Testing Deep-Water Depositional Models for the Trimmers Rock Formation

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Geol 394 H

Abstract

The deep-water depositional model for the upper Devonian Trimmers Rock Formation in central Pennsylvania should be reexamined to include aspects of more recent models. With the advent of new technology and further analysis, it is possible to further evaluate the Trimmers Rock Formation. Specifically, three deep-water depositional models are examined, to assess how the formation may fit into a part of one of these models. The presence or absence of partial turbidites provides clues into the deposition location of sediments. The field area consists of three locations northwest of Harrisburg, Pennsylvania. Three measured sections are compiled, correlated and interpreted. The Trimmers Rock Formation corresponds to the sheet-like sand complexes located in the outer part of a submarine fan. It could most closely be incorporated into the Steel et al. (2000) model.

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Introduction

Within the past fifteen years, deep-water depositional models have been enhanced and modified. The advent of new technology, such as high-resolution seismic imagery, has made this possible. Images can be made of submarine basins and channels to better understand the depositional processes. The understanding of deep-water deposition has, therefore, become much more detailed and unified.

Trimmers Rock Formation

The Trimmers Rock Formation occurs throughout central and eastern Pennsylvania (Figure 2), as well as southeastern New York, western Maryland and eastern West Virginia. Trimmers Rock is upper Devonian in age, about 385 million years old, based on its stratigraphic position (Figure 3) (Van Diver, 1990). The maximum thickness of the formation is about 1220 meters (4000 feet), and it is made up of gray, brown and green shales, graywackes, and sandstones (Frakes, 1967). The grain size ranges between fine silt and medium sand.

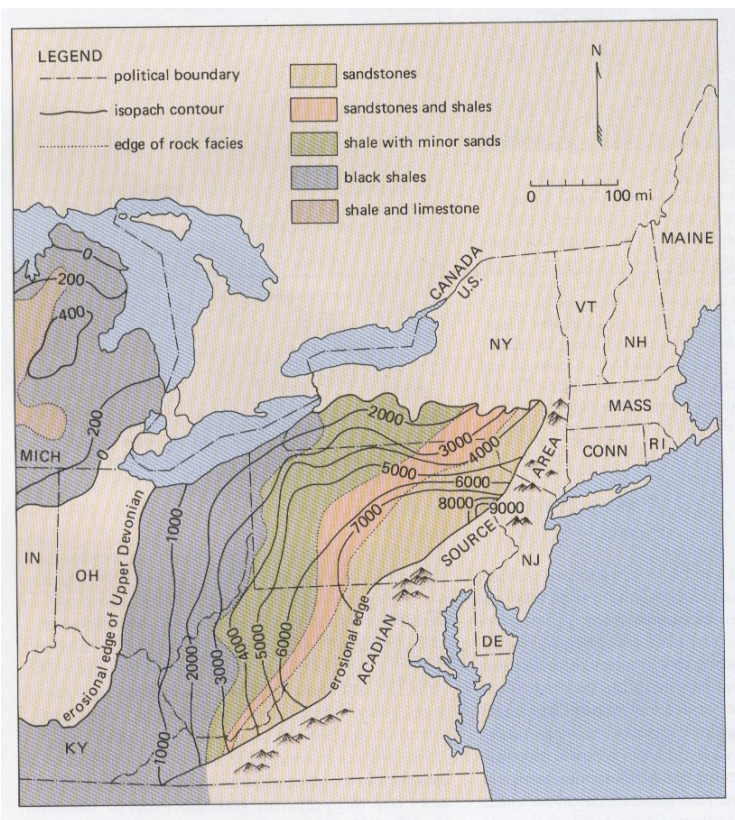

Figure 1. Lithofacies map of Upper Devonian rocks in the northeastern U.S. (Levin, 1996).

The sediments accumulated in a foreland basin that formed during the initial stages of the Acadian orogeny (Figure 1) (Van Diver, 1990). The source region of the deposit was located about 150 miles to the southeast in what is now the northwest Piedmont (Schultz, 1974). The Alleghenian orogeny then deformed and tilted the formation (Van Diver, 1990). This subsequent folding would have compressed the area by about thirty percent.

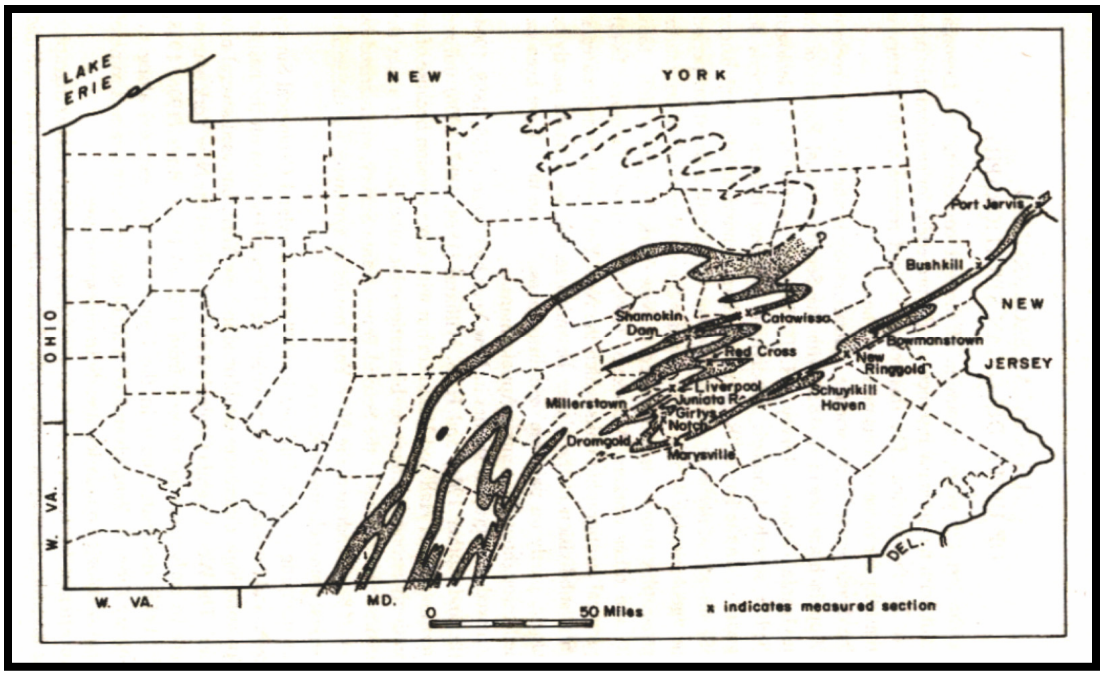

Figure 2. Trimmers Rock occurrence in Pennsylvania (Frakes, 1967).

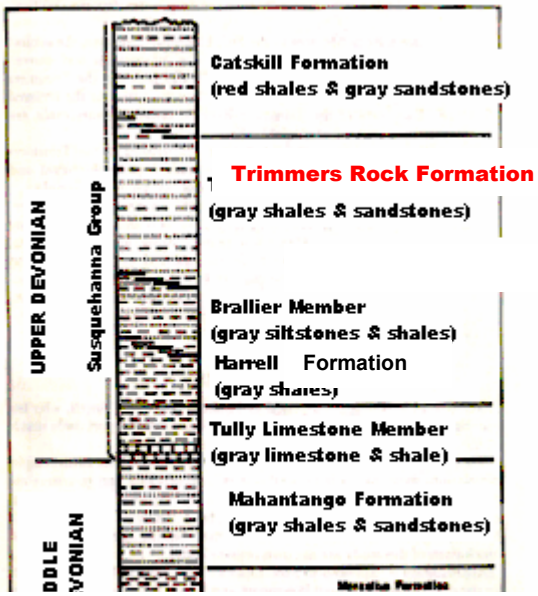

Figure 3. Position of the Trimmers Rock Fm. in geologic column (Frakes, 1967).

Previously, Trimmers Rock was thought to be the deep-water marine facies of the Catskill delta, or clastic wedge (Frakes, 1967). It is progradational, with a general upward gradation into facies abundant in sand and depleted in silt and clay. Marine turbidite deposits are also found in the region, but are unusual in their lack of sand (Schultz, 1974). Geologists have interpreted the Trimmers Rock as a transition between the deep offshore marine sediments of the Mahantango Formation, which underlies it and the shallow near-shore marine sediments of the Irish Valley Member or Towamensing Member of the overlying Catskill Formation.

Previous research focused on the extent of Trimmers Rock throughout Pennsylvania, detailed observations and descriptions of outcrops, as well as sea level fluctuations during the Devonian. Willard was the first to designate the Trimmers Rock Sandstone in 1935 (Shepps, 1963). Frakes (1967) studied outcrops in central Pennsylvania and made detailed observations and measured sections at fourteen locations of the Trimmers Rock Formation. Walker (1972) examined the upper Devonian marine – nonmarine transition throughout southern Pennsylvania. Schultz (1974) looked at outcrops in northeastern Pennsylvania.

The understanding of deep-water depositional environments was limited until the last fifteen years when compared to the current knowledge of these environments. Sedimentary and stratigraphic features of the Trimmers Rock Formation could be reexamined within their new context due to technological advances, to encompass aspects of more recent deep-water depositional models.

Deep-water Depositional Models

With a better understanding of depositional environments available, it is possible to examine the Trimmers Rock Formation in a different context. Field observations could support one of the following current deep-water depositional models:

- Steel et al. (2000) model, which consists of basin-floor fans, channel-levee systems, shelf-edge delta and slope accretion.
- Campion et al. (2000) model, which is made up of a series of channel complexes, with a channel-margin facies and a channel-axis facies.
- Beaubouef and Friedmann (2000) model, which consists of channel-lobe complexes, levee-channel complexes and drape complexes.

See Figure 4 below, for a summary of the similarities and differences between these depositional models.

Model	Grain size	Channel or Fan Complex	Associated Features
Steel et al., 2000	coarse silt – medium sand	fan & channel complex	levees, chutes, chute-mouth lobes, lower-slope channels, sheet-like turbidites
Campion et al., 2000	pebble conglomerate	channel complex	channel-axis facies, channel-margin facies
Beaubouef & Friedmann, 2000	mud – medium sand	basins & channels	mass transport complexes, distributary channel-lobe complexes, leveed-channel complexes, hemipelagic drape complexes

Figure 4. A table summary of the key components of each deep-water depositional model.

