326.5-3326.1 (.4')

CONGLOMERATE

Unit 31

3326.1-3325.9 (.2')

SANDSTONE, medium-grained, few pebbles throughout

Unit 32

3325.9-3325.7 (.2')
SANDSTONE, fine-grained, scour base
HORIZONTAL STRATIFICATION

Unit 33

3325.7-3323.1 (2.6')
CONGLOMERATE, scour base, coarse-grained matrix

Unit 34

3323.1-3322.9 (.2')
SANDSTONE, fine-grained, pebbly, sharp basal contact

Unit 35

3322.9-3321.7 (1.2')
CONGLOMERATE, coarse-grained matrix

Unit 36

3321.7-3321.2 (.5')
SANDSTONE, fine-grained, few quartz pebbles
HORIZONTAL STRATIFICATION

Unit 37

3321.2-3321.0 (.2')
MISSING

Unit 38

3321.0-3320.6 (.4')
CONGLOMERATE, coarse-grained sandstone matrix

Unit 39

3320.6-3320.0 (.6')
MISSING

Unit 40

3320.0-3319.5 (.5')
SANDSTONE, medium-grained to fine-grained FUS, pebbly
HORIZONTAL STRATIFICATION

Unit 41

3319.5-3318.3 (1.2')
SANDSTONE, fine-grained, pebbly
LARGE-SCALE LOW-ANGLE PLANAR CROSS BEDDING

Unit 42

3318.3-3318.0 (.3')
CONGLOMERATE to medium-grained SANDSTONE FUS

Unit 43

3318.0-3316.0 (2.0')

CONGLOMERATE in coarse-grained matrix

Unit 44

3316.0-3315.7 (.3')

SANDSTONE, medium-grained, pebbly

HORIZONTAL STRATIFICATION

Unit 45

3315.7-3314.7 (1.0')

CONGLOMERATE in coarse- and medium-grained matrix

Unit 46

3314.7-3314.0 (.7')

SANDSTONE/SHALE interbedded, FUS's

Sandier at bottom RIPPLED

Shalier at top HORIZONTAL STRATIFICATION

Unit 47

3314.0-3313.4 (.6')

SANDSTONE, medium-grained, pebbly, shale lenses, maybe some brachiopods

Unit 48

3313.4-3313.0 (.4')

SANDSTONE, very fine-grained

RIPPLED at bottom, HORIZONTAL STRATIFICATION at top

Unit 49

3313.0-3310.0 (3.0')

SHALE

HORIZONTAL STRATIFICATION few HORIZONTAL and VERTICAL BURROWS

Unit 50

3310.0-3309.4 (.6')

SANDSTONE, medium-grained

HORIZONTAL STRATIFICATION

Unit 51

3309.4-3309.0 (.4')

SANDSTONE, fine-grained with SHALE interbeds

SHALE is very burrowed with HORIZONTAL and VERTICAL BURROWS

RIPPLED in SANDSTONE

Thompson Heirs 8

Unit 1

2803.2-2803.0 (.2')

SANDSTONE, fine-grained

SMALL-SCALE LOW-ANGLE PLANAR CROSS BEDDING near bottom

Top is RIPPLED

Unit 2

2803.0-2802.4 (.5')

SH with 3 interbedded fine-grained SANDSTONE beds

RIPPLES, HORIZONTAL STRATIFICATION at bottom

Unit 3

2802.4-2801.65 (.75')

SANDSTONE, fine-grained, few shale lenses

TROUGH CROSS BEDDING at bottom, RIPPLES at top

Unit 4

2801.65-2801.2 (.45')

SH, with interbedded very fine-grained SANDSTONE

RIPPLES in sandstone

Unit 5

2801.2-2801.1 (.1')

SANDSTONE, fine-grained scour base

SMALL-SCALE HIGH-ANGLE PLANAR CROSS BEDDING

Unit 6

2801.1-2797.7 (3.4')

SH with few interbedded layers of very fine-grained SANDSTONE

HORIZONTAL STRATIFICATION in shale, RIPPLES in sandstone

Unit 7

2797.7-2797.5 (.2')

SANDSTONE, fine-grained, scour base

SMALL-SCALE LOW-ANGLE PLANAR CROSS BEDDING

Unit 8

2797.5-2797.4 (.1')

