Spring 5-1999

Tempestite Paleostratigraphy of the Martinsburg Fm. (Ordovician), Clinch Mt., TN

Edward Byrd Davis
University of Tennessee - Knoxville

UNIVERSITY HONORS PROGRAM

SENIOR PROJECT - APPROVAL

Name: Edward Davis

College: Arts + Sciences Department: Geological Sciences

Faculty Mentor: Dr. Tom Broadhead

PROJECT TITLE: Tempestite Paleostratigraphy of the Ordovician Martinsburg, Clinch Mt., TN.

I have reviewed this completed senior honors thesis with this student and certify that it is a project commensurate with honors level undergraduate research in this field.

Signed: Thomas W. Broadhead, Faculty Mentor

Date: 5/13/99

Comments (Optional):

Tempestite Paleostratigraphy of the Martinsburg Fm. (Ordovician), Clinch Mt., TN

Edward B. Davis

Advisor: Dr. Tom Broadhead

Abstract:

The upper 42m of the Ordovician Martinsburg Formation of eastern Tennessee consists of interbedded siltstone and limestone tempestite beds. The Martinsburg exposure atop Clinch Mountain features spectacular graded bedding and several different fossil assemblages. These range from a brachiopod dominated assemblage to a predominantly bryozoan assemblage. In order to determine quantitatively if the two assemblages are really distinct, two samples were taken from each of several of the major fossiliferous tempestite beds, for sectioning and point counts. Additionally, each pair of samples was taken with a maximum of lateral separation in order to provide an indication of lateral variation within the bed. A bed-by-bed stratigraphic section of the road cut was constructed in order to provide contextual data about the samples, and to record any long-term trends that sampling cannot.

The changing faunal composition of the exposure may be an indicator of changing water depth over time, which should be reflected within the stratigraphic section. Alternatively, the different faunal compositions may reflect sorting related to the storm events that generated the tempestites. If this were the case, little correlation would be expected between faunal composition in the tempestites and the original seafloor communities. The data point strongly to a faunal succession from a brachiopod to a bryozoan dominated assemblage, and then to a brachiopod and gastropod assemblage. The assemblages are thought to have varied with changing depth, changing from an open shelf environment, dominated by the storm deposits, to a bryozoan biostrome, and then to a shallower open environment, reworked more frequently by storms. Additionally, evidence was discovered indicating that crinoids may have been a component of the Martinsburg life assemblage but were differentially sorted out of the fossil assemblage during storm events.

Introduction:

Tempestite beds are formed by the settling of mixed sediment in the wake of a large storm event, similar to a modern hurricane (Kreisa, 1981). Such beds usually consist of fossil packstones that grade upward into laminated carbonate rich sandstone and siltstone, and finally into shale (fig. 1). Although the sediment mixing and subsequent settling associated with the formation of tempestite beds affords the opportunity for allochthonous time-averaging (Fürsich and Aberhan, 1990), tempestites are commonly found to contain autochthonous deposits that show only short-term time-averaging (Kreisa, 1981; Lehman and Pope, 1989). The fossil assemblages of tempestite fossil packstones can be classified within Model II of Johnson's (1960) classification system; that is, they show a relatively high number of intact and articulated valves, and little abrasion on the exposed surfaces of fossils. The fossils show few signs of transport, but are plainly not in life position.

Study of tempestite beds, which are depicted in figure 1, can provide important and interesting solutions to time-averaging problems, as well as paleoecological interpretations of small-scale sea level changes. Fürsich and Aberhan's (1990) study of time-averaging of fossil assemblages in nearshore and offshore environments indicates that deposits farther from shore are more likely to represent large periods of time within a time-averaged assemblage than are those near shore. This indicates that a study of the amount of time-averaging represented by a series of tempestite beds could allow conclusions to be drawn about the relative water depth or other environmental factors represented.

Failure to consider the mixing and time-averaging effects of tempestites, or the settling represented by the graded portion of the tempestite beds may lead to faulty paleoenvironmental interpretations. Westrop (1986) points out that size grading in tempestites may be interpreted as

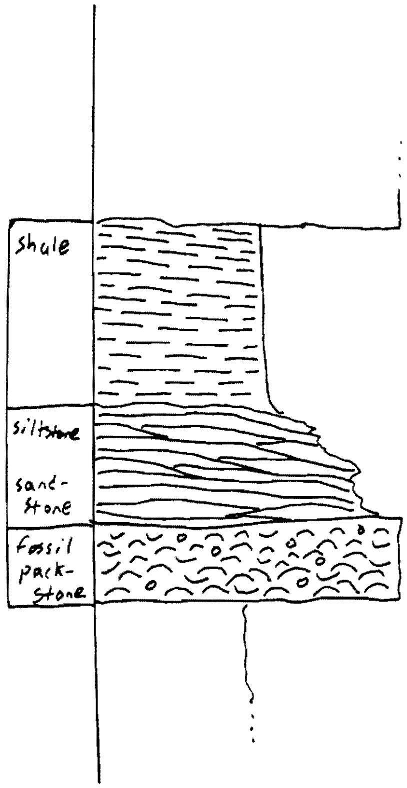


Figure 1: Idealized Graded Tempestite Sequence. (After Kreisa 1981)

ecological succession, and that variation in fossil assemblage between sections may be interpreted as community variation, when in reality such variation represents differing storm energy levels at varying depths. Similarly, although the fossil assemblage contained within a tempestite bed may fit well into Johnson's (1960) Model II, the sedimentary structures found within the bed, such as calcite void fillings, may indicate a relatively rapid burial, which seemingly should point to Model I. Johnson's Model I assemblage shows few exposure effects, and no signs of transportation, often preserving delicate details in the fossils, and is often associated with the sedimentological signs of rapid burial. Model II shows more exposure effects than Model I, preserving fewer delicate structures, but shows little in the way of additional transportation effects, implying gradual accumulation and burial of the preserved remains. Tempestites, however, show the transportation and exposure effects of Model II, but the expected sedimentology of Model I. Only careful consideration of both the sedimentary structures of the rock and the taphonomy of the fossil assemblage will lead to a proper paleoenvironmental interpretation. Finally, changing depth indicators, such as average grain size or paleoecological assemblage, within tempestite accumulations can be used, along with erosional and transport indicators, such as ripups or winnowed beds, to define regressive and transgressive events (Sageman, 1996).

The Martinsburg Formation (Middle to Upper Ordovician), named for Martinsburg, West Virginia (Geiger and Keith, 1891), outcrops from southeast New York to east Tennessee (Diehl, 1982). In Tennessee, the Martinsburg Fm. is 305m thick and consists primarily of fossiliferous limestone interbedded with shale and siltstone, with siltstone most common above the middle of the formation (Rodgers, 1953). The interbedded limestone and shale of the Martinsburg represent almost idealized storm deposits, and make this formation perfect for the study of tempestites, and for comparison with modern storm deposits (Kreisa, 1981).

This study concerns the upper third, approximately 42m, of Diehl's (1982) uppermost facies (approximately 120m), the mixed carbonate-clastic facies, which he interpreted as having been deposited on a marine ramp interior. Diehl divided this facies into six different stratigraphic units, the upper five of which are equivalent to the interval studied here, which Diehl called Outcrop P. These five units are interpreted as describing a gradual shallowing, and the associated changes in fossil content are explained by Diehl as a result of the changing depth. In the lowest of these units (Diehl's unit 12) he found 16.89 meters of interbedded nonfossiliferous shale and fossiliferous limestone tempestite beds, interpreted as the interior of the Martinsburg carbonate ramp, slightly below mean fair-weather wave base. The second unit (unit 13) was described as 8.19 meters of fossiliferous calcareous shale and limestone, interpreted as a non-wave resistant organic accumulation, or biostrome, dominated by bryozoan thickets. The third unit (unit 14) consists of 6.44 meters of interbedded, often truncated, fining upwards sequences, interpreted as slowly deposited shallow water deposits, affected by frequent storms. The fourth unit (unit 15) is very different from the others, consisting of 4.24 meters of highly bioturbated terrigenous siltstone, with only a 1% limestone component. This unit is interpreted as a siliciclastic rich, near-shore, subtidal environment, dominated by soft-bodied infauna. Diehl's final unit of the Martinsburg (unit 16) was only 0.49 meters thick, and was composed of interbedded limestone and shale. He interpreted this interval as a very shallow, subtidal environment, dominated by the energy of tidal currents.

Methods:

In this study I constructed a small-scale stratigraphic column in order to examine bed thickness in more detail, and answer questions regarding the relationship between interpreted environment and its expression in the rocks. First, I wanted to substantiate the tempestite hypothesis for the formation of the fining upward sequences. We were also interested in the relationship between different fossil assemblages and the stratigraphy, and whether the changing fossil assemblages actually reflect a faunal succession, or are an effect of hydrodynamic sorting. Finally, we were concerned with the possibility that hydrodynamic effects might dramatically change a fossil assemblage, perhaps to the point of removing an important component of the life assemblage completely.

Stratigraphic and paleontologic studies were conducted on a 42.28m exposure of Upper Ordovician Martinsburg Formation in a road cut on Tennessee Highway 25E near the top of Clinch Mountain, Tennessee, located West of the Clinch Mountain Lookout Restaurant and East of old Highway 25E (fig. 2). The exposure consists primarily of interbedded fossiliferous limestone and fissile and nonfissile siltstone. The study site extended from the lowest exposed bed of the road cut up to the boundary with the Upper Ordovician Juniata Formation, a red siltstone.

In order to provide a general context for subsequent sampling and stratigraphy, a color photomosaic (Appendix A) of the road cut was constructed. The outcrop was photographed from West to East on two rolls of 24 exposure 200-speed film. For consistency in exposure and scale, each photo was exposed for 1/125s at f11, using a 28mm lens. Each exposure was framed to include 50% of the previous exposure, in order to reduce the effect of spherical aberration on the overall mosaic. Fourteen exposures were used in the final construction of the photomosaic,

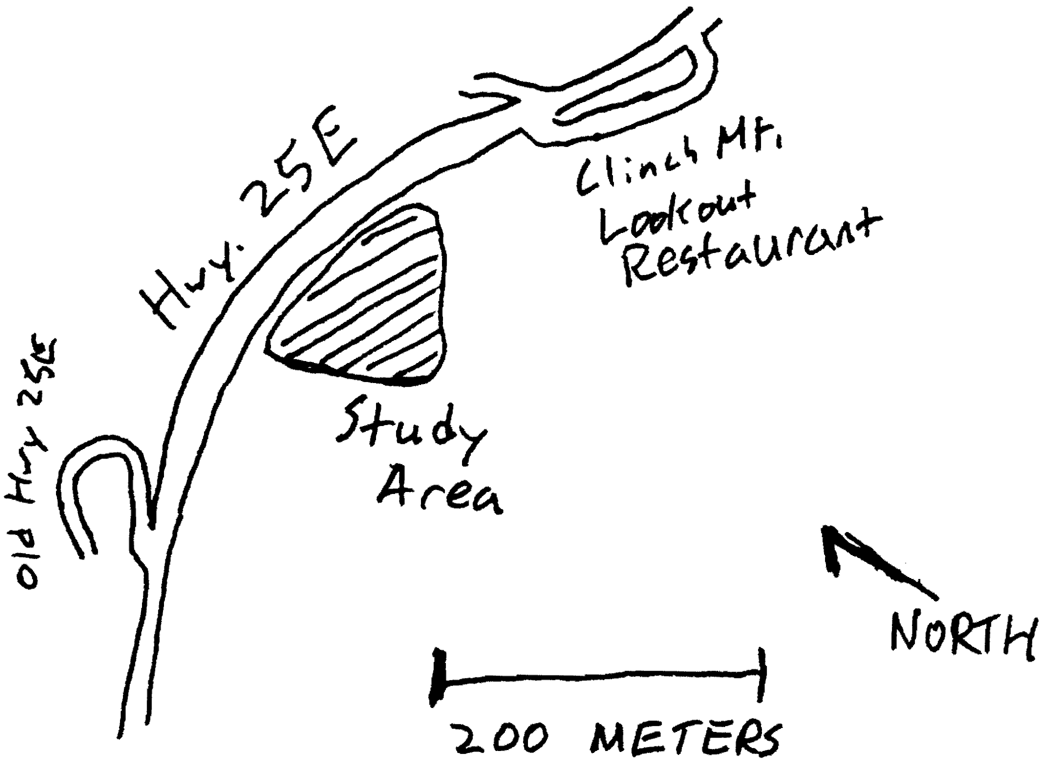


Figure 2: Map of Study Area. (After Diehl 1982)

which was subsequently scanned into JPEG file format, in order to provide easy access to field copies.

A detailed stratigraphic section of the exposure (Appendix B) was constructed between November 29, 1998 and April 16, 1999, using a 180cm Jacob's Staff, marked in 10cm increments for large intervals, and a 15cm ruler for smaller intervals. Although this phase of the project was originally only supposed to require four to six field days and stretch over only about two months, consistent inclement weather at Clinch Mountain stretched the fieldwork out to four months. The section was drawn at 1:10 scale in the field notebook, and data were recorded about the lithology, thickness, fossil content and orientation, and contacts for each unit. Also, for the siltstone units, data were collected concerning the fissility of the unit and the presence and thickness of any limestone lenses. All of these data were entered into a Microsoft Excel 97 spreadsheet and subsequently converted to SPSS 8.0 format in order to facilitate data analysis.

Eight samples were taken from the road cut (Appendix C), in order to provide better data concerning fossil content than the estimations of fossil percentages made in the field. Samples were taken from four fossiliferous limestone beds, selected for their thickness and lateral continuity. Samples 1 and 2 were taken from Unit 97; 3 and 4 from Unit 60; 5 and 6 from Unit 185; and samples 7 and 8 were taken from Units 244 and 245 (see locations in Appendix A). Each bed was sampled twice, and each pair of samples was taken with a minimum of 8m of lateral separation, in order to attempt to capture lateral variation within the bed. Each sample was cut perpendicular to bedding on a Hillquist rock saw. The cut surfaces were subsequently point-counted using a centimeter grid printed on a sheet of acetate. Each sample was marked with two dots on the cut surface, in order to facilitate orientation of the acetate grids. Two point counts were then taken of each sample, one with the intersection of gridlines centered on the reference points, counted by Edward Davis, and one count with the centers of two grid squares centered over the reference points, counted by Samantha Hopkins. Samples 7 and 8 grade from a fossiliferous layer into a nonfossiliferous, clay-rich layer, and sample 3 contained a nonfossiliferous clay layer stratigraphically below the fossil layer; only the fossiliferous sections of these samples were counted. Point counts 1a and 1b totaled 335 points, 2a and 2b totaled 248 points, 3a and 3b totaled 204 points, 4a and 4b totaled 343 points, 5a and 5b totaled 149 points, 6a and 6b totaled 316 points, 7a and 7b totaled 142 points, and 8a and 8b totaled 235 points. The points were assigned to categories based upon the fossil type or the type of matrix (micrite or calcite spar). The data from the point counts were entered into a Microsoft Excel 97 database, and subsequently converted to SPSS 8.0 format in order to facilitate data analysis.

The data from the stratigraphic section were evaluated with an ANOVA to test the relationship between lithology and fossil content (table 1). Data were checked for correlations (using Pearson's correlation coefficients) between unit thickness and fossil content, lithology and fossil content, the occurrence of different types of fossils, and lithology and upper contact type. Histograms of unit thickness frequency were constructed for several groups, based upon lithology, fossil content, and Diehl's stratigraphic units, in order to highlight any thickness-related trends (figs. 3-5).

The data from the point counts (table 2) were analyzed using several ANOVA's (table 3), dividing the groups on the basis of the sixteen individual point counts, the eight individual rock samples, and the four beds that were sampled. Also, the percentages of different fossil and matrix types found in the samples were compared using Pearson's correlations, to provide comparisons with the stratigraphic data. The point counts themselves were also correlated, in order to pick out trends between samples.

Table 1: ANOVA results relating lithology to fossil content, based upon stratigraphic data.

	Brach.	Bryoz.	Gast.	Trilo.	Traces	Infillings
df	1	1	1	1	1	1
F	426.755	32.417	1.067	2.948	3.124	55.883
Prob.	**<0.001**	**<0.001**	0.303	0.087	0.078	**<0.001**

Figure 3: Histogram of Bed Thicknesses by Lithology.

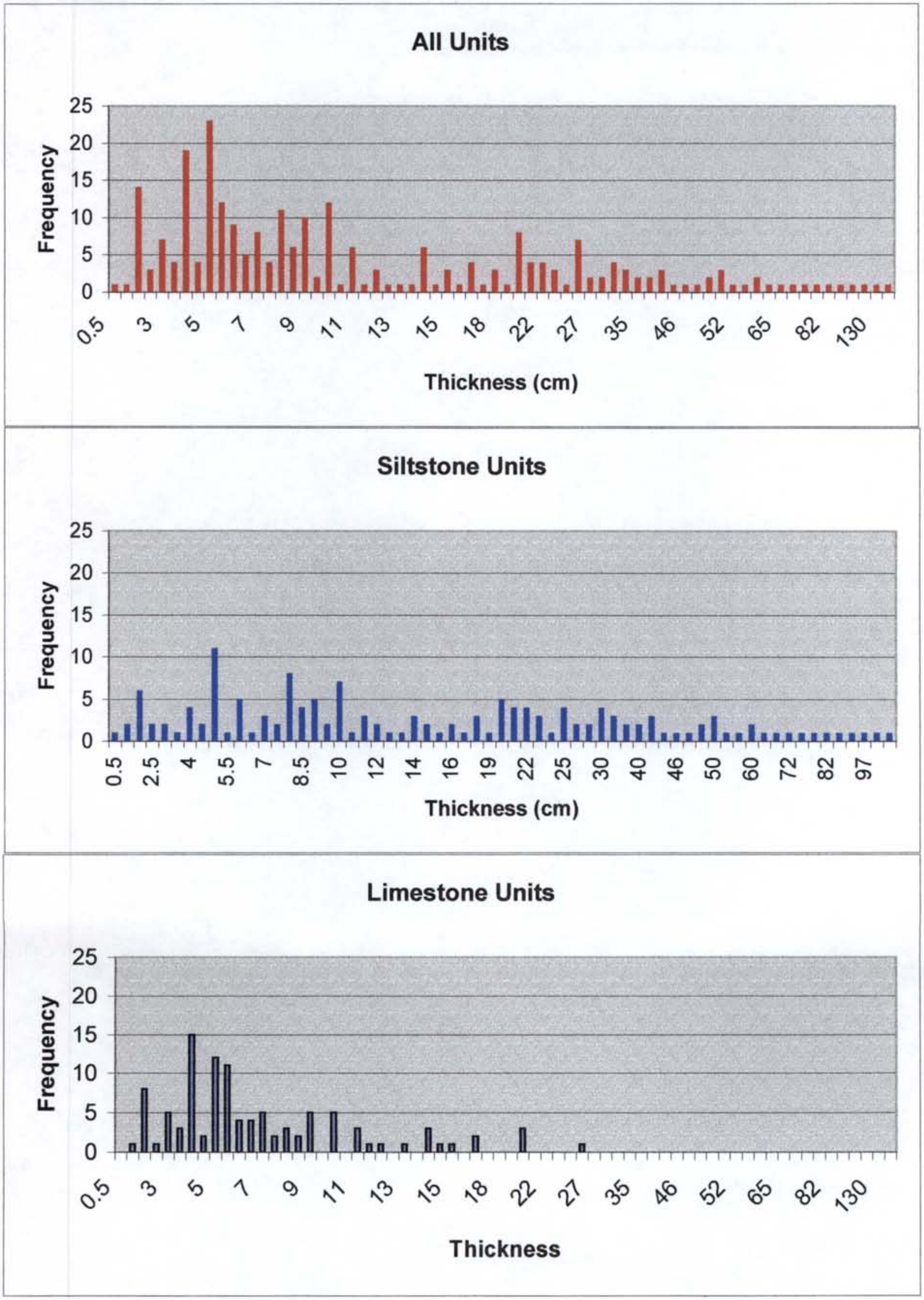


Figure 4: Histogram of Bed Thicknesses by Fossil Content.

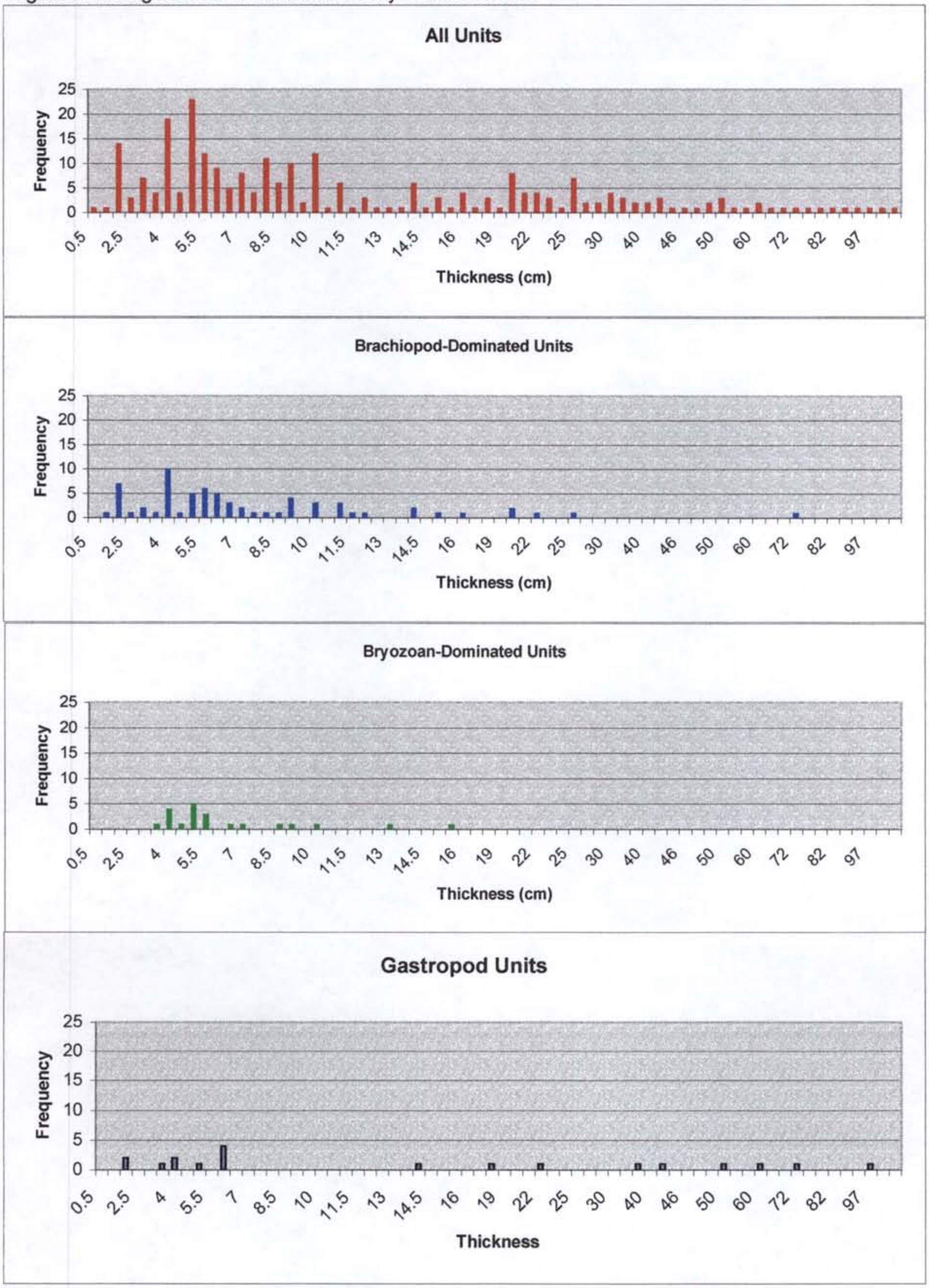


Figure 5: Histogram of Diehl's Units 12-14.