Steel et al. (2000)

R.J. Steel and his colleagues worked at outcrops located in Spitsbergen, a northern Norwegian territory. These Eocene outcrops are used "to examine the relationship between shelf-edge regime and the accumulation of sands on deepwater slope or basin-floor fans (Steel et al., 2000)." The retrogradational cycle begins with the degradation of the shelf edge, the accumulation of sandy basin-floor fans and the development of channel-levee systems on the lower slope (Figure 5). The sandy slope accumulation, caused by turbidites, pinch out. (For a discussion of turbidites, see the following section on page #.) This cycle dominated over the progradational cycle, which corresponds to a regression. In this cycle, the shelf edge is dominated by rivers and characterized by collapses. The slope contains canyons, which direct the sediments to the basin-floor fans (Figure 6).

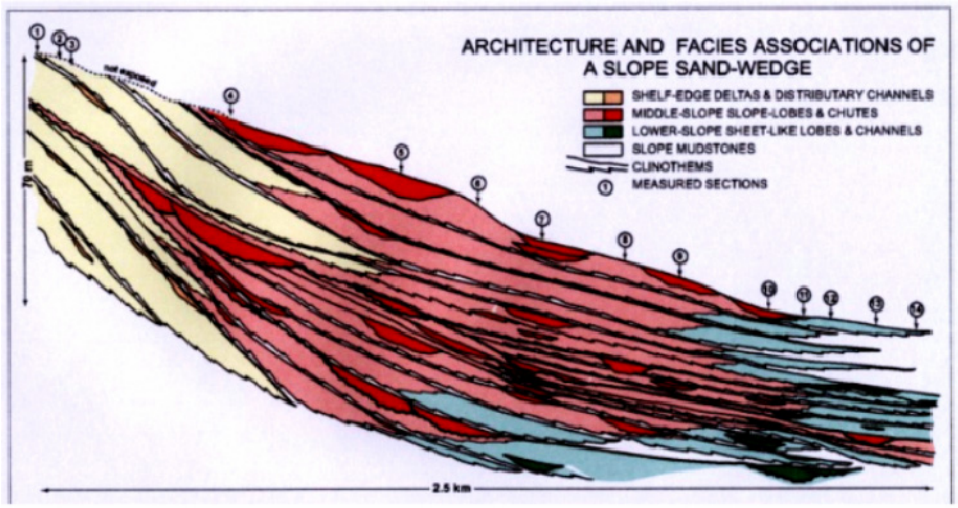

Figure 5. Architecture and facies associations within a slope-turbidite wedge (Steel et al.,2000).

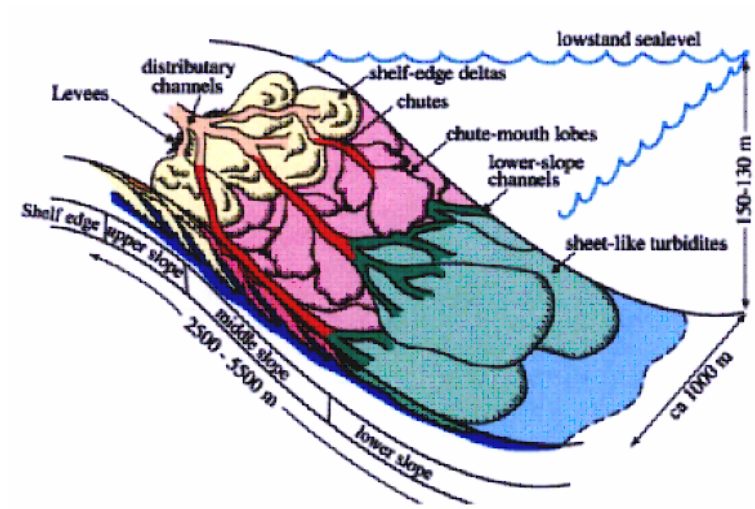

Figure 6. Mapview of shelf edge-to-slope system (Steel et al.,2000).

Campion et al. (2000)

Campion and colleagues studied three outcrops in California. All three are characterized as channel complexes, described in terms of a channel-margin facies and a channel-axis facies (Figure 7). The first outcrop is located in San Clemente, California and is Miocene in age. In this example, the channel-margin facies is less than fifty percent sand, non-amalgamated, thin bedded and has a low concentration of turbidites. The channel-axis facies is greater than ninety percent sand, amalgamated, thick bedded and has a high concentration of turbidites (Campion et al., 2000).

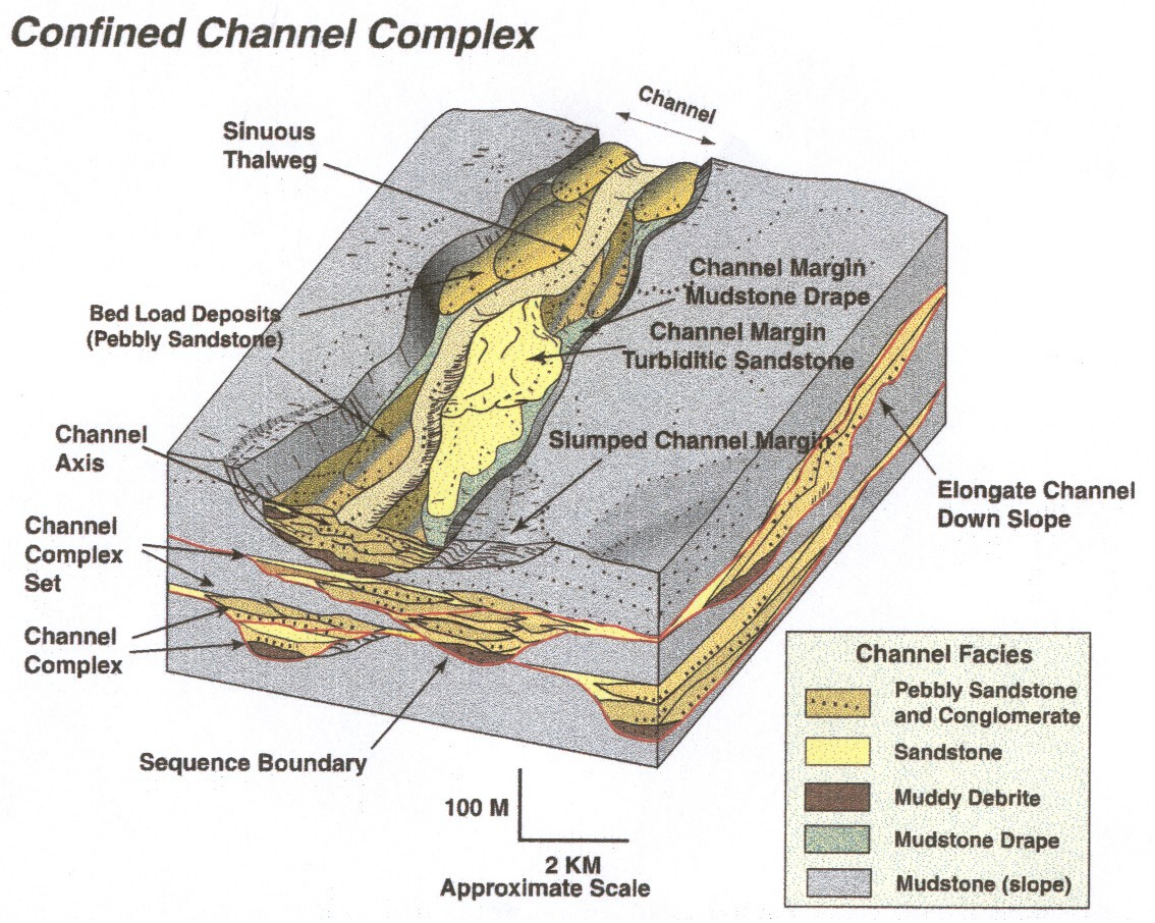

Figure 7. Schematic diagram of confined channel complex, subenvironments and associated lithofacies (Campion et al.,2000).

The second outcrop called Bidwell Point, in northern California is early Cretaceous in age. In this example, the channel-axis facies is dominated by two sequences of amalgamated channels with pebble conglomerates and clast imbrications. The channel-margin facies is dominated by two sequences. The upper sequence is non-amalgamated, with turbidites and mud-drapes. The lower sequence is made up of two channel complexes that are thin-bedded and contain silt-dominated turbidites. The third example, the late Jurassic Gravelly Ridge lenses is made up of more than five stacked channel complexes with intervening mudstone. These are amalgamated, pebble conglomerates in sinuous channels (Campion et al., 2000).

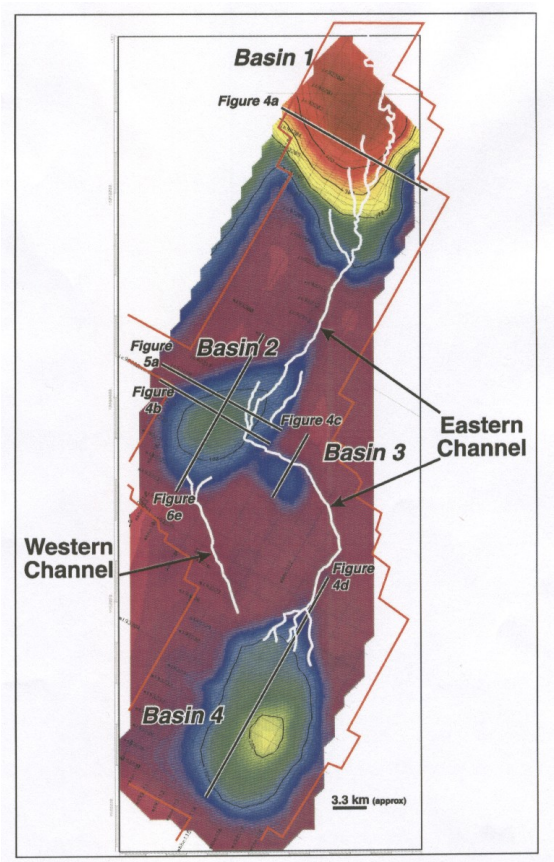

Figure 8. Isochron map of the fill of the four intra-slope basins (Beaubouef & Friedmann, 2000).

Beaubouef and Friedmann (2000)

R.T. Beaubouef and S.J. Friedmann (2000) studied the Pleistocene upper to middle Texas continental shelf using seismic imagery. The area is made up of four intra-slope basins, connected by channels (Figure 8). These basins were filled rapidly and occur in cycles consisting of mass-transport complexes, distributary channel-lobe complexes, leveed-channel complexes and hemipelagic drape complexes (Beaubouef & Friedmann, 2000).