SH

SMALL-SCALE LOW-ANGLE PLANAR CROSS BEDDING

Unit 9

2797.4-2796.9 (.5')

CONGLOMERATE interbedded with 3 fine-grained SANDSTONE layers

Unit 10

2796.9-2790.9 (5.6')

SANDSTONE, fine-grained, scattered quartz pebbles
HORIZONTAL STRATIFICATION**Unit 11**

2790.9-2790.3 (.6')

CONGLOMERATE interbedded with fine-grained SANDSTONE
CONGLOMERATE matrix is fine-grained sandstone**Unit 12**

2790.3-2788.2 (2.1')

SANDSTONE, fine-grained, shale clasts
HORIZONTAL STRATIFICATION**Unit 13**

2788.2-2787.1 (1.1')

SANDSTONE, fine-grained, few quartz pebbles
SMALL-SCALE LOW-ANGLE PLANAR CROSS BEDDING and RIPPLES**Unit 14**

2787.1-2786.5 (.6')

CONGLOMERATE with average clasts size of 4mm

Unit 15

2786.5-2785.5 (1.0')

SANDSTONE, fine-grained, few quartz pebbles, one siderite nodule
HORIZONTAL STRATIFICATION at top, SMALL-SCALE LOW-ANGLE PLANAR
CROSS BEDDING at bottom**Unit 16**

2785.5-2785.0 (.5')

CONGLOMERATE, matrix is fine-grained sandstone, few scattered shale clasts
SMALL-SCALE LOW-ANGLE PLANAR CROSS BEDDING**Unit 17**

2785.0-2784.1 (.8')

CONGLOMERATE and fine-grained SANDSTONE interbedded, few shale clasts
throughout
CONGLOMERATE matrix is fine-grained sandstone with an average clasts size of 7mm**Unit 18**

2784.1-2783.9 (.2')

SANDSTONE, medium-grained
SMALL-SCALE LOW-ANGLE PLANAR CROSS BEDDING

Unit 19

2783.9-2781.7 (2.2')

SANDSTONE, fine-grained

SMALL-SCALE LOW-ANGLE PLANAR CROSS BEDDING at bottom,
HORIZONTAL STRATIFICATION at middle, RIPPLES at top**Unit 20**

2781.7-2780.4 (1.3')

SH with interbedded very fine-grained SANDSTONE

RIPPLES in sandstone, HORIZONTAL and VERTICAL BURROWS in shale

Unit 21

2780.4-2780.0 (.4')

SANDSTONE, medium-grained, shale clasts

HORIZONTAL STRATIFICATION near top SMALL-SCALE LOW-ANGLE PLANAR
CROSS BEDDING near bottom**Unit 22**

2780.0-2778.6 (1.4')

SANDSTONE, medium-grained, few shale clasts

SMALL-SCALE LOW-ANGLE PLANAR CROSS BEDDING

Unit 23

2778.6-2777.9 (.7')

SANDSTONE, fine-grained, few shale clasts near bottom

SMALL-SCALE LOW-ANGLE PLANAR CROSS BEDDING

Unit 24

2779.9-2777.7 (.2')

SH

Sand filled VERTICAL BURROWS

Unit 25

2777.7-2777.4 (.3')

SANDSTONE, medium-grained, scour base, shale clasts at top

HORIZONTAL STRATIFICATION

Unit 26

2777.4-2777.1 (.3')

SH with interbedded very fine-grained SANDSTONE

HORIZONTAL and VERTICAL BURROWS throughout

Unit 27

2777.1-2776.9 (.2')

SANDSTONE, medium-grained

RIPPLES

Unit 28

2776.9-2775.9 (1.0')

SH and medium-grained SANDSTONE interbedded, few quartz pebbles
HORIZONTAL STRATIFICATION near top, shale is highly bioturbated with
HORIZONTAL and VERTICAL BURROWS

Unit 29

2775.9-2775.3 (.6')

SANDSTONE, medium-grained grading into coarse-grained, CUS
Brachiopod shells

Unit 30

2775.3-2773.9 (1.6')

SANDSTONE, fine-grained
SMALL-SCALE LOW-ANGLE PLANAR CROSS BEDDING