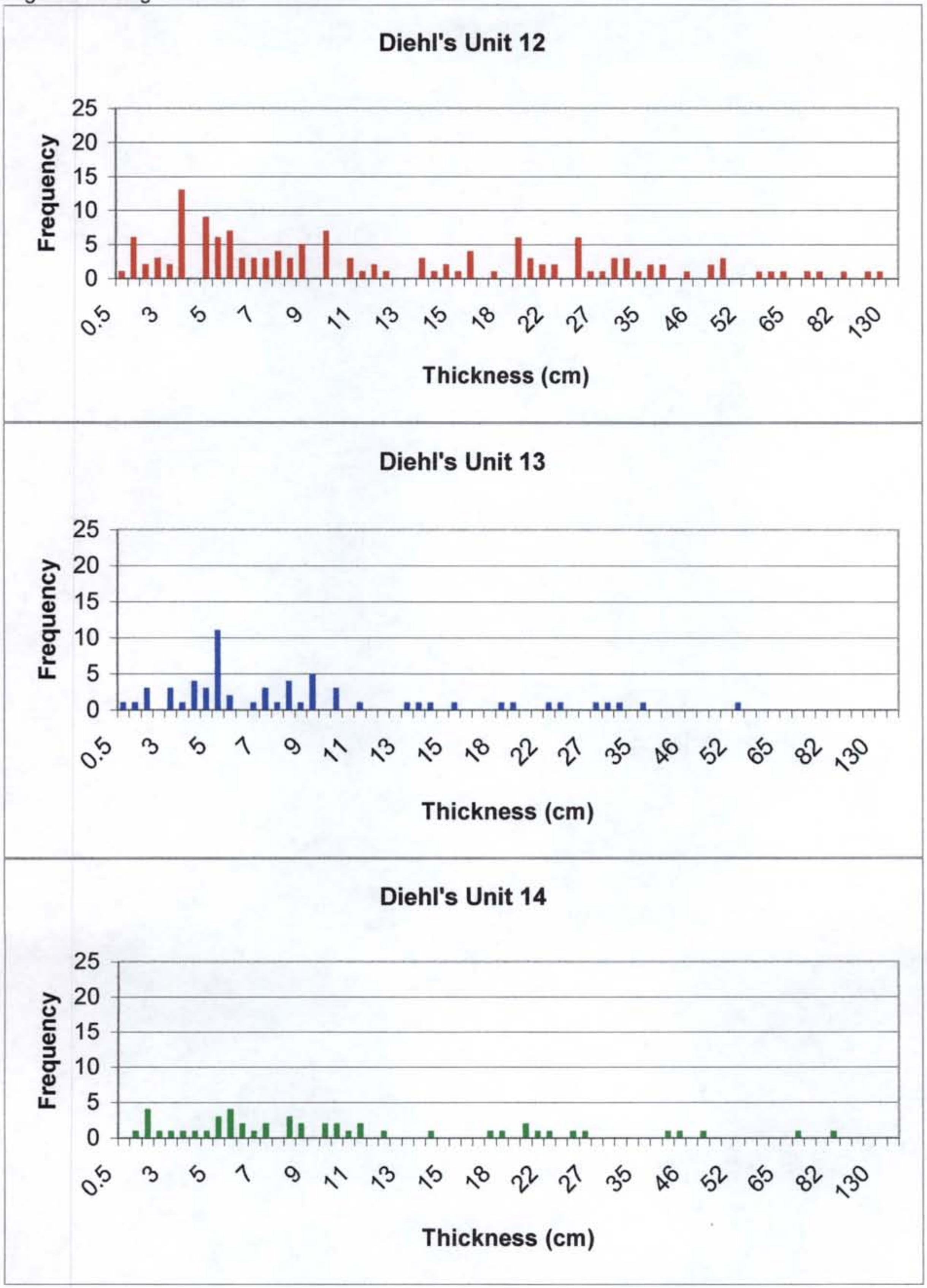


Table 2: Point count percentages.

	Brach. %	Bryoz. %	Gast. %	Trilo. %	Calcite %	Micrite %	Other %
1a	12.21	56.98	0.00	0.58	4.07	26.16	0.00
1b	11.04	55.21	0.00	0.61	4.29	28.83	0.00
2a	14.88	31.40	0.00	5.79	5.79	42.15	0.00
2b	9.45	36.22	0.00	1.57	6.30	46.46	0.00
3a	18.10	4.76	0.00	24.76	23.81	28.57	0.00
3b	32.32	3.03	0.00	9.09	7.07	48.48	0.00
4a	14.69	3.95	0.00	18.08	28.25	34.46	0.56
4b	21.69	4.22	0.00	15.06	26.51	32.53	0.00
5a	13.33	26.67	0.00	0.00	10.67	49.33	0.00
5b	12.16	39.19	0.00	0.00	5.41	43.24	0.00
6a	9.20	30.06	0.00	0.00	3.68	57.06	0.00
6b	18.95	24.84	0.00	0.65	5.23	50.33	0.00
7a	15.28	8.33	2.78	12.50	9.72	51.39	0.00
7b	27.14	5.71	7.14	5.71	2.86	51.43	0.00
8a	23.68	0.00	5.26	5.26	18.42	47.37	0.00
8b	28.93	0.83	4.13	6.61	14.88	44.63	0.00

Table 3: ANOVA's relating point count percentage and count, sample, and bed.

		Brach. %	Bryoz. %	Gast. %	Trilo. %	Calcite %	Micrite %
Count #	df	1	1	1	1	1	1
	F	3.886	8.246	14.110	0.015	0.119	10.878
	Prob.	0.069	**0.012**	**0.002**	0.904	0.736	**0.005**
Sample #	df	1	1	1	1	1	1
	F	3.162	8.517	13.667	0.001	0.199	10.703
	Prob.	0.097	**0.011**	**0.002**	0.987	0.663	**0.006**
Bed #	df	1	1	1	1	1	1
	F	3.363	7.076	15.376	0.001	0.038	9.355
	Prob.	0.088	**0.019**	**0.002**	0.980	0.847	**0.009**

Results:

The measured section of the Clinch Mountain road-cut included 259 units (Appendix B) from a total thickness of the outcrop of 4228cm. 25cm of the outcrop is covered, 729cm is fossiliferous limestone, and 3474cm is siltstone, meaning that 17.24% of the exposure is fossiliferous limestone, while 82.17% is siltstone. Limestone-siltstone couplets composed 206 units, for a total thickness of 3287cm(77.74%). Although previous investigations (Kreisa, 1981; Diehl, 1982) have reported a significant amount of shale in the upper Martinsburg, all of the terrigenous sediment in this exposure was judged to be siltstone, showing grain sizes too large and textures inconsistent with shale.

The measured units of this investigation were successfully correlated to Diehl's (1982) units 12 through 16 (table 4): units 1 through 142 (2516cm) were found to be comparable to Diehl's unit 12, units 143 through 203 (587cm) were found to be comparable to Diehl's unit 13, units 204 through 252 (690cm) were found to be comparable to Diehl's unit 14, units 253 through 257 (364cm) were found to be comparable to Diehl's unit 15, and units 258 and 259 (71cm) were found to be comparable to Diehl's unit 16.

The ANOVA relating lithology to fossil content (table 1) returned results relating brachiopods, bryozoans, and calcite infillings to rock type. Gastropods, trilobites, and trace fossils show no significance, with probability levels above 0.05, but brachiopods, bryozoans, and calcite infillings all show a high degree of significance, with probabilities less than 0.001. Brachiopods show the most importance, followed by infillings, and then bryozoans (table 1).

When stratigraphic data, such as lithology, thickness, nature of upper contact, and fossil content, were checked for correlations using Pearson's correlation coefficients, several significant relationships were highlighted. Thickness of units is significantly related to the

Table 4: Relationship between Diehl's units 12 through 16 and measured section.

Diehl Unit #	Diehl Thick.(m)	Strat. Range	Strat.Thick.(m)	Diff. in Thick.(m)
12	16.89	1-142	25.16	-8.27
13	8.19	143-203	5.87	2.32
14	6.44	204-252	6.90	-0.46
15	4.24	253-257	3.64	0.60
16	0.49	258-259	0.71	-0.22
				Total: -6.03

occurrence of brachiopods and bryozoans, with a probability of less than 0.001 for brachiopods, and less than 0.05 for bryozoans. Both show a negative correlation with thickness, i.e. that they tend to be present in thinner beds. Brachiopods, bryozoans, and calcite spar infillings show a significant positive correlation with lithology at the 0.001 level, indicating a trend towards occurrence in limestone beds. None of the fossil types show a significant correlation with the occurrence of another type of fossil, but brachiopods and trilobites both show a significant correlation (prob.<0.001) with calcite infillings. The upper contacts of the units show a significant correlation (prob.<0.01) with the lithology of the units, indicating that a siltstone unit is more likely to have a wavy upper contact, and that limestones are more likely to have gradational or planar upper contacts.

The unit thickness histograms based upon lithology showed a marked trend in the limestones towards thinner beds, whereas the siltstones showed a much more normal distribution. The thickness histograms of units based upon fossil dominance showed a similar trend towards thin beds, with the brachiopod-dominated units showing the best trend. There are too few bryozoan- or gastropod-dominated units for much of a trend to be visible in those histograms. Histograms also were constructed based upon the subdivisions of Diehl's units, but only units 12, 13, and 14 contained enough beds to construct graphs with visible trends. Diehl's unit 12 shows a long-tailed distribution, trending towards thinner units. Diehl's unit 13 shows a distribution skewed towards thin beds, and Diehl's unit 14 shows a similar, though less marked trend.

The percentages derived from the point counts are enumerated in table 2 and figure 6. Samples 3 and 4, first in stratigraphic order, from unit 60 (1269cm from base), are both largely composed of calcite and micrite, with micrite as the dominant material in the two samples.

These samples are rich in brachiopods and trilobites, but contain fewer than 5% bryozoans. Samples 1 and 2, from unit 97 (1937cm from base), contain a very different assemblage from 1 and 2. These samples are largely composed of bryozoans, with sample 1 containing greater than 50% bryozoans. Micrite, brachiopods, and calcite are also found in these samples, as well as a small amount of trilobite fragments. Samples 5 and 6, from unit 185 (2912cm from base), are dominated by micrite, similar to samples 3 and 4, but contain more than 25% bryozoans and only a small percentage of brachiopods. Micrite is the only other major component of these samples, with less than 1% of either composed of trilobites. Samples 7 and 8, from units 244 and 245 (3566.5cm from base), contain gastropods, which are unseen in the other samples. These two samples are also dominated by micrite, and contain about 25% brachiopods. Trilobites and calcite are important members of both samples, as are bryozoans in sample 7. Bryozoans are virtually absent from sample 8, however, comprising less than 1% of the sample.

The ANOVA's relating point count percentages to point count number, sample number, and bed number (table 3) show several trends. All three show significant variation in gastropods, micrite, and bryozoans, showing a degree of consistency between the three levels. Gastropod variation is most significant, followed by micrite and bryozoans. Variation in brachiopod, trilobite, and calcite spar percentages is not significant.

The point count percentages were compared using Pearson's correlation coefficients, and four groups show correlations significant at the 0.01 level. Brachiopods and bryozoans, bryozoans and trilobites, and bryozoans and calcite all have negative correlations, but trilobites and calcite share a positive correlation. Additionally, brachiopods and gastropods show a positive correlation significant at the 0.05 level.

Point counts (figure 6) were also compared using Pearson's correlation coefficients. All of the point count pairs within samples correlated with significance at the 0.01 level, except for 3a and 3b, which showed no significant correlation at all. Count 1a shows a significant correlation with 5b. Count 1b shows a significant correlation with 2a, 2b, and 5b. Counts 2a and 2b show significant correlations with 5a, 5b, 6a, and 6b. Count 3a shows a significant correlation with 4a and 4b. Count 3b shows a significant correlation with 7a, 7b, 8a, and 8b. 4a is not correlated with any other point count. Count 4b correlates with 8a and 8b. Count 5a shows a significant correlation with 6a, 6b, and 7a, but count 5b correlates with only 6a and 6b. Count 6a is correlated with 7a. 6b is correlated with 7a and 7b. 7a and 7b are both correlated with 8a and 8b.

Discussion:

The stratigraphic data recorded in this study match Diehl's five units well, but there is a marked difference in recorded thicknesses. Most of the 6.03m net difference (table 4) may be found in Diehl's unit 12 (8.27m different), which contains several small faults and folds, some of which are concealed by Tennessee Department of Transportation fences. Perhaps this small amount of structure affected Diehl's large-scale measurements. The variation could also be related to the portion of outcrop measured; Diehl's different measurements may reflect the small amount of lateral variation in thickness observed in the road cut, extended over a larger scale.

The ANOVA relating brachiopods, bryozoans, and infillings to lithology matches both the Pearson's correlations and trends observed in the field; that is, brachiopods and bryozoans tend to occur in limestone units, and calcite infillings occur exclusively in limestone units. This correlation between fossils and lithology works well with the tempestite hypothesis, as does the tendency for calcite infillings to occur under brachiopod and trilobite shells. The tendency for

Figure 6: Point Count Constituent Percentages (Page 1 of 2)

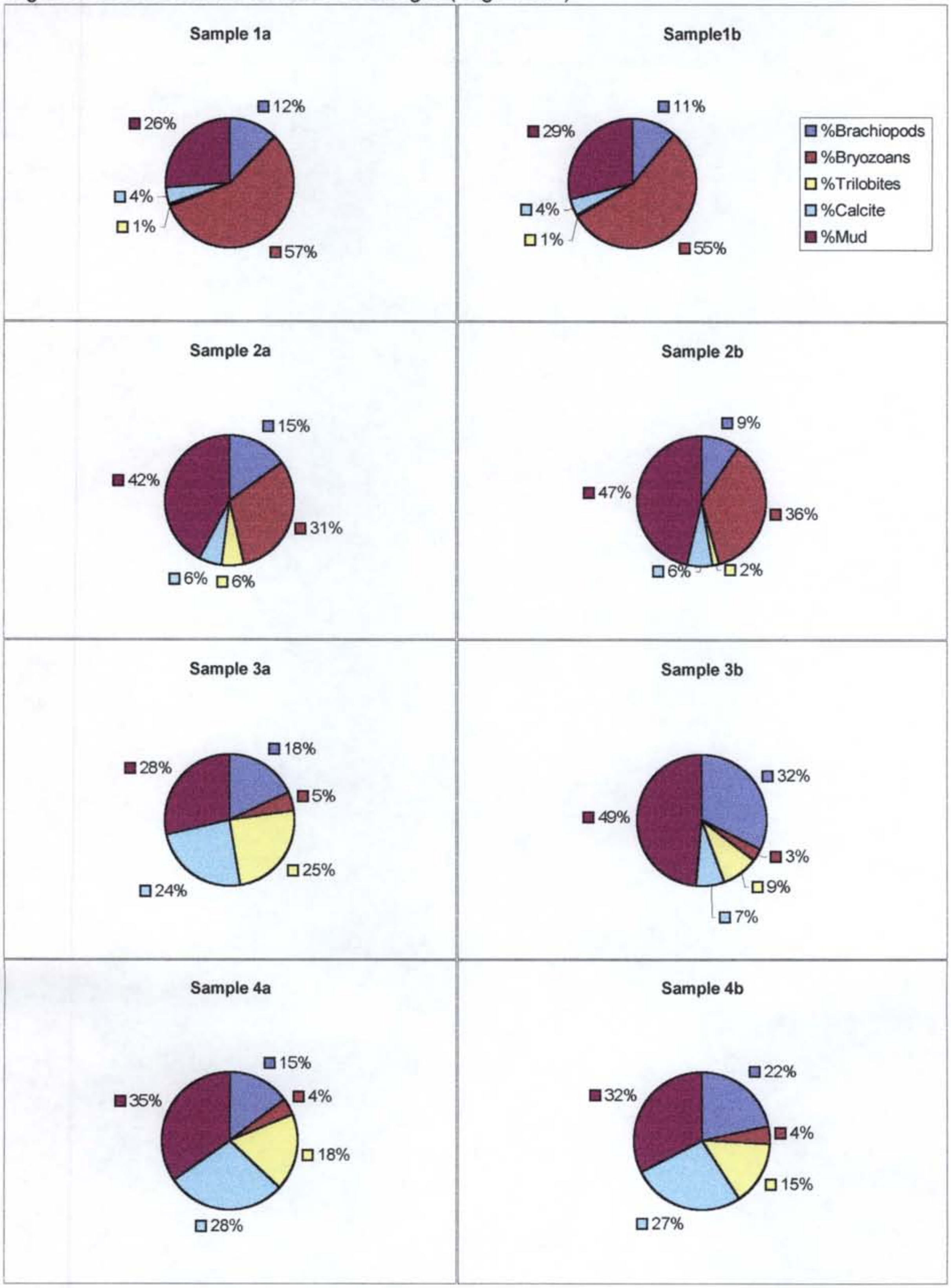
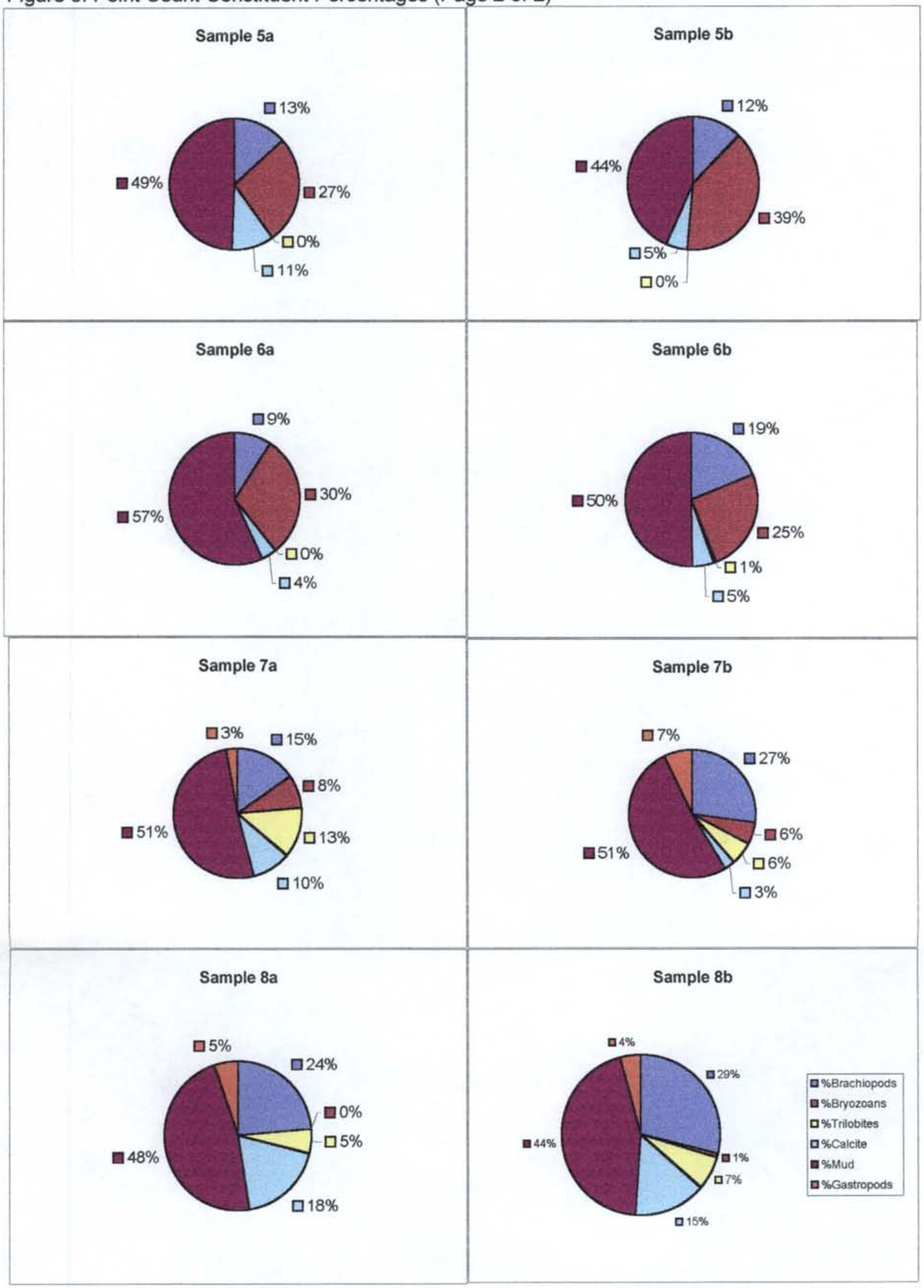


Figure 6: Point Count Constituent Percentages (Page 2 of 2)



siltstones to have wavy upper contacts and limestones to have planar or gradational contacts also fits well with the idealized tempestite sequence (fig. 1); the limestone grades into siltstone during settling, and the siltstone is truncated by the next storm event, leaving microtopography on the erosional surface. The wavy contacts associated with siltstones may also reflect load casts formed during diagenesis, or strain partitioning during uplift.