The mass transport complexes are interpreted as mud-rich slumps and debris flow deposits. The distributary channel-lobe complexes are sand-rich, fan shaped and deposited as a sheet-like flow. The leveed-channel complexes contain low to moderate amounts of sand and are interpreted as low concentration turbidites. Drape complexes represent hemipelagic mudstones. Basins began filling by the deposition of mass transport complexes with distributary-channel-lobe complexes intervening. The leveed-channel complexes formed later during the basin filling process (Beaubouef & Friedmann, 2000).

Turbidites

Much of this research has been focused around the classification of turbidites. A turbidite is the deposit of a turbidity current, which is a gravity flow of suspended sediment (Walker, 1984). The Bouma sequence, which characterizes the facies associated with turbidites, was proposed in 1962 by Arnold Bouma. The sequence is made up of five parts (Figure 9):

T_a – massive
T_b – planar bedding
T_c – current ripples
T_d – planar laminations
T_e – suspension fallout

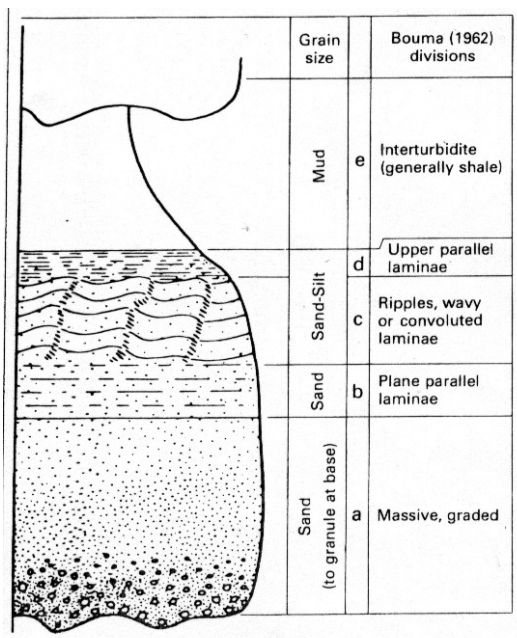

Figure 9. Classic Bouma sequence (Drake & Lyttle, 1981).

For a further discussion of the sedimentary structures within a turbidite, see the next section on page 15.

Not all parts of the Bouma sequence will always be seen within a deposit. A more axial or proximal position within a fan or channel will result in a more complete sequence. A marginal or distal position would be characterized be a less complete sequence (Figure 10).

Mutti and Normark (1991) define a turbidite fan system as “a body of genetically related mass-flow and turbidity-current facies and facies associations that were deposited in virtual stratigraphic continuity.” An erosive channel that changes to a channel complex dominates the inner fan. The middle fan is dominated by channel-levee complexes. The outer fan consists of small, distributary channels that grade into sheet-sand complexes (Stelting et al., 2000).

The four elements of deep-water depositional systems are (Stelting et al., 2000):

1) Leveed channel sands
2) Amalgamated channel sands
3) Amalgamated and layered sheet sands
4) Slumps, debris flows, marine shales

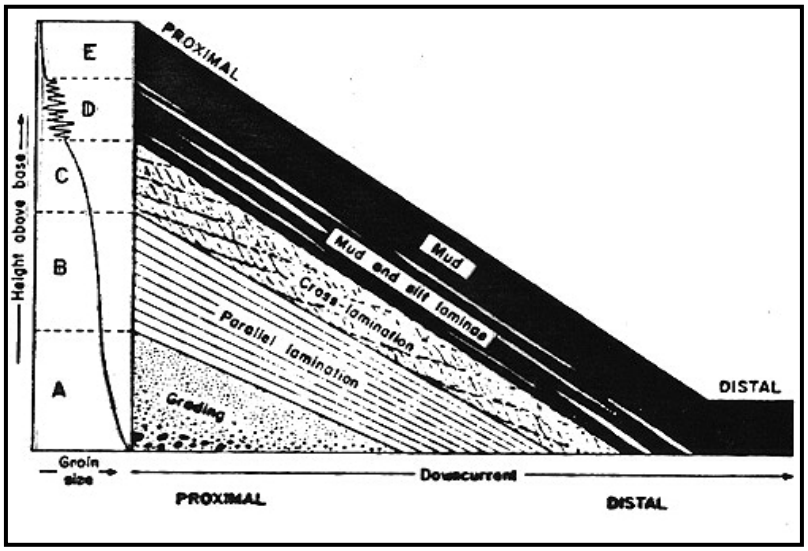

Figure 10. Facies distribution from proximal to distal (http://faculty.gg.uwyo.edu/heller).

Grain size distribution is determined by the length of transport, gradient and current force (Bouma, 2000). Coarse-grained, sand-rich systems consist of thin medium and coarse sand beds and silty shales. Fine-grained, mud-rich submarine fan systems consist of very fine-grained sand interbedded with very thin bedded shales. There is coarser sediment within an axial channel and finer sediment in distal positions or levees (Figure 11).

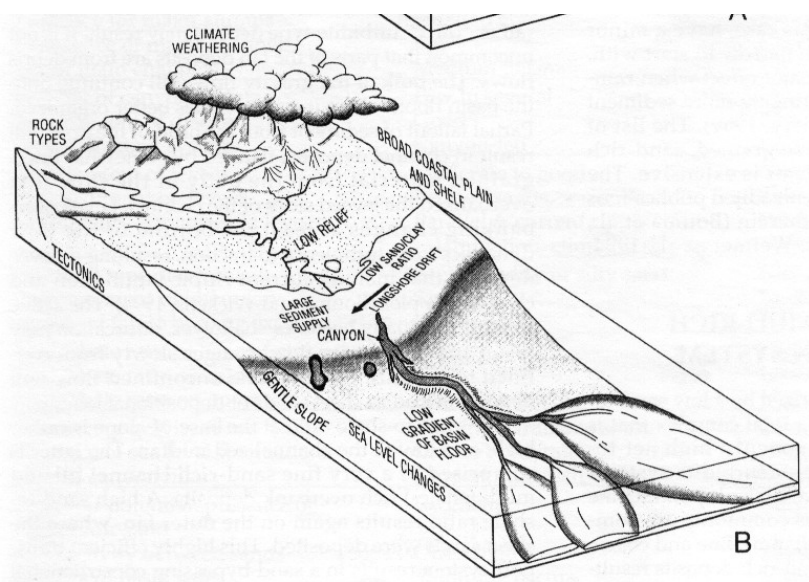

Figure 11. Fine-grained, mud-rich turbidite system (Bouma, 2000).

Within the outer fan, sheet sand layers may stack on top of one another before lateral switching occurs and another stack will be constructed. This is called compensatory stacking (Figure 12) (Bouma, 2000). Other possible stacking patterns for the sheet lobe sands include vertical stacking or shingled stacking (Bouma, 2000).

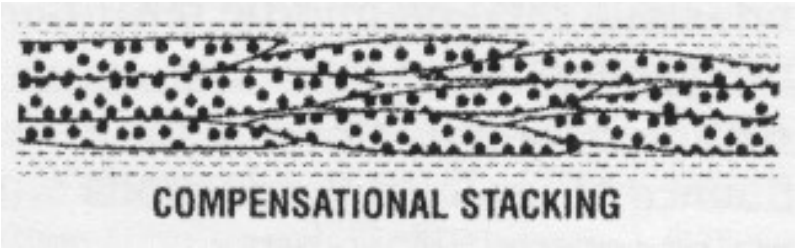

Figure 12. Compensatory stacking. (Bouma, 2000).

Morris and Normark (2000) point out that one can only compare turbidite systems if the scale, geometry and time frame for deposition are similar.

Method of Analysis

A field program was designed to incorporate the aspects needed for the project. These are as follows:

- Three to four closely spaced outcrops
- Good outcrop exposures, with limited covered intervals

Three field locations were chosen, based on their proximity to one another (Figure 13). The field area is focused northwest of Harrisburg in central Pennsylvania. Liverpool and New Buffalo are located along Route 11/15, next to the Susquehanna River. The Newport outcrop is located along the Juniata River, off of Route 34.

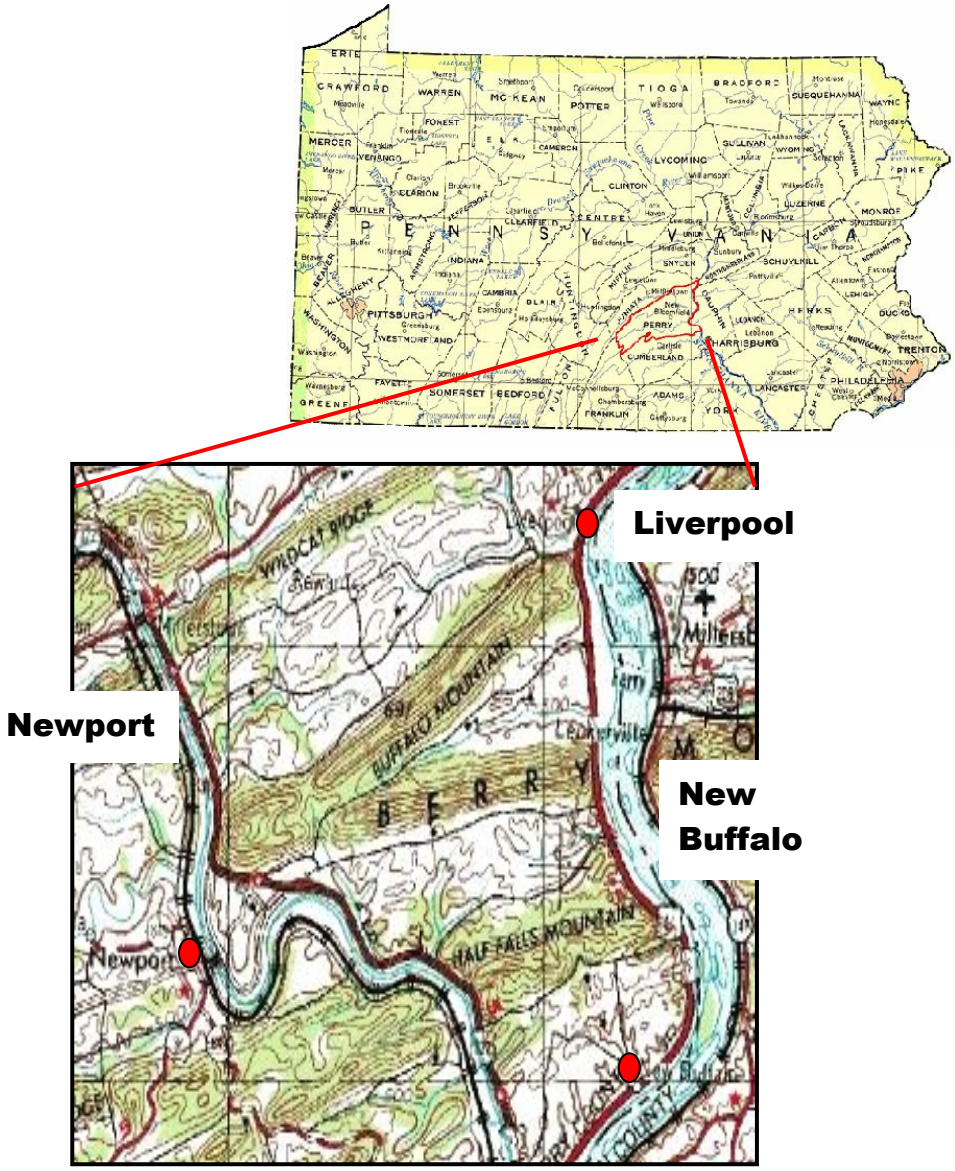

Figure 13. Field locations in Perry County, PA.