The histograms also agree with the tempestite hypothesis, showing many more thin limestone beds, and more diverse siltstone thicknesses. Also, the fossil histograms essentially reflect the tendency of the fossils to occur in limestone beds, showing the same skewness as the limestones. The histograms of Diehl's units support his interpretation, showing more of a long-tailed curve in the two tempestite units (12 and 14) and more of a regular, short-tailed distribution in the bryozoan biostrome (unit 13).

The gastropod variation in the point counts, which holds a great deal of weight in the ANOVA's (table 3), reflects a trend also observed in the stratigraphy. Few gastropods were found below the bryozoan biostrome, but several beds above the biostrome contained a large number of gastropods, possibly reflecting shallower water depth and an environment more hospitable to this type of organism.

The brachiopod variation relative to bryozoans, reflected by the negative Pearson's correlation in the point counts, is apparent in both the samples and in the road cut, as shown by figure 7, which outlines brachiopod and bryozoan variation in the study area. This variation is most simply explained by Diehl's hypothesis that it represents the development of a bryozoan biostrome, and that the bryozoans were essentially deposited in place during and after storm events. Alternatively, this change in fossil content may not reflect a true faunal succession, but may instead be the result of changing hydrodynamics with depth, resulting in an apparent

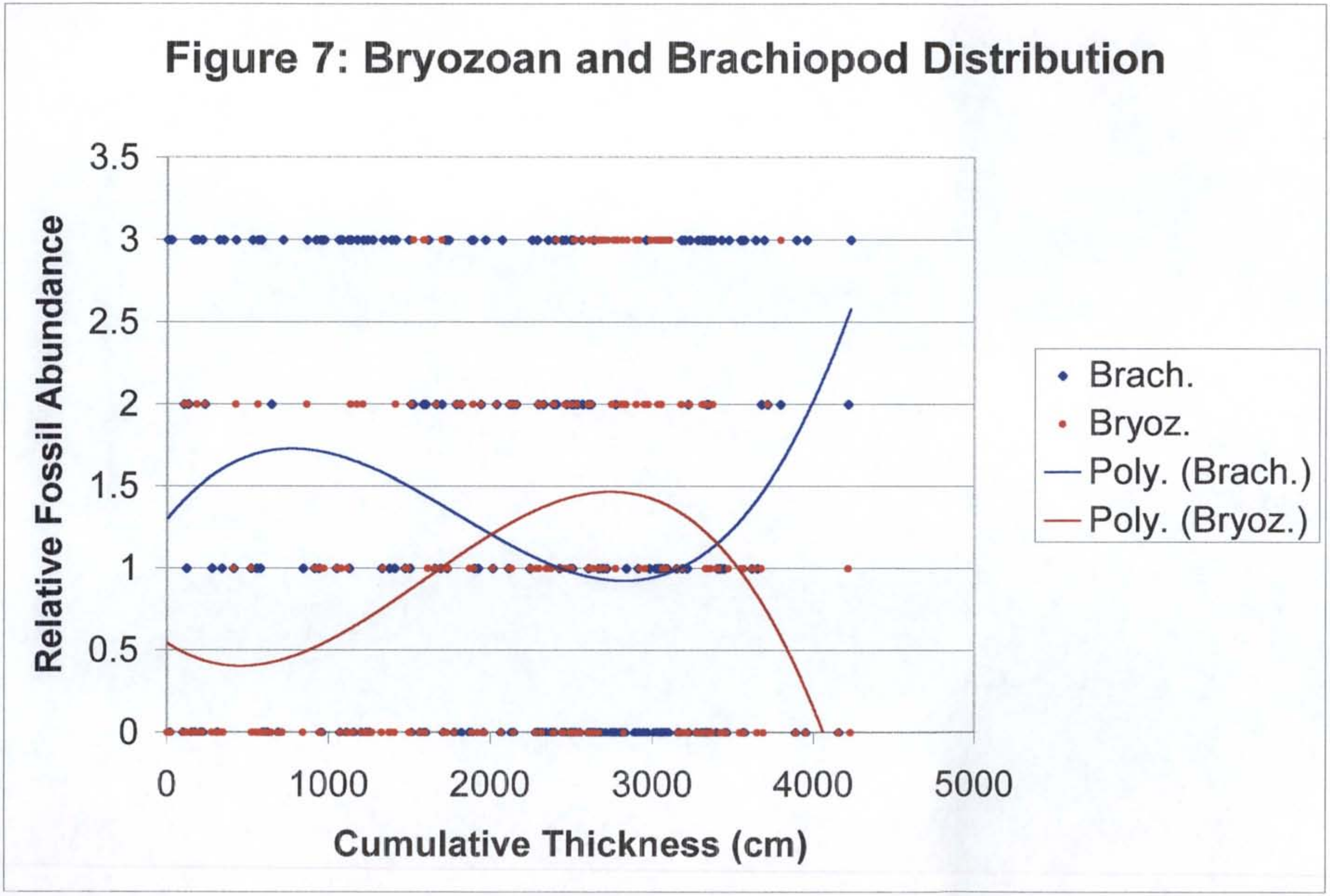


Figure 7: Bryozoan and Brachiopod Distribution
Relative Fossil Abundance
3.5
3
2.5
2
1.5
1
0.5
0
0
1000
2000
3000
4000
5000
Cumulative Thickness (cm)
Brach.
Bryoz.
Poly. (Brach.)
Poly. (Bryoz.)

succession, as outlined in Westrop (1986). The negative correlation between bryozoans and infillings may reflect the inability of bryozoan fragments to trap fluids beneath them when rapidly buried.

The lack of correlation between point counts 3a and 3b may reflect both the nature of the sample and experimental error. The vastly different percentages of trilobites and brachiopods reported for the two point counts may have arisen from confusion between the two observers as to which fossil grains should be classified as brachiopods and which as trilobites. In cross-section the two types of allochems look very similar, and without an agreement as to classification, misclassification can occur. The difference in matrix composition between the two counts, however, may be attributed to grid placement, and simply reflects the uneven distribution of calcite and micrite in the sample.

The correlation between samples 1, 2, 5, and 6 shows the relative consistency within the bryozoan biostrome (Diehl's unit 13) both laterally, between samples, and vertically, between sampled units. The correlation between samples 3, 4, 7, and 8 show a similar consistency between the two tempestite dominated sections of the outcrop, equivalent to Diehl's units 12 and 14. The correlations between samples 5 and 7 and 6 and 7 are related to the percentage of micrite in the samples and probably do not indicate an important trend, except for a slight increase in the percentage of micrite up section.

Diehl's 1982 investigation revealed only a small number of unidentifiable echinoderm plates, even though crinoids might easily have occupied the same environment as the bryozoans and brachiopods of the Martinsburg Fm. The first-order niche differentiation discussed by Ausich (1980) could allow crinoids to suspension feed in the same environment as bryozoans or brachiopods by occupying a higher portion of the water column.

The cut face of sample 3 contains the first recognizable crinoid stem from the Martinsburg Fm. (fig. 8). The fossil crinoid stem would have been unrecognizable if it were not seen in cross-section, as it is encrusted by a bryozoan. The fossil lies below the tempestite bed in a siltstone layer that shows no lamination. The possibility arises that crinoids were a part of the life assemblage on the Martinsburg carbonate ramp and were differentially removed, either during decomposition or during the storm events that periodically reworked the sediment. Lewis (1980) points out that echinoderm ossicles, because of their microporous structure, may become filled with decompositional gasses after the death of the animal and float away. Also discussed is the relatively low specific gravity of echinoderm ossicles, which may lead to different hydrodynamic behavior than that of the denser shells of other phyla, resulting in some winnowing in high energy environments. In either case, the only crinoid stem fragment that was not removed from the Martinsburg Fm. was encrusted by a bryozoan, altering its specific gravity and other hydrodynamic properties. Alternatively, this piece may have floated in during a period of relatively low energy, aided by its low specific gravity, and may not reflect the life assemblage at all.

The Clinch Mountain exposure of the upper 42m of the Martinsburg Fm. contains a series of fining upwards sequences, interpreted as tempestites, that record shallowing of the Martinsburg carbonate ramp through changing bed thicknesses and frequency. As the environment shallowed, it changed from an open ramp interior to a bryozoan biostrome. The biostrome was eventually superceded by another, shallower open environment, which graded into a subtidal high-energy environment. This environmental interpretation is supported by the stratigraphic evidence, which shows a tendency towards thinner beds and more limestone in the

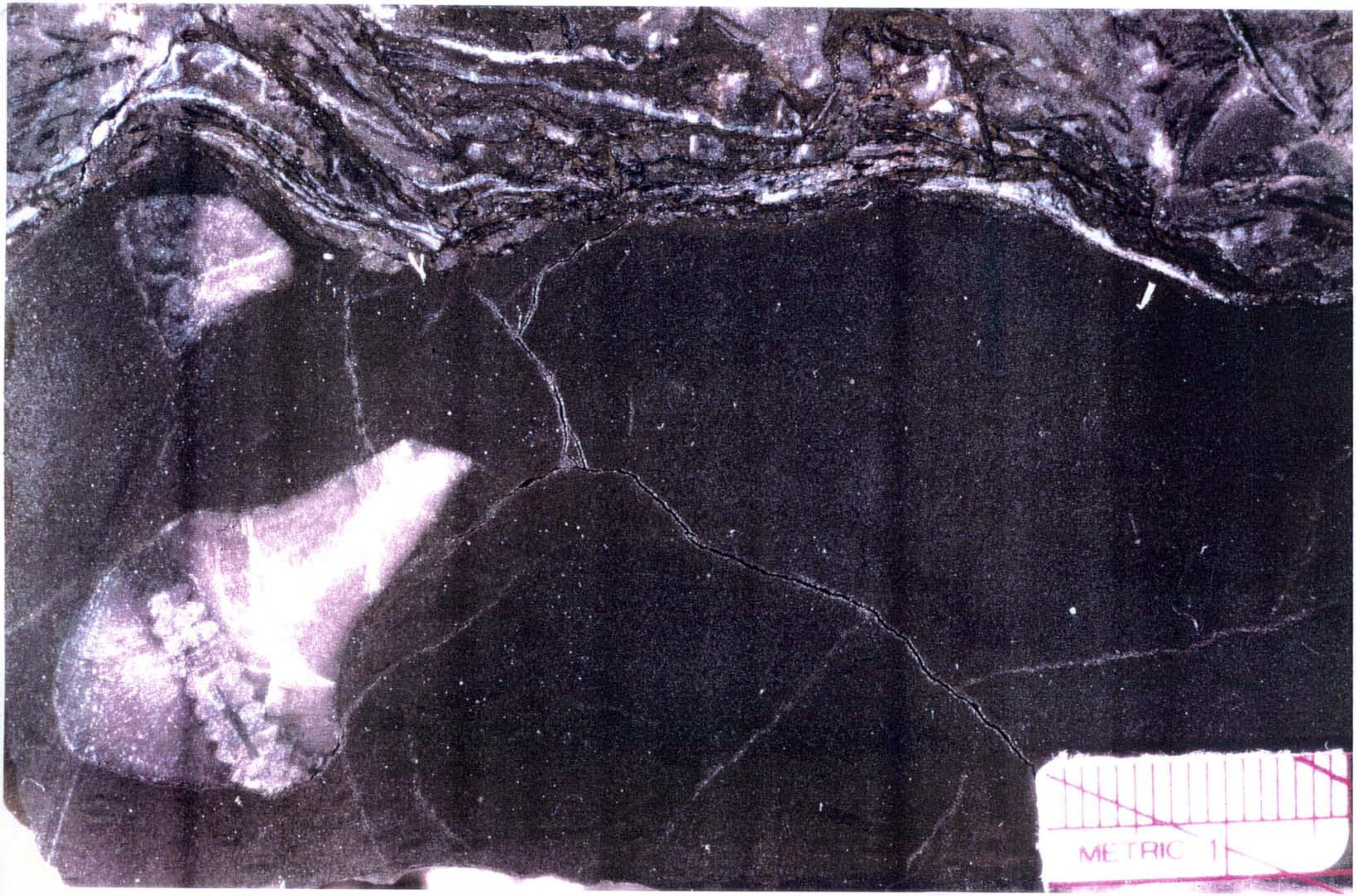


Figure 8: Closeup of Crinoid Fragment with Encrusting Bryozoan from Sample #3.

open shelf environment and thicker beds and more siltstone in the shallower, more restricted biostrome.

The consistency of brachiopod shell percentages in the point count data indicates that the limestone beds of the tempestite sequences record assemblages representative of the life assemblage, implying that storm activity served only to time-average the assemblage and did not remove or add any skeletal material. One alternative explanation proposes that the storm events preferentially sorted the death assemblage, based upon hydrodynamics that vary with depth. This may mean that Diehl's unit 13 reflects only hydrodynamic sorting and does not truly represent a different life assemblage. The rarity of crinoid fossils may also indicate that hydrodynamic sorting is an important preservational factor in tempestite beds, but the effect may be limited to echinoderm skeletal material as a result of the unique microstructure and hydrodynamic characteristics of echinoderm ossicles. The point count evidence, however, does not agree with the depth-dependant shape-sorting interpretation, showing 10% to 20% brachiopod shells in every sample, including those from the bryozoan biostrome (Diehl's unit 13). Preferential shape sorting for bryozoan skeletal fragments would have reduced the percentage of brachiopod valves recorded in the fossil assemblage.

Acknowledgements:

I would like to thank Samantha Hopkins for her help with the fieldwork and point counts, as well as her invaluable help with typing stratigraphic descriptions and presenting this project to the University of Tennessee Geology Department. I would also like to thank Molly McNeeley for her assistance with SPSS 8.0. Finally, I would like to thank Dr. Tom Broadhead, whose guidance and support have made this project a fitting capstone to my undergraduate career.

Cited References

Ausich, W.I. 1980. Synecology — Niche Differentiation. In Broadhead, T.W. and J.A. Waters, eds. Echinoderms: Notes for a short course. The University of Tennessee, Knoxville, Department of Geological Sciences, Studies in Geology 3: 59-72.

Diehl, W.W. 1982. Depositional environments and paleoecology of the Middle and Upper Ordovician Martinsburg Formation of Grainger County, Tennessee. Unpublished M.S. Dissertation, University of Tennessee, Knoxville: 242.

Fürsich, F.T. and M. Aberhan. 1990. Significance of time-averaging for palaeocommunity analysis. Lethaia, 23: 143-152.

Geiger, H.R. and A. Keith. 1891. The structure of the Blue Ridge near Harper's Ferry. Geological Society of America Bulletin, 2: 155-164.

Johnson, R.G. 1960. Models and methods for analysis of the mode of formation of fossil assemblages. Geological Society of America Bulletin, 71: 1075-1086.

Kreisa, R.D. 1981. Storm-generated sedimentary structures in subtidal marine facies with examples from the Middle and Upper Ordovician of Southwestern Virginia. Journal of Sedimentary Petrology, 51: 823-848.

Lehman, D. and J.K. Pope. 1989. Upper Ordovician tempestites from Swatara Gap, Pennsylvania: Depositional processes affecting the sediments and paleoecology of the fossil faunas. Palaios, 4: 553-564.

Lewis, R. 1980. Taphonomy. In Broadhead, T.W. and J.A. Waters, eds. Echinoderms: Notes for a short course. The University of Tennessee, Knoxville, Department of Geological Sciences, Studies in Geology 3: 27-39.

Rodgers, J. 1953. Geologic map of East Tennessee with explanatory text. Tennessee Division of Geology, Bulletin, 58: 168.

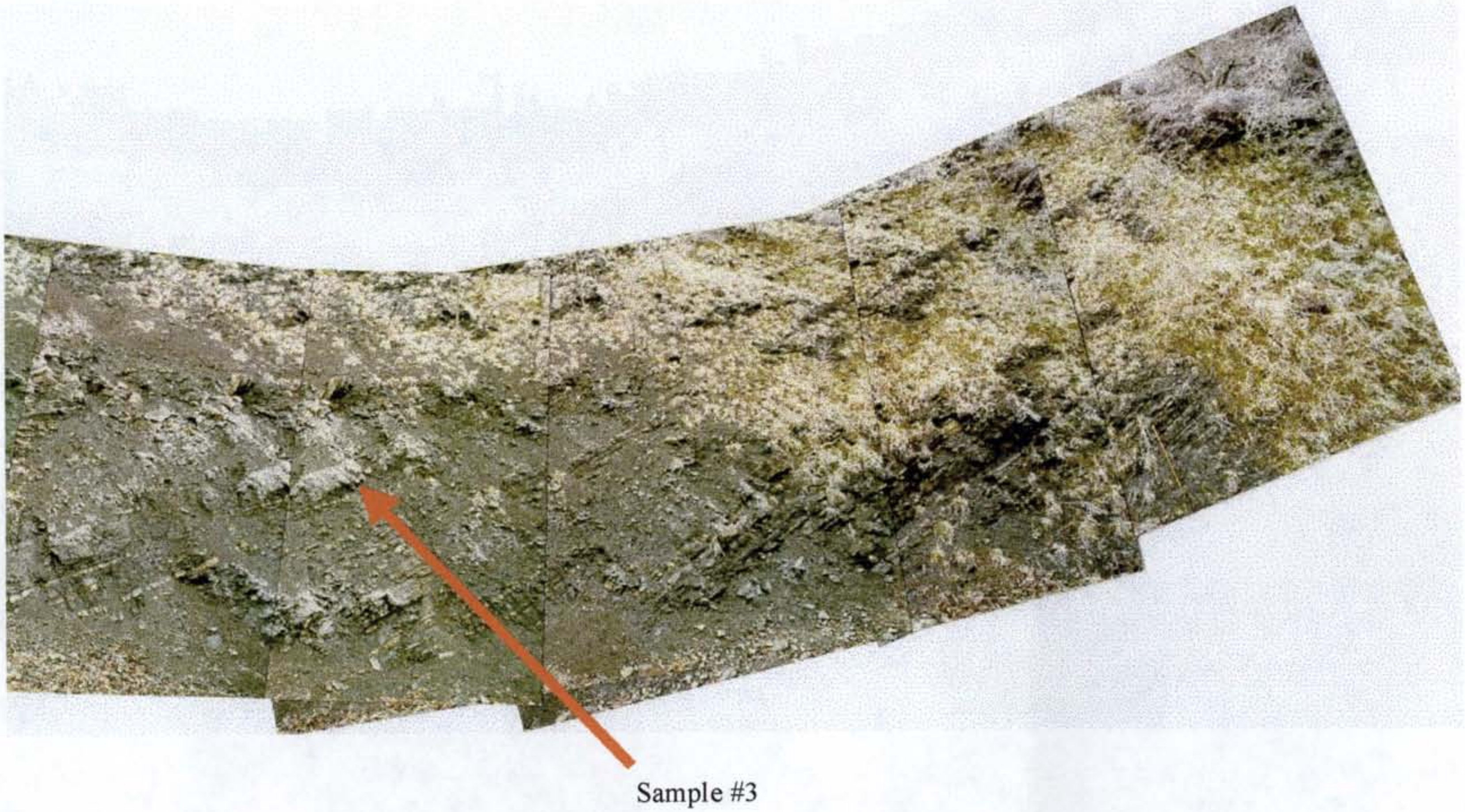
Sageman, B.B. 1996. Lowstand tempestites: Depositional model for Cretaceous skeletal limestones, Western Interior Basin. Geology, 24: 888-892.

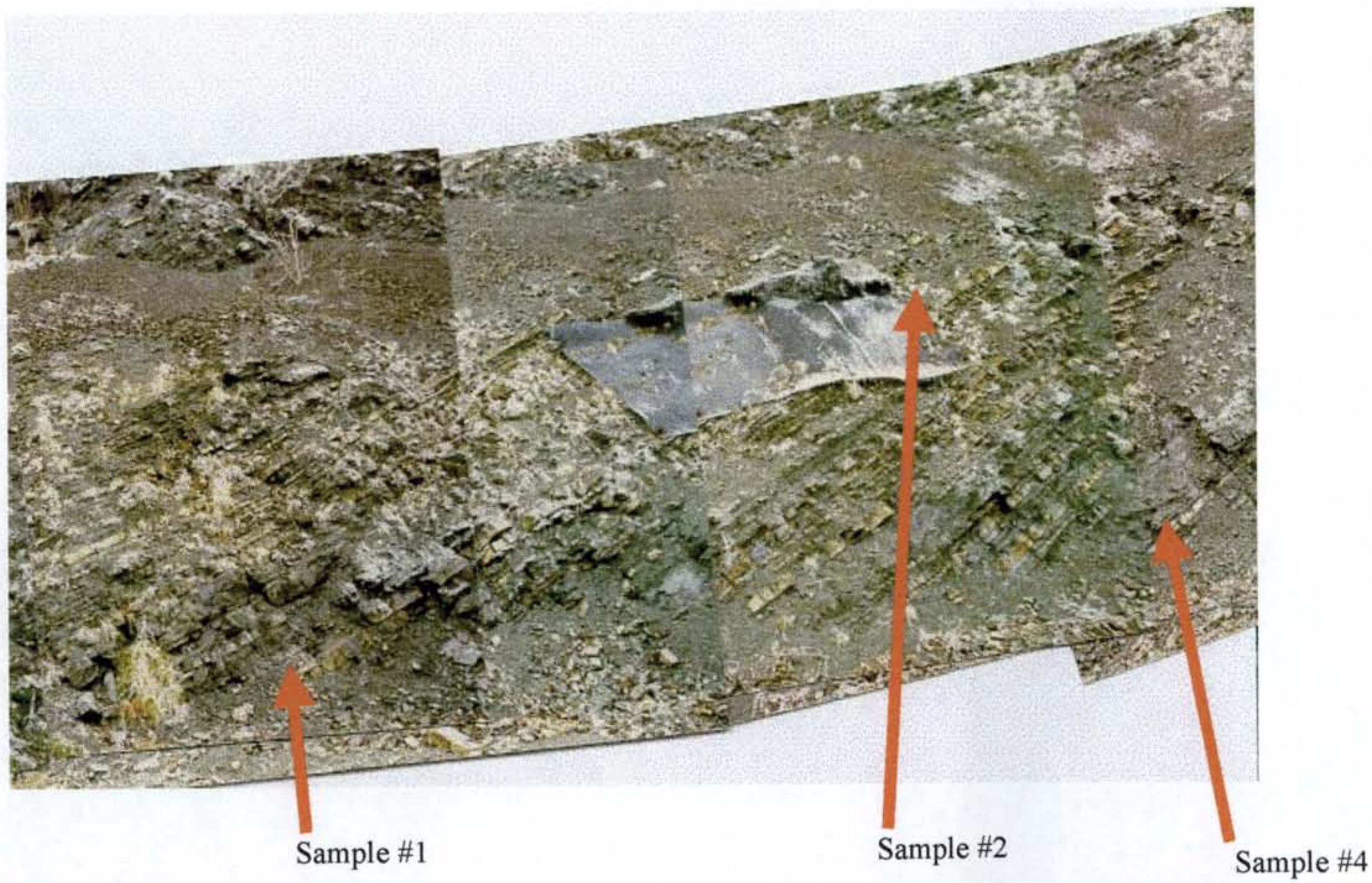
Westrop, S.R. 1986. Taphonomic versus ecologic controls on taxonomic relative abundance patterns in tempestites. Lethaia, 19: 123-132.

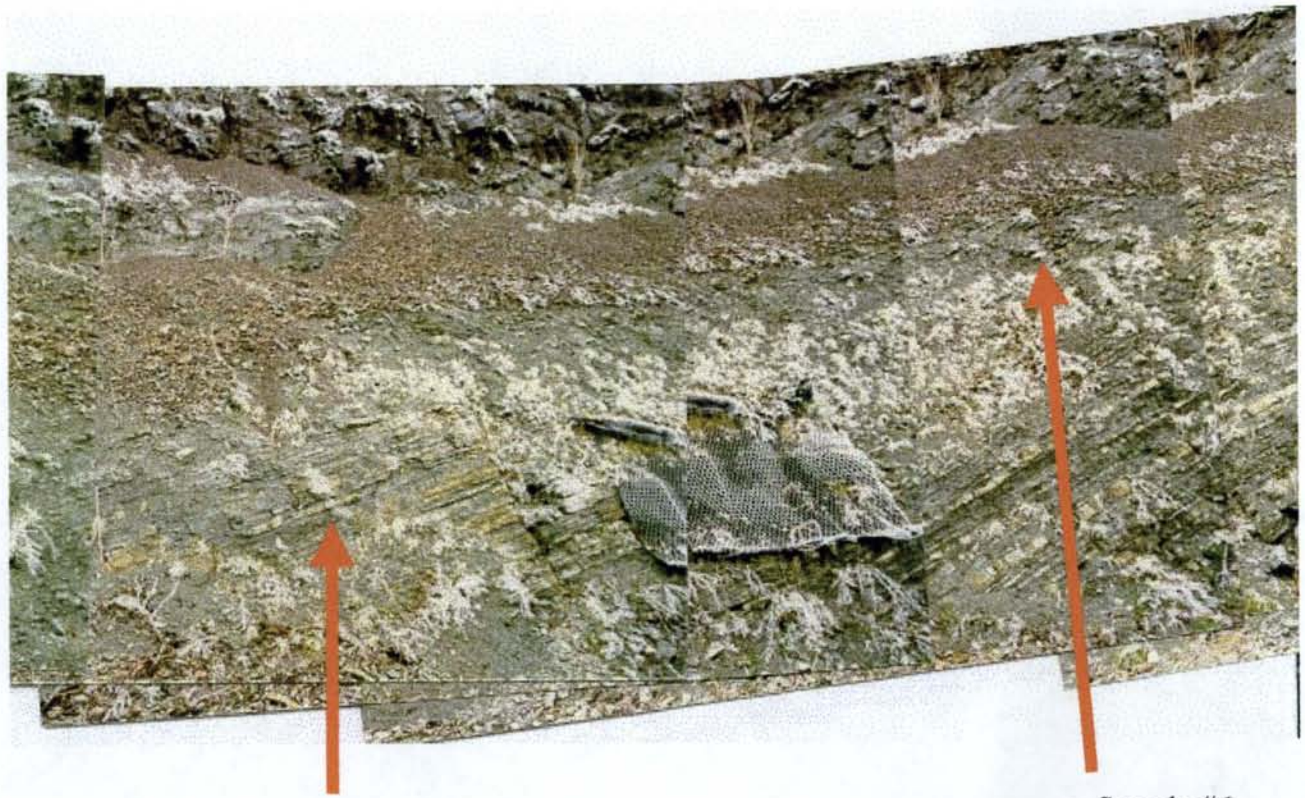
Appendix A:

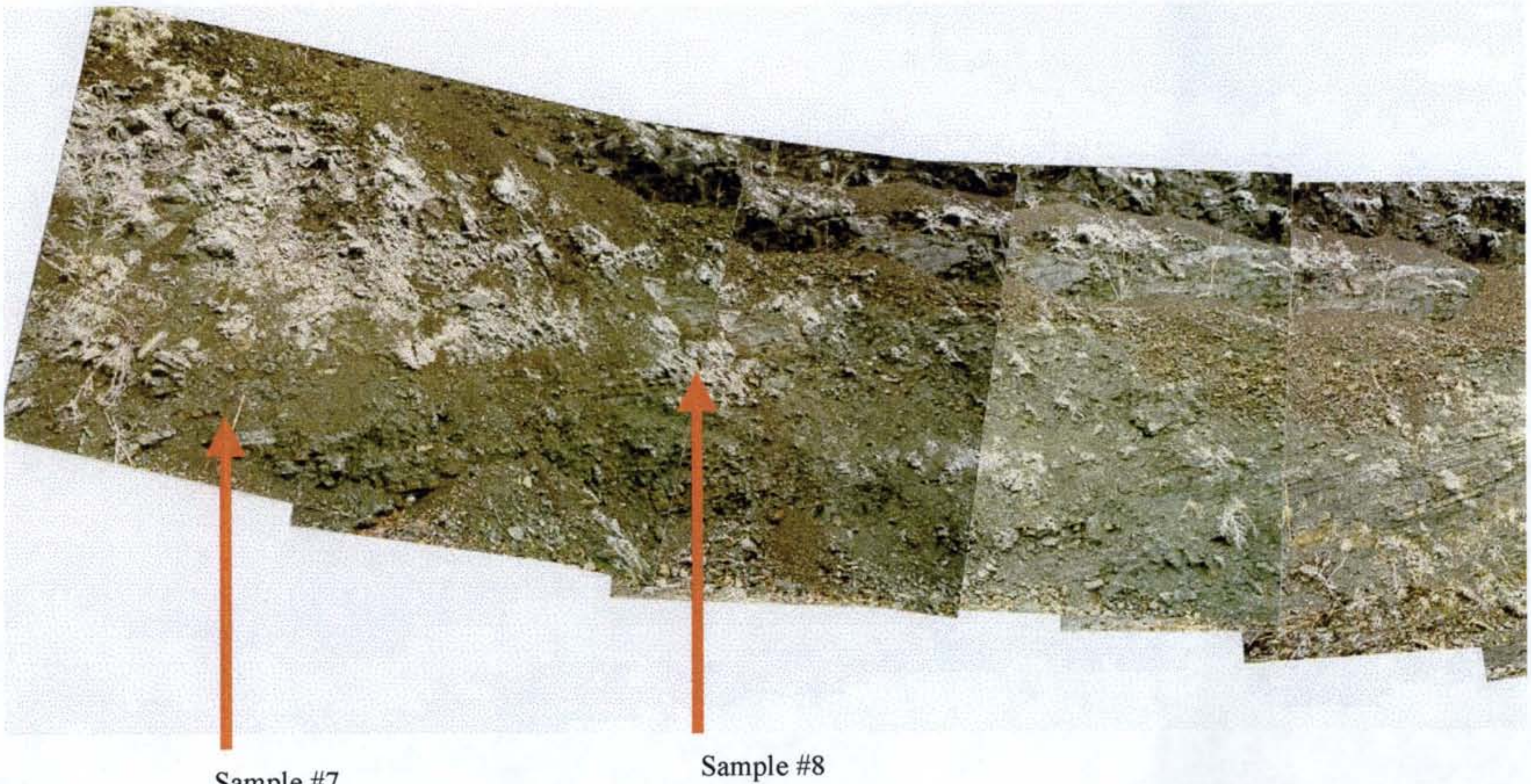
Photomosaic with sample locations indicated.

180cm Jacob's staff for scale.


Sample #3


Sample #1
Sample #2
Sample #4


Sample #5
Sample #6

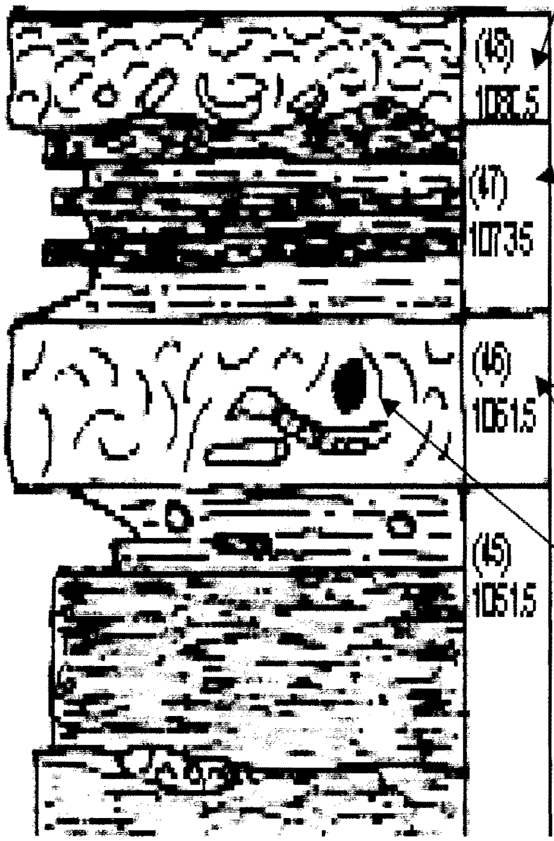

Sample #7
Sample #8

Appendix B:

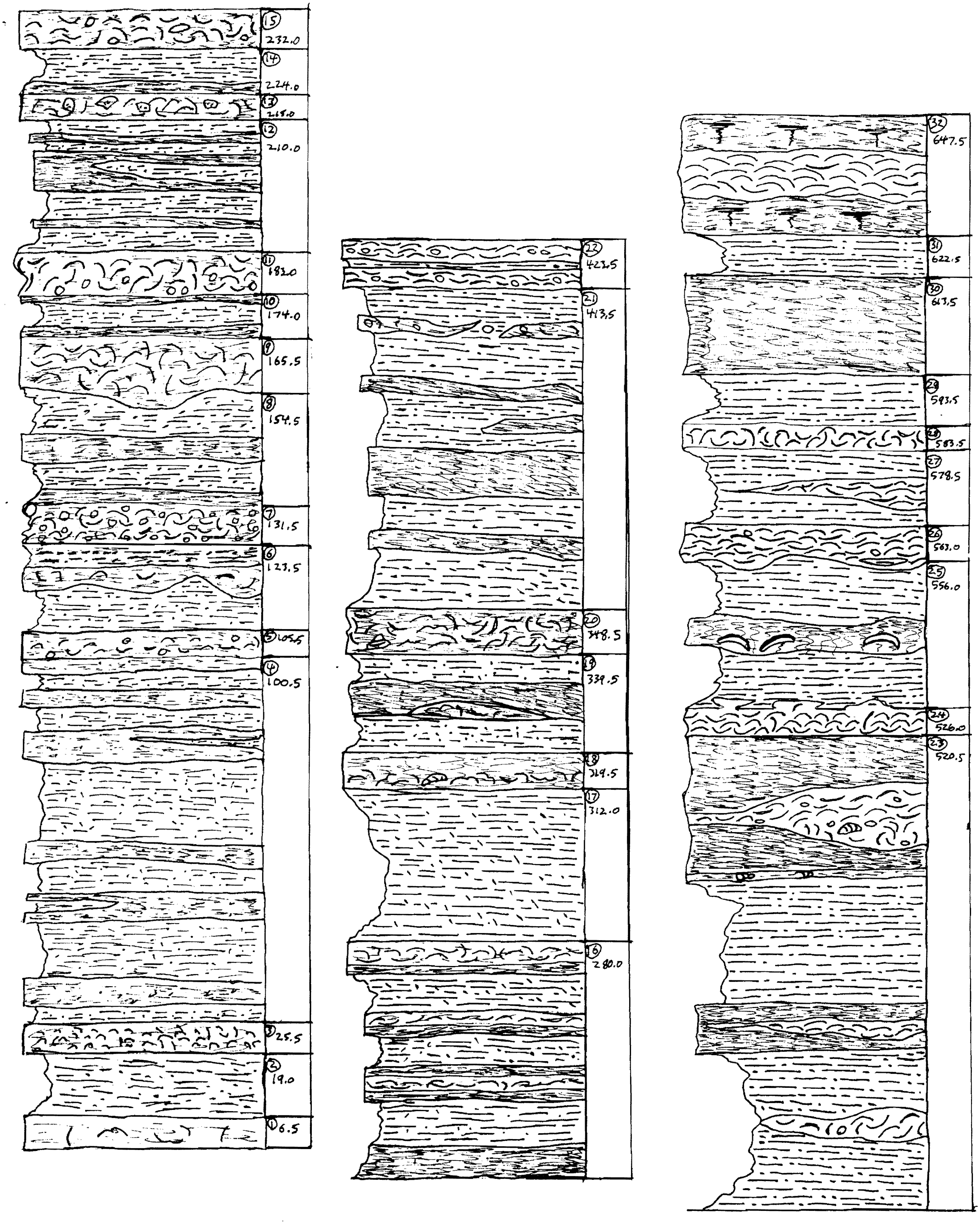
Stratigraphic Section and Descriptions

Explanation of measured stratigraphic section

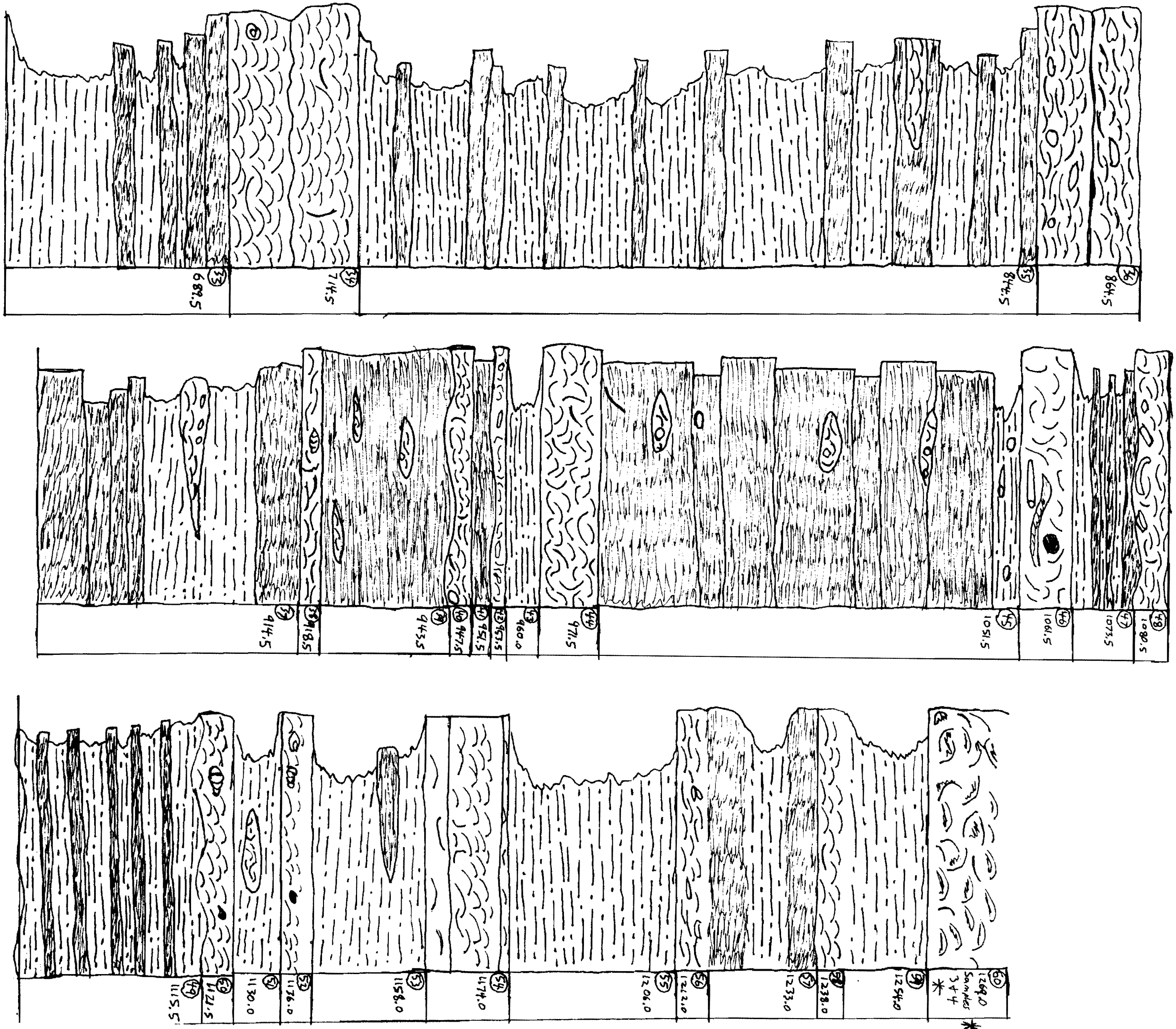
- This expanded section of the column shows the major rock and fossil types found in the Martinsburg atop Clinch Mt.