Three measured sections were made, containing the following data: lithologies, grain sizes, bed thickness, bed geometry, sedimentary structures and general trends.

Lithology is a description of the sediment type within a rock. Examples include sandstone, shale or limestone. This classification of rock types is based on the petrology of the rock.

Grain size is determined for a bed using a grain size comparison chart and a hand lens. Each grain size class corresponds to a specific range in micrometers (Figure 14). Determining grain size is naturally a subjective process, where one must adjust one's eye to see the minute differences within individual grains. The error associated with this measurement is perhaps one

grain size class. However, if one person is continuously making this determination of grain size, then it should be fairly consistent.

Grain size class	**Grain Size Range (μm)**
Mud	1 – 4
Fine Silt	4 – 16
Coarse Silt	16 – 62
Very Fine Lower Sand	62 – 88
Very Fine Upper Sand	88 – 125
Fine Lower Sand	125 – 177
Fine Upper Sand	177 – 250
Medium Lower Sand	250 – 350
Medium Upper Sand	350 - 500

Figure 14. Grain size chart, showing grain size classes and associated grain sizes in micrometers.

Bed thicknesses are measured using a tape measure and sometimes a Jacob's staff. This measurement is taken perpendicular to the bedding surfaces. The breakdown for bed and lamina thickness is shown in Figure 15.

Bed geometry is the two-dimensional representation of the bed shape over a lateral extent. Possibilities include tabular (sheet), lenticular and lensoidal (Tucker, 2003).

Sedimentary structures are structures within the sedimentary rock that formed when the sediments were deposited. They may be present on the upper or lower bedding surfaces and within beds. Examples include planar bedding, parallel laminations, asymmetrical current ripples, massive bedding, trough cross-bedding, flute casts, scours, soft sediment deformation, burrows and fossils. Important aspects to note about the fossils present include their occurrence as a zone or lens, abundance, diversity and preservation. Sometimes only the fossil imprints remain, which have been filled with carbonate material post-deposition.

A typical Bouma sequence would contain a suite of sedimentary structures. The lower portion would have massive bedding, with no apparent internal structure. Above this is planar bedding, which is composed of parallel beds. Overlying this is a section with either asymmetrical current ripples on the surface of a bed or trough cross-bedding within it. Cross-bedding is produced from a current. Planar laminations are above this, which are essentially thin,

parallel beds. The top portion is made up of suspension fallout, which is fine sediment that has settled out of a waning flow.

Size	Terminology
> 1 m	Very thickly bedded
0.3 m – 1 m	Thickly bedded
0.1 m – 0.3 m	Medium bedded
30 mm – 0.1 m	Thinly bedded
10 mm – 30 mm	Very thinly bedded
3 mm – 10 mm	Thickly laminated
< 3 mm	Thinly laminated

Figure 15. Terminology of bed thickness (Tucker, 2003).

Extraordinary hand specimens were at times taken from the individual outcrops, to further analyze later. Pictures of these samples and the sedimentary structures included therein can be seen in the next section.

The three measured sections are of the same approximate 20-meter interval, based on Frakes' correlation chart (Figure 16). This correlation chart is at times problematic because the scale for the chart was intended to be one inch to one hundred feet. However, the total length of the measured section on the correlation chart does not correspond to the length in the detailed description of each location. Perhaps data are left off of the correlation chart or maybe there is a scale error. This difficulty is overcome when one is at each location, comparing the actual outcrop with the correlation chart. Covered intervals or long shale and/or siltstone units are key in locating the desired 20-meter intervals at each location.

Another problem was encountered and overcome during this process. The Newport section was the first to be measured. After further inspection, it was concluded that this section was located in the top portion of Siltstone Unit 5C. The problem with this is that this interval corresponds to a covered interval at New Buffalo and a reduced interval at Liverpool. Therefore, it was decided that instead of measuring this interval at New Buffalo and Liverpool, a portion of Siltstone Unit 4 would be measured instead. The location of Shale Unit 4 within the outcrop was key in finding these particular sections.

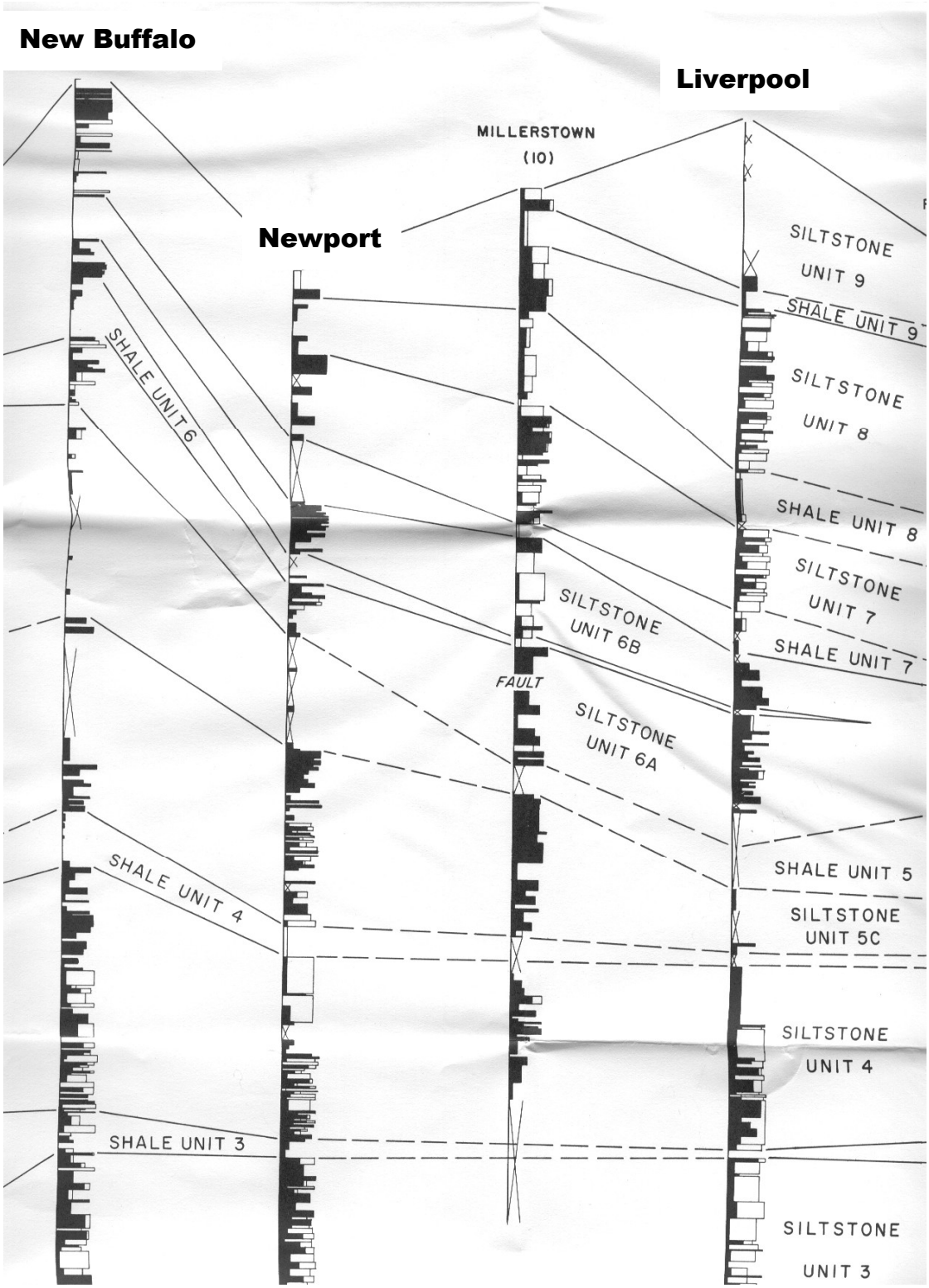

Figure 16. Chart showing correlation of New Buffalo, Newport and Liverpool measured sections (Frakes, 1967).

Presentation of Data

Data collected and presented for each of the three outcrops include a description of each measured interval, pictures of sedimentary structures, a corresponding phtotopan picture of the individual outcrops and a detailed 20-m measured section.

Newport

The entire outcrop of the Trimmers Rocks Formation at Newport is about 470 meters long. It is overlain by the red fluvial beds of the Catskill Formation, which grade into the deep-water rocks over a somewhat short interval. The outcrop is made up of three main sections separated by two covered intervals with a few small exposures in between.

The upper section contains multiple cycles of the thickening and thinning of bed thicknesses. The beds themselves are sandstone with intervening muddy beds. This section contains brachiopod fossils, ball and pillow structures as well as possible slump or debris flow features. The measured interval corresponds to the middle of the three sections and is described in further detail below. The lower section corresponds to a much sandier interval. It contains a high abundance of fossils, such as brachiopods and crinoids. Current ripples and planar laminations are also clearly visible. Below this section, the outcrop is largely covered and therefore it is not possible to discern a boundary with underlying formation.

The measured interval is about 20 meters (Figures 22, 23). See legend for all measured sections in Figure 21. The outcrop consists of very fine lower to fine lower sand beds with intervening shales (Figure 20). It is sandiest at the base of the section and siltiest towards the top. It is thicker-bedded at the base and thinner-bedded at the top.

Sedimentary structures within this interval include the following: planar laminations, current ripples (Figures 18, 19), scours, flutes (Figure 17), soft sediment deformation and burrows. Cycles of planar bedding and trough cross-bedding are recurring throughout the individual thicker sandstone beds.

Figure 17. Flutes on the under surface of a bed.

Figure 18. $T_{a\,bc}$ bed, with 3 cycles of T_{bc} beds.

Figure 19. Sample with T_{bcd} beds.

Figure 20. Corresponding photopan of Newport measured section.

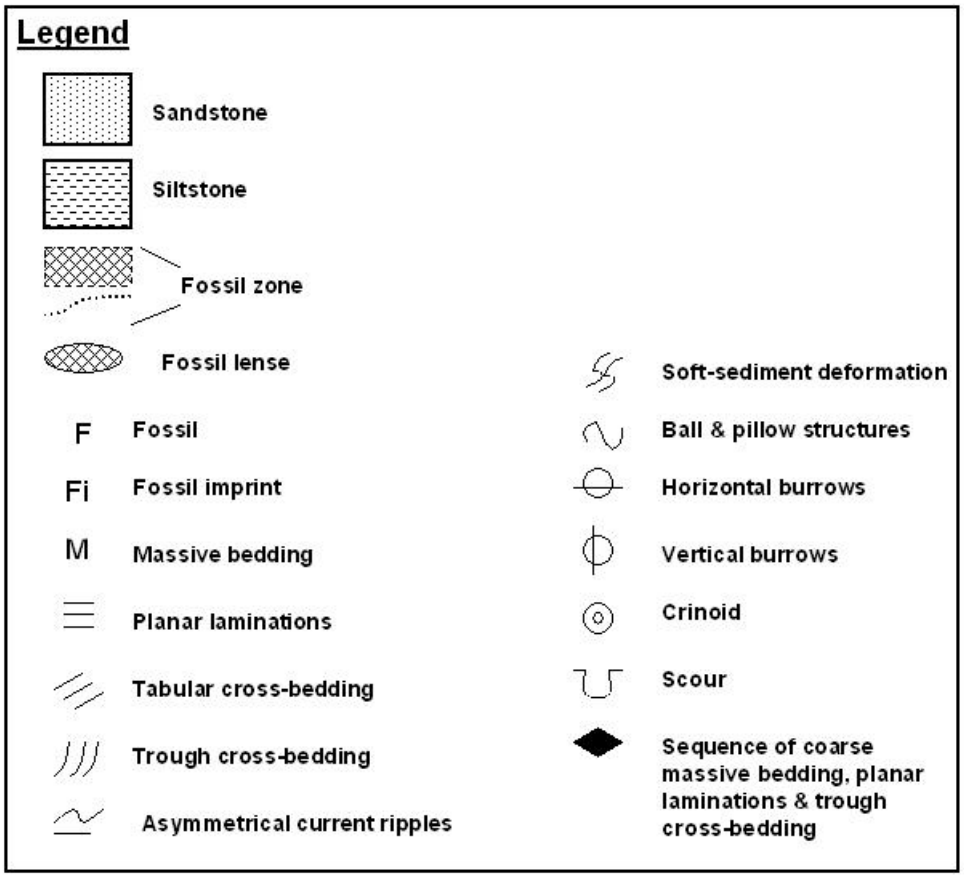

Figure 21. Legend for all measured sections.

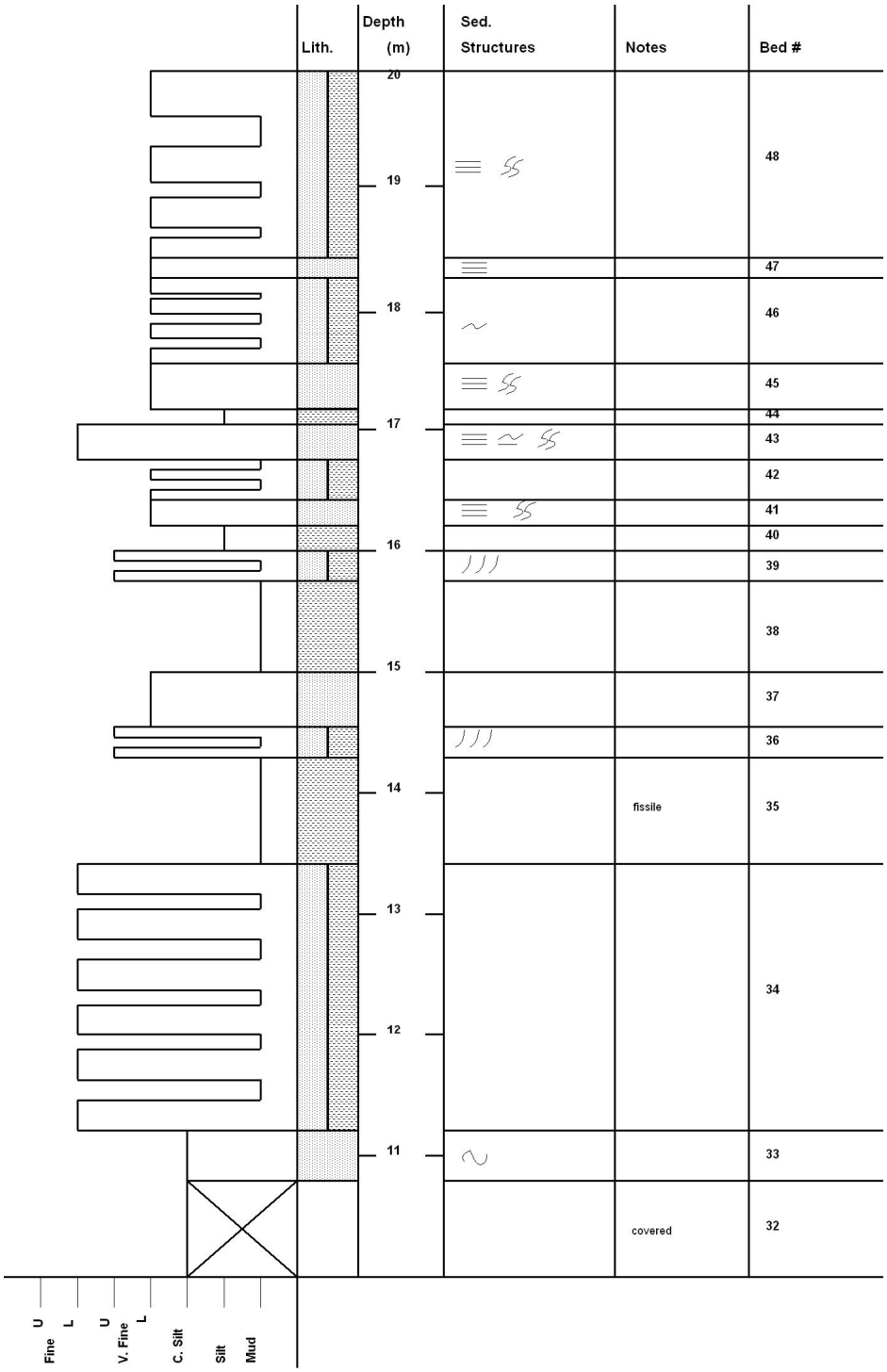

Figure 22. Newport measured section, 10 m – 20 m.

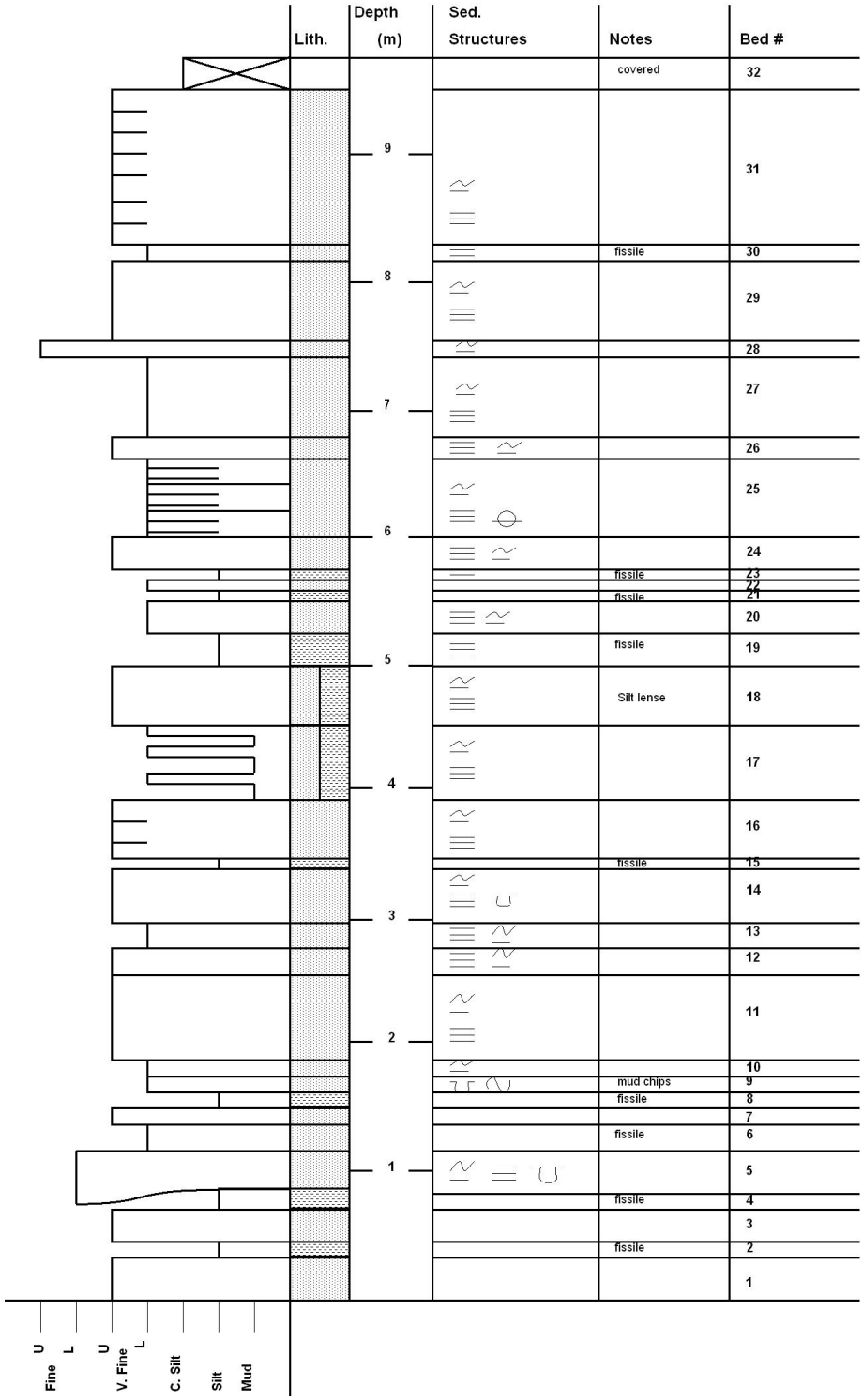

Figure 23. Newport measured section, 1 m – 10 m.