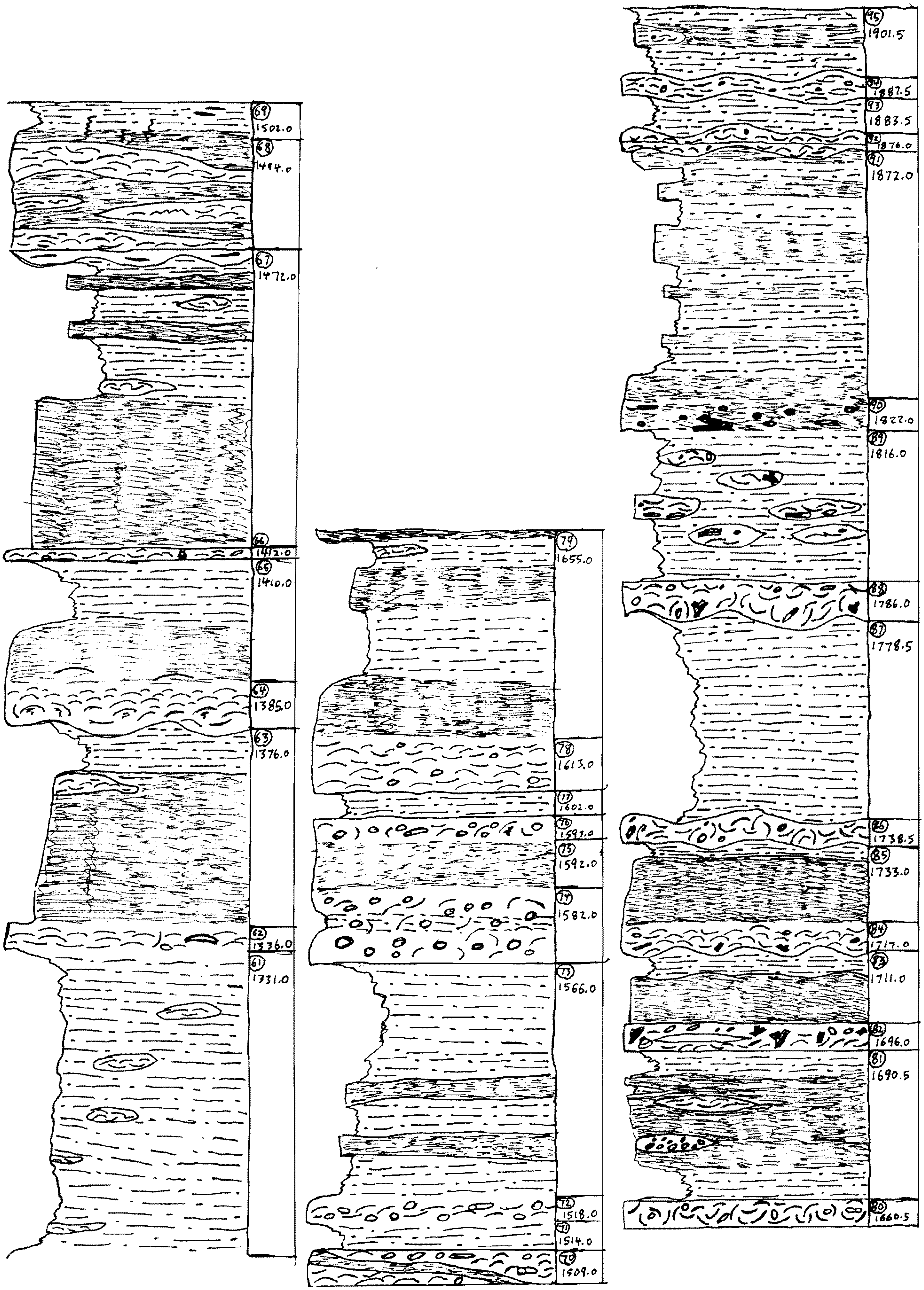


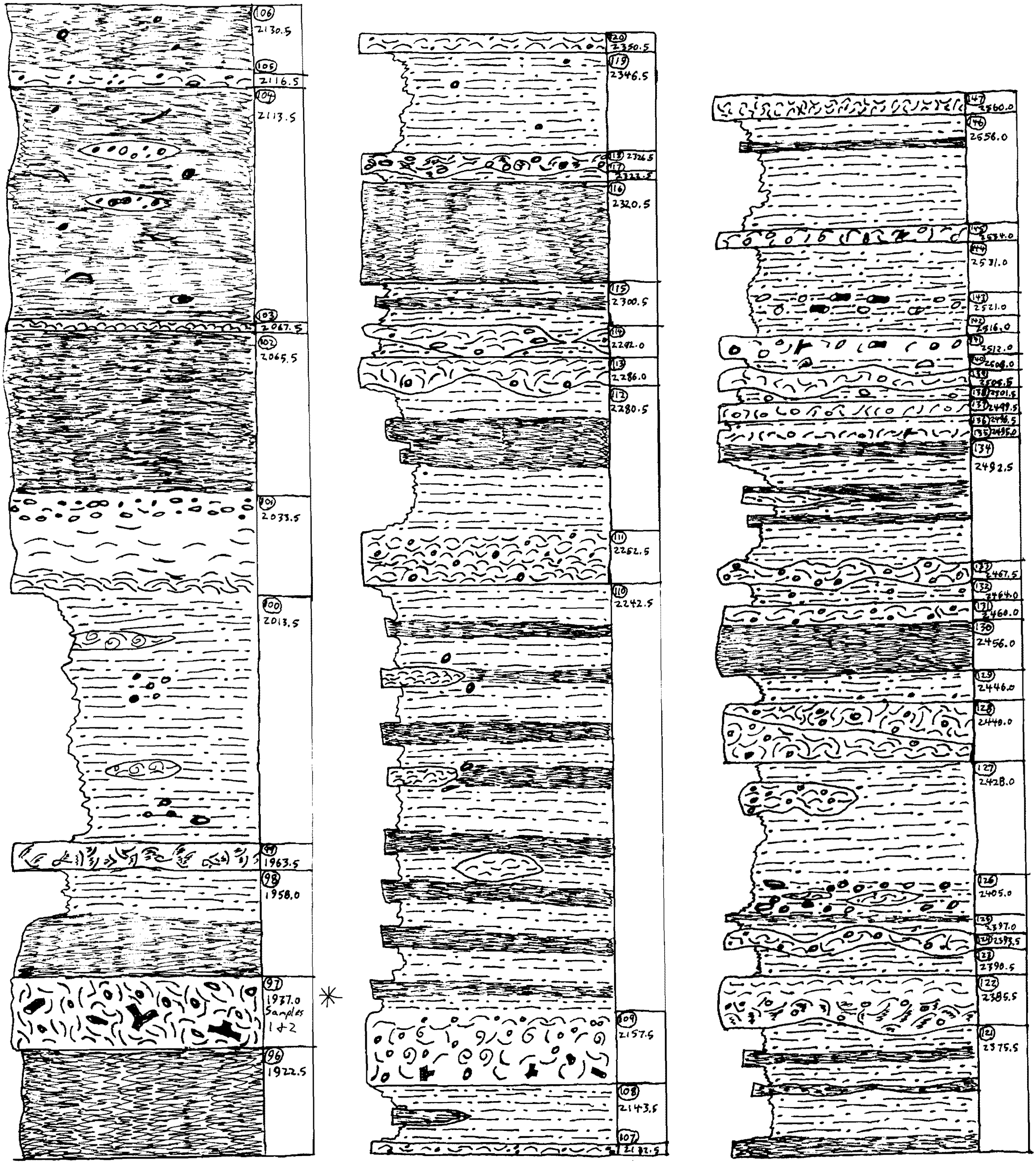
- Unit (48) is a fossiliferous limestone, and shows abundant brachiopods, mostly oriented concave down. It has a wavy lower contact, possibly representing preserved topography from a period of erosion. The fossiliferous limestones represent periods of settling immediately after storm events.
- Unit (47) is a nonfossiliferous siltstone, with fissile and nonfissile interbeds. Fissile layers are more easily broken, and show up as deep recessions in the weathering profile at left. The siltstones represent periods of relative calm between the storm events.
- Unit (46) is a fossiliferous limestone, showing abundant brachiopods again, and a few large bryozoans, the large circle and foreshortened rod at the right of the illustration.



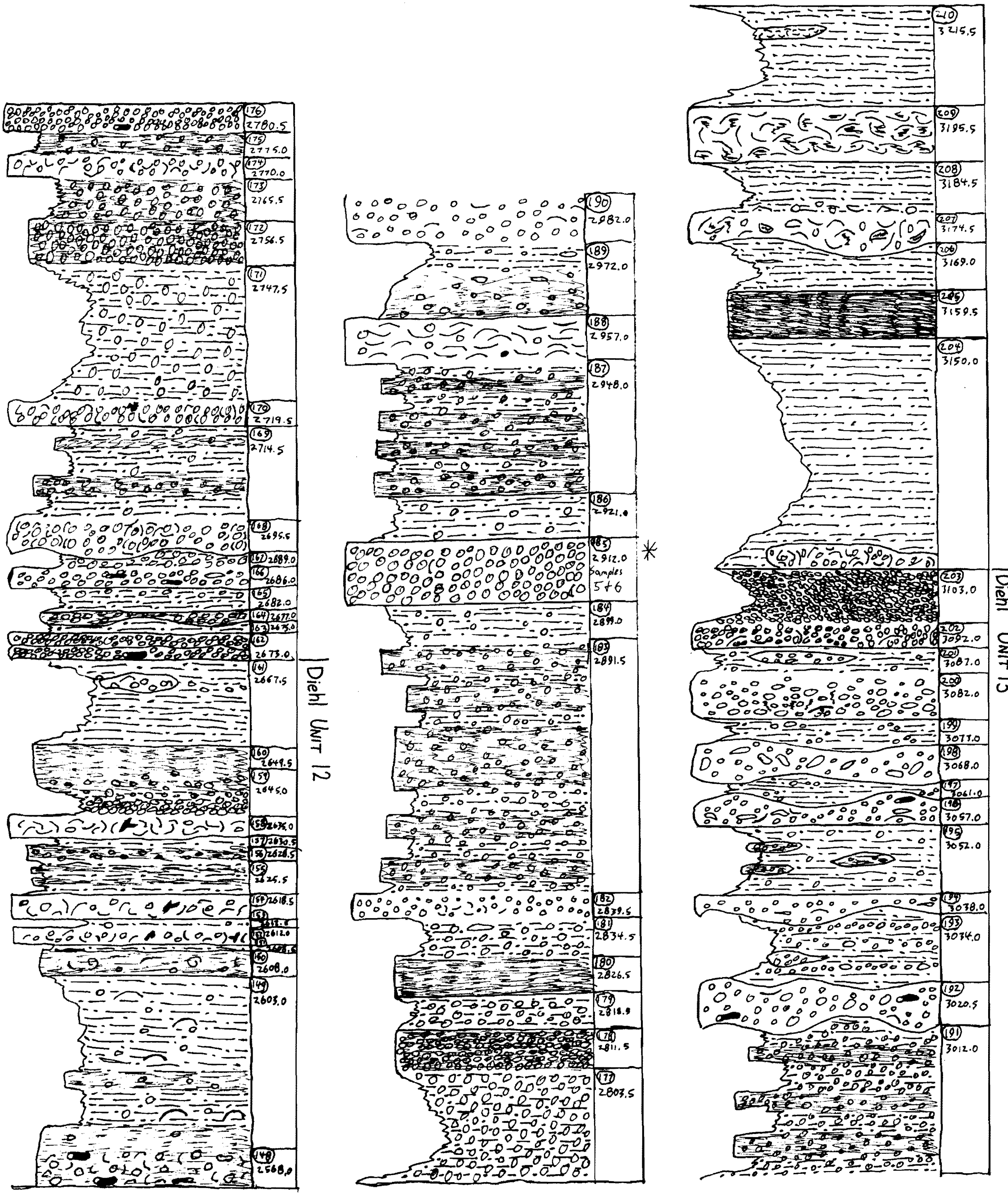
15
232.0
14
224.0
13
215.0
12
210.0
11
182.0
10
174.0
9
165.5
8
154.5
7
131.5
6
123.5
5
105.5
4
100.5
3
25.5
2
19.0
1
6.5
22
423.5
21
413.5
20
348.5
19
339.5
18
329.5
17
312.0
16
280.0
32
647.5
31
622.5
30
613.5
29
593.5
28
583.5
27
578.5
26
563.0
25
556.0
24
526.0
23
520.5


688.5
714.5
844.5
864.5
914.5
918.5
943.5
947.5
951.5
953.5
960.0
971.5
1051.5
1061.5
1073.5
1080.5
1115.5
1121.5
1130.0
1158.0
1174.0
1206.0
1212.0
1233.0
1238.0
1254.0
1269.0
Samples 3+4

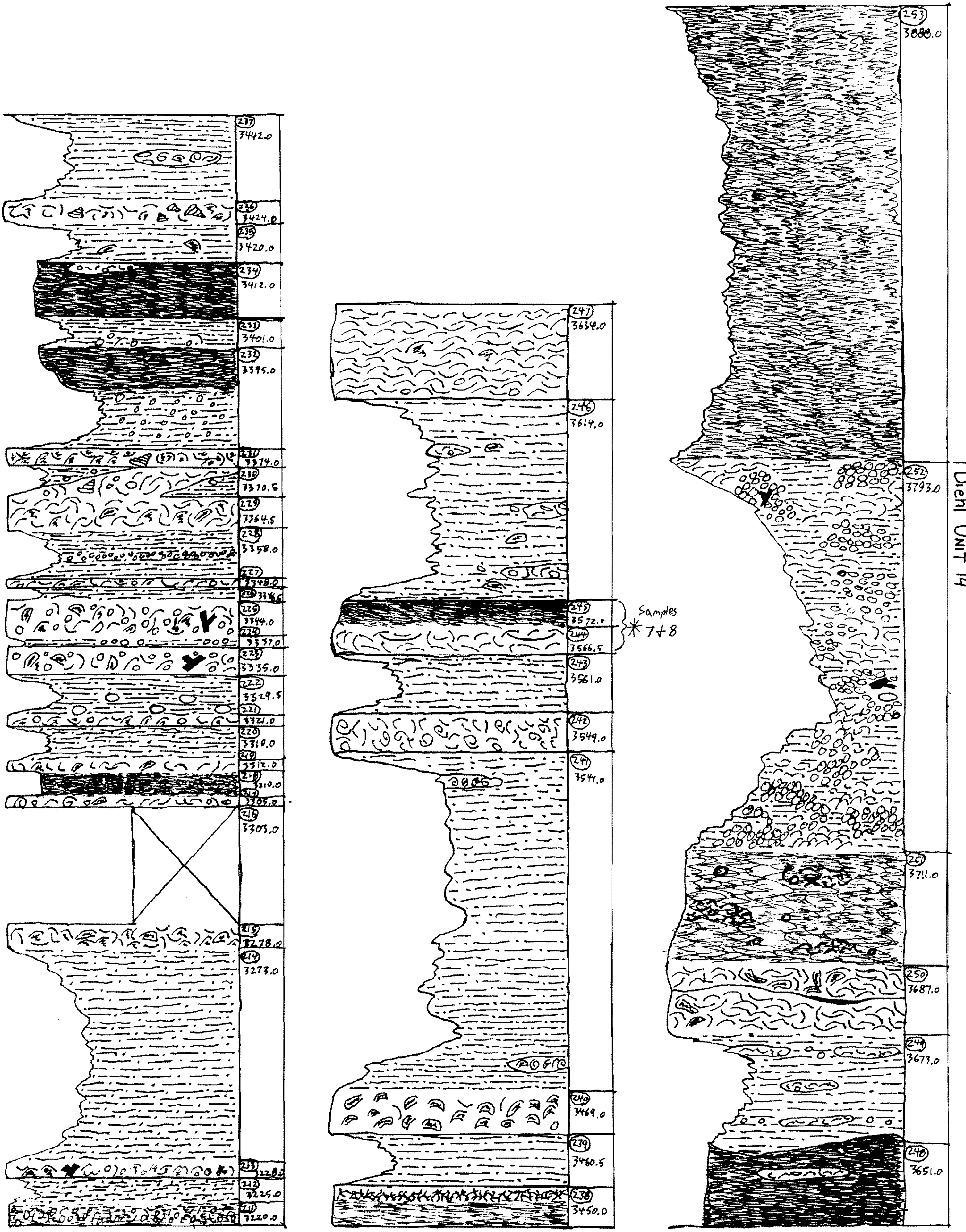

69 1502.0
68 1494.0
67 1472.0
66 1412.0
65 1410.0
64 1385.0
63 1376.0
62 1336.0
61 1331.0
79 1655.0
78 1613.0
77 1602.0
76 1597.0
75 1592.0
74 1582.0
73 1566.0
72 1518.0
71 1514.0
70 1509.0
95 1901.5
94 1887.5
93 1883.5
92 1876.0
91 1872.0
90 1822.0
89 1816.0
88 1786.0
87 1778.5
86 1738.5
85 1733.0
84 1717.0
83 1711.0
82 1696.0
81 1690.5
80 1660.5



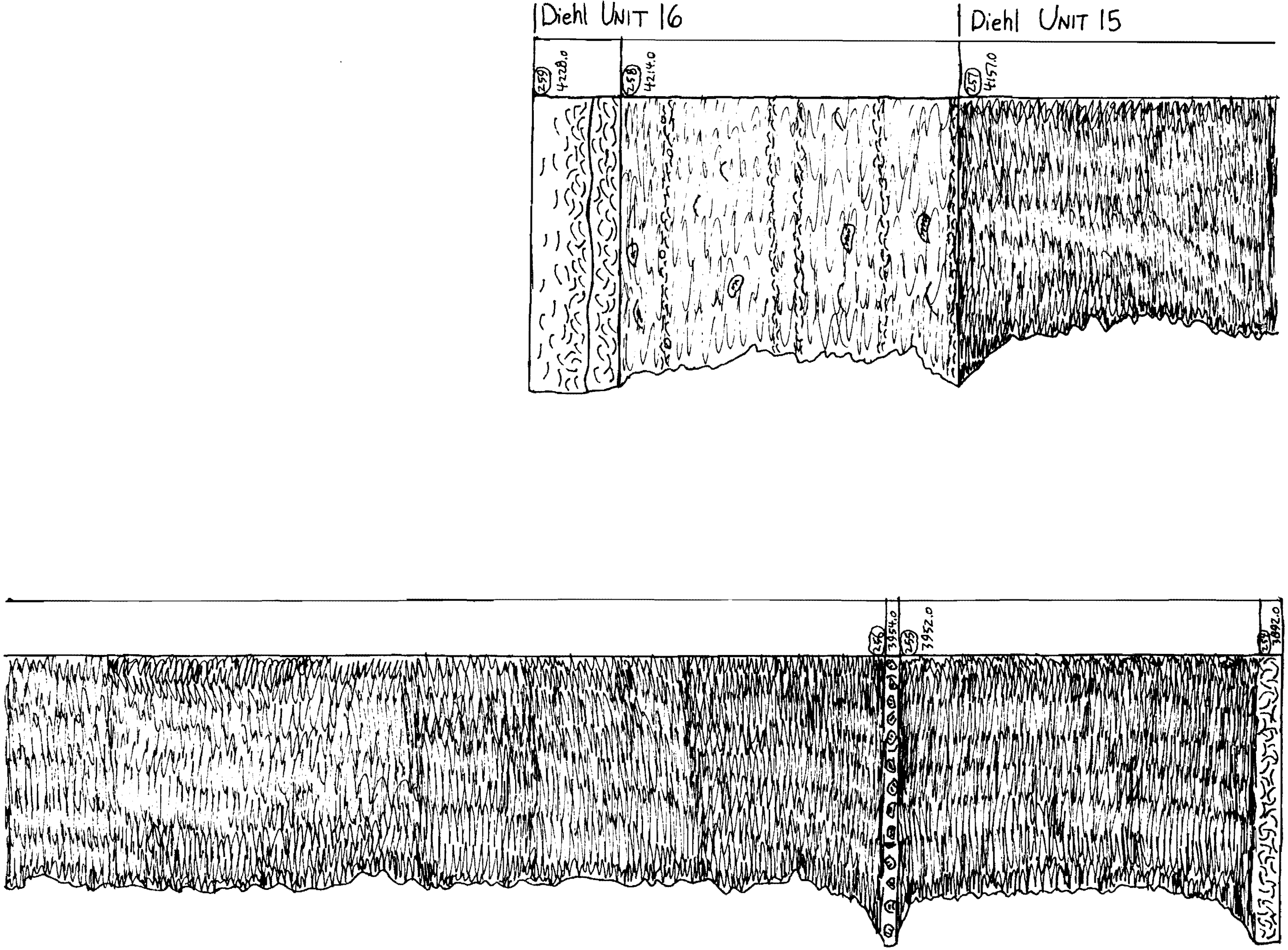
106 2130.5
105 2116.5
104 2113.5
103 2067.5
102 2065.5
101 2033.5
100 2013.5
99 1963.5
98 1958.0
97 1937.0 Samples 1+2
96 1922.5
120 2350.5
119 2346.5
118 2326.5
117 2323.5
116 2320.5
115 2300.5
114 2292.0
113 2286.0
112 2280.5
111 2262.5
110 2242.5
109 2157.5
108 2143.5
107 2132.5
147 2560.0
146 2556.0
145 2534.0
144 2531.0
143 2521.0
142 2516.0
141 2512.0
140 2508.0
139 2504.5
138 2501.5
137 2499.5
136 2498.5
135 2495.0
134 2492.5
133 2467.5
132 2464.0
131 2460.0
130 2456.0
129 2446.0
128 2440.0
127 2428.0
126 2405.0
125 2397.0
124 2393.5
123 2390.5
122 2385.5
121 2375.5



176 2780.5
175 2775.0
174 2770.0
173 2765.5
172 2756.5
171 2747.5
170 2719.5
169 2714.5
168 2695.5
167 2689.0
166 2686.0
165 2682.0
164 2677.0
163 2675.0
162 2673.0
161 2667.5
160 2649.5
159 2645.0
156 2628.5
155 2625.5
154 2618.5
2612.0
150 2608.0
149 2603.0
148 2568.0
Diehl Unit 12
190 2982.0
189 2972.0
188 2957.0
187 2948.0
186 2921.0
183 2912.0
Samples 5+6
184 2899.0
183 2891.5
182 2839.5
181 2834.5
180 2826.5
179 2818.5
178 2811.5
177 2803.5
210 3215.5
209 3195.5
208 3184.5
207 3174.5
206 3169.0
205 3159.5
204 3150.0
203 3103.0
202 3092.0
201 3087.0
200 3082.0
199 3077.0
198 3068.0
197 3061.0
196 3057.0
195 3052.0
194 3038.0
193 3034.0
192 3020.5
191 3012.0
Diehl Unit 13



237 3442.0
236 3424.0
235 3420.0
234 3412.0
233 3401.0
232 3395.0
231 3374.0
230 3370.5
229 3364.5
228 3358.0
227 3348.0
226 3346
225 3344.0
224 3337.0
223 3335.0
222 3329.5
221 3321.0
220 3319.0
219 3312.0
218 3310.0
217 3305.0
216 3303.0
215 3278.0
214 3273.0
213 3228.0
212 3225.0
211 3220.0
247 3634.0
246 3614.0
245 3572.0
244 3566.5
Samples 7+8
243 3561.0
242 3549.0
241 3541.0
240 3469.0
239 3460.5
238 3450.0
253 3880.0
252 3793.0
251 3711.0
250 3687.0
249 3673.0
248 3651.0
Diehl Unit 14



Diehl UNIT 16
Diehl UNIT 15
259
4228.0
258
4214.0
257
4157.0
256
3954.0
255
3952.0
254
3892.0

---Planar Contact—

18) 7.5cm Limestone containing brachiopods less than 4cm in diameter, in random orientations. Some infillings present, especially in lower part of unit.

---Planar Contact---

17) 32cm Siltstone, fissile, contains no fossils.

---Gradational Contact---

16) 48cm Siltstone with several 2cm interbedded fossil layers. These layers contain brachiopods and pink calcite infillings, but no bryozoans.

---Gradational Contact---

15) 8cm Limestone, fossil hash of brachiopods and bryozoans. Random orientation grades upward to horizontal orientation.

---Planar Contact---

14) 9cm Siltstone, mostly fissile, similar to (12). Contains no fossils.

---Gradational Contact--

13) 5cm Limestone with some brachiopods in random orientations. No fossil hash.

---Planar Contact---

12) 27cm Siltstone, interbedded fissile and nonfissile. Contains no fossils.

---Planar Contact---

11) 9cm Limestone, brachiopods and bryozoans, randomly oriented. Bryozoans concentrated near base of bed. Some crystalline calcite infillings.

---Planar Contact---

10) 8.5cm Siltstone, mostly nonfissile with a thin layer of fissile thin beds. Upper nonfissile layer truncated by next limestone bed. No fossils.

---Gradational Contact---

9) 11cm Limestone, many brachiopods, oriented parallel to bedding. Orientation grades upward from random to horizontal. No bryozoans, but many crystalline calcite infillings.

---Wavy Contact---

8) 23cm Siltstone, both fissile and nonfissile. No fossils.

---Gradational Contact---

7) 8cm Limestone, brachiopods and bryozoans. Brachiopod shells broken but unworn. Random orientation of fossils.

---Planar Contact---

6) 18cm Siltstone with occasional brachiopods. One large massive layer, 5.5-7cm thick, with wavy base. Both fissile and nonfissile. No fossils.

---Planar Contact---

5) 5cm Limestone, brachiopods up to 3cm in diameter, some branching bryozoans. Brachiopods tend to be parallel to bedding.

---Gradational Contact---

4) 75cm Siltstone, both fissile and nonfissile, with pinching beds. No fossils.

---Planar Contact---

3) 6.5cm Limestone, brachiopods and fossil hash, as in (1).

---Planar Contact---

2) 12.5cm Siltstone, very fissile. No fossils.

---Planar Contact---

1) 6.5cm Limestone, brachiopods up to 2cm in diameter, fossil hash.