New Buffalo

The outcrop at New Buffalo is about 750 meters in total. It is overlain by the red Catskill beds which grade into the Trimmers Rock Formation over a longer interval than is seen at Newport. It is underlain by what Frakes thought is the Tully Limestone. The outcrop contains one main covered interval with two main sections of exposure.

The upper section contains a two-tiered interval of sandstone beds with minor intervening shale beds. One set of preliminary data was gathered within this section. The section contains fossil zones, like seen in Figure 24. Planar laminations, asymmetrical current ripples, along with horizontal and vertical burrows are all present.

The lower section looks quite different from the upper section. It contains a greater silt content than the upper section and includes cycles of vaguely bedded siltstone units. The measured interval is towards the middle of this section. Above it is a very thick siltstone package with minor partings that continues for about 25 m. Overlying this package, are much sandier and thicker beds with some intervening shale units.

The interval measured was about 20 meters (Figures 28, 29). The interval consists of a range of grain sizes from coarse-grained siltstones to fine upper sandstone beds. The section begins with a fining upwards trend and two thicker siltstone units. The beds then begin to coarsen and thicken upwards, with a more gradual change back into finer siltstone units again (Figure 27).

Sedimentary structures within this interval include the following: planar laminations, asymmetrical current ripples, trough cross-bedding, scours and fossil lenses and zones, containing both carbonate fossil fragments and the imprints or trace fossils of them. Cross-sections of crinoids are seen on the top surfaces of many beds. Fossil zones occur towards the bottom of almost all of the thick sandstone beds (Figures 25, 26).

Figure 24. Fossil zone.

Figure 25. Fossil zone with overlying planar bedding.

Figure 26. Fossil zone within a rock sample.

Figure 27. Corresponding photopan of New Buffalo measured section.

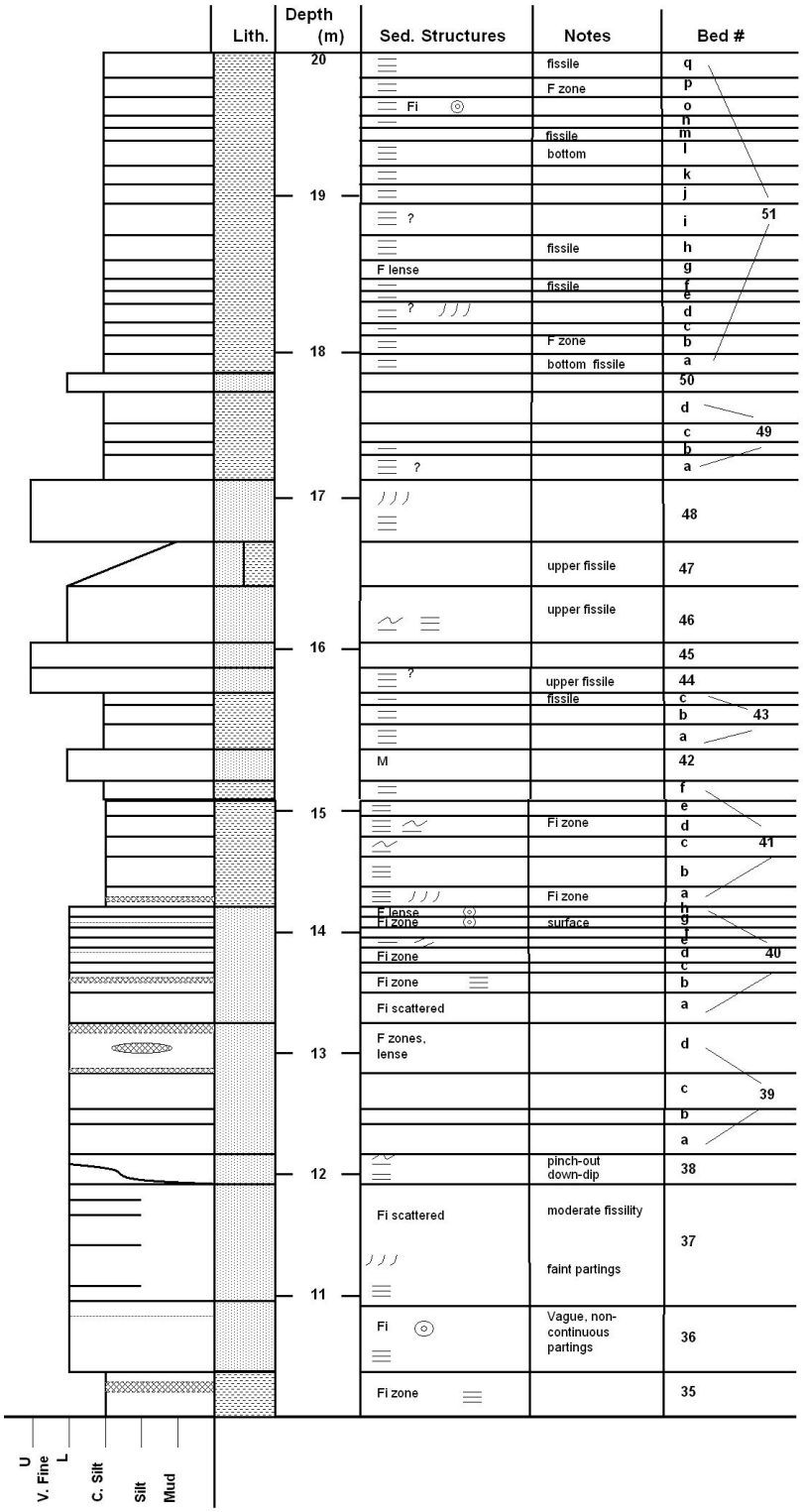

Figure 28. New Buffalo measured section, 10 m – 20 m.

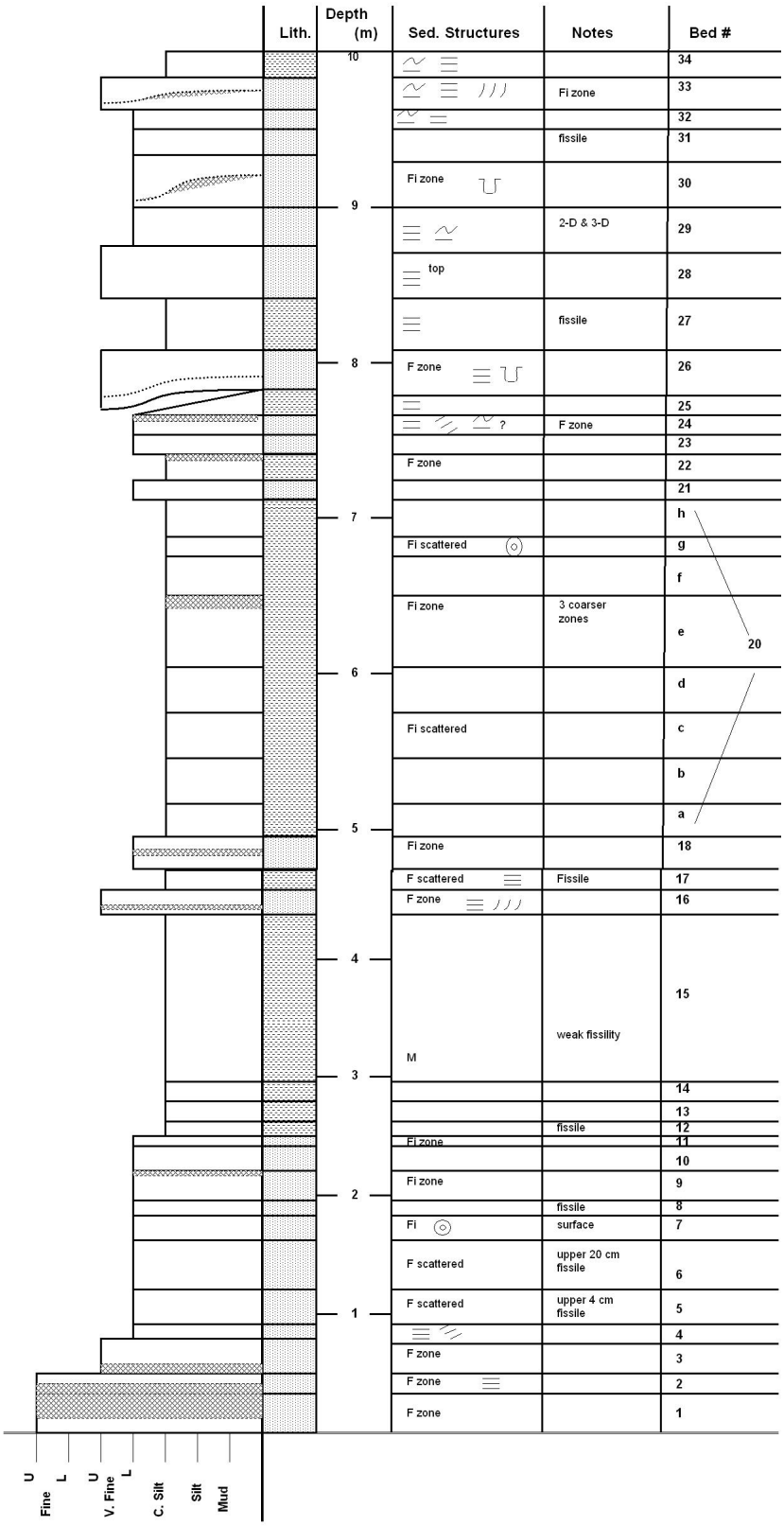

Figure 29. New Buffalo measured section, 1 m – 10 m

Liverpool

The Liverpool outcrop corresponds to a length of 700 meters. It is overlain by the red-bedded Catskill Formation, which slowly graded into the Trimmers Rock Formation. It is underlain by what Frakes thought is the Tully Limestone. The outcrop contains one main covered interval with patchy exposures and two sections of exposure.