---Planar Contact---

30) 20cm Siltstone, nonfissile, with concrete-like texture and containing no fossils. Some small fractures with slight displacement and slickensides sufaces are visible.

---Planar Contact---

29) 10cm Siltstone, fissile and containing no fossils.

---Gradational Contact---

28) 5cm Limestone containing randomly oriented brachiopods, less than 2cm in diameter. Most of the shells are intact.

---Gradational Contact---

27) 15.5cm Siltstone containing 5cm fossiliferous lenses. The lenses contain brachiopods, averaging 2.5cm in diameter and oriented parallel to bedding. Many of the shells are broken.

---Planar Contact---

26) 7cm Limestone, some bryozoans, and brachiopods averaging 3cm in diameter. The fossils are oriented parallel to bedding. Some clay partings, not contiguous.

---Gradational Contact---

25) 30cm Siltstone, fissile and nonfissile. Large individual brachiopod valves, almost all oriented concave down, averaging 4.5cm in diameter.

---Gradational Contact---

24) 5.5cm Limestone, many brachiopods, <2.5cm. Most are oriented parallel to bedding, with a few exceptions. Many fragmented shells.

---Planar Contact---

23) 97cm Siltstone, interbedded fossiliferous and nonfossiliferous. Several large lenses of fossiliferous material. The fossiliferous lenses contain brachiopods and bryozoans that grade upward from random to horizontal orientations. The nonfossiliferous material is fissile and nonfissile siltstone with a few gastropods in the nonfissile layers.

---Planar Contact---

22) 10cm Limestone with siltstone parting (1cm in middle of unit). Many brachiopods, <3cm in diameter, oriented parallel to bedding. Some calcite infillings, and a few bryozoans, 0.5cm in diameter.

---Planar Contact---

21) 65cm Siltstone with interbedded fissile and nonfissile layers, mostly fissile. Some bryozoans in last 7cm; some brachiopods, 0.5cm or less.

---Planar Contact---

20) 9cm Limestone, closely packed brachiopods averaging 2cm in diameter, with a mostly micrite matrix. Random orientations.

---Planar Contact---

19) 20cm Siltstone, mostly fissile, some trace fossils. A few fossil lenses, between 2 and 3cm thick, with brachiopods and no calcite infillings.

---Wavy Contact---

41) 4cm Nonfissile siltstone, no fossils.

---Wavy Contact---

40) 4cm Fossiliferous limestone, containing mostly brachiopods, 1-2cm in diameter, with thin, flat shells, mostly oriented parallel to bedding.

---Wavy Contact---

39) 25cm Siltstone, nonfissile. A few small lenses of the same material as (38), less than 1.5cm thick, and 50cm wide. A few brachiopods can be found in the non-fossiliferous intervals.

---Planar Contact---

38) 4cm Limestone, fossiliferous. Thin, disarticulated brachiopods, mostly concave down, all parallel to bedding. A small number have calcite infillings. A few have visible serrated openings. A few small bryozoans are also present.

---Planar Contact---

37) 50cm Siltstone, nonfissile, bioturbated. One lens of fossiliferous material, 8cm thick, about 40cm wide, containing brachiopods about 2cm in diameter, and some bryozoans. The brachiopods are found in the lower part of the lens, and the bryozoans are isolated in the upper part.

---Planar Contact---

36) 20cm Limestone, fossiliferous, with clay parting at about 10cm. Lower part of unit is approximately 30% bryozoans, 70% flat-shelled brachiopods. Brachiopods oriented parallel to bedding, and are about 2cm in diameter. The bryozoans are about 1cm in diameter and are also oriented parallel to bedding. The upper part of the unit consists entirely of brachiopods, oriented parallel to bedding, and about 2cm in diameter.

---Planar Contact---

35) 130cm Siltstone, no fossils, except for a lens fossiliferous siltstone, containing brachiopods, concave down, partially filled with crystalline calcite. Mostly fissile, 25% nonfissile. One prominent iron-rich layer 35cm from top.

---Planar Contact---

34) 25cm Limestone, fossiliferous, with a wavy clay parting in middle. Many thin , flat brachiopod shells, about 2cm in diameter, mostly concave down. A few shells in other orientations. Some skeletal allochems and crystalline calcite.

---Planar Contact---

33) 42cm Siltstone, lower half fissile, becoming less fissile in upper portion.

---Planar Contact---

32) 25cm Siltstone, bioturbated, with 10cm fossiliferous interval. Brachiopods, 90% concave down, 10% concave up, some with a slight angle to the horizontal, and many skeletal allochems.

---Planar Contact---

31) 9cm Siltstone, no fossils, very fissile.

---Planar Contact---

52) 6cm Fossiliferous limestone grading up to nonfissile siltstone. Contains 75% brachiopods, oriented concave down, 20% bryozoans, less than 0.5cm in diameter and oriented parallel to bedding, and 5% gastropods.

---Planar Contact---

51) 8.5cm Fissile siltstone with no fossils. Contains one 2cm limestone lens with mostly fossil hash and a few randomly oriented brachiopods

---Planar Contact---

50) 6cm Fossiliferous limestone, containing 10% gastropods, about 0.5cm in diameter, 90% thin, flat-shelled brachiopods, oriented parallel to bedding, and less than 1% bryozoans. Calcite infillings present in some of the fossils. The fossils grade out of the rock towards the top of this unit.

---Gradual Contact---

49) 35cm Mostly fissile siltstone, with some bioturbated nonfissile layers. A few gastropod molds, small brachiopod valves, and horizontal burrows are present.

---Planar Contact---

48) 7cm Fossiliferous limestone. The lower part contains randomly oriented brachiopods, up to 3cm in diameter, and large bryozoans, averaging about 1.5cm in diameter, with a maximum diameter of 3cm. The upper half of the unit contains all brachiopods, oriented parallel to bedding.

---Wavy Contact---

47) 12cm Siltstone, fissile and nonfissile interbeds. No fossils.

---Planar Contact---

46) 10cm Limestone, containing randomly oriented fossils, 90% thin shelled brachiopods and 10% bryozoans, both less than 1cm in diameter. Some crystalline calcite infillings.

---Planar Contact---

45) 80cm Bioturbated siltstone, containing isolated brachiopods and bryozoans. A few Limestone lenses, less than 5cm thick, are present. Lenses contain large bryozoans, and some large brachiopods. A few bryozoans, less than 0.5cm in diameter can be found in a fissile interval in the last 5cm of the unit.

---Planar Contact---

44) 11.5cm Limestone, containing mostly brachiopods, about 2cm in diameter, randomly oriented. A small number of bryozoans are present, averaging about 0.5cm in diameter.

---Planar Contact---

43) 6.5cm Fissile siltstone, no fossils.

---Planar Contact---

42) 2cm Fossiliferous limestone containing 25% bryozoans, about 1cm in diameter, and 75% brachiopods, about 1.5cm in diameter. Brachiopods include articulated specimens as well as whole and partial disarticulated valves.

---Planar Contact---
65) 25cm Siltstone, grading upwards form nonfissile to fissile. A few flat brachiopods at base, less than 1.5cm in diameter.
---Gradational Contact---
64) 9cm Fossiliferous limestone. At bottom, contains large brachiopods, averaging 2cm in diameter, randomly oriented, with calcite infillings. The top 3cm consists of shell hash, fragments less than 0.5cm, oriented parallel to bedding.
---Wavy Contact---
63) 40cm Nonfissile siltstone, top 10 cm fissile. A limestone lens may be found 12 cm from the top, 2cm thick, 70cm in lateral extent. The lens contains brachiopods, oriented parallel to bedding, some fossil hash, and a few calcite infillings.
---Gradational Contact---
62) 5cm Limestone, fossiliferous, containing brachiopods, ranging from 1.5-2cm in diameter. All are oriented parallel to bedding, and the largest are consistently concave down. A few articulated specimens are present, containing calcite fillings between the valves. A few bryozoans are also present.
---Gradational Contact---
61) 62cm Nonfissile Siltstone with a few limestone lenses, less than 2cm thick, extending about 30cm laterally. Lenses contain flat brachiopods, less than 1cm in diameter, mostly concave down.
---Gradational Contact---
60) 15cm Fossiliferous limestone containing 2cm brachiopods in random orientations and calcite infillings.
---Planar Contact---
59) 16cm Nonfissile and fissile siltstone with no fossils.
---Gradational Contact---
58) 5cm Fossiliferous limestone with brachiopods, mostly concave down, all parallel to bedding, lots of calcite infillings present.
---Planar Contact---
57) 21cm Nonfissile and fissile siltstone with no fossils.
---Gradational Contact---
56) 6cm Fossiliferous limestone, with flat brachiopods parallel to bedding, trilobites, bryozoans, and gastropods.
---Planar Contact---
55) 32cm Fissile siltstone with no fossils.
---Planar Contact---
54) 16cm Fossiliferous limestone; Bottom 5cm has few fossils, irregularly distributed, next 10cm very fossiliferous, with some calcite infillings, top 1cm like bottom 5cm. Fossils present include brachiopods, most concave down, with some vertically oriented and a few concave up, and a very few bryozoans.
---Planar Contact---
53) 22cm Fissile siltstone with a 3cm thick lens of nonfissile siltstone, no fossils present.

---Planar Contact---

77) 5cm Fissile siltstone with no fossils

---Planar Contact---

76) 5cm Fossiliferous limestone containing 75% bryozoans oriented parallel to bedding and 25% 1cm brachiopods in random orientations.

---Gradational Contact---

75) 10cm Nonfissile siltstone with no fossils.

---Gradational Contact---

74) 16cm Fossiliferous limestone containing 25% 1.5cm brachiopods in random orientations, 50% bryozoans, 25% fossil hash. Some calcite infillings present. Middle 2cm has high silt content.

---Planar Contact---

73) 48cm Fissile siltstone with a few non-fissile areas, no fossils present.

---Gradational Contact---

72) 4cm Fossiliferous limestone containing 75% bryozoans oriented parallel to bedding and 25% brachiopods oriented concave down. Also some calcite infillings present.

---Gradational Contact---

71) 5cm Fissile siltstone with no fossils

---Planar Contact---

70) 7cm Fossiliferous limestone with a large lens of nonfissile siltstone (containing no fossils). Below the siltstone are mostly brachiopods less than 1.5cm in diameter, concave down and some bryozoans. Above the siltstone are many bryozoans, about 0.5cm in diameter, with only a very small number of brachiopods, still concave down.

---Planar Contact---

69) 8cm Interbedded nonfissile and fissile siltstone, small number of brachiopods present, only in nonfissile siltstone. Fossils oriented perpendicular to bedding.

---Gradational Contact---

68) 22cm Fossiliferous limestone and siltstone. Several large fossil lenses, up to 10cm thick, with several meters of lateral extent, with nonfissile siltstone in between. No fossils in siltstone. Limestone contains brachiopod shell fragments less than 1cm in diameter, mostly parallel to bedding. A few large bachiopod valves present, mostly concave down. Less than 1% bryozoans and gastropods.

---Planar Contact---

67) 60cm Siltstone, fissile and nonfissile. A few limestone lenses, 2-3cm thick, containing randomly oriented brachiopods, gastropods, and a few bryozoans. Lenses also contain some crystalline calcite. In the top 5cm of the unit are large ripple marks, above which are some horizontal burrows.

---Planar Contact---

66) 2cm Limestone, fossiliferous. Brachiopods present, oriented parallel to bedding on the top and bottom of the unit, randomly oriented in the middle. A few gastropods and bryozoans are present, as well as some calcite infilling.

---Gradational Contact---
90) 6cm Nonfissile siltstone containing long pieces of 1cm bryozoans.
---Gradational Contact---
89) 30cm Fissile siltstone with a few 5cm thick fossiliferous limestone lenses. Lenses contain 2.5cm brachiopods and long pieces of 1cm bryozoans, all oriented parallel to bedding.
---Planar Contact---
88) 7.5cm Fossiliferous limestone containing 50% 1.5cm brachiopods and 50% 1cm bryozoans. Orientations are random near the base, grading upward to parallel to bedding.
---Wavy Contact---
87) 40cm Fissile siltstone with no fossils.
---Wavy Contact---
86) 5.5cm Fossiliferous limestone containing 90% 2cm brachiopods and 10% 0.5cm bryozoans, both in random orientations. Also contains a few calcite infillings.
---Wavy Contact---
85) 16cm Nonfissile and fissile siltstone with a few brachiopods at lower boundary.
---Gradational Contact---
84) 6cm Fossiliferous limestone containing mostly flat, 3cm brachiopods, oriented concave down with a few 0.5cm bryozoans.
---Wavy Contact---
83) 15cm Nonfissile and fissile siltstone containing no fossils.
---Planar Contact---
82) 5.5cm Fossiliferous limestone with a 1cm lens of nonfissile siltstone. Below the lens and at the base of the bed, contains mostly brachiopods oriented parallel to bedding. Everywhere else, bed contains 1cm bryozoans in random orientation and a few gastropods.
---Planar Contact---
81) 30cm Nonfissile siltstone with some fissile siltstone. One 3cm fossiliferous limestone lens present, containing mostly brachipods and a few bryozoans all oriented parallel to bedding. One of nonfissile beds contains 1.5cm bryozoans.
---Planar Contact---
80) 5.5cm Fossiliferous limestone containing 50% 1cm brachiopods and 50% 1cm bryozoans. Orientations are random, grading upward to parallel to bedding. Some calcite infillings present.
---Planar Contact---
79) 42cm Fissile and nonfissile siltstone containing a 1cm thick fossiliferous limetone lens. Within the lens are mostly brachiopods and a few bryozoans, both about 0.5cm in diameter. Lower 1cm of this bed contains ripup from bed below.
---Gradational Contact---
78) 11cm Fossiliferous limestone containing 90% 1cm flat brachiopods mostly oriented concave down, with a few concave up. Also 10% bryozoans parallel to bedding. Calcite infillings present.

---Planar Contact---

104) 46cm Nonfissile siltstone with 2 lenses of fossiliferous limestone of less than 0.5cm thickness. Siltstone contains a few scattered brachiopods and bryozoans. Lenses contain 1.5cm bryozoans.

---Planar Contact---

103) 2cm Fossiliferous limestone containing 0.5cm brachiopods oriented parallel to bedding, mainly concave down.

---Planar Contact---

102) 32cm Nonfissile siltstone with no fossils.

---Gradational Contact---

101) 20cm Fossiliferous limestone. Lower portion contains abundant 2.5cm brachiopods parallel to bedding. Middle portion contains a few scattered brachiopods and trilobites. Upper portion contains 50% 1cm bryozoans and 50% articulated 1cm brachiopods shells with calcite infillings.

---Gradational Contact---

100) 50cm Fissile siltstone with some lenses of fossiliferous limestone. Siltstone contains a few scattered 1.5cm bryozoans. Lenses contain 3cm brachiopods and 1cm gastropods.

---Planar Contact---

99) 5.5cm Fossiliferous limestone containing 2cm brachiopods and a few trilobites, as well as calcite infillings.

---Planar Contact---

98) 21cm Fissile and nonfissile siltstone with no fossils.

---Planar Contact---

97) 14.5cm Fossiliferous limestone, containing 50% 2cm brachiopods and 50% 2cm bryozoans in random orientations. Site of collection of samples 1 & 2.

---Planar Contact---

96) 21cm Nonfissile siltstone, bottom 1cm contains 0.5cm brachiopods oriented parallel to bedding. Bed possesses concrete-like weathering profile.

---Planar Contact---

95) 14cm Fissile and nonfissile siltstone. Nonfissile intervals contain large lenses of fossil material, containing 80% 0.5cm brachiopods mostly oriented concave down and 20% 0.5cm bryozoans oriented parallel to bedding.

---Wavy Contact---

94) 4cm Fossiliferous limestone containing 80% 0.5cm brachiopods and 20% 0.5cm bryozoans, all oriented parallel to bedding.

---Wavy Contact---

93) 7.5cm Fissile siltstone with no fossils.

---Wavy Contact---

92) 4cm Fossiliferous limestone containing 90% 1cm brachiopods and 10% 0.5cm bryozoans, all oriented parallel to bedding. Clay parting present in middle of unit.

---Wavy Contact---

91) 50cm Fissile and nonfissile siltstone with a 2cm lens of nonfissile siltstone containing bryozoans, as in (90).

---Planar Contact---

119) 20cm Fissile siltstone with a few 1cm bryozoans.

---Planar Contact---

118) 4cm Fossiliferous limestone containing 50% 1.5cm flat brachiopods, mostly concave down, 40% 1cm bryozoans, and 10% 1cm gastropods. A few of brachiopods are articulated. Some calcite infillings present.

---Wavy Contact---

117) 2cm Fissile siltstone with no fossils.

---Planar Contact---

116) 20cm Nonfissile siltstone with no fossils. Concrete-like weathering profile.

---Planar Contact---

115) 8.5cm Fissile and nonfissile siltstone with a few 1cm bryozoans.

---Gradational Contact---

114) 6cm Fissile siltstone and fossiliferous limestone. Limestone contains 2.5cm brachiopods, some of which are articulated and filled with calcite, as well as 2.5cm bryozoans and fossil hash. Most are oriented parallel to bedding. Siltstone contains a few 0.5cm bryozoans.

---Planar Contact---

113) 5.5cm Fossiliferous limestone containing mostly 2cm brachiopods and, near the bottom, a few 1cm bryozoans. Orientation grades upward from random to bedding parallel. Lots of calcite infillings.

---Wavy Contact---

112) 28cm Fissile and nonfissile siltstone with no fossils.

---Gradational Contact---

111) 10cm Fossiliferous limestone containing 90% 2cm brachiopods and 10% 1cm bryozoans, all oriented parallel to bedding.

---Planar Contact---

110) 85cm Fissile and nonfissile siltstone with a few 3cm thick lenses of fossiliferous limestone. Lenses contain 0.5cm brachiopods oriented parallel to bedding. Siltstone near lenses contains 1cm bryozoans parallel to bedding.

---Gradational Contact---

109) 14cm Fossiliferous limestone containing 40% 2.5cm brachiopods, 40% 1cm bryozoans, and 20% 1cm gastropods. Orientation is random at base, grading upward to parallel to bedding. Some calcite infillings present.

---Planar Contact---

108) 11cm Fissile siltstone with a 5cm thick lens of nonfissile. No fossils present.

---Planar Contact---

107) 2cm Fossiliferous limestone containing 50% 1cm brachiopods and 50% 1cm bryozoans, all oriented parallel to bedding.

---Planar Contact---

106) 14cm Nonfissile siltstone containing a few 0.5cm bryozoans.

---Gradational Contact---

105) 3cm Fossiliferous limestone containing 50% 1cm brachiopods and 50% 1cm bryozoans all oriented parallel to bedding.

---Gradational Contact---

134) 25cm Fissile and nonfissile siltstone with a 2cm thick fossiliferous limestone lens. Limestone contains 90% 0.5cm brachiopods in random orientation and 10% 0.5cm bryozoans oriented parallel to bedding.

---Wavy Contact---

133) 3.5cm Fossiliferous limestone containing 50% 1cm bryozoans, 50% 1cm brachiopods all in random orientations

---Wavy Contact---

132) 4cm Fissile siltstone with a few 0.5cm bryozoans.

---Planar Contact---

131) 4cm Fossiliferous limestone containing 80% 1cm brachiopods and 20% 1cm bryozoans, all parallel to bedding. Some fossil hash also present.

---Gradational Contact---

130) 10cm Nonfissile siltstone with no fossils.

---Planar Contact---

129) 6cm Fissile siltstone with no fossils.

---Planar Contact---

128) 12cm Fossiliferous limestone with a diagonal clay parting. Limestone contains 90% 1cm brachiopods and 10% 1cm bryozoans, all in random orientations.

---Planar Contact---

127) 23cm Fissile siltstone with a 5.5cm fossiliferous limestone lens. Limestone contains 50% 1cm brachiopods and 50% 1cm bryozoans, all oriented parallel to bedding. Some fossil hash also present.

---Gradational Contact---

126) 8cm Fossiliferous siltstone with a 3cm thick limestone lens. Siltstone contains 1.5cm bryozoans. Limestone contains 0.5cm brachiopods and 0.5cm bryozoans, both in random orientations.

---Gradational Contact---

125) 3.5cm Fissile siltstone with no fossils.

---Wavy Contact---

124) 3cm Fossiliferous limestone containing 70% 1cm brachiopods and 30% 1cm bryozoans, all with random orientations. Small amount of calcite infillings present.

---Wavy Contact---

123) 5cm Fissile siltstone with no fossils.

---Planar Contact---

122) 10cm Fossiliferous limestone containing 50% (2cm) brachiopods and 50% 2cm bryozoans. Orientation grades up from random to bedding parallel. Contains calcite infillings. Top 1cm contains only fossil hash and tiny brachiopods, parallel to bedding.

---Wavy Contact---

121) 25cm Fissile and nonfissile siltstone. Some nonfissile layers contain numerous <0.5cm bryozoans. A few large bryozoans near top boundary of unit.

---Planar Contact---

120) 4cm Fossiliferous limestone with 0.5cm brachiopods and a few <0.5cm bryozoans. Also contains fossil hash. All oriented parallel to bedding.

---Gradational Contact---
152) 3.5cm Fossiliferous limestone containing 80% 1cm bryozoans parallel to bedding and 20% 0.5cm brachiopods oriented randomly.
---Planar Contact---
151) 0.5cm Fissile siltstone with no fossils.
---Planar Contact---
150) 5cm Nonfissile siltstone with a few fossils, which include 0.5cm brachiopods, 1cm gastropods, and 0.5cm bryozoans.
---Planar Contact---
149) 35cm Interbedded fissile and nonfissile siltstone containing <0.5cm bryozoans. Fissile siltstone also contains 2cm brachiopods oriented parallel to bedding.
---Gradational Contact---
148) 8cm Nonfissile fossiliferous siltstone containing 80% 1cm bryozoans oriented parallel to bedding and 20% 0.5cm brachiopods in randome orientation.
---Planar Contact---
147) 4cm Fossiliferous limestone containing 0.5cm brachiopods in random orientation.
---Planar Contact---
146) 22cm Fissile siltstone containing one 1cm bed of nonfissile siltstone.
---Planar Contact---
145) 3cm Fossiliferous limestone containing 50% 0.5cm bryozoans and 50% 0.5cm brachiopods. Orientations grade upward from random to parallel to bedding.
---Planar Contact---
144) 10cm Fissile siltstone with no fossils.
---Gradational Contact---
143) 5cm Fissile siltstone containing abundant bryozoans oriented parallel to bedding.
---Gradational Contact---
142) 4cm Fissile siltstone with no fossils.
---Planar Contact---
141) 4cm Fossiliferous limestone containing 75% 1cm bryozoans and 25% 0.5cm brachiopods, both in random orientations.
---Gradational Contact---
140) 2.5cm Fissile siltstone containing a few brachiopods, <0.5cm in diameter and in random orientations, mostly articulated.
---Wavy Contact---
139) 4cm Fossiliferous limestone containing 99% 0.5cm brachiopods in random orientation and 1% bryozoans parallel to bedding.
---Wavy Contact---
138) 2cm Fissile siltstone containing some 0.5cm bryozoans
---Planar Contact---
137) 3cm Fossiliferous limestone containing 50% 0.5cm brachiopods in random orientation and 50% 1cm bryozoans parallel to bedding.
---Planar Contact---
136) 1.5cm Fissile siltstone with no fossils.
---Gradational Contact---
135) 2.5cm Fossiliferous limestone containing 90% 0.5cm brachiopods in random orientation and 10% <0.5cm bryozoans parallel to bedding. Some calcite infillings.

---Planar Contact---

169) 19cm Fissile and nonfissile siltstone with some areas of abundant 1cm bryozoans. Throughout, 0.5cm bryozoans are present in lower concentrations.

---Gradational Contact---

168) 6.5cm Fossiliferous limestone containing mostly 0.5cm bryozoans oriented parallel to bedding, with areas of concentrated 0.5cm brachiopods in random orientations.

---Wavy Contact---

167) 3cm Fissile siltstone containing abundant bryozoans, <0.5cm in diameter and oriented parallel to bedding.

---Gradational Contact---

166) 4cm Fossiliferous limestone containing 0.5cm bryozoans oriented parallel to bedding.

---Planar Contact---

165) 5cm Fissile siltstone with a few 1cm bryozoans near the top.

---Planar Contact---

164) 2cm Nonfissile siltstone with abundant 0.5cm bryozoans oriented parallel to bedding.

---Wavy Contact---

163) 2cm Fissile siltstone with no fossils.

---Planar Contact---

162) 5.5cm Fossiliferous limestone with a clay parting. Contains 0.5cm bryozoans oriented parallel to bedding.

---Planar Contact---

161) 18cm Fissile siltstone containing a 2cm fossiliferous limestone lens. Limestone contains 50% 0.5cm brachiopods and 50% <0.5cm bryozoans, all oriented randomly. Bryozoans also present in siltstone around limestone lens.

----Planar Contact---

160) 4.5cm Nonfissile siltstone containing no fossils.

---Gradational Contact---

159) 10cm Fissile siltstone grading up into nonfissile siltstone. Bryozoans of 0.5cm diameter are abundant near the base, but become more scarce near the top. All are oriented parallel to bedding.

---Gradational Contact---

158) 4.5cm Fossiliferous limestone containing 90% 1cm brachiopods and 10% <0.5cm bryozoans, all oriented randomly.

---Planar Contact---

157) 2cm Fissile siltstone with no fossils.

---Gradational Contact---

156) 3cm Nonfissile siltstone with abundant 0.5cm bryozoans oriented parallel to bedding.

---Gradational Contact---

155) 7cm Interbedded fissile and nonfissile siltstone containing no fossils.

---Planar Contact---

154) 5cm Fossiliferous limestone containing 50% 0.5cm brachiopods and 50% <0.5cm bryozoans all oriented randomly.

---Planar Contact---

153) 1.5cm Fissile siltstone with a few 1cm bryozoans oriented parallel to bedding.

---Gradational Contact---

187) 27cm Fissile and nonfissile siltstone with abundant 1cm bryozoans.

---Planar Contact---

186) 9cm Fissile siltstone with come 1cm bryozoans.

---Planar Contact---

185) 13cm Fossiliferous limestone containing 99% 1cm bryozoans and 1% <0.5cm brachiopods. Site of collection of samples 5 & 6.

---Planar Contact---

184) 7.5cm Fissile siltstone containing some 1cm bryozoans.

---Gradational Contact---

183) 52cm Fissile and nonfissile siltstone with abundant 1cm bryozoans oriented parallel to bedding.

---Gradational Contact---

182) 5cm Fossiliferous limestone containing 0.5cm randomly oriented brachiopods and 1cm bryozoans oriented parallel to bedding. Fossils grade laterally from brachiopods to bryozoans.

---Gradational Contact---

181) 8cm Fissile siltstone with abundant 1cm bryozoans.

---Gradational Contact---

180) 8cm Nonfissile siltstone with no fossils.

---Planar Contact---

179) 7cm Fissile siltstone containing abundant 1cm bryozoans.

---Planar Contact---

178) 8cm Nonfissile siltstone with very abundant 1cm bryozoans.

---Gradational Contact---

177) 23cm Fissile siltstone containing abundant 1cm bryozoans.

---Planar Contact---

176) 5.5cm Fossiliferous limestone containing 0.5cm bryozoans oriented parallel to bedding.

---Gradational Contact---

175) 5cm Fissile siltstone with some bryozoans of <0.5cm diameter oriented parallel to bedding.

---Gradational Contact---

174) 4.5cm Fossiliferous limestone containing 80% 0.5cm bryozoans oriented parallel to bedding and 20% 1cm brachiopods in random orientations

---Gradational Contact---

173) 9cm Fissile siltstone containing abundant bryozoans of <0.5cm diameter, oriented parallel to bedding.

---Gradational Contact---

172) 9cm Nonfissile siltstone containing very abundant 1cm bryozoans.

---Gradational Contact---

171) 28cm Fissile siltstone containing abundant 1cm bryozoans oriented parallel to bedding.

---Gradational Contact---

170) 5cm Fossiliferous limestone containing 95% 1cm bryozoans oriented parallel to bedding and 5% 1cm brachiopods in random orientations.

---Gradational Contact---
202) 5cm Fossiliferous limestone with 90% 0.5cm bryozoans oriented parallel to bedding and 10% 0.5cm brachiopods in random orientations.
---Planar Contact---
201) 5cm Fissile siltstone with a 2cm limestone lens containing 1cm bryozoans. Siltstone has a few small bryozoans oriented parallel to bedding.
---Gradational Contact---
200) 9cm Fossiliferous limestone containing 99% 0.5cm bryozoans and 1% 1cm brachiopods oriented parallel to bedding. A few calcite infillings also present.
---Planar Contact---
199) 5cm Fissile siltstone with a few 1cm bryozoans oriented parallel to bedding and concentrated in small areas.
---Wavy Contact---
198) 7cm Fossiliferous limestone containing 1cm bryozoans in random orientation.
---Wavy Contact---
197) 4cm Fissile siltstone with a few 0.5cm bryozoans oriented parallel to bedding and concentrated in small areas.
---Wavy Contact---
196) 5cm Fossiliferous limestone containing 99% 1cm bryozoans and 1% 2cm brachiopods, all oriented parallel to bedding.
---Planar Contact---
195) 14cm Fissile siltstone with lenses of nonfissile siltstone. Contains 1cm bryozoans, mostly in nonfissile layers.
---Planar Contact---
194) 4cm Fossiliferous limestone containing 95% 0.5cm bryozoans oriented parallel to bedding and 5% 0.5cm brachiopods oriented randomly.
---Wavy Contact---
193) 13.5cm Fissile siltstone with a few 1cm fossiliferous limestone lenses. Siltstone contains some 1cm bryozoans, generally separated into layers. Limestone contains smaller bryozoans.
---Wavy Contact---
192) 8.5cm Fossiliferous limestone containing 95% 1cm bryozoans parallel to bedding and 5% 2cm brachiopods, mostly articulated and with calcite infillings.
---Wavy Contact---
191) 30cm Siltstone, mostly fissile with two 2cm nonfissile layers. Abundant 1cm bryozoans throughout.
---Gradational Contact---
190) 10cm Fossiliferous limestone containing 90% 0.5cm bryozoans and 10% 0.5cm brachiopods, all oriented parallel to bedding.
---Gradational Contact---
189) 15cm Nonfissile siltstone, grading up to fissile siltstone. Abundant bryozoans grading up in size from 2cm to 0.5cm, all parallel to bedding.
---Planar Contact---
188) 9cm Fossiliferous limestone with 90% 0.5cm brachiopods and 10% 1cm bryozoans, all oriented parallel to bedding.

---Gradational Contact---

218) 5cm Nonfissile siltstone with no fossils.

---Gradational Contact---

217) 2cm Fossiliferous limestone containing 60% brachiopods of 1cm diameter, some articulated, oriented randomly, 35% 1cm bryozoans oriented parallel to bedding, and 5% gastropods in random orientations. Some calcite infillings.

---Gradational Contact---

216) 25cm COVERED INTERVAL

---Gradational Contact---

215) 5cm Fossiliferous limestone with 1cm brachiopods in random orientations, some articulated. Calcite infillings present.

---Gradational Contact---

214) 45cm Fissile siltstone with no fossils.

---Gradational Contact---

213) 3cm Fossiliferous limestone containing 80% 1cm brachiopods, 20% 0.5cm bryozoans, both in random orientations. Also, straight-shelled nautiloid found. Some calcite infillings present.

---Planar Contact---

212) 5cm Fissile siltstone with no fossils.

---Gradational Contact---

211) 4.5cm Nonfissile fossiliferous siltstone containing 50% 1cm brachiopods oriented parallel to bedding and 50% 1cm bryozoans oriented parallel to bedding.

---Planar Contact---

210) 20cm Fissile siltstone containing a 1cm lens of fossiliferous limestone. Lens contains 0.5cm brachiopods and calcite infillings, fossil orientations grading upward from random to parallel to bedding.

---Planar Contact---

209) 11cm Fossiliferous limestone with 1cm brachiopods in random orientations. Some calcite infillings.

---Planar Contact---

208) 10cm Fissile siltstone with a few bryozoans, mainly near the base, and a few 0.5cm brachiopods.

---Gradational Contact---

207) 5.5cm Fossiliferous limestone with 80% 1cm brachiopods, some articulated, all in random orientations, and 20% 0.5cm bryozoans oriented parallel to bedding. Some calcite infillings present.

---Wavy Contact---

206) 9.5cm Fissile siltstone with no fossils.

---Planar Contact---

205) 9.5cm Nonfissile siltstone with no fossils, concrete-like texture.

---Planar Contact---

204) 47cm Fissile siltstone with a 4cm fossiliferous limestone lens. Limestone contains 50% 1cm bryozoans oriented parallel to bedding and 50% 1cm brachiopods in random orientations.

---Planar Contact---

203) 11cm Fissile siltstone with VERY abundant 1cm bryozoans.

---Planar Contact---
233) 6cm Fissile siltstone with some 0.5cm bryozoans and some 1cm brachiopods, both near base of unit.
---Gradational Contact---
232) 21cm Fissile siltstone grading up to nonfissile siltstone with a few 0.5 cm bryozoans in fissile areas.
---Planar Contact---
231) 3.5cm Fossiliferous limestone with 90% 1cm brachiopods and 10% 1cm gastropods, both in random orientations, and with abundant calcite infillings.
---Planar Contact---
230) 6cm Interbedded fissile siltstone and fossiliferous limestone. Fossils present in both lithologies, but less abundant in siltstone. Composed of 60% 1cm brachiopods, many articulated, 30% 0.5cm bryozoans, and 10% 0.5cm gastropods.
---Gradational Contact---
229) 6.5cm Fossiliferous limestone with 1cm brachiopods in random orientations, some articulated. Very small amount of calcite infillings.
---Gradational Contact---
228) 10cm Fissile siltstone with <0.5cm bryozoans oriented parallel to bedding and concentrated primarily in the middle of the unit.
---Planar Contact---
227) 1.5cm Fossiliferous limestone with 80% 0.5cm brachiopods and 20% 0.5cm bryozoans, all oriented randomly. Calcite infillings present.
---Planar Contact---
226) 2.5cm Fissile siltstone with no fossils.
---Gradational Contact---
225) 7cm Fossiliferous limestone with 50% 0.5cm brachiopods, many articulated, and 50% 0.5cm bryozoans, all oriented randomly. Calcite infillings present, especially in articulated brachiopods.
---Gradational Contact---
224) 2cm Fissile siltstone with a few small areas of concentrated bryozoans, about 1.5cm in diameter and oriented parallel to bedding.
---Planar Contact---
223) 5.5cm Fossiliferous limestone with 50% 1cm brachiopods, many articulated, and 50% 1cm bryozoans, all in random orientations. Some calcite present.
---Planar Contact---
222) 8.5cm Fissile siltstone with a few 1.5cm bryozoans concentrated in layers.
---Gradational Contact---
221) 2cm Fossiliferous limestone with 80% 1cm brachiopods and 20% 0.5cm bryozoans, all in random orientations. Also contains calcite infillings.
---Planar Contact---
220) 7cm Fissile siltstone with no fossils.
---Gradational Contact---
219) 2cm Fossiliferous limestone with 1cm brachiopods oriented randomly, many articulated. Calcite infillings also present.

---Planar Contact---

247) 20cm Fossiliferous limestone with 1cm brachiopods and a very few 1cm bryozoans (mostly at the base), all parallel to bedding. Also contains small amount of calcite infilling.

---Planar Contact---

246) 42cm Fissile siltstone with several 2cm fossiliferous limestone lenses. Limestone contains mostly 1cm brachiopods, a few <0.5cm bryozoans, all in random orientations. Siltstone contains a few bryozoans and articulated brachiopods.

---Planar Contact---

245) 5.5cm Nonfissile siltstone with no fossils. Bed makes up top half of samples 7 & 8.

---Gradational Contact---

244) 5.5cm Fossiliferous limestone with 1.5cm brachiopods in random orientations, as well as <1% bryozoans. Bed makes up bottom half of samples 7 & 8.

---Planar Contact---

243) 12cm Fissile siltstone with no fossils.

---Planar Contact---

242) 8cm Fossiliferous limestone with 70% 1cm brachiopods, 25% 1.5cm gastropods, and 5% 0.5cm bryozoans, all in random orientations. Fossils become less abundant higher in the unit.

---Planar Contact---

241) 72cm Fissile siltstone with two 3cm fossiliferous limestone lenses. Limestone contains 80% brachiopods, mostly articulated and filled with calcite, and 20% gastropods, all in random orientations.

---Gradational Contact---

240) 8.5cm Fossiliferous limestone with abundant 1cm brachiopods, mostly articulated and filled with calcite. Also contains <1% 0.5cm bryozoans.

---Planar Contact---

239) 10.5cm Fissile siltstone with no fossils.

---Planar Contact---

238) 8cm Nonfissile siltstone with some burrows, mostly near top of unit.

---Planar Contact---

237) 18cm Fissile siltstone with one 4cm fossiliferous limestone lens. Limestone contains 1cm articulated brachiopods and 1cm gastropods.

---Gradational Contact---

236) 4cm Fossiliferous limestone with 80% 1cm brachiopods and 20% 1.5cm gastropods, all in random orientations. Calcite infillings also present.

---Gradational Contact---

235) 8cm Fissile siltstone with a very few 0.5cm articulated brachiopods in random orientations.

---Planar Contact---

234) 11cm Nonfissile siltstone with 2cm lens of limestone. Limestone contains 0.5cm bryozoans and brachiopods all in random orientations. Bed has concrete-like weathering profile.

---Planar Contact---

259) 14cm Fossiliferous limestone with a clay parting. Contains few fossils in lower 3cm. Fossils present are 0.5cm brachiopods and fossil hash in random orientations, with a small quantity of calcite infillings.

---Planar Contact---

258) 57cm Semifissile siltstone containing five layers of concentrated fossils. Outside fossil concentrations, some articulated brachiopods and individual valves, averaging 1cm in diameter, present in random orientations. Within fossil concentrations, fossil hash and, in some layers, 0.5cm bryozoans.

---Planar Contact---

257) 203cm Semifissile siltstone with no fossils. Like unit 253.

---Gradational Contact---

256) 2cm Fossiliferous limestone with 1cm brachiopods in random orientations, many articulated.

---Planar Contact---

255) 60cm Semifissile siltstone with no fossils. Like unit 253.

---Gradational Contact---

254) 4cm Fossiliferous limestone containing 1cm brachiopods in random orientations.

---Planar Contact---

253) 95cm Semifissile siltstone with no fossils. Similar in appearance to lower Juniata formation rocks, by gray-green in color, rather than red.

---Gradational Contact---

252) 82cm Fossiliferous fissile siltstone, containing 60% bryozoans and 40% brachiopods, 0.5-0.75cm in diameter and randomly oriented. Fossil distribution irregular and clumped.

---Gradational Contact---

251) 24cm Nonfissile siltstone with some 1cm bryozoans and lenses of 1cm bryozoans.

---Gradational Contact---

250) 14cm Fossiliferous limestone with a clay parting. Contains 0.5cm brachiopods, some articulated, in random orientations. Also contains calcite infillings.

---Gradational Contact---

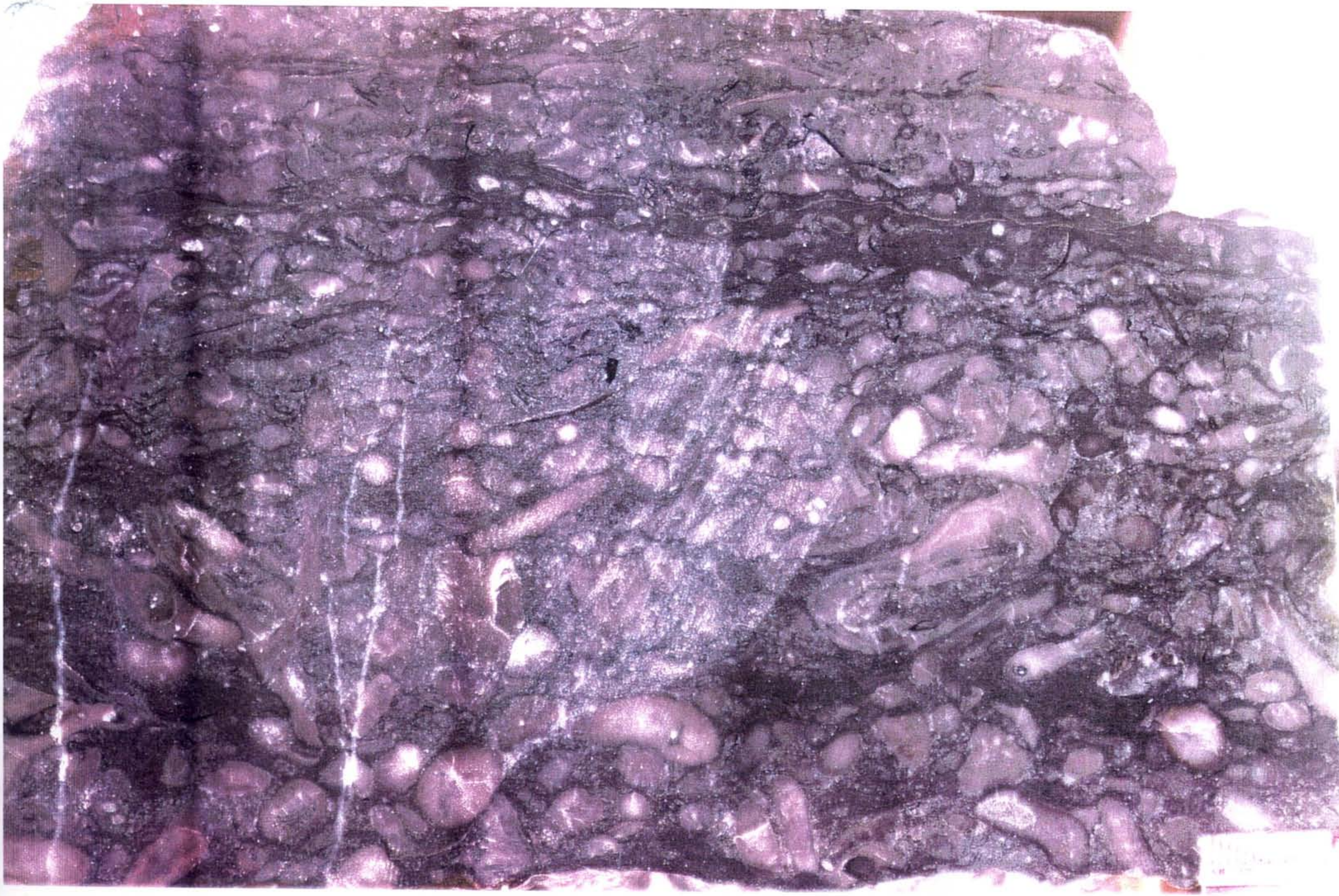
249) 22cm Fissile siltstone with many 2cm lenses of fossiliferous limestone. Limestone contains 0.5cm brachiopods in random orientations, as well as a few (<1%) 1cm bryozoans. Siltstone also has a very few bryozoans.