This outcrop as a whole is much silty and less sandy than the other two locations. The upper section is composed of siltstone and shale packages with minor, intervening sandstone beds.

The lower section is composed of mostly siltstone packages with few intervening sandstone beds. This section contains vertical drill holes throughout most of the section, making it more challenging to discern individual bed boundaries. The measured interval was about 20 meters (Figures 34, 35) within the upper part of this section.

This interval contains a range of grain sizes from coarse siltstones to fine lower sandstone beds. It is composed of multiple thick siltstone packages with partings (Figure 33). Within each thin sub-bed, there is often a sequence of coarse, massively bedded material, which is overlain by planar laminations and then trough cross-bedding.

Sedimentary structures within this interval include the following: asymmetrical current ripples of varying wavelengths (Figure 32), planar laminations (Figure 31), trough cross-bedding, carbonate shell fragments, fossil lenses, trace fossils, vertical burrows. The cross-sections of crinoids are present on the top surfaces of some beds, as is seen at New Buffalo (Figure 30).

Figure 30. Crinoid cross-sections on the top surface of a bed.

Figure 31. Planar laminations overlain by trough cross-bedding.

Figure 32. Asymmetrical current rippled surface.

Figure 33. Corresponding photopan of Liverpool measured section.

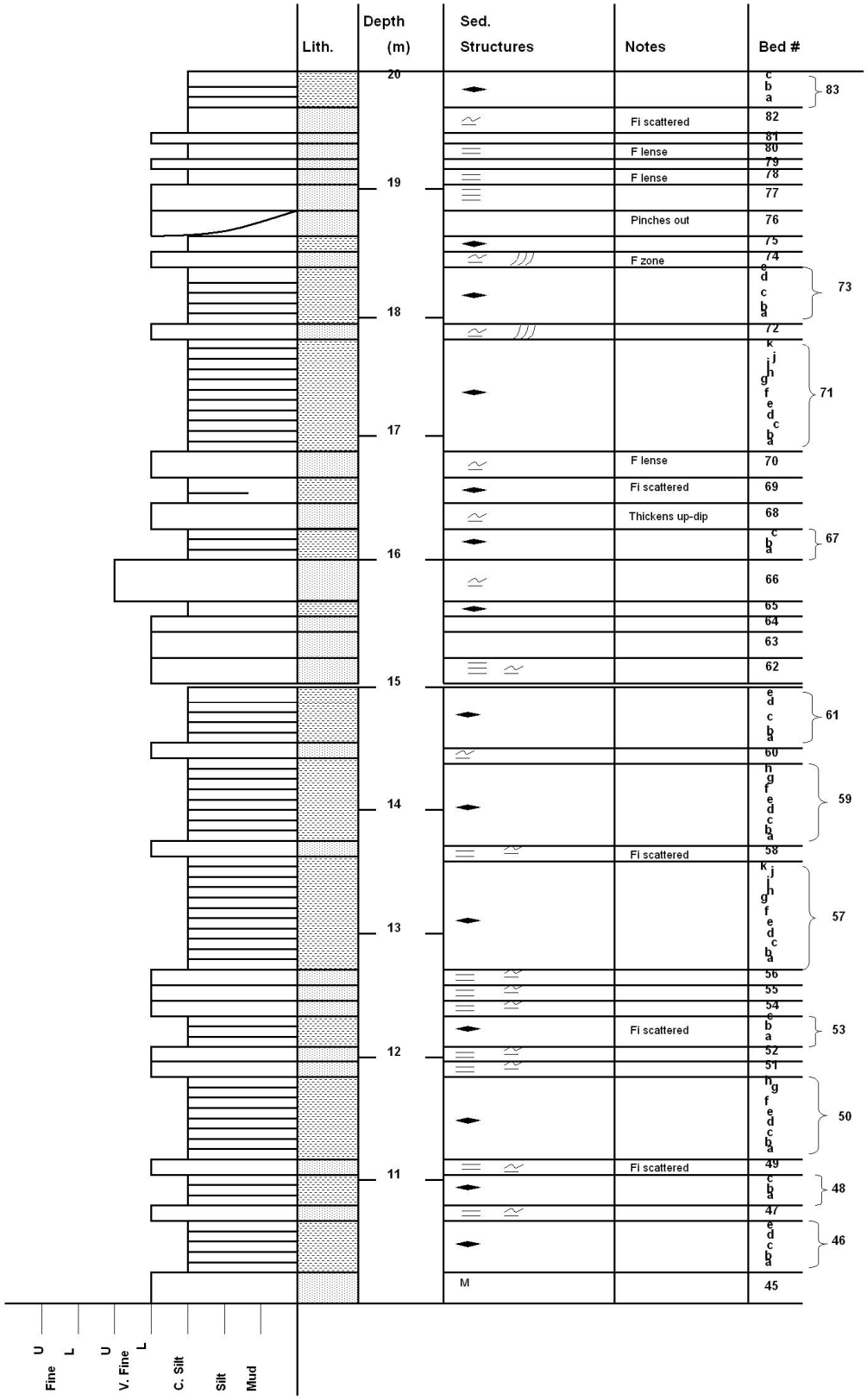

Figure 34. Liverpool measured section, 10 m – 20 m.

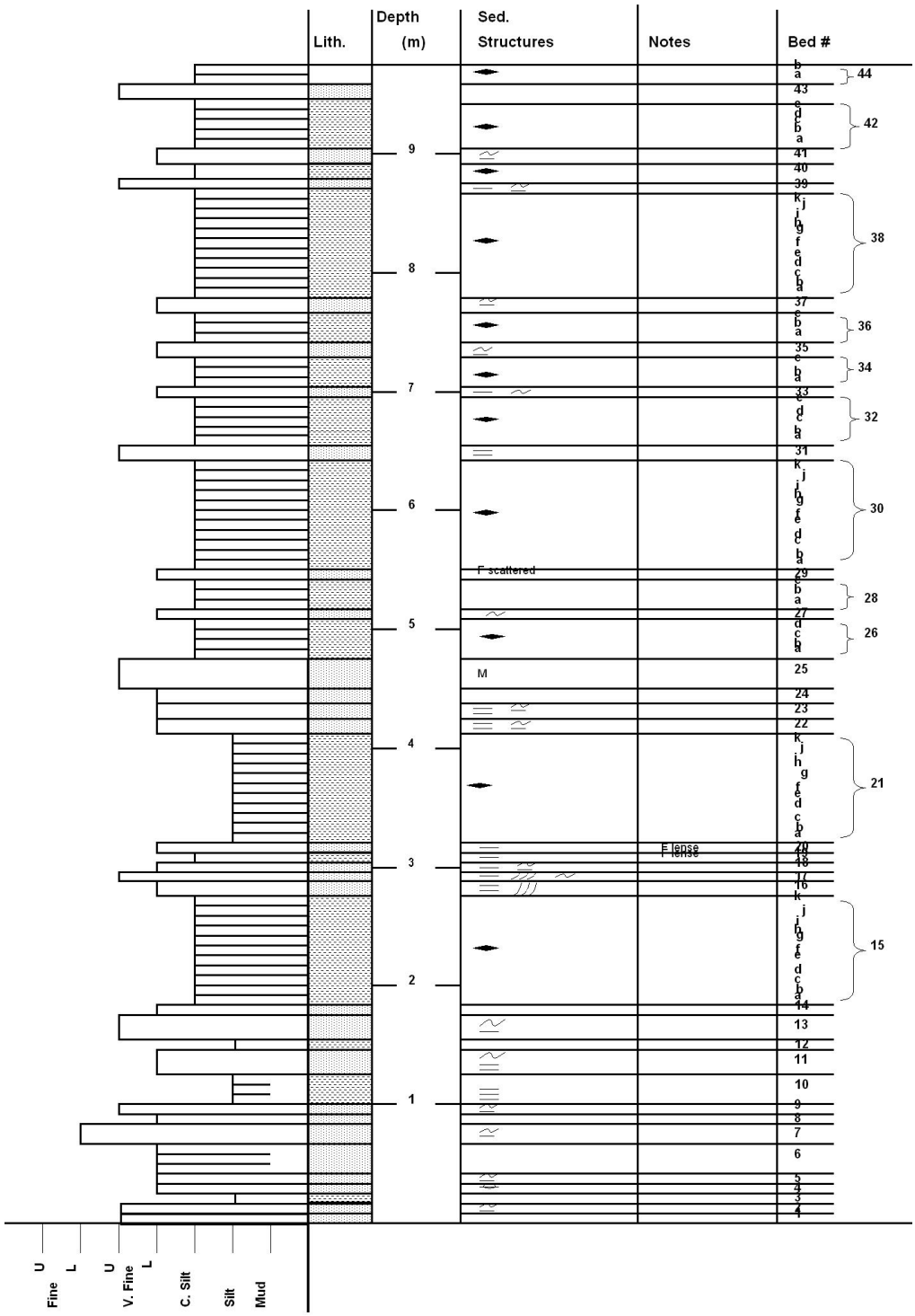

Figure 35. Liverpool measured section, 1 m – 10 m.

Analysis of Uncertainty

There are four different types of uncertainty associated with this project. The numerical data are the most concrete. Bed thickness measurements were made using a tape measure, with uncertainty of .01 m. This is the precision of the measurements. Although measurements could have been taken with a precision of .0001 m, this was not feasible because it is impossible to record that amount of detail in a measured section log.

Determining the grain size class of the particles within an individual bed also has an uncertainty associated with it. The error associated with this measurement is perhaps one grain size class. However, if one person is continuously making this determination of grain size, then it should be fairly consistent.

Accuracy can be dealt with on two levels. Correlation is a larger uncertainty, because it places a certain level of credibility on the correlation chart provided by Frakes (1967). The purpose of the project was to measure the same interval at the three locations. This is possible if the correct interval is located within the outcrop. If the correct interval is not located and measured, then the interpretations made from these correlations could be inaccurate as well.

The interpretations are also associated with a level of uncertainty. They are based upon the collected data of the measured sections and the relevant literature. The interpretations also have multiple levels of analysis. A first-order explanation examines the relationship that the outcrop locations have to a particular part of a submarine fan. A second-order understanding puts the outcrops into the context of one of the three deep-water depositional models.