---Wavy Contact---

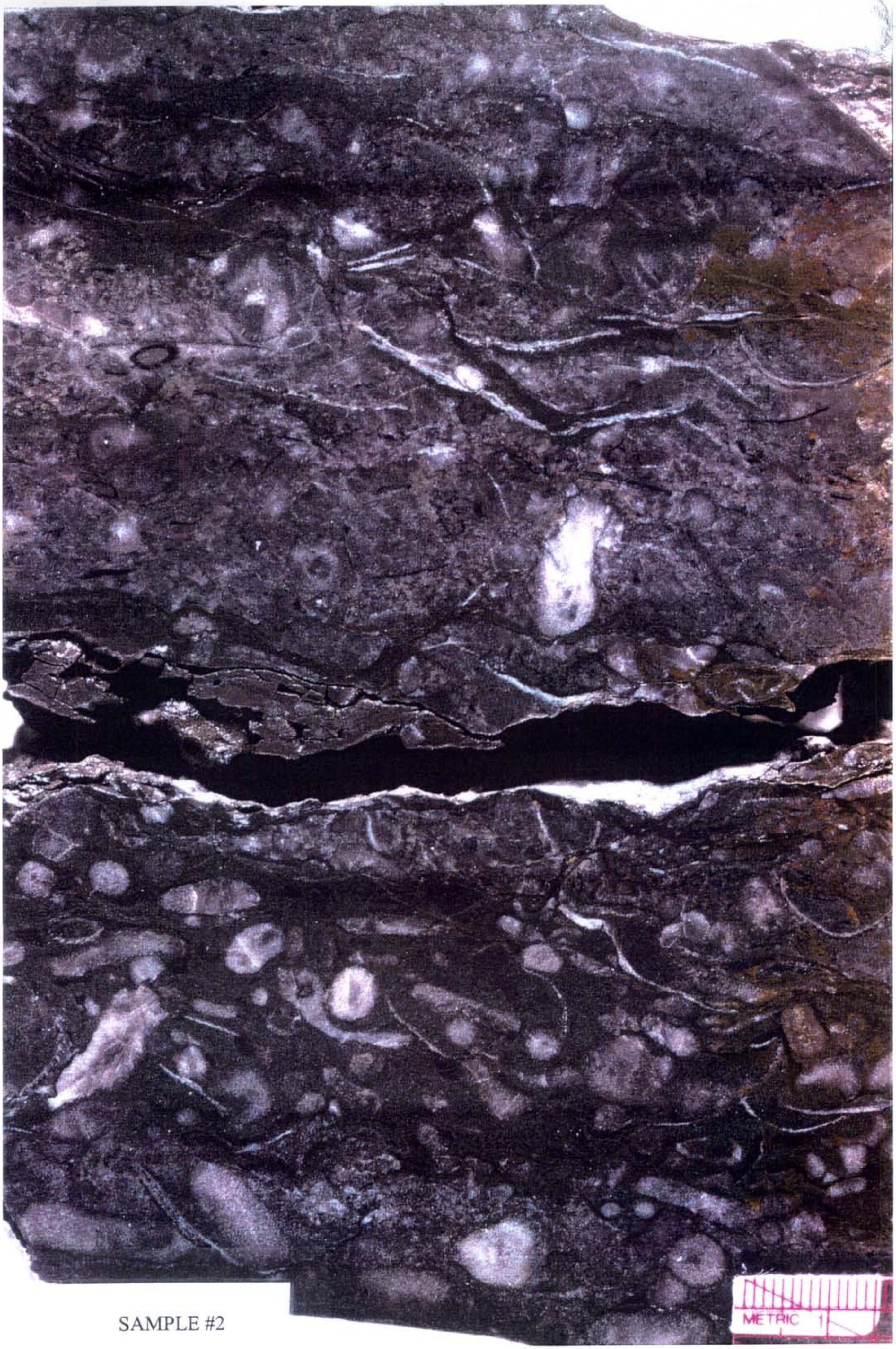
248) 17cm Nonfissile siltstone with 3cm lens of 0.5cm brachiopods oriented parallel to bedding.

Appendix C:

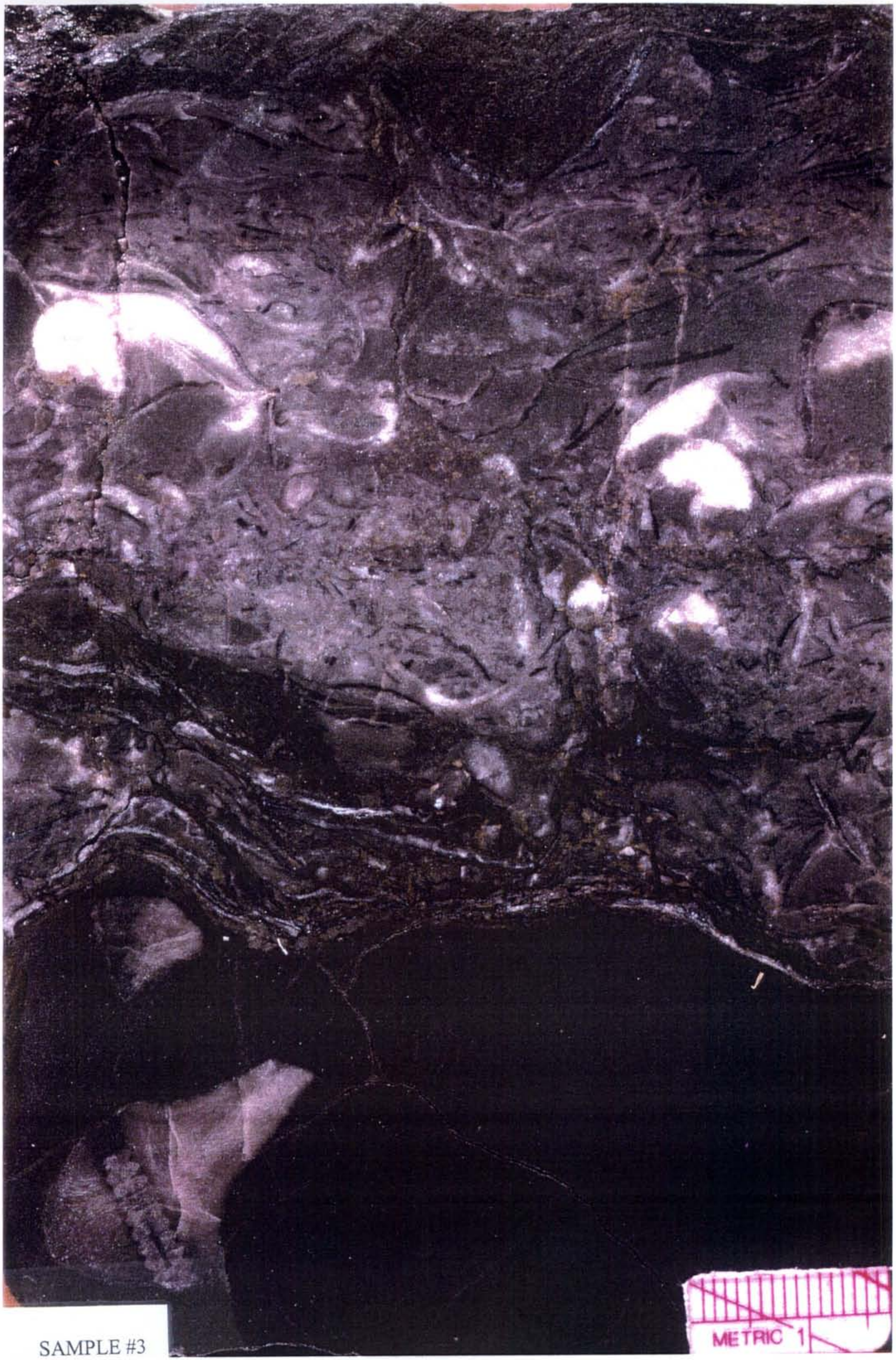
Photographs of Rock Samples



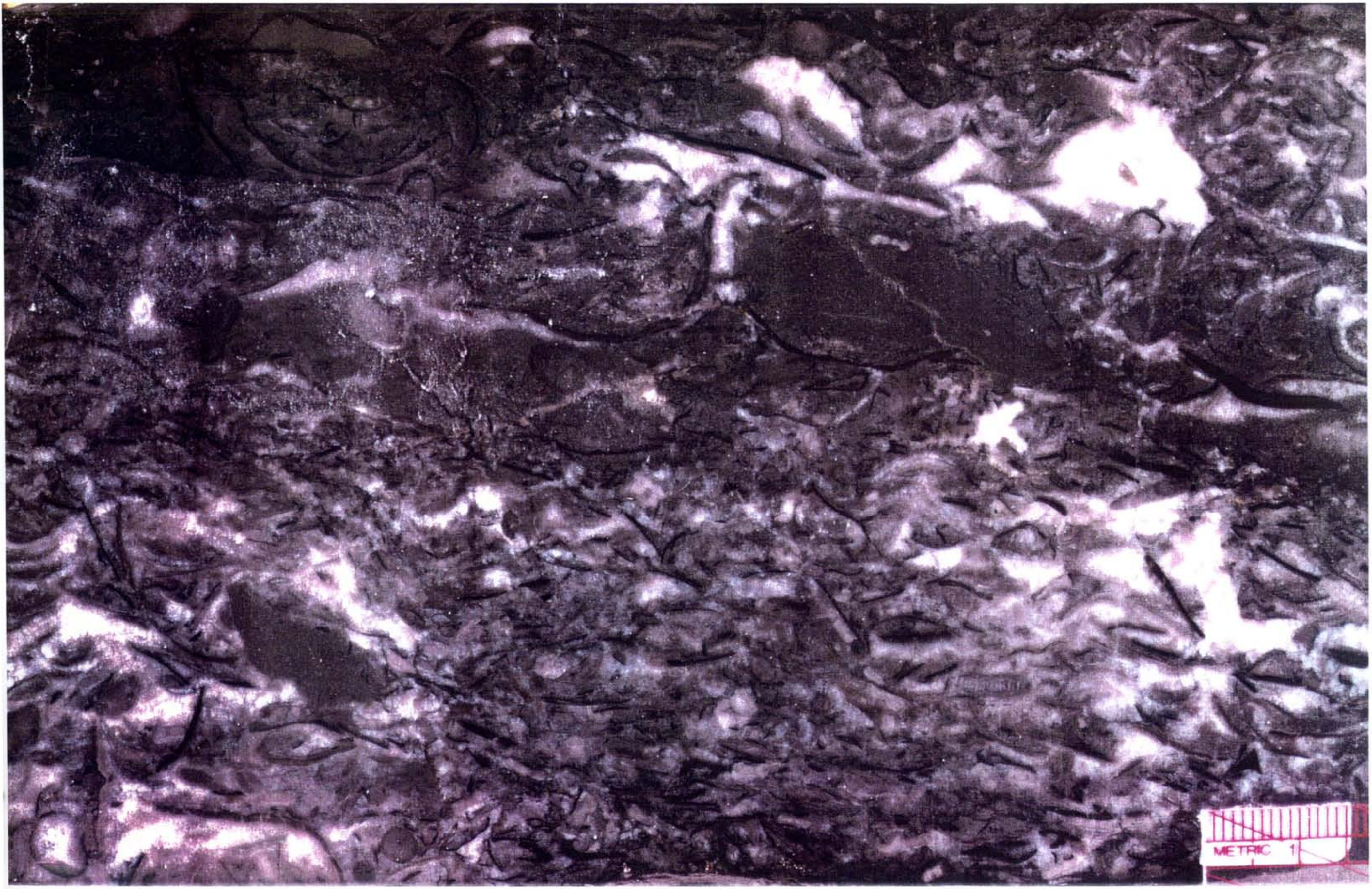
SAMPLE #1



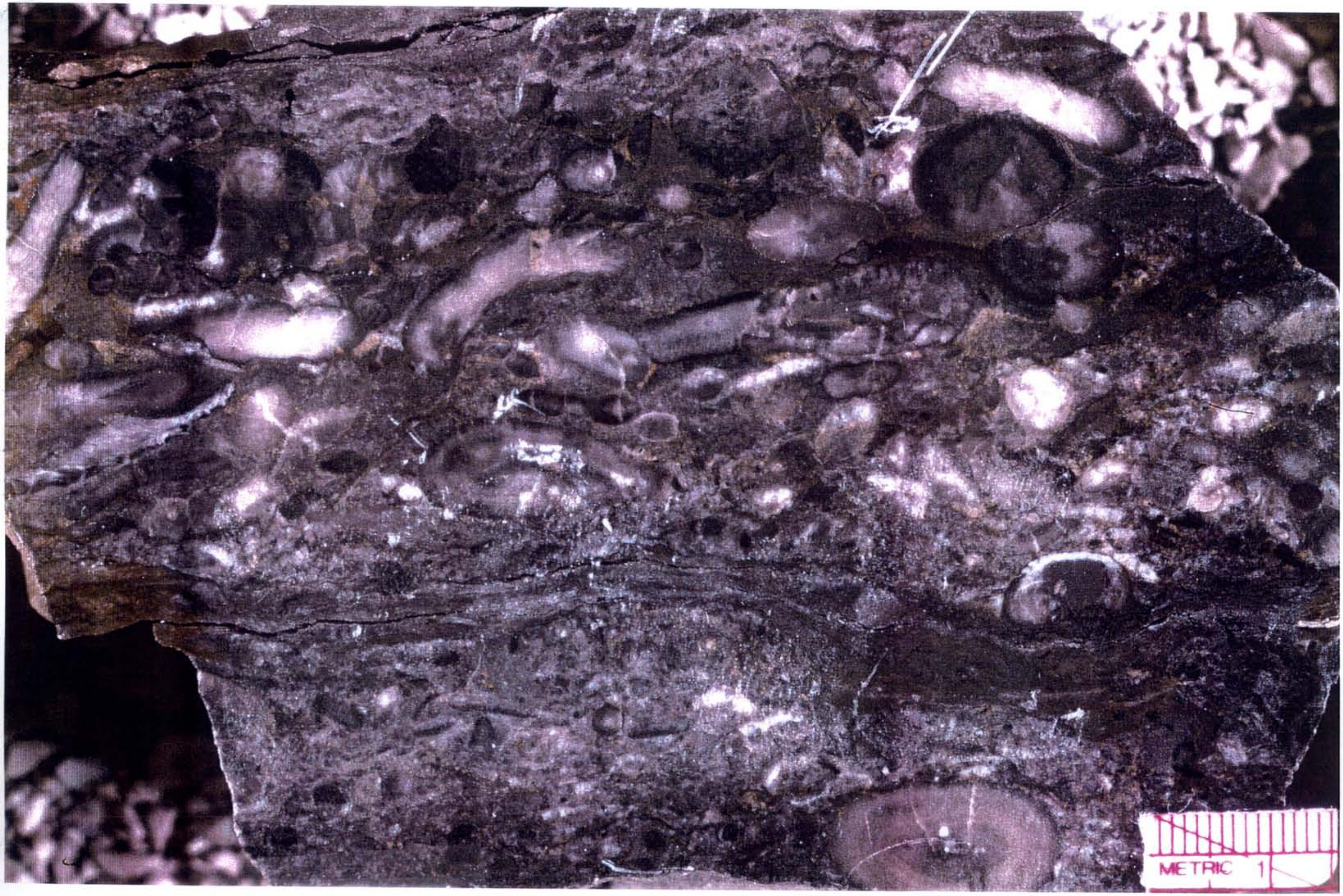
SAMPLE #2



SAMPLE #3

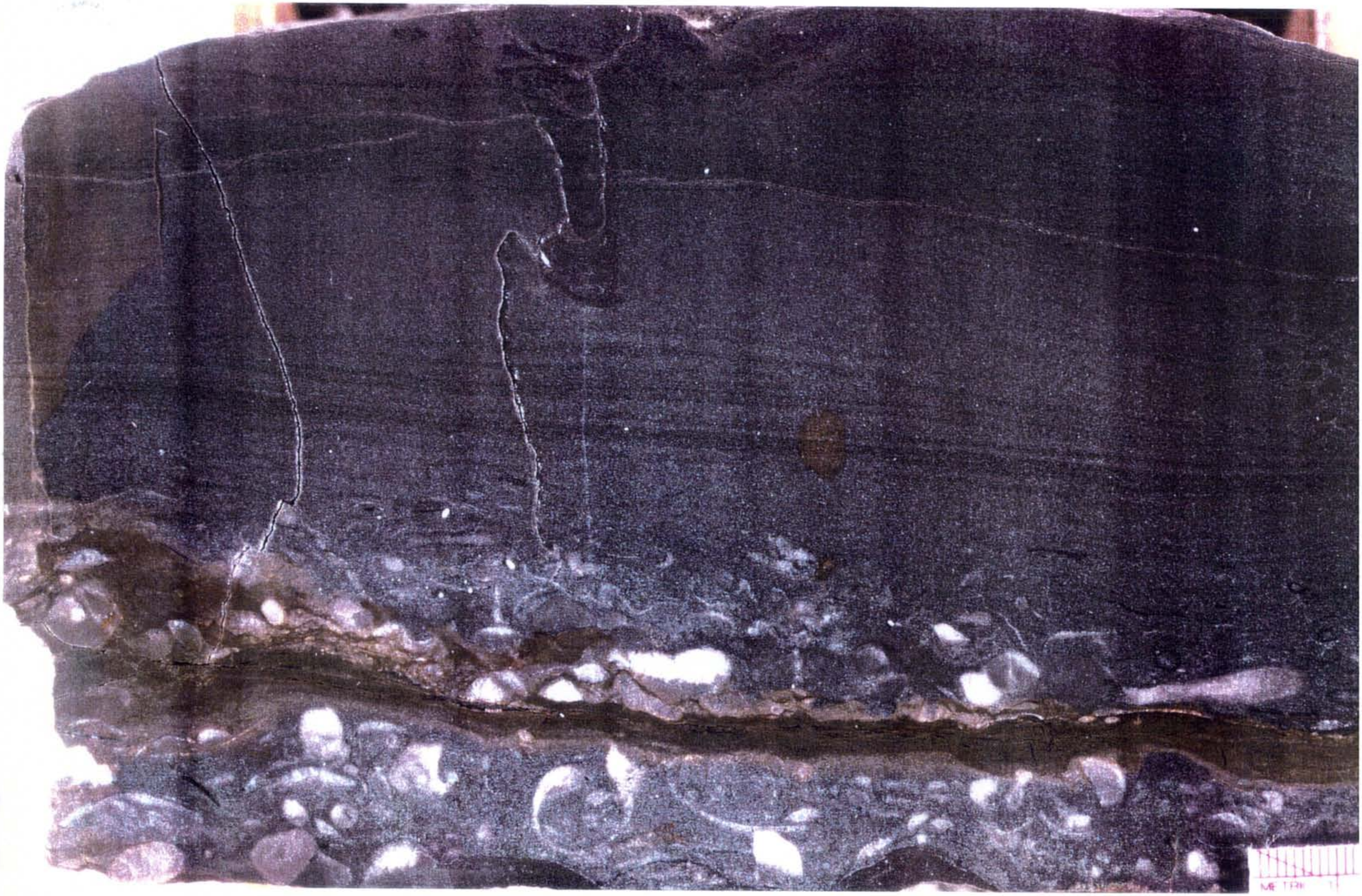


SAMPLE #4

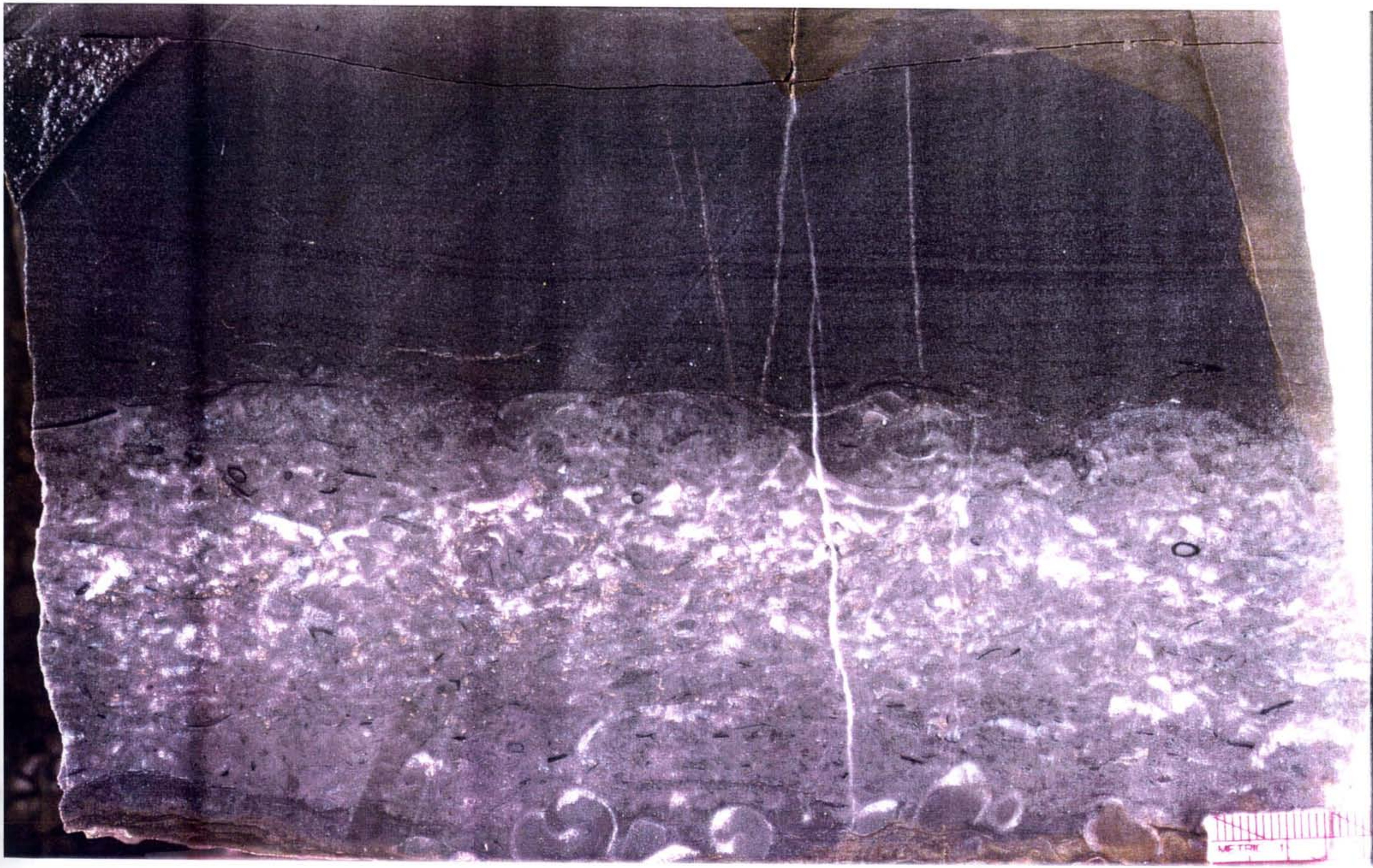


SAMPLE #5

SAMPLE #6



SAMPLE #7



SAMPLE #8