Discussion of Results

The Trimmers Rock Formation was deposited as sheet-like turbidites in the outer part of a submarine fan. Each field location corresponds to a position within a single sheet-like turbidite. It therefore incorporates aspects of the Steel et al. (2000) model.

Each outcrop corresponds to an approximate position within one to three sheet-like turbidite lobes (Figure #). It is not possible to determine whether or not the three locations correspond to one particular sheet-like turbidite lobe, because the scale cannot be determined. It is also difficult to establish whether the observed characteristics within an outcrop correspond to an axial or proximal position as compared to a marginal or distal position.

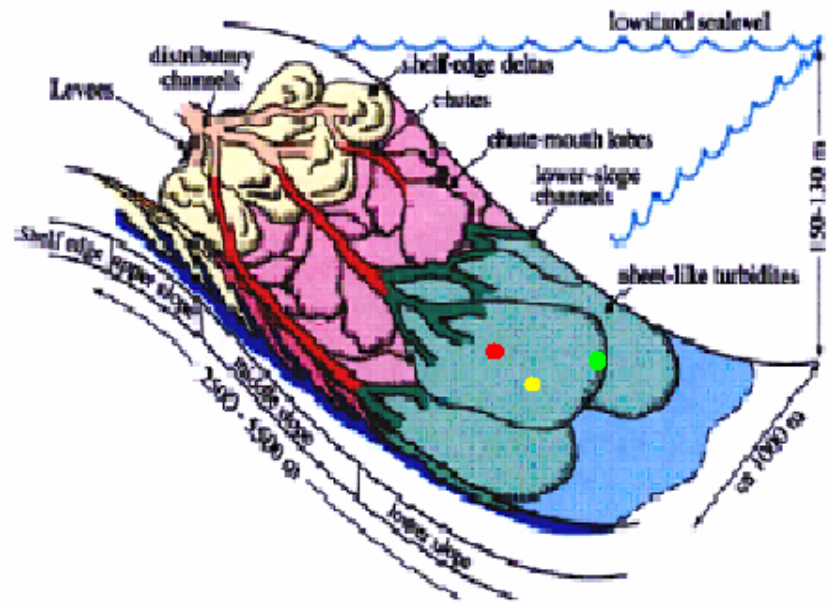

Figure 36. Sheet-like turbidites with approximate locations of outcrops noted. Newport = red, New Buffalo = yellow, Liverpool = green (modified from Steel et al. 2000).

Based on the aforesaid information, the Newport outcrop would most likely correspond to a more axial or proximal position within a fan. It contains the highest sand content of the three locations and largest grain sizes. The Liverpool section would correspond to a position that in much more marginal or distal within a fan complex. It has the highest silt content of the three locations and the smallest variation in grain size. The New Buffalo outcrop then would correspond to a position within these two end-members.

The folds in the region play a minor role in the relationship between the outcrops. If the area were “unfolded”, it would correspond to approximately a thirty percent extension in the northwest – southeast direction (Figure #). This would not change the relationship very much of the three locations to one another. Essentially, the relationship would remain very similar to the present connections to each other.

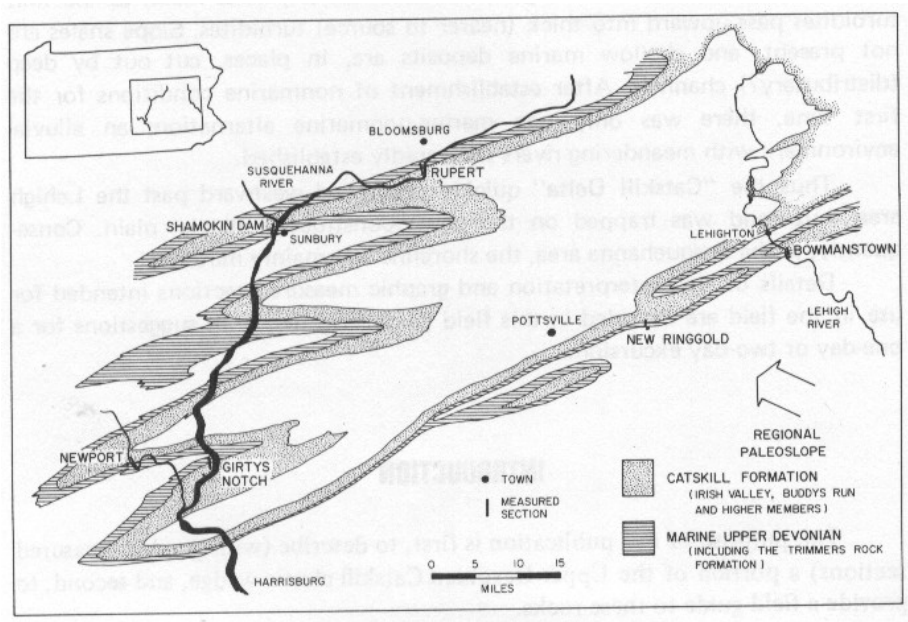

Figure 37. Folds in the region (Walker, 1972).

The measured sections correspond to sheet-like sand complexes in the outer part of a submarine fan. The packages observed at the three locations incorporate aspects of these sheet-like sand complexes. They are very fine-grained sands interbedded with very thin bedded shales. Channeled sands and levee deposits would not appear as was observed.

Combining all of the above data into one deep-water depositional model would most closely follow the Steel et al. (2000) model. Steel et al. (2000) characterize the lower shelf regime as having thin-bedded sheet-like beds with fine-grained laminated sandstones with current ripples and very fine-grained sandstone or siltstone cappings, up to a few centimeters thick. The basin-floor fan system is made up of rippled to parallel-laminated thin beds (< 50 cm) interbedded with structureless and/or parallel-laminated, thick bedded units (>50 cm).

Suggestions for Future Work

The Trimmers Rock Formation still has many aspects, which have yet to be studied and fully understood. Future work should focus on lengthening measured sections within outcrop locations and improving correlation techniques. Expanding the field area to encompass more field locations would also be useful in this research. Correlation could also be constrained through comparative biostratigraphy.

Conclusions

The three outcrops of the Trimmers Rock Formation correspond to sheet-like tubidites in the outer part of a submarine fan in the Steel et al. (2000) model. The localities integrate aspects of the sheet-like turbidites, with varying Bouma sequences. Each outcrop represents a different location within a turbidite lobe, based on the bed thicknesses and grain sizes therein. “Because of the wide range of sedimentary processes and sedimentary types, predicting depositional environments and facies distribution in fine-grained turbidite systems can be a challenging endeavor” (Bouma, 2000).

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Bibliography

Beaubouef, R.T. and S.J. Friedmann. "High Resolution Seismic/Sequence Stratigraphic Framework for the Evolution of Pleistocene Intra Slope Basin, Western Gulf of Mexico: Depositional Models and Reservoir Analogs." GCSSEPM Foundation 20th Annual Research Conference: Deep-Water Reservoirs of the World. Dec 3 – 6, 2000.

Bouma, A.H. "Fine-Grained, Mud-Rich Turbidite Systems: Model and Comparison with Coarse-Grained, Sand-Rich Systems." *Fine-Grained Turbidite Systems*. Eds. A.H. Bouma and C.G. Stone. AAPG Memoir 72 / SEPM Special Publication 68: 9-20. 2000.

Browne, G.H., R.M. Slatt and P.R. King. "Contrasting Styles of Basin-Floor Fans and Slope Fan Deposition: Mount Messenger Formation, New Zealand." *Fine-Grained Turbidite Systems*. Eds. A.H. Bouma and C.G. Stone. AAPG Memoir 72 / SEPM Special Publication 68: 143-152. 2000.

Campion, K.M. et al. "Outcrop Expression of Confined Channel Complexes." GCSSEPM Foundation 20th Annual Research Conference: Deep-Water Reservoirs of the World. Dec 3 – 6, 2000.

Drake, A.A. and P.T. Lyttle. "The Accotink Schist, Lake Barcroft Metasandstone, and Popes Head Formation – Keys to an Understanding of the Tectonic Evolution of the Northern Virginia Piedmont." Geological Survey Professional Paper 1205. United States Government Printing Office, Washington D.C. 1981.

Frakes, L.A. *Stratigraphy of the Devonian Trimmers Rock in Eastern Pennsylvania.* Harrisburg: Pennsylvania Geological Survey, 1967.

Glaeser, J. D. *Upper Devonian Stratigraphy and Sedimentary Environments in Northeastern Pennsylvania*. Harrisburg: Pennsylvania Geological Survey, 1974.

Levin, H. L. *The Earth Through Time.* 5th ed. Fort Worth, TX: Saunders College Publishing, 1996.

Schultz, L.D. *The Stratigraphy of the Trimmers Rock Formation in Northeastern Pennsylvania.* Dissertation. Lehigh Univ., Ph.D. 1974.

Sixsmith, P.J. et al. "Anatomy and Stratigraphic development of a basin floor turbidite system in the Laingsburg Formation, main Karoo Basin, South Africa." *Journal of Sedimentary Research* 74 (2004): 239 – 254.

Steel, R.J. et al. "Deltas vs. Rivers on the Shelf Edge: Their Relative Contribution to the Shelf-Margins and Basin-Floor Fans." GCSSEPM Foundation 20th Annual Research Conference: Deep-Water Reservoirs of the World. Dec 3 – 6, 2000.

Stetling, C.E., A.H. Bouma and C.G. Stone. "Fine-Grained Turbidite Systems: Overview." *Fine-Grained Turbidite Systems*. Eds. A.H. Bouma and C.G. Stone. AAPG Memoir 72 / SEPM Special Publication 68: 1-8. 2000.

Tucker, M.E. *Sedimentary Rocks in the Field*. 3rd ed. West Sussex, England: John Wiley & Sons Ltd., 2003.

Van Diver, B.B. *Roadside Geology of Pennsylvania*. Mountain Press Publishing Co, 1990: 165, 183-184.

Walker, R.G. "Turbidites and Associated Coarse Clastic Deposits." *Facies Models*. Geological Association of Canada, 1984: 171 – 188.

Walker, R.G. *Upper Devonian Marine – Nonmarine Transition, Southern Pennsylvania*. Harrisburg: Pennsylvania Geological Survey, 1972.

Appendix

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I pledge on my honor that I have not given or received any unauthorized assistance on this assignment. This includes plagiarizing.

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